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Engaging with Nature through Technology: a Scoping Review of HCI Research

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Technological progress has often been measured by the extent to which it shields and protects us from the harshness of nature. At the same time, it has long been recognised that our resulting disengagement from nature negatively affects our wellbeing, and impedes the awareness of our vital dependence on natural environments. To understand how HCI has considered the possibilities that digital technology offers for engaging with nature, we conducted a scoping review encompassing more than 20 years of HCI research on nature engagement. We compare the orientations, motivations, and methodologies of different threads within this growing body of work. We show how HCI research has enabled varied forms of direct and indirect engagement with nature, and we develop a typology of the roles proposed for technology in this work. We highlight promising and under-utilised approaches to designing for nature engagement, and discuss directions for future research.

CCS CONCEPTS • Human-centered computing ~ Human computer interaction (HCI) ~ HCI theory, concepts and models

Additional Keywords and Phrases: nature, nature engagement, scoping review

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1 INTRODUCTION

Technological development in the industrialised world has gradually removed people from nature, reducing their environmental understanding, awareness and appreciation. At present, over 50% of the global population lives in cities, and this proportion is predicted to grow to nearly 70% by 2050 [172]. Digital technology is often seen as continuing our disconnection from nature through "extinction of experience" [50,147], with excessive screentime and absorption in digital

media blamed for people spending less time outdoors and correspondingly paying less attention to physical surroundings. At the same time, the value of providing better access to natural environments through designed interventions has been promoted in such diverse arenas as urban planning and architecture, health and psychology, and the ecological and environmental sciences. Identifying opportunities for digital technologies to contribute to public *re-engagement* with nature is of growing interest to technology designers and researchers who wish to redress the balance.

In this paper we present a scoping review of work in HCI over the past 25 years that seeks to understand and renew people's relationship with nature and natural environments. Key examples of this work include studies of tools to support learning about ecology in the classroom [145] and in the wild [133], and technology-enabled citizen science that broadens participation in ecological monitoring to address environmental issues [41,53,121]. Further, there have been several workshops that have focused on specific aspects of nature engagement (e.g., [56,57,70]) and some notable but partial surveys and critical reflections on specific topics such as technologies for children's interactions with nature [5], digital design in 'natural places' [14] and design for gardening [132]. However, to date there has not been a broad survey of work done on nature engagement by HCI researchers and the theoretical and practical perspectives that HCI has brought to bear.

One of the challenges facing a review of research in this area is that much relevant work is being done in neighbouring disciplines, such as psychology [150], health [18] and environmental social sciences [86]. However, we believe that it is important and valuable to first understand what has been contributed through the unique perspectives and methodologies of HCI. By focusing on HCI publications over the past quarter of a century, our scoping review aims to identify (1) the overarching theoretical perspectives on human-nature-technology relationships taken by existing HCI research, and (2) ways that digital technologies are being deployed to support nature engagement in HCI. Our scoping review contributes the following:

- a first analysis of how the field of HCI has investigated digital technology for human engagement with nature;
- a typology of forms of nature engagement using the dimensions of *directness* and *distance*, and a typology of the roles played by digital technologies in nature engagement;
- informed suggestions on directions for future research on the theory and design of technologies for nature engagement.

2 BACKGROUND

Before turning to our survey, in this section we briefly identify what we consider to be significant elements of the broader historical and conceptual context of work on nature engagement in HCI.

2.1 Technology and Human-Nature Relations

The effect of technology and modernity on human-nature relations is a topic of long-standing significance in philosophy, the humanities, and the arts, with renewed and pressing importance in the era of ecological crisis. Notions of human separation from nature, as a consequence of tool-making, inventions and science, can be traced back to early writers such as Gilgamesh [11] and to ancient Western philosophers such as Plato [1:63]. In recent decades, such thinking has been taken up by philosophers [116], historians [169] and ecologists [162]. Recurrent themes are that human artefacts, constructions and systems have enabled us to subjugate nature, and ultimately removed us from the natural world altogether. For some, the separation from nature is seen to have commenced with the first development of tools [16] while others argue that it began with the emergence of writing [1], farming [141] or the Medieval antecedents to industrialisation [169]. During the Age of Enlightenment in Western societies, prevailing Cartesian notions of an essential split between the realms of mind and the material body positioned humans as separate from, and superior to, nature and other animals.

Such concepts provided a foundation for modern scientific thinking and the rise of technology and industry. Indeed, Adorno & Horkheimer described the Enlightenment as being "founded upon the drive to master and control nature" [63], and the expansion of Western scientific modes of thinking and associated technologies as a program of "disenchantment of nature" [63].

Running in parallel with this long history of disconnection from nature, there has been a counter flow of ideas and design initiatives aimed at reconnecting modern societies with natural environments. These include the widespread creation of National Parks and urban parkland, including zoological and botanical gardens, as spaces for public recreation, healthy exercise and education [12], and the concurrent evolution of nature tourism [124]. Art and cultural media have long endeavoured to bring wild nature to civilized populations. A common theme in Romantic art is the portrayal of unpredictable nature [42], and Victorian literary authors such as Thomas Hardy explored interconnections between ancient, natural landscapes and rural life in an era of mechanisation and upheaval [115]. Many town planning and architectural movements in the 20th century, such as Frank Lloyd Wright's "Organic Architecture", have aimed at harmonious integration of the built environment with natural surrounds [38], and in recent decades have evolved to incorporate "biophilic" elements [77] and "ecological" sensibilities [164]. Contemporary nature documentaries present anthropogenic threats to the planet [69], while essayists have drawn attention to the rough "edgelands" [142] at town fringes, highlighting the shifting boundaries between natural and urban places [47].

The recent expansion of digital technologies is seen by many as continuing and exacerbating the disenchantment of nature described by Adorno and others, now re-expressed through notions such as the "extinction of experience" [147]. Within such narratives, screen-based technologies and digital entertainment are liable to reduce time spent outdoors amongst young people in particular [27]. Such concerns intersect with popular efforts to reduce or reject use of networked technologies, from "digital detoxes" to off-grid lifestyles [119,139,157].

A growing array of digital initiatives inherit from the lineage of efforts to provide people with opportunities to re-connect with and experience nature. There is a now an expanding body of HCI research on this topic, encompassing a wide range of technologies developed and applied with various objectives, including human wellbeing, education and ecological awareness, scientific projects and conservation.

