

NatureHCI: Towards Designing Computer-Enriched Nature Experiences

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Abstract

This report documents the proceedings and outcomes of a NatureHCI seminar, in which 21 researchers and academics from across the world gathered at Schloss Dagstuhl, Germany, to discuss the grand challenges that this field currently faces. We present the activities developed day by day, including PechaKucha self-introductions, collaborative workshops, hands-on design sessions, and group discussions. Finally, we present the pathways that attendees proposed to start addressing the seminar’s critical question: how interactive technologies can be designed responsibly to improve our experience of nature, thereby strengthening our connection with nature, which benefits health and wellbeing? Ultimately, with this report, we hope to inspire upcoming Dagstuhl Seminar proposals interested in advancing the field of HCI.

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1 Executive Summary

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In July 2025, the seminar brought together 21 international experts from diverse fields, including Human-Computer Interaction, Environmental Science, Design, Psychology, and Cultural Studies, to explore how digital technologies can facilitate and enhance our interactions with the natural environment. The following report documents the seminar and the efforts of the participants to investigate the underlying opportunities and challenges in developing interactive systems to engage with nature.

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We define “NatureHCI” as research in which the researcher’s intent is to learn something about how interactive computing technology mediates or might mediate engagement with nature. This definition intentionally allows for diverse interpretations of “nature” while focusing on the mediating role of technology in human-nature relationships. Interactive technologies offer instrumental benefits by guiding individuals to natural areas, using enhanced navigational aids and disseminating information about these environments through visualization techniques. Additionally, machine learning algorithms can identify patterns in nature-related activities, aiding in planning. On an experiential level, technologies such as virtual reality can simulate natural settings for those with limited access, wearable technologies can enhance sensory experiences, and drones can provide innovative forms of visual interactions within natural landscapes. In response, such NatureHCI systems can support novel engagements based on different cultural and human perspectives.

This body of work shows the growing research interest in NatureHCI systems. Efforts to map the field and to provide systematic ways to design HCI systems have recently emerged. However, what is still missing is a coherent framework for understanding how these technologies support positive and responsible interaction with nature. This must be investigated urgently as a response to a profound planetary shift: The fact that the anthropogenic mass exceeded all living biomass in 2020 demonstrates a fundamental transformation in the relationship between technology and nature. This historic turning point elevates the question of how to design and evaluate technology use in natural environments from academic interest to planetary necessity.

In this context, NatureHCI emerges not as another subdiscipline of HCI but as an essential response to existential challenges. Climate change accelerates ecosystem disruption while biodiversity loss approaches irreversible tipping points. Simultaneously, urbanization disconnects billions from direct nature experience, leading to what Richard Louv termed “nature deficit disorder.” Indigenous knowledge systems face erosion just when their wisdom is most needed. Yet this moment of crisis also presents unprecedented opportunity. Ubiquitous computing enables new forms of nature engagement, sensor networks can monitor ecosystem health at previously impossible scales, augmented and virtual reality technologies can bring nature experiences to those physically distant, artificial intelligence begins to decode non-human communication, and global connectivity enables rapid sharing of solutions across cultures and ecosystems.

This seminar builds on more-than-human design theory, post-phenomenology, and environmental psychology, demonstrating that NatureHCI requires fundamentally interdisciplinary approaches that balance technological innovation with ecological sensitivity, cultural awareness, and ethical responsibility. Therefore, this seminar invited experts from around the world and with diverse backgrounds, who could recognise the importance of integrating technological advances with environmental sciences and indigenous knowledge systems to address critical gaps in the field. Most importantly, the diversity of participants allowed for the discussion of several methodological approaches that could begin to constitute a distinctive NatureHCI approach, differing markedly from laboratory-based HCI methods.

The seminar produced several significant outcomes that will shape NatureHCI’s development as a field. First, participants developed an initial identification of a grand challenges framework that addresses the complexity of designing technology for natural environments. These challenges emerged from recognizing that HCI’s traditional approaches often fail when confronted with nature’s unpredictability, multiple timescales, and more-than-human stakeholders. Since then, the elucidation of these grand challenges has been finalized and submitted to a major conference in the field. Perhaps most surprisingly, an animated dis-

cussion on the final day led to a proposal to form a special interest group on “Augmented Animals.” This emerged from Professor Inami’s observation that “augmented humans are now too small – maybe we can say augmented animals.” Rather than augmenting animals for human benefit, this initiative explores how technology might help other species adapt to human-modified environments. Beyond academic outcomes, the seminar catalyzed a vibrant research community committed to collaborative action. Participants are committed to creating an open repository of nature-entangled design methods, making innovative approaches accessible to researchers worldwide.

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3 Seminar Goals and Format

The seminar pursued four interconnected goals that shaped its structure and outcomes. First, establishing conceptual foundations for NatureHCI as a coherent research area required defining scope and boundaries, identifying core research questions, mapping relationships to adjacent fields, and developing shared vocabulary. Second, identifying grand challenges provided focus for future research efforts. Rather than generating an exhaustive list of all possible research directions, the seminar aimed to surface the most critical and generative challenges – those that, if addressed, would significantly advance the field while contributing to planetary wellbeing. Third, building community was recognized as essential infrastructure for an emerging field. Academic research often proceeds through individual efforts, but NatureHCI's inherent interdisciplinarity and global scope require collaboration. Fourth, catalyzing concrete action ensured that insights wouldn't remain trapped in academic discourse. Thus, we encouraged participants to create publication plans from collaborative discussions.



■ **Figure 1** Participants engaging in different activities throughout the seminar. Top Left: Sharing coffee breaks. Top Right: Sharing a ride. Bottom Left: Sharing a bus ride to the hike. Bottom Right: Playing volleyball.

To achieve these goals, prior to the seminar, the organizers asked the participants to prepare a pitch (Pecha Kucha format), including the following elements: an introduction of each participant (including their hobbies), a presentation of their relevant NatureHCI

work, their expectations for the seminar, the rationale behind the choice of the recommended reading, and the grand challenges they see in the NatureHCI field. The recommended readings were collected in a shared folder, and more were added throughout the week. A spreadsheet “who has what to offer” was shared prior to the seminar, with a focus on sharing activities in nature that could be done during the week. Participants also engaged in sport activities like running, volleyball, and table tennis. Mornings typically began with provocative presentations or structured workshops, while afternoons allowed for self-organized activities. Some groups conducted impromptu experiments in the castle grounds, testing ideas about technology in nature using available materials. Others engaged in deep philosophical discussions about the nature of nature itself. Evening sessions ranged from formal presentations to storytelling circles where participants shared personal experiences that had drawn them to NatureHCI.

This rhythm – alternating between intensive intellectual work and reflective practice – proved crucial. As one participant observed, “We couldn’t have developed these ideas sitting in a windowless conference room. Being surrounded by nature, hearing the birds each morning, walking the forest paths – our environment taught us as much as our discussions.”

3.1 Day 1: PechaKucha Self-Introductions and Initial Explorations

The seminar took place in one of the Dagstuhl’s conference rooms. Beforehand, the organizers established several work group materials, such as whiteboards, flipover sheets, sticky notes, and markers, to allow participants to record their thoughts and opinions and share them at a glance within the room. The seminar opened with an interactive icebreaker designed to encourage quick connections among participants and cultivate a playful, enthusiastic atmosphere. Participants formed a circle, each introducing themselves by stating their name, accompanied by a distinctive bodily gesture. The group then repeated both the name and gesture. With each new introduction, all previous names and gestures were reiterated in sequence. After the engaging introductory activity, organizer Florian ‘Floyd’ Mueller provided the opening remarks, which contextualized the seminar and set the basis for the discussion of designing for NatureHCI. Floyd encouraged participants to add, while listening through the various introductions, their thoughts on “challenges and opportunities” and the “taxonomy classifications” of designing for NatureHCI to the available flipover sheets at any time during the session.

Next, each participant introduced themselves through a PechaKucha-format presentation. The constrained format forced presenters to distill their vision for NatureHCI into compelling narratives rather than comprehensive literature reviews. Each participant shared their work related to natureHCI, including prototypes, findings, recommended readings, and grand challenges identified through their work and experience. This approach was inspired by earlier HCI efforts that highlighted key challenges during prior similar seminars. The summary of the presenter’s talk is documented in section 4.

3.2 Day 2: Demonstration session and group discussion on the NatureHCI challenges

To spark discussion and inspire creative thinking, several participants brought demos of their NatureHCI work. During a dedicated two-hour session, participants explored eight interactive demo tables. These ranged from water-based interactions through surfing, to plant-responsive interfaces, footwear interactions that adapt music based on walking or



■ **Figure 2** Pecha Kucha sessions, where all participants introduced their research related to SportsHCI.

running, a navigation glove for skiing in the mountains and an artifact designed for bird sound identification. Presenters shared their motivation and inspiration behind each demo, explained how they designed their systems, and reflected on their key learnings, highlighting what worked, what could be improved, and what they might approach differently in future iterations. These demonstrations are detailed in section 5.



■ **Figure 3** Group discussions carried out during the seminar.

The remainder of the day was spent working further on elaborating Grand Challenges for the field of NatureHCI. This was prepared beforehand by organiser Michael Jones through a collaborative brainstorming session. Professor Jones began the brainstorming activity by using the following three questions as prompts: What is NatureHCI? What is important to NatureHCI? And what are the next problems to solve in NatureHCI?

To explore these questions, participants were divided into smaller groups of four to five members. Each group appointed a scribe to document ideas and a reporter to present the group's discussion insights. The brainstorming activity was structured into three rounds, each corresponding to one of the guiding questions. For each round, groups were given 10 minutes to discuss the question and record their thoughts on one-third of a shared flip chart designated for that round. Following the group work, each reporter presented their group's reflections in a 5-minute report, which was then followed by a brief open discussion. This

opened up the discussion to the question of what nature is. What is the difference between NatureHCI, OutdoorHCI and SportsHCI? How can we define the boundaries between reality and virtuality? What design tools and methodologies are needed to support research and practice in NatureHCI?

3.3 Day 3: Reflections on the NatureHCI domain and contributions; Hike

On the morning of the third day, organiser Michael Jones continued to guide the discussion on the previous day's main ideas. Participants were reshuffled and reorganized into three new groups to further explore key thematic questions. Each group focused on one of the following: (a) What is NatureHCI? (b) What design methods and adaptations are needed for NatureHCI? and (c) What are the boundaries between NatureHCI, SportsHCI, and OutdoorHCI? The third question was explored through the use of a Venn diagram, with participants tagging examples and ideas into the relevant categories to better understand where overlaps and distinctions emerged. The boundary cases identified during the Venn diagram activity were later revisited in a one-hour plenary session with the full group of experts. This session provided an opportunity to further unpack and discuss ambiguous or overlapping examples, aiming to reach a clearer understanding of how these cases fit within the categories.



■ **Figure 4** Participant discussing NatureHCI's scope with different examples from SportsHCI and OutdoorsHCI.

In the afternoon, participants joined the traditional Saarschleife Tafeltour hike in the region. Organizers suggested taking the opportunity of walking together to share career mentoring advice. The organizers proposed a walk at the treetop lookout tower at Saarschleife while engaging in a discussion about whether the tower was disrupting the natural landscape or nicely integrated. The participants observed and discussed the treetop structure in relation to the seminar topics and how they navigated the hike: First, they noticed the interactive elements spotted at the site directed their thinking towards stakeholder experiences and involved them in the design process. For example, tree boxes for squirrels (including an image of a squirrel using the tree box) should factor in children's accessibility when designing interactive and informative installations. Second, participants' attention was directed to the dominant species, events, and challenges faced at the ecological site through installations.

Third, most participants disagreed with the need for the tree-top structure, citing the disruption of the natural landscape and the existing natural lookout as their reasons.



■ **Figure 5** Participants engaging in the traditional hike.

3.4 Day 4: Grand Challenges identification

In the morning of the fourth day, organizer Masahiko Inami facilitated a strategic discussion on ways to group the grand challenges identified so far. The focus was now on identifying in the notes both what is currently known and what remains uncertain about NatureHCI and designing for interactions with and within natural environments. These reflections provided a foundation for collaboratively identifying the grand challenges in the field. A “grand challenge” was defined as an important and difficult problem that usually requires long-term effort, often spanning a decade, and has the potential to inform multiple research questions. Each grand challenge was framed in terms of a “lack of knowledge” or “limited understanding”, and included an implicit or explicit call to action for the research community. We clustered the collected data in a collaborative and reflexive manner, where discussions evolved from practice and theory in an intertwined way, going back and forth between design examples and abstract knowledge. As we wanted to let the participants’ experiences drive the emergence of the individual challenges, we allowed the clustering of the notes from the initial presentations to emerge organically. Finally, participants were divided into groups to elaborate on proposed themes, including design-related grand challenges, human–nature relationship challenges, technology-related challenges, and those concerning users and stakeholders. Midway through the activity, the groups were reshuffled to encourage the exchange of diverse perspectives. The groups presented the highlights in a plenary session, providing a brief description of each possible revised challenge and its associated sub-challenges. We then iteratively refined these to create our final grouping of grand challenges, aiming to reach consensus while capturing the key ideas discussed. In Section 6, we present the identified grand challenges in detail.

3.5 Day 5 Wrap-up, Conclusive Remarks, and Concrete Follow up Actions

The last morning of the seminar was devoted to wrapping up all the ideas and insights collected during the week. The organisers proposed a dedicated writing session to advance on the first collaborative outcome of the seminar, a Grand Challenges paper for a high-level HCI venue.

By the end of that morning, the organizers were mainly dedicated to the report, but also defined and divided the responsibilities for the follow-up actions. For all concrete “next step actions”, and based on personal interests and preferences, the group assigned a main person as the “lead” and listed all the participants interested in committing to work on the task.

4 Overview of Talks

4.1 Human Augmentation in Natural Environments

Masahiko Inami (University of Tokyo, JP)

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Drawing inspiration from 17th-century scientist Robert Hooke’s conception of the microscope as an “artificial organ” to enhance the five senses, Inami positioned technology not as separate from nature but as a means to deepen our relationship with it. His proposed “Supersensory Nature Perception” aims to make perceivable natural phenomena beyond human perception – such as UV patterns, infrasound, and magnetic fields – thereby fostering greater empathy and understanding of the natural world.

Practical implementations include the “MagniFinger” finger-mounted microscope system designed to transfer expert botanists’ skills to beginners, technology that visualizes plant-insect interactions in real-time, and gut microbiome sensing research that deepens understanding of internal natural ecosystems. These innovations embody an approach that incorporates Japanese concepts of *wa* (harmony) and *ma* (space/pause), extending human sensory capabilities while respecting natural rhythms and cycles rather than seeking to control nature.

My research transcends Western dualism of nature versus technology, suggesting possibilities for constructing new relationships between humans and nature through augmentation technology. Through interdisciplinary collaboration with botanists and ecologists, his work integrates technological and ecological perspectives, facilitating new discoveries and understanding in the natural world.

4.2 Exertion and nature

Florian ‘Floyd’ Mueller (Monash University – Melbourne, AU)

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Exertion experiences can benefit from nature, and interactive technology can support this. We demonstrate this through a series of research design works around integrated nature exertion experiences. The results of these works suggest interesting ways forward for NatureHCI

research, in particular, how the design can highlight experiential aspects, facilitating playful experiences. Ultimately, with our work, we want to enhance our knowledge around the design of NatureHCI experiences to help people understand who they are, who they want to become, and how to get there.

4.3 Cultural Perspectives on Nature and Technology

Michael Jone (Brigham Young University – Provo, US)

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Outdoor recreation creates opportunities for people to engage with nature. I think of engagement with nature as engagement the specific time, place, and communities in which the recreation takes place. For example, engagement with time includes engagement with time-varying conditions that exist during the recreation experience. Framed this way, we can talk about interactive computing technology use during nature recreation in terms of it's impact on engagement with time, place, and community. I take a post-phenomenological view on how technology impacts engagement. In the post-phenomenological view, technology mediates engagement with nature to create different forms of engagement. Taking the post-phenomenological perspective on engagement with place, time and communities creates a rich design space in which we can explore different ways in which different technologies create new forms of nature recreation.

4.4 Technological Mediation of Human–Nature Relationships

Zhuying Li (Southeast University – Nanjing, CN)

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Human-nature interaction contributes significantly to wellbeing. Within the context of NatureHCI, I am interested in how technology can mediate the relationship between humans and nature, and how people experience nature, particularly in urban environments where direct contact with natural elements has become increasingly limited. This inquiry can be approached from various dimensions. One important aspect is the spatial-temporal dimension. Due to constraints of space and time, people often have limited opportunities to engage with nature. Technology can help identify and create such moments of engagement, supporting more frequent and meaningful interactions. Another dimension concerns our lived experience in highly digital and urban settings, where human attention is often directed toward screens and mediated activities. Here, technology can play a role in redirecting attention back toward natural phenomena and fostering a deeper sense of awareness and connection. Finally, I would like to extend this exploration toward accessibility and inclusivity, ensuring that technologies designed to reconnect humans with nature can benefit diverse groups and abilities. Through these perspectives, I hope to understand how NatureHCI can support equitable, restorative, and sustained forms of human-nature engagement that enhance overall wellbeing.