2.2 Perspectives on Nature Engagement

Having identified key ideas from broad histories of technology's influence on human engagement with nature, we turn now to how human-nature engagements have been conceptualised and studied. The ways in which people seek to engage with nature are shaped by prevailing sociocultural understandings and orientations. The rise of science during the Enlightenment placed a new emphasis on observing and explaining natural phenomena. This led to various innovations in Western countries, such as the 19th-century tradition of naturalism as an amateur pursuit and as a component of school education. In this tradition, direct experience of nature is regarded as a virtuous pastime and critical to children's learning [49,98]. In recent decades this thinking intersects with environmentalism, and growing acknowledgement and evidence that contact with nature, and feeling part of nature, are essential to forming the attitudes and behaviours required to address our ecological crisis [20]. Other research has explored the association of nature experiences with *place attachment* [84], and with *environmental identity* [123], giving rise to new measurement scales, including the *New Ecological Paradigm* [43], the *Connectedness to Nature* scale [96], and measures of *biospheric values* [54,95].

The value of spending time in nature for personal and collective wellbeing has been studied and theorised in multiple ways. *Attention Restoration Theory* proposes that entering an environment which does not require directed attention (such as natural settings) allows for restoration of performance, and perhaps subjective wellbeing [73]. An alternative framework,

Ulrich's psycho-evolutionary *Theory of Stress Reduction* [163], outlines the way in which pleasing natural environments act upon nervous systems to increase wellbeing, and reduce anxiety or stress. Both of these theories draw on the biophilia hypothesis, the notion that people are inherently drawn to connections with the natural world [78]. Therapeutic interventions involving visiting nature, such as *wilderness therapy* [134], are now receiving substantial scholarly attention, with *forest bathing* found to be effective in reducing stress indictors, as compared to relaxation in urban environments [111].

In a similar vein, environmental and social scientists have drawn attention to the negative effects of our diminishing experiences of nature, through notions such as the *extinction of experience* [147], and Louv's broader formulation of *Nature Deficit Disorder* [91], both related to the disconnection of modern urban societies from the natural world. This body of work also suggests that attitudes to nature are shaped not only by direct contact but also by "vicarious" experiences, such as reading books, watching televisual media, or discussing nature with friends or family [148]. This quality of the directness or indirectness of nature experience foreshadows an important dimension in the survey of HCI studies that we present in this paper.

The understanding of nature as a place that people can visit, directly or indirectly, is underpinned by the deep-rooted concept of an ontological divide between humans and nature, which is being challenged by recent transdisciplinary perspectives. The notion of "natureculture", introduced by Donna Haraway, and broader notions of ongoing interspecies entanglements [60,85,126] have been taken up by scholars in multiple disciplines. The concept of human-nature inseparability is increasingly influential in HCI scholarship which seeks alternatives to exploitative and capitalist orientations in technology design, through paradigms such as socio-ecological relations [25] and "being attentive" [87] to the more-than-human world. Engagement with nature, from this perspective, requires the development of new practices that involve "staying with", "making with" and "arts of noticing", in ways which seek to attend to more-than-human worlds and dissolve boundaries between nature and culture [61,126,161].

We seek to understand how these diverse perspectives figure in HCI research, and how they give rise to different orientations to technology for nature engagement, as part of charting the overall trajectory of this body of work.

3 METHODS

We undertook a scoping review: a methodology used to explore and summarise existing literature relating to broad research questions, and identify research gaps. Scoping reviews are valuable for investigating how a topic has been covered within a heterogeneous body of work which has not previously been comprehensively reviewed [6]. Our review followed Arksey & O'Malley's framework for best practice in scoping reviews. This involved five stages: identifying research questions; identifying relevant articles; selecting articles; charting the data; and collating, summarizing, and reporting results.

3.1 Identifying Research Questions

In undertaking this scoping review we sought to understand how HCI has approached the issue of engagement with nature. Given that *nature* is a contested term and *engagement with nature* is a broad notion with multiple interpretations, we made early efforts to define these terms and thereby set the boundaries of our literature search. We began by adopting a dictionary definition of nature, which was refined during the initial search. This definition corresponds to common usage of the term as used to denote *the natural world*:

> "the phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to humans or human creations" [154].

We initially defined *nature engagement* to involve:

people experiencing, learning about or interacting with nature.

During the literature search we iteratively refined this definition of nature engagement. We responded to the diverse interactions with nature addressed in the HCI research we were reviewing, to clarify our focus on experiences of the natural world, and the understandings and attitudes that are bound up with that. Through the search and the first round of the review, we delineated the definition of *nature engagement* to include:

- sensing e.g. watching or listening to nature;
- capturing, e.g. photographing, video or audio recording nature;
- learning, e.g. understanding ecological processes or learning to identify species;
- analysing, e.g. categorising nature-based media or reflecting on natural phenomena;
- enjoying, e.g. appreciating natural environments or features;
- shaping, e.g. enhancing an environment by removing litter;
- utilising e.g. manipulating natural materials for art or play;
- protecting, e.g. collecting nature data for advocacy;
- and nurturing, e.g. gardening or tending nature sites.

Accordingly, this scoping review does not include all work related to technologies used in natural environments, but rather only those which explicitly address *nature engagement*, as defined above. For example, we include publications on the ideation of hiking equipment to improve the experience of enjoying and photographing nature [4]; the design of digital interventions to support children's interactions with nature in outdoor play [32]; and the intersection of technologies with notions of "mastery over nature" in mountaineering [23]. However, we exclude research on technology for use outdoors that does not give explicit attention to nature engagement, such as an analysis of hikers' digital communities and preparations [82]; a field study examining how digital playground installations intersect with children's games and their social context [8]; and design of collaboration tools for use by wilderness search and rescue teams [68].

The HCI literature encompasses varied conceptualisations of nature which required our initial definition to be further elaborated. Firstly, "the landscape" includes not only "wild" and semi-wild places such as forests and mountains but also urban nature, such as parks and gardens. We identify these latter places as part of nature as they offer valuable opportunities for engaging with the natural world, even if they could be understood to be "human creations". Nature engagement also takes place in homes and other indoor settings, for example through interactions with plants and recordings of local wildlife. Secondly, the expanding body of work on animal-computer interaction (ACI) requires us to consider more closely which animal interactions might comprise nature engagement. In keeping with common understandings of *nature*, we exclude domesticated animals such as pets and farm animals, but include wildlife. Consequently, ACI research that studies companion animals and agriculture is excluded from this survey. In the same vein, we excluded work in which plants are used as input / output or as part of an interactive system and where there was no attention to engagement with plants or the natural world. We also excluded work in which the products and systems of nature are conceptualised purely as resources to sustain human life and societies, such as energy use, food production, recycling and air pollution. Thus we excluded from our survey some work in Sustainable HCI which has been previously surveyed [40,59]. As these definitions were established, we revisited previously reviewed papers to check whether they should be included.

Adopting the definitions of nature and nature engagement above, this scoping review addresses the following research questions:

1. What are the overarching theoretical perspectives on nature engagement that frame HCI research?
2. In what ways are digital technologies being deployed for nature engagement in HCI research?