4.5 Virtual Nature

Tuomas Kari (Natural Resources Institute Finland (Luke) – Helsinki, FI)

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As an orienteer from childhood and current active trail runner, I have ventured in nature all my life. I have always been interested in technology, nature, and wellbeing. My current research topic, virtual nature, combines these three areas of personal and professional interest. Virtual nature refers to solutions where a nature environment is delivered virtually by utilizing digital technology. Research has shown that virtual nature can induce various psychophysiological benefits to its users. Virtual nature can be used as a recovery space in workplaces, educational facilities, and similar, as well as to bring nature experiences to people who have limited access to nature, such as people with disabilities, aged people in elderly care homes, hospital patients, people living in large cities, etc. A central challenge in disseminating virtual nature solutions more widely is to make (more) people understand that virtual nature is not meant to replace actual nature contact but rather to provide an alternative in situations where (and when) access to actual nature is limited or not available. It is also central to research and develop virtual nature solutions to meet different purposes.

4.6 Local Perspectives and Cultural Heritage in NatureHCI

Siiri Paananen (University of Lapland – Rovaniemi, FI)

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Nature is sometimes perceived as untouched or empty, but landscapes are woven with stories, meanings, and histories – especially when viewed through local perspectives. My work in NatureHCI, at the Lapland User Experience Research Group, explores how interactive technologies can reveal and highlight these hidden layers, making them accessible and engaging for wider audiences. I'm interested in how digital tools like XR and AI, together with participatory design, can support a pluriversal approach – acknowledging and valuing different relationships with nature, especially those from Indigenous and local communities. For me, it's important that NatureHCI works alongside these communities, using technology in respectful and meaningful ways. At Dagstuhl, I look forward to exploring how we can design technology that supports connection to the living landscapes we share. This work builds on our research group's experience in NatureHCI, as well as combining outdoor and cultural heritage HCI research.

4.7 Challenges and opportunities for nature-oriented design

Sarah Webber (University of Melbourne, AU)

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As a lifelong camper and hiker, I use a range of mobile apps to explore and learn about wildlife and landscapes. This reflects a scientific nature learning orientation. However, people adopt varied modes of nature engagement, and so can benefit from different types of

digital tools, and have different needs and tolerances for distraction, unobtrusiveness, and mediation. More-than-human thinking challenges HCI researchers to develop design methods that can include non-humans and ecosystems as stakeholders. Amidst mounting concern regarding e-waste, environmental degradation and slowing of human population growth, new priorities emerge, such as decentering the human, and designing systems that support ongoing familiarity and relationships with non-humans and ecosystems. Models of post-growth innovation, zero-waste products, and systems to support communities in managing commons, may be fruitful directions for HCI to contribute to flourishing socio-environmental systems.

4.8 Reimagining Nature HCI: Connecting Inner and Outer Ecologies Through the Sensory Body

Nandini Pasumarthy (Monash University – Melbourne, AU)

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Our relationships with nature are not just visual or cognitive – they are embodied, interoceptive, and shaped by inner ecologies like breath, gut rhythms, and sensory memory. Drawing on research in gut health, play, and interaction design, this abstract explores how NatureHCI might move beyond representation to attune with what the body already senses. It proposes a design approach grounded in energetic coherence and local co-creation, where user interaction with nature aligns with the rhythms of place, season, and sensation. Through playful, multisensory, and body-led experiences, this abstract reimagines NatureHCI as a space for co-regulation, grounding, and reciprocal connection between inner and outer ecologies.

4.9 How can HCI engage people from kindergarten to old age in caring for biodiversity?

Margot Brereton (Queensland University of Technology – Brisbane, AU)

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Habitat loss, invasive species and climate change are significantly affecting biodiversity and ecosystems, causing changes to the abundance and geographic range of many species, interfering with their life cycles and interactions with other species. Although continental scale sensing infrastructure to monitor biodiversity is in place, and AI has begun to classify fauna sounds, technology needs significant help from people to make accurate findings. Moreover, data collection and scientific analysis alone do not build broader community interest and capability to act. Current approaches to citizen science focus on scientific need rather than building user interest (e.g. Zooniverse), offering top-down, repetitive, highly structured tasks to classify data e.g., is this frog call present in this sound bite? This talk discusses the need for new approaches to engage people with nature. From local concerns and community members as young as those in kindergarten, we discuss how HCI can scale from local to global to develop interest in and custodianship of our natural environment and all of its amazing species.

4.10 Why should NatureHCI investigate outdoor water activities?

Maria Fernanda Montoya Vega (Monash University – Melbourne, AU)

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Aquatic environments encompass 70% of the natural environments on the planet, including the ocean, lakes, rivers and other freshwater sources. Human engagements with such natural environments span many industrial, cultural and recreational activities, approaching water as a resource or as a site for leisure. However, within HCI, recreational engagements with aquatic environments have not yet fully benefited from interactive technologies beyond limited applications focusing on athletic performance. Similar to how interactive technologies have enhanced the enjoyment of on-land outdoor activities, I see the potential of interactive experiences to boost IN-SITU experiences in aquatic environments, which could support their conservation, raise ecological awareness and promote physical and mental health. Hence, given the scale and importance of aquatic ecosystems and the potential for interaction design to shape the future interactions in such environments, this domain deserves focused attention within NatureHCI.

4.11 Accessibility in NatureHCI

Jasson Wiese (University of Utah – Salt Lake City, US)

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Many outdoor experiences are inaccessible by default. They were not necessarily designed that way—the natural world can be a harsh and unforgiving place. How then should we think about accessibility when we are designing technological experiences for the outdoors? Do we make our designs accessible even if the environment in which they are used is not accessible? Do we focus on trying to make nature more accessible? Or do we simply ignore accessibility concerns in this context because it's simply too hard? I'd like to challenge this community to engage meaningfully with accessibility as a first class consideration for the outdoor contexts in which we are working. Finally, if we do accept this challenge we need to engage with how we can ensure participation by all people, not simply the “least disabled,” who are typically the easiest to engage with traditional HCI methods.

4.12 Human-Plant interaction

Hong Luo (Monash University – Melbourne, AU)

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Advances in interactive technologies offer new opportunities to enhance human–nature engagement. Although human–plant interaction (HPI) research has begun to explore this area, current systems appear to focus on unidirectional interactions between plants and humans. In contrast, the idea of bidirectional interactions where technology mediates a mutual exchange between humans and plants has received far less attention. As a new form

of interaction between humans and nature, bidirectional interactions provide people with opportunities to re-engage and experience nature, while offering the potential to enhance the connection between humans and nature. Given the significance of fostering such reciprocal relationships, this area of research warrants greater focus, with the aim of enriching our bond with nature and moving toward a more integrated coexistence.

4.13 Augmenting human experience and skills in mountainous outdoor environments

Florian Daiber (DFKI – Saarbrücken, DE)

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In the last years, sports technology has become ubiquitous and there has been a large body of work in HCI as well as commercial products including apps and wearables that aim to enhance human experiences in the outdoors. Moving in (extreme) outdoor environments requires certain physical and cognitive skills and HCI in the outdoors has the potential to track human experiences and provide guidance to exist in and with nature respectfully. In our research we investigate the adoption and usage of technologies in outdoor activities such as mountaineering, climbing and running with a particular focus on their interaction with nature. We are especially interested in technologies that track and assist users in their individual needs in nature. The preparation for as well as assistance during the outdoor activity is of interest. In [18] we investigated how climbing technology that enables similar features as running and cycling technologies is perceived by climbers. The goal of the survey is to gain insight in the acceptance of technology in climbing. The main finding of the survey is that the sample can be divided into leisure-oriented outdoor climbers and sports-oriented indoor training enthusiasts. In [16] we investigated how technology intersects with the concept of mastery in the context of mountaineering, a domain that deeply values skill, autonomy, and experience. Rather than focusing solely on usability or efficiency, we argue that designers must consider how technological interventions impact the experiential, ethical, and cultural dimensions of outdoor sports in nature.

4.14 Sensory immersion in NatureHCI

Carey Jewitt (University College London, GB)

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There is a need and benefits to fostering alternative visions of digital communication. The rapid expansion of techniques of simulation and sensory manipulation beyond the visual in virtual and mixed reality is central to the futures trajectory of digital communication. This sensory turn is primarily predicated on high-fidelity human-centric replication of complex human sensory processing. However, the dominance of a human-centric replication paradigm can be problematic and limiting for HCI. 1) It grounds digital communication in a technical and limited view of the senses which severely constrains the range of digital sensory experiences available to people and can lead to misaligned sensorial design. 2) Tends to presuppose a homogeneous, able-bodied user, thereby excluding countless other embodiments

and possibilities of communication. 3) Locks us in our current ways of perceiving and knowing and restrictive modes of relating to one another. 4) Holds back innovation by anchoring the digital in the physical human world. Drawing inspiration from animal and plant sensory worlds provides a speculative springboard to generate new reconfigurations for sensorial immersion technologies beyond the human centric.

4.15 Designing With, Not Just For, Nature: A Post-Anthropomorphic Approach to Human-Plant Interaction

Rakesh Patibanda (Monash University – Melbourne, AU)

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This talk traces an evolving relationship with plants, from early life experiences to advanced research in mental health, virtual reality, and bodily interaction. This trajectory culminated in PlantMate, a system exploring shared bodily control between humans and plants through playful engagement. Initial work, focused on technological novelty, prompted critical reflection on embedded anthropocentric biases in design. This introspection led to a reframing of interaction design through a post-anthropomorphic lens. Drawing on recent advances in more-than-human design, I presented four artifacts: Ant Apparatus, Breathing with Plants, Being with Plants, and Symbiotic Breather. These projects serve as provocations, urging a reconsideration of technology not merely as a human tool, but as a mediator in entangled, multispecies relationships. I conclude by posing open questions about designing with nature, emphasising the importance of listening across differences, embracing ambiguity, and enabling nonhuman actors to co-author shared futures.

4.16 Tech on the Trail: Investigating Nature on Socio-technical Journeys

Scott McCrickard (Virginia Tech – Blacksburg, US)

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This work seeks to understand and develop ways that technology is used (or avoided) on trails and in trail-like settings, especially extended and multi-day hikes, where different user goals and desires affect our behaviors and interactions with others. Technology is often targeted for use in heavily populated urban environments, but thousands of people take technology on their outdoor adventures, raising questions about appropriate use when in a more isolated and natural environment. These environments provide some level of separation for most people from technologies, but a need for community and communication still exists for hikers and different groups and trail stakeholders (e.g., friends on the trail, family back home, trail maintainers) and on society.

4.17 Real-World Terrain and Gait Recognition with Ground-Aware Smart Footwear

Don Samitha (Monash University – Melbourne, AU)

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Everyday, billions of people use footwear for walking, running, or exercise. Of emerging interest are “smart footwear”, which help users track gait, count steps or even analyse performance. However, such nascent footwear lack fine-grain ground surface context awareness, which could allow them to adapt to the conditions and create usable functions and experiences. Hence, this research aims to recognize the walking surface using a radar sensor embedded in a shoe, enabling ground context-awareness. Using data collected from 23 participants from an in-the-wild setting, we developed several classification models. We show that our model can detect five common terrain types with an accuracy of 80.0% and further ten terrain types with an accuracy of 66.3%, while moving. Importantly, it can detect the gait motion types such as “walking”, “stepping up”, “stepping down”, “still”, with an accuracy of 90%. Finally, we present potential use cases and insights for future work based on such ground-aware smart shoes.

4.18 Enabling Mobile XR Interaction in Dynamic Natural Environments

Andrii Matviienko (KTH Royal Institute of Technology – Stockholm, SE)

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Interaction on-the-go allows users to interact with technology in dynamic contexts, e.g., walking, running, driving, or flying. The biggest challenges with this type of interaction are (1) users’ inattention to surrounding environments, making traditional forms of input difficult to use, and (2) users’ inability to use their bodies freely due to interactions that require certain body parts. Particularly, interaction on-the-go in XR is largely underexplored in nature and for interaction with and within nature and requires special attention and consideration since people in nature engage with different and varying activities, spanning from hiking and climbing to camping and playing games. XR enables interactions and visualizations that can represent objects that are occluded or are impossible to see with biological vision. Moreover, existing XR experiences and solutions are typically limited to individual, indoor, visual, and auditory perceptions, neglecting the outdoor environment in nature.

4.19 From Story to Shift: Designing Climate Empathy Through Games and Behavioral Insight

Ambika Shahu (IT:U Interdisciplinary Transformation University – Linz, AT)

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What if experiencing the life of a farmer affected by climate change could change how we think about our own actions? Through empathy-driven role-playing games, players must make tough decisions as a farmer grappling with climate change, choosing between short-term survival and long-term sustainability. This interactive storytelling approach draws players into complex scenarios, building emotional connections and prompting reflection on real-world climate choices. Alongside, we also explore how psychological factors such as habits, perceived control and social expectations influence people’s willingness to adopt greener commuting methods, such as using public transport, cycling or shared automated vehicles. Our research reveals how mental shortcuts, policy gaps and the perception that climate change is “too far away” (in terms of time, space or relevance) can hinder action. By blending narrative with behavioural science, we aim to inspire new approaches to designing technology that brings climate realities closer and sparks meaningful change.

4.20 Accessibility in the nature

Amad Alsaleem (University of Utah – Salt Lake City, US)

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When we talk about accessibility and nature, the conversation usually centers on ramps, paths, and removing obstacles to access. But the real barrier may lie in how we design experiences, especially we aim for safety only not the possibility. In our work, through the design of adaptive shared-control systems, we empower individuals with tetraplegia to engage in extreme sports like sailing and skiing, not as passengers, but as active participants. Based on our work, I will talk about how adaptive systems can distribute control while leaving critical decisions in the hands of the user. The result: users gain agency, not just access – by designing experiences that give users the right to fail in a safe and meaningful way. This talk will discuss the design challenges of shared-control interfaces in unpredictable natural environments and explore how technology can support fuller, more enjoyable outdoor experiences.

4.21 Bringing social sciences to the management of nature and outdoor experience

Bill Borri (Deakin University – Melbourne, AU)

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I travel from the lands of the Wurundjeri and the Salish peoples. As a conservation social scientist, I bring both quantitative and qualitative research methods. I am a pluralist, with various epistemological, ontological and axiological stances. Q. What does it mean to “be”

in Nature? At the University of Montana, I focused on wilderness and wildlands: a place apart, a freedom to be, beyond the hand of human domination. The USA shares a heritage from nature, with a geography of hope. Q. What types of place, identity and character? Many Americans and Australians have begun and grown their relationship to nature on public lands and, yet, we live in a time of increasing privatisation and private control of nature. Disney, as one of the largest managers of outdoor experiences, creates mediated, commodified, and constructed nature. Q. Will hyper-reality overwhelm the real?

5 Overview of interactivity session

The second day of the seminar was introduced by organizer Michael Jones, starting off with a “demonstration session” that involved live interactive demonstrations of systems and technologies relating to NatureHCI.

Florian Daiber demonstrated FootStriker [19], a self-contained wearable that detects heel striking while running with a pressure-sensitive insole. Heel striking is corrected in real-time to mid/forefoot running by applying electrical muscle stimulation (EMS) on the calf muscle. Florian discussed potential scenarios for EMS-based training in nature with the participants.



Figure 6 Left: Florian Daiber demonstrating the Footstriker. Right: Sirii Paananen demonstrating the Glove Navigator.

Sirii Paananen demonstrated Glove Navigator [23], a wearable graphical navigator display integrated into a skiing glove. Sirii showcased this prototype for participants, which was made using a standard faux leather mitten and a smartphone. A 50x50 mm opening was cut on the mitten’s upper part near the fingertips, and the phone was slid into the modified seam. The phone has a navigation app installed, displaying an arrow towards a target. The navigation target can be set up before skiing into the slopes.

Nathalie demonstrated the Virtual Campfire project [8], asynchronous video storytelling using the Marco Polo app, aiming to connect older and younger adults while enhancing engagement with nature. Nathalie shared the study results with participants, highlighting how the project created discussions on personal experiences and memories tied to natural settings. In this project, they found that storytelling served as a useful icebreaker, with nature acting as a catalyst for meaningful intergenerational communication.

Hong Luo presented PlantMate [32] a platform enabling bidirectional touch-based interaction. PlantMate translates users’ touch into bioelectrical stimulation to enhance plant growth while translating a plant’s electrical signals under varying environmental conditions

(e.g., temperature, humidity) into electrical muscle stimulation for users. Hong shared with participants how plants can be perceived as interactive agents, redefining human-plant relationships through discernment and affective touch. Participants engaged with this prototype by attaching the EMS electrodes to their forearms.



Figure 7 Left: Nathalie presenting Virtual campfire to Professor Masahiko. Right: PlantMate system being experienced by a participant.

Maria Montoya demonstrated OceanEcho [33], a surfing wearable embedded with vibrotactile actuators, a thermal pad, headphones and a location system, aiming to foster surfers' connectedness with the ocean. Participants engaged with OceanEcho by wearing it near the water fountain, simulating ocean contact, while the prototype played nature-related sounds (such as dolphin and whale sounds), providing heat and vibration stimuli that represented the ocean state (swell direction).



Figure 8 Left: Maria Montoya demonstrating OceanEcho to participants. Right: Participant experiencing OceanEcho near the fountain.

Margot demonstrated Ambient Birdhouse [50] a novel IoT design for the home that seeks to encourage awareness and discovery of birds outside. The Ambient Birdhouse can be placed inside a house and plays media of local birds – sometimes giving clues about them. Bird houses are connected and users can share bird media from their phone, challenging other users to identify them. Participants enjoyed listening to different bird sounds that transported them to nature. Margot shared with participants that this prototype’s playful nature had an immediate grasp on children, prompting them to learn bird calls.