3.2 Identifying and Selecting Articles

We conducted three rounds of searching and selection of articles. As our aim was to focus on HCI research, we started with an initial search of the ACM Digital Library, which provided a manageable point of entry for the review. We searched all full-text publications of the ACM Digital Library for the terms "nature" and "environmental" in Title and Keyword fields. From the results of this first search we identified venues with publications on this topic that corresponded to our interest in HCI: CHI, CSCW, DIS, IDC, Ubicomp, Proc. HCI, ToCHI, OzCHI, ACI. We scanned keywords and titles to identify additional search terms to include in our second round of article identification: "bird", "wildlife", "animal", "forest", "biodiversity". Secondly, we searched for the additional search terms in Title and Keyword fields of the nine venues named above. We tested several other keywords, including "ecology", "ecological", "outdoor", "tree", "wild" and "wilderness" but found that these were not fruitful in identifying work with a focus on nature engagement. For terms such as "ecology" and "wild" this was largely due to frequent metaphorical usage in the ACM Digital Library corpus. We examined outputs of the NatureCHI workshop series, held at CHI 2016 and MobileHCI 2017 [56–58], to identify relevant works and authors.

Lastly, we examined the reference lists of articles identified in previous searches, and the lists of citing articles (discovered via Google Scholar), to identify additional relevant articles. In keeping with common approaches to scoping reviews, we iteratively developed and refined the criteria for inclusion and exclusion, based on our unfolding mapping of the literature and identification of candidate search terms and sources during the search [113]. We screened all items for relevance based on title and abstract, and during full-text review we checked each item against the following inclusion criteria:

- deals with nature engagement (as defined above), and the use (or potential use) of technology as part of such engagement;
- concerns human-computer interaction, rather than engineering research on computational technologies or methods;

3.2.1Limitation of scope

One effect of our limiting the scope to HCI venues was that the search did not include other related research in neighbouring disciplines such as ecology, environmental social sciences and biology. This aligns with our aim of examining the state of HCI research on this topic but does mean that work on this topic being conducted in other fields is not represented. We acknowledge also that our review reproduces the skew of the HCI literature base towards work conducted in Western, educated, industrialised, rich and democratic (WEIRD) countries. As a result, the review reflects the corresponding orientations of the literature, in terms of the kinds of nature studied and perspectives on nature adopted.

3.3 Charting the Data

Our four-member research team reviewed the selected papers, using the "descriptive-analytical" approach referred to by Arksey et al. [6] as "charting the data". Each paper was assigned to one person, who extracted key information from each paper using two templates. While some papers were relatively straightforward to review and chart, others involved discussion and two or more readings (by different team members) in order to satisfactorily capture the research and theoretical perspectives. The first author developed the initial version of the template, which was piloted by all other

members of the team and amended based on group discussion. This was repeated three more times, adjusting the questions and categories specified in the template to capture the types of research, technology and nature engagement encountered in the literature. Through this process, we created two templates, one for empirical studies and a second for other types of work, such as position papers and surveys. We revisited papers reviewed using early versions of the template so that the final versions of the templates were applied universally. Using these templates, we captured summary data relating to the research questions, along with specific descriptive information about the articles. For example, we recorded the country where the researchers were based, the type of methods used and the aim of the work, the technology proposed and the anticipated users. We compiled the data into an Excel spreadsheet for analysis and summary. Throughout this iterative process the research team met regularly to discuss the scope of the review, definitions and categories.

3.4 Collating and Summarising Results

The first and second authors summarised the extracted data to gain an overview of the extent of the studies in terms of the types of technologies proposed, the types of studies, the geographical distribution and the publication venues. To address our first research question, we examined theoretical perspectives on nature engagement outlined in the position papers and surveys. This was supplemented by an analysis of the perspectives (where stated) underpinning the empirical studies. To address our second research question, we examined the ways in which technologies have been proposed to support different modes of engagement and analysed the papers in terms of the ways that they use technology. From that we identified six categories of roles for technology, described in Section 5. In examining the technologies, we summarised from our charted data:

- intervention types and who they are for;
- motivation and theoretical underpinnings;
- the claims made for this approach;
- evidence provided for claimed outcomes;
- challenges or limitations identified;
- suggestions offered for future research.

4 THE LANDSCAPE OF HCI RESEARCH ON NATURE ENGAGEMENT

In this section, we present results of our analysis based on categories and dimensions defined prior to commencing the scoping review, corresponding to the summary data and information recorded through charting the data.

4.1 Characteristics of the literature

4.1.1Progression of the literature

Our review process captured a total of 103 publications. These range from fully peer-reviewed articles and book chapters involving design research, qualitative work or quantitative investigations, through to artistic works, workshop proposals, literature reviews and position papers (see Subsection 4.3). We charted the number of articles across year of publication and article quality, showing how this literature has grown and changed over time. (Figure 1).

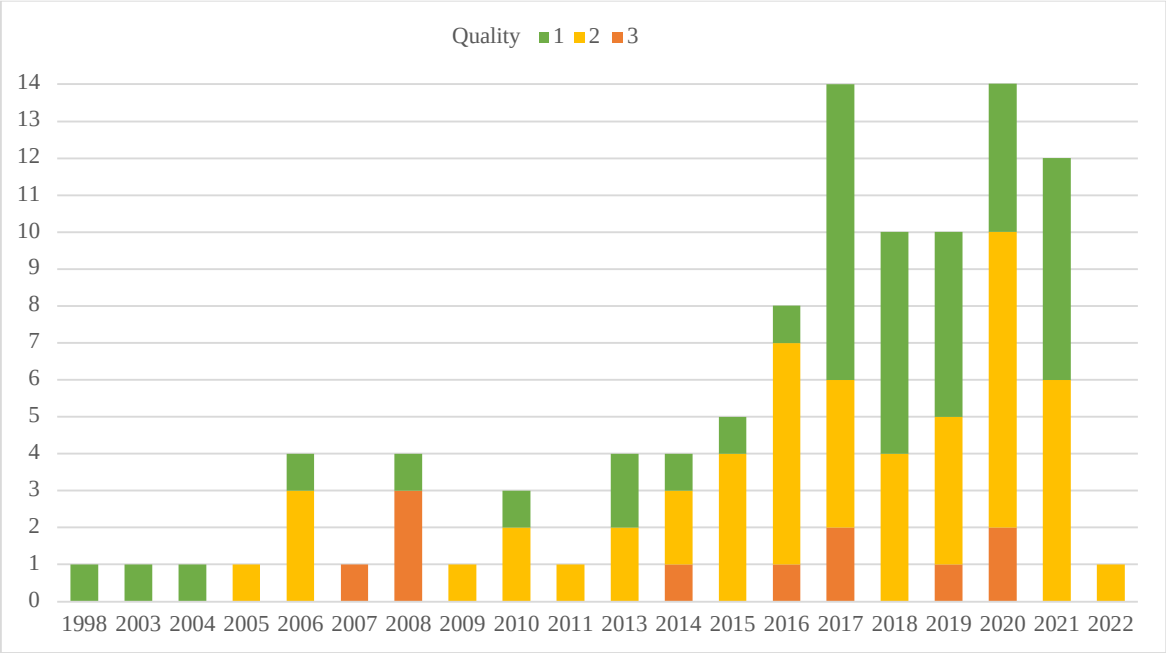

Figure 1: Number of articles across year of publication, by quality, where highest quality was equivalent to a full peer-reviewed paper at a top ranked conference (quality = 1) and the lowest rating signifies lightly peer-reviewed papers (quality = 3)

Our sample comprises papers from 19 different publication outlets. We found that the most popular venues for HCI research on nature engagement are the ACM CHI conference, where 40 of the 103 papers (39%) were published, followed by the ACM conference on Interaction Design and Children (IDC, 15 papers), Designing Interactive Systems (DIS, 8 papers), OzCHI (8) and CSCW (5 papers). Other venues where HCI nature engagement research has been published include conferences such as Animal Computer Interaction (2 papers), Ubicomp and CHI Play (1 paper each), journals such as Personal & Ubiquitous Computing and CSCW (2 papers) the International Journal of Mobile Human Computer Interaction (IJMHCI, 1 paper), as well as book chapters (7) , and articles in Interactions magazine, where 3 articles addressed issues relevant to nature engagement [26,31,121].

The composition of our sample indicates that nature engagement is of interest to researchers across the field of HCI, and that nature engagement has strong representation at CHI, the premier venue for HCI research. The distribution of work across multiple venues indicates that HCI employs a variety of approaches to addressing nature engagement, and that nature engagement can be achieved in different ways. Work presented at DIS, for example, reports designerly approaches to promoting nature engagement [72,109], whereas work at CSCW addresses social forms of engagement with nature [19,131]. One unanticipated finding was the high rate of publication at IDC, due to HCI researchers frequently seeking to engage children with nature in order to encourage children to spend time outside, or encourage exploration and learning.

4.1.2Countries of affiliation

The papers in our sample were authored by authors from 14 different countries. The most prevalent country of affiliation was the USA (42 papers) followed by Australia (24 papers) and the United Kingdom (22 papers). Representing Asia, there

were 6 papers from Japan, 2 from China and 1 each from Tawain and South Korea. 4 papers had Canadian authors, 3 had authors from Namibia and 1 had authors from Panama. The remaining countries were all European: Finland (6), Denmark, Sweden (both 3 papers), Ireland, Germany (both 2 papers), Iceland and Belgium (1 paper each). (For papers with multiple authors, we counted the country of each author; thus the total number of affiliations exceeds the number of papers in our sample.)

This distribution indicates that HCI research on nature engagement has been conducted across the world, but predominantly in Western countries; thus this literature may reflect Western ideals about what qualifies as nature engagement, how that engagement might be achieved, and whether it is appropriate to use technology to mediate engagement with nature. On the other hand, this distribution may simply reflect a broader pattern in HCI research. An interesting question for future research could be to investigate whether different underlying perspectives have influenced the character and acceptance of research on technology-supported nature engagement. It should be noted that an author's country of affiliation does not always reflect the context of research. For example, some papers authored in Australia reported fieldwork in Asian countries, such as Bhutan [36,37].

4.1.3Technologies used

We examined the technologies that were designed, studied or evaluated in the 103 publications. 29 publications did not report on a specific technology, either because they were literature reviews and position papers [5,14], or because they were studies of social practices that lead to nature engagement. For example, O'Hara studied the practice of geocaching and how players become motivated to explore natural environments when looking for hidden caches [102].

Our review revealed that a diverse range of hardware and software for supporting nature engagement has been explored by HCI research. The most common type of device used was a bespoke prototype (28), i.e. novel technologies for nature engagement such as Soro et al.'s Ambient Birdhouse [149], an interactive device that used audio and video recordings of birds to encourage families' engagement with wildlife in their garden. 18 studies used smartphones, 6 adopted tablets such as the iPad and 5 involved user interaction with a computer or laptop, while 4 older studies used handheld devices such as PDAs or an iPod to support exploration of outdoor settings or learning about nature. Specialised applications were included in 28 of the papers, with several papers reporting on GPS-enabled mobile apps for capture of nature media and data, e.g. [105,110,125,135,136]. Other papers examined software for annotation (5) and several included websites or web applications (4). 13 involved data visualisation such as audio spectrograms, 10 comprised games or included elements of gamification, 10 included interactive film or video clips, while 7 used digital maps such as Google Maps. Output modalities, in addition to smartphone, tablet and laptop screens, included audio output (18) and bespoke displays (8). Several studies used virtual and augmented reality, including head-mounted variants (5), mobile AR and VR (4) and virtual 3D worlds viewed on a desktop computer (2). Functionality and hardware components most commonly involved were environmental sensors to measure factors such as sound, light, or moisture (12) [22,83,88], sensors for input (13), GPS (11), cameras for still photography (10) or video (5), and audio recording (7).

4.1.4Users

We categorised the papers according to the envisaged users of the technology described in each paper. For 4 papers no user cohort was specified, for example several workshop papers considered multiple technology types for diverse user groups. Of the remaining papers, 29 involved designing technology for, or with, children. These studies typically involved the design and preliminary evaluation of a technology that aims to stimulate children's interest in nature. In 3 papers, educators such as schoolteachers were involved in the research, while 3 studies involved family members such as parents

in addition to the children. A further 4 publications targeted "households", which can be understood to include children. 23 studies were aimed at designing for the general public. Another 9 focused on supporting the activities of professional nature experts, including ecologists, naturalists, or conservation workers.

The remaining papers addressed a diverse range of specific cohorts. These included zoo visitors (5 publications), people undertaking outdoor recreation (5), remote communities (2) tourists (2), gardeners (2), hunters and forest farmers (2), blind and partially sighted users (2), or office workers (2). 8 papers focused on technology designers or HCI researchers, exploring methods and conceptual approaches for including the natural world. Older adults and college students were mentioned only in 1 publication each.

4.2 Perspectives on HCI and nature engagement

This section describes the overarching theoretical perspectives on nature engagement that frame HCI research on this topic, and charts the emergence of new perspectives reflected in position papers and critical surveys.

4.2.1Nature as the subject matter of biological science

Much of the literature we reviewed focuses on the natural world as an area of scientific study and education, with aims to offer students and scientists new ways to learn about the natural world. Interventions for school students inherit from the tradition of nature study for children, as an important aspect of Western education. An important focus of such work is the opportunity for technology to support direct, hands-on learning and social forms of learning. As archetypal examples, HCI projects such as the Ambient Wood [133], Tangible Flags [24] and EcoRaft [159] employ tangible interactive devices for students to learn collaboratively about nature. Alternative approaches include the use of geo-located applications to learn about nature in situ [136] and use of recording and capture devices to support constructivist, student-centred learning approaches [156].