Figure 9 Left: Margot Brereton demonstrating Ambient Birdhouse. Right: Participants engaging and sharing during the demo session.

6 Defining NatureHCI: Scope and Boundaries

The first major topic during day 3 tackled the foundational question that had haunted previous gatherings: What exactly is NatureHCI? Previous workshops had operated with implicit understandings that often diverged significantly. Some participants assumed NatureHCI meant any technology use outdoors. Others focused on environmental sensing. Still others emphasized nature education or conservation applications. This diversity had generated creative work but hindered field formation. The workshop began with individual reflection. Participants spent ten minutes writing about what had brought them to NatureHCI – personal experiences, research questions, societal concerns. Sharing these stories revealed profound differences. One researcher described childhood summers with grandparents who taught plant identification, lamenting how urbanization severed such connections. Another confessed to discovering nature only through Pokemon Go, which led to actual hiking. An indigenous scholar explained how their community saw no separation between nature and technology – both were gifts requiring respectful use.

Small groups then tackled the question “What is and isn’t NatureHCI?” through concrete examples. Heated debates arose. Was a fitness tracker used while hiking NatureHCI? Most said no – unless the research investigated how tracking affected nature experience. What about a VR relaxation app featuring forest scenes? Maybe – if it studied whether virtual nature fostered real nature connection. Agricultural sensing networks? Depends – precision farming for maximum yield seemed different from systems helping smallholders work with natural cycles. Through affinity diagramming, key concepts emerged. “Mediation” appeared

repeatedly – NatureHCI seemed less about specific technologies than about how technologies mediate human-nature relationships. “Intent” proved crucial – commercial products might use identical technologies but with different purposes. “Nature” itself resisted definition – participants agreed that prescribing what counts as nature would exclude important work.

The full group then engaged in collaborative wordsmithing, projecting draft definitions and editing in real time. Tensions arose between precision and inclusivity. Computer scientists pushed for specificity while anthropologists warned against premature closure. After ninety minutes of intensive discussion, consensus emerged around the definition that would guide the week: “NatureHCI research is research in which the researcher’s intent is to learn something about how interactive computing technology mediates or might mediate engagement with nature.”

Participants appreciated how this definition provided clarity while maintaining flexibility. It distinguished NatureHCI from adjacent fields – not all OutdoorHCI was NatureHCI, not all SustainabilityHCI was NatureHCI – while allowing diverse approaches. The focus on mediation opened theoretical connections to philosophy of technology. Leaving “nature” undefined acknowledged cultural differences while requiring researchers to be explicit about their own definitions. The workshop concluded by identifying boundary objects – concepts that would help distinguish NatureHCI work. These included focus on human-nature relationships rather than purely human or purely natural phenomena, attention to how technology transforms these relationships rather than just enabling them, and commitment to understanding rather than just building. With definitional clarity achieved, the seminar could move to identifying specific challenges.

7 Defining the Grand Challenges on NatureHCI

During the Pecha Kucha presentations and group discussions, notes on challenges and opportunities were written on flipcharts for later analysis. After the day 2 brainstorming session, discussing the NatureHCI scope and the next problems to solve in NatureHCI an initial list of grand challenges were identified by participants, which included: access to nature, culture influences on the experience of nature, safety and risk in nature, simulated natural environments, awareness of non-human entities, antropomorphism of nature, variety of scales and live forms in nature, community knowledge of nature, sustainability design for nature, unpredictability of nature, mutualistic experiences in nature, understanding nature and learning from nature, design methods from other disciplines applicable to natureHCI, collaboration with government and local communities, connectivity in nature and diversity of users in nature. During day 3, the list was further refined with the following questions considered:

- What is NatureHCI?
- How does NatureHCI overlap with SportsHCI and OutdoorsHCI?
- What design challenges are related to methods and adaptations that are needed for NatureHCI?
- Can the challenge be solved within the next 10 years?

After a general consensus on the definition of NatureHCI, the other questions were the focus of the discussions during day 3. By the end of this day, organizer Michael Jones documented the reflection of day 3 group discussions on a shared document proposing a final list of grand challenges, including design-related grand challenges, human–nature relationship challenges, technology-related challenges, and those concerning users and stakeholders. These

challenges were also listed using a Miro board, in which we clustered the collected data on the flipover sheets in a collaborative and reflexive manner, where discussions evolved from practice and theory in an intertwined way, going back and forth between design examples and abstract knowledge. As we wanted the participants' experiences to drive the emergence of individual challenges, we allowed the clustering of notes to emerge organically. Overall, high-priority design challenges included designing for non-human stakeholders, addressing temporal mismatches, ensuring equitable access, and developing appropriate evaluation methods. Other challenges were identified in debates around power and connectivity, indigenous and community knowledge, and evaluation metrics.

During day 4, organiser Inami led the discussion on each challenge by creating breakout groups to further discuss and document the proposed four grand challenges themes. Mid-way through the activity, the groups were reshuffled to encourage the exchange of diverse perspectives. The groups presented the highlights in a plenary session, providing a brief description of each possible revised challenge and its associated sub-challenges. We then iteratively refined these to create our final grouping of grand challenges, aiming to reach consensus while capturing the key ideas discussed. Throughout this process, we remained mindful of the time constraints of the workshop format. In the next subsections, we present a summary of such challenges at participants conceptualized during the final day of the seminar.

On the final day, organizer Michael Jones called for an overview of the challenges discussed. Rather than minor editing, participants undertook wholesale reconsideration of how to frame NatureHCI's challenges. The original structure organized challenges by discipline – technology challenges for engineers, design challenges for designers, and social challenges for social scientists. But NatureHCI's fundamental insight was that such divisions failed when addressing human-nature relationships. A sensing network designed by engineers without considering cultural meanings would fail. A beautifully designed interface ignoring technical constraints would never deploy. Social interventions ignoring material realities would remain theoretical. Through rapid iterative discussion, a new organizing principle emerged. Each grand challenge should focus on a core aspect of human-nature relationships, with implications for different stakeholders embedded within rather than separated out. This structure better reflected the field's commitment to integration and avoided reinforcing disciplinary silos. In the next subsection we show the efforts of participants during day 5 to conceptualized a comprehensive list of grand challenges in NatureHCI.

7.1 The Challenge of Designing for Non-Human Stakeholders

Perhaps no challenge better exemplifies NatureHCI's paradigm shift than the question of how to design with and for non-human entities. Traditional HCI assumes human users whose needs can be articulated through interviews, observations, and participatory design. But how do we understand the needs of a forest, the preferences of migrating birds, or the wellbeing of soil microbiomes? Thus, there is a lack of understanding on how to design for non human stakeholders.

We recognize that current HCI methods embed anthropocentric assumptions. User-centered design centers humans by definition. Even when we design for pets or livestock, we typically prioritize human interpretations of animal needs. NatureHCI requires more radical approaches that grant genuine stakeholder status to non-human entities.

Recent work provides starting points. Researchers like Tomico and colleagues [57] have proposed methods for engaging with nature as an active participant rather than passive context. Their repository of “nature-entangled design” methods includes techniques like sensory walks where designers attempt to perceive environments from non-human perspectives, temporal mapping that reveals natural rhythms typically ignored in human-centered timescales, and material dialogues where natural elements participate in form-giving. Yet these methods remain nascent, requiring significant development to address NatureHCI’s scope.

An associated design challenge is considering the the design for different temporal scales in nature. An oak tree experiences the world across centuries, while mayflies complete entire lifecycles in hours. Soil formation occurs over millennia, while fungal networks communicate in seconds. Thus, it is still unclear how to develop methods sensitive to this temporal diversity. Long-Term Ecological Research provides one model, with studies spanning decades to capture slow environmental changes. But NatureHCI needs approaches that work within typical project timescales while remaining sensitive to longer rhythms. This might involve designing studies that explicitly plan for handoffs across researcher generations, creating protocols for community-maintained observations, or developing simulation methods that compress long timescales into manageable periods.

The challenge extends to entities beyond human sensory capabilities. Many animals perceive ultraviolet patterns invisible to us. Plants communicate through chemical signals we cannot smell. Electromagnetic fields guide migration in ways we barely understand. NatureHCI must develop methods for engaging with these hidden dimensions of nature. This might require technological mediation, for example using sensors to translate ultrasonic bat calls into human-audible frequencies or chemical signals into visual patterns. But such translation raises questions about representation and meaning. How do we ensure translations preserve rather than distort non-human experiences? How do we avoid imposing human interpretive frameworks on fundamentally different ways of being?