Reflection on this work has prompted some attention to the ways that these uses of technology may be shaping the practice of ecological science and understandings of nature. Drawing on social studies of science, Jackson et al. [66] highlighted how the expanding computational infrastructure used to conduct ecological science are impacting on field work and the implications for ecology as a vocation. More recently, Pimentel has offered a critical reflection on educational extended reality wildlife encounters, and the potential for negative impacts on public understanding of related issues and conservation outcomes [114].

4.2.2Nature as something to appreciate and protect

Considerable attention has been given to the design and use of technology to expand participation in science and conservation work by enabling the public to help document and protect the natural world. In pace with the broad uptake of smartphones, researchers such as Preece have called for technologies to promote citizen science and involve people in biodiversity projects [121]. An important notion in this vein of work is that nature has inherent value, so that HCI should aim to engage people to care about "nature on its own terms" [5,41], which Bidwell aligns with an "Arcadian" view of nature, and contrasts with resource-oriented perspectives [14]. In line with broader trends in HCI research, a substantial strand of this research explores the interweaving of user engagement, entertainment, social dynamics and cultural context into the design of technologies for citizen science [36,75,109,165]. Some interventions aim to increase time spent in wild or semi-wild places as part of appreciating and protecting them, or collecting data [10,17,99,125]. In contrast, Kobayashi's project to design for human-biosphere-computer interaction at a distance [80] is motivated in part by the aim of reducing

human presence in sensitive nature areas to protect biodiversity. The importance of balancing promotion with protection in the design of technology for nature engagement is noted in reflections on citizen science projects [99,117].

4.2.3Nature as human habitat

Consideration of the particular characteristics of "the outdoors" as a space where humans and non-humans interact with technology has broadened HCI attention to interactions with nature [56,97,168]. Bidwell and Browning draw attention to the anthropocentric and urban-centric perspectives which dominate technology design, and call for more consideration of embodied and affective nature experiences, seasonal variation and temporal patterns of rural life [14]. The importance of nature contact and place attachment is reflected in Coyne's analysis of the ways in which that digital technologies might interrupt people's innate responses to the natural environment [31], in explorations of technology to support nature play [32], and in work which attempts to provide natural stimuli (visual, auditory or tactile) to support psychological wellbeing and social bonding [101,128,140]. Technology use in outdoor activities such as children's play, hiking, climbing and hunting demands renewed design focus on ubiquitous computing that recedes into the background [4,56,70,97,155,171]. For example, Anderson and Jones, guided by Kaplan's attention restoration theory [73], envision unobtrusive digital devices for hikers which allow easy capture of video and automated safety updates to friends back home [4]. There is growing awareness that expanding use of digital technologies for tracking animals in outdoors spaces provides new sites of intersection between the natural world and technology design: "animal-landscape interactions" are now bound up with technological interventions for wildlife [83,168].

4.2.4Natureculture and human-nature entanglements

There has been a notable response in HCI to notions of natureculture and human-nature entanglement, articulated by theorists such as Haraway [60] and Puig de la Bellacasa [126]. This is bound up with an expanding sense that design disciplines are implicated in impending environmental disasters, and that new design approaches are urgently needed to change course [87]. In this vein, Coyne investigates the ways that digital technologies are shaping the boundaries we construct between the human and natural worlds [31]. Analysing technologies for mountain climbing, Cheverst draws attention to prevalent tropes of "mastery over nature", and proposes speculative design as a pathway to incorporate notions of entanglement and human-technology hybrids in future technologies [23]. A small but growing proportion of nature engagement research aims to promote attention to non-human life in design practice and in daily life, and calls for design which allows for new forms of cohabitation and interaction between humans and non-humans [146]. Tsing's methodological approach centred on the "arts of noticing" has been influential in research into technologies to foster relationships with lifeforms such as fungi [29,88] and fermentative bacteria [21]. This orientation is also engendering new appreciation of the potential for design which incorporates natural processes, such as decomposition [90].

4.3 HCI methods for nature engagement

We examined the methodologies used in the 103 papers. We found that the most commonly adopted methods were design research (53 papers) and qualitative studies (55 papers). These approaches were often combined (in 41 papers) to create a technology prototype and conduct a small-scale field trial using observations or interviews with the intended user group. Papers that included only qualitative research were typically studies of existing practices and how these might inform technology for nature engagement, or were standalone evaluations of commercial systems or technologies that had been developed elsewhere.

By comparison, only 13 studies involved quantitative research. 6 involved an artwork or were informed by artistic practice, such as Kobayashi's exhibition of the Fukushima Audio Census artwork, which aimed to engage people with the natural environment surrounding the Fukushima nuclear reactor disaster [81]. Other paper types in our survey included 15 position papers, 3 literature reviews, 6 methodological discussions and 5 workshop proposals.

Several papers investigated and proposed new methods for research and design for nature engagement. We identify two key challenges addressed by these works. The first challenge relates to capturing the embodied, experiential dimensions of direct contact with natural phenomena and outdoors activities, as input to design activities. Cumbo [33] found that chest-mounted GoPro video cameras can be used to effectively capture children's perspective on their nature-based play, in ways that reflect the social, situated and spatial-temporal dimensions of their experience. Bidwell and Browning explored a 'point of view' camera and collection of natural artefacts as 'probes' for capturing *in situ* experience of being in nature and associated meaning-making processes [13]. Altarriba [3] trialled a broader range of "from-the-wild" methods, including written notes, photos, voice memos, visual diary and post-trip reflections, with the aim of conducting co-design in the course of outdoor activities such as hiking and foraging, targeting future technologies to enrich nature experiences. An alternative approach proposed by Stahl et al. [151] entails the use of natural materials and processes as inspiration and grounding for design, by including them in physical sketches; an approach that can be used in natural settings or in a design lab.

The second important methodological challenge lies in addressing and including nature in design activities. Animal-computer interaction (ACI) researchers have proposed that interaction design techniques can be extended to include animals as stakeholders and as design partners [94] through incorporating scientific knowledge and expertise; and this approach is now being extended to ecosystems [158]. The influence of ACI is discernible also in work which investigates the inclusion of plants in designing for nature engagement [65,152], including the ethical dimensions of research involving "vegetal subjects" [48] and the extent to which plants benefit from different types of design responses [7,29]. More-than-human perspectives on interactions with nature are giving rise to methodological research into de-centering the human in design. Drawing on Tsing's "arts of noticing" method, Clarke and others investigated approaches such as speculative, participatory inclusion of non-humans in cities [26]. Responding to the concept of naturecultures [60], Liu turned to photography to notice and examine juxtapositions and entanglements between the natural and the cultural [89]. Biggs and colleagues [15] employed autoethnography to investigate noticing non-humans as a method for design which decentres the human, revealing the "hard psychological work" involved in reconfiguring the self as designer and researcher. Quitmeyer and Kelly argue for the value of designing and building nature engagement technologies in the settings where they will be used [127]. These methodological contributions highlight the difficulty of researching and designing with nature, and point to the potentially valuable role that HCI can play in constructing a positive role for technologies in human-nature relations, by promoting engagement with nature.

5 TYPOLOGIES OF TECHNOLOGY USE IN NATURE ENGAGEMENT

This section presents two typologies which we developed through the scoping review. We present (1) a model of directness and distance dimensions in nature engagement through technology, including *direct* nature experiences and various types of *indirect* nature experiences, and (2) six categories of roles for technologies in supporting nature engagement.

We propose that examining HCI work on nature engagement through these typologies allows for better understanding of its motivations and underpinnings, and consideration of its trajectory. The typologies reveal aspects of technology use which have particular relevance to HCI, relating to issues of mediation, affordances, digitisation, design and deployment choices, and the relationship between technologies and their context of use. We argue that this model enables us to

distinguish the contributions that HCI, relative to other disciplines, can make to this topic. This analysis enables us to chart the trajectory of this body of research and develop an understanding of possible future technology uses and potential outcomes, positive and negative.

5.1 Dimensions of directness and distance in nature engagements

Through review and summary of the literature, we found that digital technologies are being deployed to support direct experiences of nature and allow various forms of indirect nature engagement. In analysing these different forms of engagement, we drew on the influential model of Grudin [55] for classifying research in computer-supported cooperative work (CSCW), which identified *place* and *time* as the two axes for a typology of technology options for supporting human-to-human interaction. According to the typology we offer, nature engagements can be understood to span two dimensions of variation: the *distance* from nature and the *directness* of experience (Table 1).

Distance, as an analogue to *place* in Grudin's typology, refers to the extent to which the user is removed from nature. We identify three levels of distance: *in situ* engagement, where the user is in physical or sensory contact with nature; *ex situ: nearby* engagement, where the user engages with nature that is close by, such as a backyard or local nature spot; and *ex situ: distant* engagement with nature which is remote from the user. We distinguish *ex situ: nearby* interventions from other types of *ex situ* engagements, as they address specific sites, animals, plants or phenomena that elicit a particular form of interest, and with which users might gain familiarity over time, and so offer interesting opportunities and properties.

The second dimension of variation is *Directness* of experience, which concerns how nature is perceived, whether *directly* - through being *in*, or *in contact* with nature - or *indirectly*, through different forms of mediation and abstraction. *Directness* subsumes the dimension of *time*, (per Grudin [55]), as well as other critical aspects of nature engagement. *Direct* engagement involves contact with physical nature, and occurs *in situ*. This corresponds to an established definition of *direct* contact with nature: "time outdoors interacting with nature (natural environments and associated biodiversity)" [148]. We identified in the literature three degrees of *indirectness* of nature engagement enabled by digital technologies, offering different possibilities in terms of temporal elements (including synchrony), verisimilitude, and abstraction. We use the term *mediated* engagement to denote viewing or consuming media such as photographs, video or audio recordings of nature. *Abstracted* nature entails representations such as data visualisations or fact sheets. Finally, *simulated* nature relates to computer-generated naturalistic environments, animals and plants, such as virtual immersive environments or 3D models.

5.1.1Direct Nature Engagement

Technology for direct experiences of nature commonly involves real time, unfiltered experiences of specific environments or elements of the natural world. For example, researchers have explored how technology might support activities including children's free-roaming nature play [32,34], independent nature exploration for blind and partially sighted people [9,10], gardening [92,132], geocaching [62,100,102] and informal enquiry-based exploration of local nature [74].

	DISTANCE from nature		
DIRECTNESS of experience	***In Situ***	***Ex Situ: Nearby***	***Ex Situ: Distant***
Direct	Direct contact with nature		
Indirect			
Mediated	Mediated nature experienced while in direct contact with nature. E.g. Animal media viewed at the zoo [156].	Mediated nature experienced while close to the nature depicted E.g. Images of backyard nature captured using camera trap [51]	Mediated nature experienced at a remove from nature. E.g. Interactive video for classroom science learning [145]
Abstracted	Interacting with abstract representations of nature while in nature E.g. Categorising and annotating nature photos while outdoors [74]	Abstract representations of local nature. E.g. Public installation for learning about local bats [72]	Interacting with abstract representations of nature at a remove from nature. E.g. Ecoacoustic visualisations for citizen science [109]
Simulated	Interacting with computer-generated nature while in nature E.g. AR video installations in zoos, showing virtual animals alongside visitors [93]	Interacting with computer-generated representation of local nature. E.g. Virtual replica of field education site [39]	Interacting with computer-generated nature at a remove from nature. E.g. Virtual, game-like experience of nature [129]

Table 1: A typology of *distance* from nature and *directness* of experience in nature engagements through technology

5.1.2Mediated Nature Engagement

Interventions involving mediated nature generally aim to enable sensing or viewing nature in ways that are not feasible in real-world interactions. Natural phenomena are recorded through photography, video or audio capture, affording replay or transmission for synchronous or asynchronous experiences. This can involve sensorially rich, complete representations which stand in for direct experience of nature [128] but may also be selected, filtered or altered in subtle ways; for example, video and timelapse photography allow for temporal compression of ecological processes [145]. In the context of in situ interactions, a variety of sensing devices have been developed to sense natural phenomena which would otherwise be imperceptible [44,88,133,143], encouraging new forms of experimental exploration and appreciation. Some forms of mediated in situ interactions, including watching video, can attract concerns that they distract people from enjoying nature directly [31], but may alternatively allow for deeper engagement and closer observation [103,133]. Mediated nature can be experienced ex situ nearby, for example to view or hear local wildlife [51,137,138,165], or at a distance, to learn about exotic animals in the classroom [145] or to create customised nature soundscapes to aid work performance [101]. Interactions with mediated nature can strengthen direct engagements with nature, for example participants reported paying closer attention to bird calls outdoors after accessing bird media at home, through the Ambient Birdhouse [149]. Coyne suggests that technologically mediated nature, such as photography, might strengthen the desire for contact with nature [31].