Working iteratively with non-human stakeholders presents additional challenges. In human-centered design, we prototype, test, gather feedback, and refine. But how does a tree provide feedback on a design? How do we know if our interventions benefit or harm ecosystem health? NatureHCI needs new protocols for iterative design with non-verbal, non-human participants. In this regard, we can learn from other disciplines. For example, some researchers explore behavioral indicators: does wildlife approach or avoid installations [37, 35]? Do plants thrive or struggle in proximity to technologies[34, 15]? Others investigate physiological measures such as stress hormones in animals, growth rates in plants, and diversity indices in ecosystems [49]. Still others pursue more speculative approaches such as attempting interspecies communication through shared substrates like mycelial networks or water flows [39].

In summary, NatureHCI researchers need to identify appropriate constructs and measures to design for non-human wellbeing, which may require deep collaboration with ecologists, ethologists, and conservation biologists. To start advancing this challenge, researchers can investigate how to recognise risks and potential benefits of technology to non-humans, how to develop tools to navigate and represent knowledges about specific places, flora, and fauna and how to develop guidance to help designers select between, combine, and effectively deploy a range of methods to investigate the needs of non-humans.

7.2 The Challenge of Technology Innovation for Nature Interactions

We discussed the core challenges of developing NatureHCI systems, technologies that could coexist with, rather than resist, natural environments. Instead of assuming that existing devices could simply be adapted for outdoor use, we exposed how current technological infrastructures fundamentally fail in nature. When mapping breakdowns of conventional technologies in the wild, we realised that electronics designed for controlled indoor environments succumbed to water infiltration, temperature fluctuations, and UV degradation. Technological interventions have also shown how plastics cracked, metal connections loosened, and animals damaged or displaced equipment during in the wild studies. Additionally, biological growth, from algae to fungi, tend to obscure sensors and solar panels. These failures reveal an implicit anthropocentric assumption: that nature is a hostile backdrop to be resisted, rather than a collaborator in design. These challenges became the foundation to reflect on a set of development principles for nature-robust systems. Devices must “breathe” without leaking, withstand temperature extremes without active control, and either repel or harmonize with biological growth. They must also be resilient to animal curiosity – coexisting unobtrusively within ecosystems. Yet, robustness alone is insufficient.

Natural dynamics are not merely obstacles, but potential resources for innovation. For example, could dew be harvested for cooling? Could daily temperature swings drive thermoelectric energy? Could plant movements generate cryptographic randomness? We believe NatureHCI researchers can start exploring these questions to understand how to leverage environmental variability, and open up new NatureHCI horizons. Among the most pressing challenges we identified was energy autonomy. Conventional batteries violated leave-no-trace ethics and require replacement, while solar cells depend on rare materials. We consider that NatureHCI researchers need to explore alternative energy pathways, such as piezoelectric rain capture, microbial fuel cells, and gravitational energy storage. Although individually modest, these methods hinted at hybrid low-power ecosystems for sustainable computing.

Finally, the problem of communication in connectivity-scarce environments was a recurrent topic. Without cellular or stable satellite links, we see the need to investigate delay-tolerant interactions and opportunistic networking, where data travels through humans, animals, or natural signals such as bioluminescence or plant electrophysiology. These unconventional approaches could prioritize integration and endurance over immediacy.

Overall, developing technology for NatureCI demands more than technical fixes; it requires rethinking the relationship between technology and the living world. Hence, NatureHCI researchers could start addressing this challenge by investigating a research agenda spanning material resilience, ecological energy systems, bio-hybrid computing, and distributed communication.

7.3 The Challenge of Evaluation and Assessment of Human-Nature Interactions

How do we know if NatureHCI interventions succeed? Traditional HCI evaluation methods [30], such as usability tests, performance metrics, and user satisfaction scores, fail to capture the complexity of human-nature relationships. Natural settings resist laboratory control. Effects may take years to manifest. Success might mean different things to humans, non-human organisms, and ecosystems. Hence, there is a lack of knowledge on how NatureHCI can develop evaluation approaches that are adequate to this complexity.

We recognize that standard HCI evaluation assumptions don't hold in natural settings. Controlled experiments require controlling variables, but nature resists control. Replication requires consistent conditions, but no two forests are identical. Statistical power requires large sample sizes, but deploying hundreds of devices might harm the ecosystems we are trying to help. Particularly, longitudinal evaluation presents special challenges. While a usability study might last hours, understanding NatureHCI's impacts might require years [9]. For example, does a technology that initially increases nature connection maintain that effect over time? Do systems deployed to support conservation actually improve ecosystem health? These questions cannot be answered through brief studies.

NatureHCI researchers could adapt methods from ecology and conservation biology, using before-after-control-impact designs that compare sites with and without interventions over extended periods [12]. Moreover, NatureHCI researchers have started to employ adaptive management approaches that treat deployment as an ongoing experiment, continuously adjusting based on observed outcomes. Another evaluation method is to explore participatory evaluation where communities define success metrics based on local values and monitor progress themselves [47].

Although multi-stakeholder evaluation frameworks attempt to address the benefit balance between human-nature relationships by assessing impacts across different groups [5], such as humans of various backgrounds, different species, and ecosystem processes; this multiplies complexity. For example, it is unclear how do we compare stress reduction in humans against stress increase in wildlife [56, 38], or how do we balance indigenous cultural values against scientific conservation goals?

The challenge of assessing human-nature relationships extends to developing new constructs and measures specific to NatureHCI. Existing scales for nature connection, developed primarily through correlational studies [14], may not capture how technology mediates the novel interactions NatureHCI designers are proposing. Hence, we need new instruments sensitive to the unique dynamics of technologically mediated nature experiences. Some researchers have explored novel evaluation approaches aligned with NatureHCI's values. Phenomenological methods attempt to capture the qualitative richness of nature experiences [57]. Multispecies ethnography follows effects across human and non-human participants [13]. Arts-based methods use creative expression to surface impacts that resist quantification [6]. These approaches sacrifice traditional notions of objectivity for deeper insight into lived experience.

In summary, to start addressing this challenge, NatureHCI researchers can start investigating how to develop reliable, nuanced methods to assess how technology impacts a person's subjective experience of spending time in nature, how to continue to evolve methods and tools to evaluate impacts on nature connections, and develop new methods, scales, and evidentiary standards for multidisciplinary evaluation of non-human impacts, drawing on environmental assessment, life-cycle assessment, and more-than-human methods.

7.4 The Challenge to Design Rich, Embodied and Multisensory Experiences in Nature

Nature experiences are inherently multisensory and embodied, yet digital representations of nature and mediated experiences are frequently criticised for their sensory and affective impoverishment, lacking the richness and embodied depth of direct encounters [58]. This gap poses a major challenge for NatureHCI, which seeks not only to enhance sensorial and

embodied experiences through technology, but also to extend human perception beyond its natural limits. While such extensions offer possibilities for deeper understanding and connection with nonhuman worlds, they demand speculative and epistemic leaps to imagine, sense, and represent the life-worlds of nonhumans – what Jewitt et al. describe as “an entangled digital umwelt” [25].

A central difficulty lies in the visual bias of digital media. There is growing critical recognition that digital representations of the world privilege the visual [25, 40], but nature experiences are multisensory and embodied. Studies have begun to incorporate varied sensory experiences into virtual nature experiences, most commonly smell [63, 31, 52]; and touch [51]. This is important because multiple sensory pathways are (probably) involved in benefits of nature experiences [17], especially sound, smell, taste, touch. However, integrating these modalities in coherent, contextually responsive ways remains an open challenge.

More-than-human design frameworks push these concerns further by treating embodied encounters with animals, plants, weather, and land as active design materials rather than static contexts. For example, [3] highlight Indigenous concepts of relational accountability and embodied co-presence with land in participatory design. In this vein, work at the intersection of NatureHCI and OutdoorsHCI foregrounds the locative, embodied interactions of hikers, runners, etc. with their environment [27]. Rao et al. [45] call for reconceptualisation of smart building design around biophilic interactions, in ways that promote greater attention to embodied sensations and diverse sensory experiences. Still, the challenge persists: how can technologies genuinely attune us to more-than-human bodies and environments, rather than abstracting or instrumentalising them? Emerging work in HCI has started to surface hidden dimensions of embodiment by exploring experiences below the threshold of consciousness. For example, recent work has explored the possibility of surfacing human-gut interactions for reflection, well-being and “visceral conversations” [42], and circadian rhythms [2]. Notably, more research is needed into the multisensory pathways involved in beneficial nature experiences and [17]. For example, despite HCI attention to the experience of being in forests [41] and broader research into forest bathing, there is a lack of HCI research exploring interactions with phytoncides (antimicrobial volatiles emitted by plants) [17]. These omissions underscore a broader challenge: to design for sensory modalities and ecological processes that lie beyond conscious perception.

Jewitt [25] calls for a reimagining of digital communication technologies beyond the audiovisual paradigm, shaped by diverse cultural and ecological perspectives. This entails developing expanded, multisensory communication models, incorporating haptic, olfactory, and environmental sensing, to foster deeper forms of co-presence and more-than-human sociality. Through speculative and participatory design, NatureHCI can thus begin to map new sensory worlds – a “digital umwelt” that does not merely replicate human experience but reconfigures communication across species and ecologies. Within this broader agenda, sound emerges as a particularly promising yet underexplored frontier. As Bakker [7] illustrates, digital listening technologies are already transforming our ability to connect with elephants, sperm whales, bats, and bees, revealing how acoustic mediation might serve as a bridge toward richer, more reciprocal relationships with the more-than-human world.

Overall, NatureHCI researchers could start addressing these challenges by investigating how we can reimagine technologies for new ways of communicating and living with the more-than-human world and by creating methods and toolkits that support designers in engaging with the perceptual worlds of non-humans.

7.5 The Challenge of Leave-No-Trace Design

The technology industry's design ethos – rapid prototyping, constant iteration, and planned obsolescence – conflicts sharply with environmental ethics of minimizing impact [59]. Each discarded prototype embodies hidden costs: rare earth elements extracted through destructive mining, water-intensive data center operations, and electronic waste accumulating in ecosystems. For NatureHCI, this tension raises a central challenge: how can interactive systems be designed in alignment with leave-no-trace principles?

Addressing this requires rethinking core assumptions of the design process. Conventional HCI practices rely on disposability, assuming prototypes can be easily replaced or discarded. Yet in natural settings, there is no “away” – everything remains within ecological cycles. Researchers argued that design methods must evolve to prevent technological residues from persisting in the environment [26].

One approach involves prolonging low-fidelity prototyping. Rather than moving quickly to electronic models, designers could work longer with natural materials such as branches, grasses, clay, and sand – materials that can safely return to ecosystems when discarded. This extends design experimentation while reducing environmental footprint.

However, many NatureHCI systems depend on computational components that resist such substitution. This highlights the challenge of developing biodegradable electronics, including cellulose-based substrates, protein-derived polymers, and carbon conductors from renewable sources. Though still experimental, these innovations suggest pathways toward ecologically compatible computation [36].

Energy systems pose another critical difficulty. Conventional batteries and solar panels rely on toxic materials and complex manufacturing. NatureHCI researchers explored alternative, low-impact energy sources – wind, water flow, temperature differentials, microbial metabolism – each producing modest power but aligning with natural energy rhythms.

More radically, leave-no-trace might mean leaving no physical trace at all [60]. Could NatureHCI exist purely in software, using devices people already carry? Could interactive installations biodegrade or self-dismantle after use, ensuring full reintegration with their environment? Designing for disassembly and reuse further supports circular material lifecycles.

Finally, researchers emphasized that sustainability should not only minimize harm but also actively contribute to ecosystem health. Drawing on regenerative design, NatureHCI could envision systems that provide habitat, filter water, or enrich soil while sensing or computing. The goal thus shifts from leaving no trace to leaving beneficial traces – where technology becomes a participant in ecological regeneration rather than a source of waste.

7.6 The Challenge of Cultural Perspectives

NatureHCI risks perpetuating colonial patterns if it assumes universal relationships between humans, nature, and technology. Different cultures hold radically different concepts of what nature is, how humans should relate to it, and what role technology should play [29, 61]. How does NatureHCI respect and support this diversity while building coherent knowledge?

The challenge begins with recognizing that “nature” itself is a cultural construct. Many indigenous languages have no word separating nature from culture – the divide that seems fundamental to Western thought simply doesn't exist [46]. Some cultures see nature as kin requiring reciprocal relationships. Others view it as a resource for human use. Still others understand nature as teacher, adversary, or manifestation of the sacred [29, 20]. These different understandings lead to different technological approaches. A culture viewing nature

as kin might develop technologies facilitating communication and care. One seeing nature as teacher might create technologies for observation and learning. These aren't just different applications of neutral technology but fundamentally different technological paradigms.

Consider how different cultures approach the question of whether technology belongs in natural settings. Some embrace any tool that deepens understanding or connection. Others maintain strict boundaries between technological and natural spaces. Some integrate new technologies into traditional practices. Others see technology as inherently alienating from natural relationships. NatureHCI cannot assume any single approach is correct [21].

This challenge requires developing what we might call “ontological flexibility” – the ability to work within different worldviews without imposing our own. This goes beyond surface-level cultural sensitivity to engaging with different fundamental assumptions about reality. It means recognizing that other knowledge systems aren't primitive versions of Western science but sophisticated ways of understanding that may grasp aspects of nature that Western approaches miss [29].

Indigenous knowledge systems offer particular insight for NatureHCI [1]. Many indigenous peoples have developed sophisticated technologies for living sustainably within specific ecosystems over millennia [10]. These technologies – from fish weirs that selectively harvest while maintaining populations to controlled burns that enhance ecosystem health – demonstrate deep integration between human needs and natural cycles. They suggest possibilities for NatureHCI systems that work with rather than against natural processes.

But engaging with indigenous knowledge raises critical questions about intellectual property, benefit sharing, and cultural appropriation [11]. Too often, Western researchers have extracted traditional knowledge without reciprocating benefits or respecting cultural protocols. NatureHCI must develop ethical frameworks ensuring that collaboration genuinely benefits indigenous communities rather than exploiting their knowledge.

The challenge extends to supporting multiple cultural approaches within single systems. A NatureHCI platform might need to accommodate users who want detailed scientific data alongside those seeking spiritual connection, those focused on resource extraction alongside those practicing reciprocal care. Rather than averaging these differences into bland universality, how do we create systems that support multiple valid approaches?

7.7 The Challenge of Accessibility and Inclusion in Nature

Accessibility and inclusion are essential to ensure that everyone – regardless of physical, cultural, or socio-economic background – can engage with nature through technology. NatureHCI offers a unique opportunity to augment, mediate, and transform nature experiences for people who face systemic barriers to access, including physical impairments, mobility constraints, exclusion of Indigenous knowledge systems, and inequitable resource distribution [22, 55].

However, designing inclusive nature-based technologies is far from straightforward. NatureHCI's mission, to explore and shape human–technology–nature relationships, positions it to address such barriers, yet research in this area often assumes normative bodies, capabilities, and contexts, inadvertently marginalizing those whose connection to and stewardship of nature are most vital [54]. To ensure equitable participation, NatureHCI must consider constraints such as cost, time, mobility, policy, and uneven technological access. Without deliberate attention, the field risks reproducing the exclusionary patterns observed in other HCI domains.

The challenge is systemic. Barriers to accessing both nature and technology are rooted in structural inequities, including policies, infrastructure, and socio-economic disparities that cannot be solved by isolated technological interventions [53]. For example, even individuals without impairments face economic and geographic barriers to aquatic recreation [24], where equipment and travel costs restrict access to coastal or freshwater environments. Meanwhile, aquatic ecosystems are often home to Indigenous and Aboriginal communities for whom tourism-based or recreational engagement may represent a cultural and environmental trade-off [48]. Thus, accessibility in NatureHCI cannot rely on a universal model; it must account for diverse and context-specific needs.

In the broader HCI community, research on disability and accessibility has advanced significantly in recent years, particularly around ageing, mobility, and visual impairments, yet NatureHCI research remains fragmented, often limited to specific sites, abilities, or technologies. Examples include voice descriptions for nature imagery to aid visually impaired users, or Alsaleem et al. (2020)'s work on augmented navigation for paraplegic skiers [4]. Studies addressing social interaction phobias [43] and virtual nature experiences [28] demonstrate potential to expand accessibility for those with mobility or socio-economic constraints, though such approaches are still emerging.

To move forward, NatureHCI researchers could start investigating how to balance nature access and environmental protection by partnering with local communities. For example, in Colombia, a conservation area alternates open-access tourism periods with closures for ecological recovery [62]. Researchers can also examine how intersecting barriers, disability, mobility, economic, and policy constraints, jointly shape accessibility to both technology and nature, and how to engage with people experiencing accessibility barriers to co-design meaningful, self-directed engagements with nature.

In summary, addressing accessibility and inclusion in NatureHCI requires rethinking beyond individual devices or interfaces toward reshaping the systemic conditions that determine who can access and benefit from nature–technology interactions. Through collaboration with Indigenous leaders, policymakers, and local communities, NatureHCI can create frameworks that open both nature and technology to those historically excluded from them.

7.8 Synthesis: Challenges as Invitations

These grand challenges interconnect in ways that prevent addressing them in isolation. Designing for non-human stakeholders requires cultural sensitivity to different ways of understanding non-human agency. Leave-no-trace design must account for unpredictability that might damage delicate prototypes. Evaluation methods must assess impacts across stakeholders while respecting cultural differences in what constitutes benefit or harm.

Rather than viewing this interconnection as complication, we might see it as invitation to develop truly integrated approaches. The challenges call for new forms of collaboration crossing disciplinary and cultural boundaries. They demand methods that work with rather than against complexity. They require patience, humility, and acceptance of irreducible uncertainty.