5.1.3Abstracted Nature Engagement

Abstracted forms of nature include datasets, information visualisations, field notes, and games which represent natural phenomena. Through abstraction, sensed nature is translated into forms which are not recognisable as the original percept but may highlight otherwise-hidden aspects of the scene. Some such experiences are synchronous, involving representations of live data [72], while others involve data collected over extended periods [109], or allow for temporally extending interactions with nature [30]. In situ interactions with abstracted nature often involve generating or interacting with structured nature-based media and information, through tasks such as cataloguing and species identification, cataloguing photos, discussing or describing nature [74,104,125]. In such interactions, there is an interplay between direct nature experiences involving exploration and observation, which are captured and then catalogued or analysed ex situ, nearby [74,104]. Ex situ abstracted representations of nearby nature have been deployed in the form of public installations to learn about local bats through access to data and facts [72] and visualisations aiming to promote awareness of urban nature [146]. Nature in its abstracted form is amenable to analysis ex situ at a distance, and is often deployed in interventions for citizen science, aligning with the aim of enabling decentralised involvement in scientific activities online through visualisations or discussion [30,35,106,109,131].

5.1.4Simulated Nature Engagement

Simulated nature engagements, via computer-generated environments, flora and wildlife, are of growing interest as replacements for direct contact with nature. Immersive, multisensory 3D technologies are being used to explore the utility of experiences which are highly similar to being in nature. These can involve recreation of specific spaces, e.g. [39], or creation of generic natural environments [129]. Such creations obviate the time-related constraints of engaging with nature, and allow novel ways of experiencing temporal dimensions of the natural world. There is interest in the possibility of gaining wellbeing benefits from virtual natural environments through games [129], and in immersive interactive environments to develop connections with wildlife [114]. Simulated nature to be experienced ex situ, nearby, has been proposed - for example, a virtual representation of a nature education site is offered for student learning and engagement immediately after onsite activities [39]. Instances of simulated nature deployed in situ were not encountered in our review of HCI literature but have been reported in online media and industry reports; for example, large-screen displays presenting virtual animals alongside zoo and museum visitors, which have seen recent popularity [93].

5.2 Roles of technology in nature engagement

In this section we describe a typology comprising six roles for digital technology that we identified in the HCI literature. For each type, we outline the types of technologies and deployments, users and domains, claims and evidence for outcomes and challenges and limitations identified.

5.2.1Revealing and familiarising

Responding to contemporary concerns about disconnection from nature, several interventions propose to help people see features of the natural world that would otherwise be hidden or go unnoticed, through photography, video and audio recordings. These include camera traps for households to become familiar with backyard wildlife through repeated sightings [51,165]; NatureCollections, a mobile app to encourage young people to capture, categorise and share nature photographs [74–76]; a ‘Camera for the invisible’ to capture phenomena such as temperature and CO2 [143]; and interactive audio recordings to engage with nature recovery in a nuclear disaster zone [80].

This stream of work aims to connect people with nature to foster environmental concern through exploration and curiosity, engaging activities, and social interaction. The value of photographing backyard animals lies, for Gaver et al., in the opportunity to glimpse their "parallel lives" [51] and for Vella et al. in the exploration of more-than-human entanglements, situated within a history of nature sense-making through photography [165]. Design and evaluation of the NatureCollections app draws on theory related to Joint Media Engagement [75] and Human-nature connection [76]. These studies aim to engender and respond to curiosity about local nature, promote exploration and noticing through entertaining, creative and social activities, and encourage learning together with family and household, tactics which are recommended for engaging children with nature [45].

Evaluation of NatureCollections [74–76] indicated that the mobile app was successful in encouraging young people to explore and pay attention to nature and prompting nature-related family interaction. Qualitative study of household use of commercial camera traps [165] and data collected opportunistically about public use of DIY cameras [51] revealed that people were motivated by curiosity about local wildlife and interest in native animals, and that appealing or interesting images of individual backyard animals prompted reflection about animals' lives, household discussion and online sharing of photographs. Two of the studies do not report an evaluation [81,143].

5.2.2Pooling knowledge

There is a substantial history of technologies for distributed data capture, notably in alignment with citizen science initiatives [121,121] and, to a lesser extent, as part of education programs [136,156]. Interventions for use in nature commonly deploy smartphone or earlier mobile, handheld technologies for activities such as recording the presence of specific species [99], monitoring ice coverage [110] photography to contribute to monitoring projects [120], and reporting on crowding in nature tourism destinations [112]. Technologies to temporally extend these activities beyond the nature encounter include social media [19,131], desktop applications, and visualisations for analysis and cataloguing of data [109,136]. Custom built prototypes have been used with a variety of user types, to collect local knowledge and for monitoring endangered species. These user types include remote communities and people with local knowledge [36,37], students [46], visitors to nature reserves [112,117,122], naturalists [30,99,109,127] and the broad public [131].

There has been much interest in technological approaches to decentralising and scaling up environmental science through data collection [110,120–122] and analysis which leverages the expertise of naturalists and local knowledge [37,99]. Involving young people in data collection is positioned as a valuable educational activity [46]. Two interventions are motivated by the aim of improving the tourist experience [112,118]. Studies of this type of technology have a strong focus on the question of how to engage and motivate and include consideration of gamification [110], engaging and meaningful interfaces for hobbyists [30,107–109] and social media to promote volunteering [19,131]. Another important theme in these studies involves attending to social interaction [46], to existing practices of collaboration [30,92,99,108] and to socio-environmental context and cultural beliefs [37] in the design of interventions.

5.2.3Nature on demand

The documented human benefits of contact with nature have resulted in several interventions which provide experiences of nature through video or audio recordings, or virtual simulations which can be accessed at any time. In these interventions, mediated and simulated nature is generally packaged in a form that erases its association with a specific place, or with specific living entities. The primary motivations for these interventions are wellbeing and mood enhancement [28,101,128,129]. Technologies include nature soundscapes [28,101] a photorealistic nature "window" [128] and a virtual, 3D gaming environment [129]. Digitally-enhanced interactions with plants, or artificial plant-like artefacts, can also be

understood as a form of nature on demand [140]. In addition, a virtual reality nature scene is proposed to help tourists to prepare for an upcoming nature experience [118]. These studies mostly involve only small scale, qualitative evaluations and are therefore able to make only modest claims about their effects. Reetz et al. use physiological sensors and questionnaires to measure stress levels during interactions with virtual natural and urban environments, finding that their simulated nature intervention does not achieve the envisaged effect of alleviating stress.[129]

5.2.4Learning about nature

HCI research has a long history of designing science education tools. Early examples were classroom-based, allowing students to watch and interact with nature videos to learn about animal behaviour and ecology [145]. Mobile platforms allow for a broad range of in situ learning interventions, such as identifying trees using an AR-equipped tablet [174], digital devices for hands-on experimentation in nature [44,170]; activity-based learning through capture of audio recordings related to zoo animals [104,105] and capturing species information in a virtual replica of a field trip site [39]. Learning about *local* nature is targeted by the Ambient Birdbox, which provides household access to digital media for learning about birds [149] and a proposed mobile app to provide information for conservation volunteers [17].