Most fundamentally, these challenges invite us to reconsider HCI's basic assumptions when applied to nature contexts. The field's roots in making technology useful and usable for humans may need fundamental expansion to include making technology beneficial for the more-than-human world. This doesn't mean abandoning human-centered values but situating them within larger ecological contexts.

The challenges also reveal NatureHCI's potential contributions beyond specific applications. By grappling with non-human stakeholders, the field pushes HCI to consider more diverse forms of agency and intelligence. By addressing temporal mismatches, it explores how technology might support rather than accelerate human relationships with time. Engaging cultural diversity demonstrates possibilities for pluralistic rather than universal design.

Perhaps most importantly, these challenges position NatureHCI as a field of hope in the anthropocene [44]. Rather than depicting technology and nature as inevitably opposed, they outline possibilities for beneficial integration. Rather than lamenting what's been lost, they focus on what might be cultivated. Rather than prescribing single solutions, they embrace the diversity of approaches needed for diverse contexts.

As participants repeatedly noted during the seminar, these truly are “grand” challenges – they will not be solved by single researchers or even single institutions. They require sustained collective effort over years and decades. But their grandness also makes them worthy of our best efforts. In addressing them, we address some of the most pressing questions of our time: How can humanity live sustainably on Earth? How can technology serve rather than subvert ecological wellbeing? How can diverse cultures collaborate while maintaining their distinctiveness? The challenges thus serve not as discouragements but as beacons, guiding NatureHCI toward futures where human and natural flourishing support rather than oppose each other.

8 Research Agenda and Future Directions

The seminar's final sessions transformed insights and aspirations into concrete plans. Participants recognized that without specific commitments, even the most inspiring discussions would dissipate upon returning to daily academic pressures. The research agenda that emerged balanced an ambitious vision with pragmatic steps.

8.1 Immediate Actions and Short-term Priorities

Before leaving Dagstuhl, participants made specific commitments with deadlines and designated leads. The immediate priority was submitting a comprehensive grand challenges paper to CHI 2026. Unlike typical conference papers authored by small teams, this would represent the full community's collective intelligence. Writing groups formed around each major challenge, with coordinators ensuring coherence across sections. Monthly video calls would maintain momentum, with drafts circulating for feedback. The paper would acknowledge all seminar participants as contributors while identifying core authors who led writing efforts.

Establishing NatureHCI's presence at major conferences emerged as another immediate priority. Beyond the grand challenges paper, participants committed to proposing workshops at CHI, DIS, TEI, and Ubicomp. Each workshop would focus on different aspects, such as methods, ethics, technology, and applications, while building toward a coherent research program. Workshop proposals would be coordinated to avoid overlap and ensure progression across venues.

The methods repository is aimed to be launched by December 2025. Rather than waiting for perfect infrastructure, they would begin with a simple shared platform, adding sophistication as the collection grew. Each method would include theoretical grounding, practical instructions, case studies of use, and reflections on limitations. Review processes would ensure quality while encouraging experimentation.

The Augmented Animals Special Interest Group emerged unexpectedly from a final-day comment that captured imaginations. When organizer Inami suggested that “augmented humans are now too small, maybe we can say augmented animals,” participants immediately began envisioning possibilities. Unlike other groups that formed early and met throughout the week, this group crystallized in the final hours, demonstrating the seminar’s generative environment. Despite forming late, the group generated remarkable momentum. They planned a workshop at the Augmented Humans conference to explore the concept further. They identified potential collaborators in veterinary science, wildlife biology, and animal cognition. They drafted ethical guidelines specific to animal augmentation. Most importantly, they demonstrated how NatureHCI could radically expand conceptions of who benefits from interactive technology.

8.2 Medium-term Development

Over the next two to three years, participants envisioned the gradual institutionalization of NatureHCI within the HCI community. This development may begin through special tracks or workshops embedded within established conferences, with the longer-term goal of forming a dedicated symposium. In parallel, academic programs could introduce NatureHCI content into curricula, initially through special-topics seminars and subsequently through certificate programs or specialized degree pathways.

Research infrastructure is expected to expand from individual projects toward shared and sustained resources. Field stations designed for NatureHCI research could provide controlled environments for longitudinal studies. Distributed sensor networks would enable cross-site data comparison, while fabrication facilities focused on sustainable prototyping and materials innovation would support experimental development. Although these initiatives would require substantial investment, they would establish the foundation for systematic, interdisciplinary research.

To sustain this growth, participants identified the need for diversified funding strategies. Large-scale collaborative grants could support infrastructure establishment and shared datasets, while smaller grants may foster exploratory or proof-of-concept projects. Partnerships with industry may provide technical or material resources, contingent on maintaining research independence. Foundation and philanthropic support could address equity, conservation, and community engagement goals, while government agencies may recognize NatureHCI’s relevance to climate resilience, environmental stewardship, and public health.

8.3 Long-term Vision

Looking toward 2035, participants envisioned NatureHCI evolving from an emerging topic into an established research field with measurable social and ecological impact. Its principles would be embedded in mainstream technology design, where ecosystem considerations accompany user experience. Conservation organizations would routinely employ NatureHCI methods, and universities would graduate researchers fluent in both computational and ecological thinking. At a broader level, NatureHCI was imagined to contribute to transformative shifts in human–nature relations. Technologies designed with its principles would enable urban populations to sustain connections with nature, while supporting rural and Indigenous communities in sharing local knowledge and maintaining cultural integrity. Global sensor networks could advance ecosystem understanding while upholding data sovereignty and ethical

governance. By this stage, the field would have developed robust theoretical, methodological, and ethical frameworks for studying and designing technology in natural contexts. Crucially, NatureHCI would exemplify alternatives to extractive technology paradigms, fostering reciprocity rather than exploitation, sustainability rather than consumption, and connection rather than separation. Through such approaches, the field would demonstrate how technology can participate in regenerative rather than destructive relationships with the natural world.

8.4 A Living Agenda

Participants emphasized that the NatureHCI research agenda should remain a living framework rather than a fixed plan. Regular community gatherings would reassess priorities in light of emerging insights and changing environmental contexts. Inclusivity was seen as essential – actively welcoming new voices to sustain diversity and prevent institutional stagnation. Equally important was a commitment to transparency: acknowledging and learning from failures while sharing successful practices openly across the community. This adaptive orientation drew inspiration from ecological principles. Like resilient ecosystems, the research community would thrive through diversity, flexibility, and collaboration. Such a structure would enable NatureHCI to evolve organically and sustain long-term inquiry across disciplines and geographies.

Ultimately, participants described NatureHCI not merely as another research domain, but as a collective response to broader planetary challenges. The agenda embodies a commitment to engaged, responsible scholarship that bridges technology, ecology, and society – establishing both a shared sense of purpose and a practical foundation for continued development.

9 Conclusion: Seeds Planted at Dagstuhl

As participants prepared to depart Schloss Dagstuhl on the final morning, a palpable sense of accomplishment mixed with anticipation filled the air. The week had exceeded expectations, transforming thirty individuals with overlapping interests into a coherent community with shared purpose. Yet everyone recognized this was beginning rather than culmination – seeds planted that would require careful tending to flourish. Finally, the contributions of this seminar are: **Intellectual Contribution:** The seminar defined NatureHCI as the study of how interactive computing mediates human–nature engagement, distinguishing it from both OutdoorHCI and SportsHCI. A grand challenges framework outlined enduring research tensions, such as designing for nonhuman stakeholders and aligning prototyping with leave-no-trace ethics. Methodological innovations like phenology circles and multispecies personas demonstrated that new epistemic approaches are required, not mere adaptations. Cross-disciplinary integration enriched understanding, linking computing, design, ecology, and Indigenous knowledge. **Community Formation:** The event transformed shared interest into an emerging research community. Working groups coalesced into functional teams, strengthened by global diversity in geography, discipline, and career stage. Participants emphasized maintaining openness and inclusivity by recruiting underrepresented voices, ensuring the field remains plural rather than exclusive. **Practical Outcomes:** Concrete outputs ensured momentum: a CHI 2026 grand challenges paper, a methods repository, and pilot studies to test ideas across contexts. These pragmatic activities, such as publishing, teaching, funding, were recognized as essential for institutionalizing NatureHCI. **Challenges Acknowledged:**

Participants noted systemic obstacles: academic incentives favoring individual over collective work, disciplinary funding silos, and the urgency of environmental change. Ongoing tensions, innovation vs. environmental critique, universality vs. locality, were reframed as productive forces sustaining intellectual vitality. Vigilance against commercial co-optation was deemed crucial to preserve the field's ethical grounding.

Ultimately, the seminar's legacy lies in cultivating a field that unites technological innovation with ecological care, laying the foundation for sustained, responsible research into human–technology–nature relations.

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