The majority of studies related to learning about nature concern children and educators [2,39,44,105,145,170,174]. For the most part, these papers are motivated by the understanding that active nature-based exploration and experimentation can foster interest in nature [39,145,170,174]. Two recent studies in this category are underpinned by recognition of the importance of childhood experiences of nature and their role in developing environmental values [22,44]. A smaller number of studies investigate learning nature learning for families and households [149], conservation volunteers [17] and ecologists [35,127].

Notably, these studies do not include evaluation of learning outcomes. Technology trials provide broad insights into the opportunities for technologies to prompt interest in nature and engagement with learning [104,145,170,174]. Soro et al. offer detailed qualitative findings based on a trial of the Ambient Birdbox conducted with five families, pointing to the ways in which learning was supported by playful design and the integration of the technology into family life [149].

5.2.5Discovering and navigating nature sites

There is longstanding HCI interest in the design and use of location-based technologies to promote interest and awareness of nature sites. An early example is the ‘Questing’ application for handheld PDAs, used to promote young people’s interest in local nature spots by creating treasure hunt activities [125]. Several studies explore practices involving discovery and navigation that might be supported using technology, including geocaching [102], children’s nature play [32,34], and exploration of nature by people who are blind or partially sighted [9,10].

Investigation into children’s nature play maintains that time in nature promotes mental and physical wellbeing, and intrinsic value for nature through place attachment, while loss of access to nature is associated with biophobia and loss of independent mobility [32,34]. Similarly, sensory and emotional engagement are valued [9] as part of time in nature for physical and mental health [10]. Exploration of nature as part of a social, collaborative experience, is positioned as a strong foundation for young people’s participation in citizen science and inquiry-based learning about nature [46]. Other works in this category do not feature explicit links to theory.

The ‘Questing’ application was found, through a pilot study and formative evaluation, to have positive impacts on interest in technology, stewardship and student engagement [125]. Other published studies in this category report investigation of the problem space, and do not include implementation or evaluation, e.g. [10,32,102].

5.2.6Experiencing nature from other perspectives

Several studies explore how technology can allow people to see or interact with the natural world in new ways through interactivity, visualisation and speculative designs. With the aim of drawing attention to human-nature entanglements, Smith and colleagues offer three interventions for tracking wildlife, visualising plant and animal cycles and understanding the urban wildlife that "co-habits" with human populations [146]. Digital installations used by zoo animals have been found to provide zoo visitors with new perspectives on the animals' behaviour [79,167]. Two studies explore how people can interrogate the world of fungi. Liu draws attention to human-fungi entanglements, using portable sensing technologies [88], while Correa explores how mycelium growing kits and templates might enable interspecies creativity [29]. Kobayashi proposes speculative design pieces that allow people to interact with nature at a distance, through wearable technology and installation pieces connected to networked audio devices located in a forest [80]. Sharing in another person's outdoor activities is possible through the use of camera, microphone and even telepresence robot, [62,100] but was found to be limited by the lack of non-audiovisual sensory experiences such as smells and the feeling of the sun. An interactive installation, JeL, to promote breath synchronisation was developed and evaluated by Stepanova and colleagues with the aim of creating a sense of connection to nature[153]. Silver and colleagues offer experimental interactive technologies ("Modern Nature Gifts") for playful and creative interactions with the environment, including "MmmTss", for making music from nature recordings, and "Glowdoodle," for drawing with any object, leaving a trail of light in the air [144].

Several of these works are informed by notions of human-nature entanglement, post-humanist attention to the more-than-human world, and the concept of naturecultures, which asserts the inseparability of nature and culture [88,146]. In contrast, Stepanova's work draws on the notion of self-transcendence and communal creation to create a feeling of connection [153]. "Modern Nature Gifts" are proposed as a means to encourage interaction with and knowledge of "modern nature" (defined as including urban nature and things found in one's personal surrounds) [144]. Publications in this category present technologies which have been developed and deployed but do not report evaluation of the impacts on attitudes towards nature.

6 DISCUSSION

In presenting our scoping review of HCI research on technology-supported engagement with nature, we have reported dimensions that characterise the landscape of work , and presented an analysis of deeper themes through the identification of two typologies. In this section, we consider what our analysis suggests about this body of work, and consider its future directions and its connection to adjacent fields of study.

6.1 The shape of HCI research on nature engagement

Our scoping review confirms that studies of technology-supported nature engagement have been a part of HCI for at least 25 years. However, this research has taken place in somewhat isolated pockets that are not often acknowledged as belonging to a unified field of research. Work in this area has connections to Sustainable HCI in terms of its orientation towards ecological issues, and in the intention to shape knowledge, attitudes and behaviour regarding the natural environment and ecological crises. There are overlaps also with the field of ACI, sharing a consideration of interspecies interactions and the intention to sensitise HCI to the interests and needs of non-humans. Nonetheless, our scoping review reveals a body of work with discernible patterns and threads, and shared aims, approaches and challenges. We found these patterns to be sufficiently coherent to develop two typologies which support consideration of the ways that technologies might be designed to reverse the extinction of experience caused by over-engagement with the digital realm, and which help to identify gaps and opportunities for future research.

The first typology we proposed concerns the directness of contact with nature that is supported by technology. Direct experience of nature is understood to be richer and more beneficial in terms of nature connectedness and personal wellbeing [50,91,160], but raises issues of access and equity. HCI work draws attention to alternative and diverse forms of indirect nature engagement that can be offered equitably through mediated, abstracted or simulated nature, and how these vary with the user's distance from natural phenomena. Indirect experiences allow for extended and ongoing nature contact, and may be the only available way to regularly access nature for urban populations who lack the means or opportunity to travel outside the city. Many interventions achieve their value through combining direct and indirect forms of nature engagement. For example, indirect nature interventions can encourage people to spend time directly experiencing nature through participating in games or volunteer activities, or can allow for more depth in later direct encounters by building knowledge or familiarity with wildlife. Direct nature encounters can thereby be extended or deepened through mediated, abstracted or simulated nature experiences. Ideally, these different types of interaction might promote a virtuous cycle: an ongoing interplay between direct exploration and observation of physical surroundings, interspersed with learning, analysing and sharing through mediated or abstracted engagement. All of these patterns are evidenced in the HCI work reviewed here, and we intend this first typology to clearly capture them.

Our second typology identifies six roles for technology in nature engagement, which align loosely but not exclusively with three broad motivations in the literature reviewed. Firstly, participation in science and conservation is often the motivation for technologies which allow for *learning and pooling knowledge about nature* . The goals of contributing to human activity and wellbeing are most closely aligned with *nature on demand* and *discovering and navigating nature sites.* The goal of shaping human-nature relationships (for example, increasing nature connectedness or awareness) is a primary driver for interventions which allow *experiencing nature from other perspectives,* as well as other categories. These six categories involve different levels of interactivity, cognitive engagement, learning, and sociality.

6.2 Future Research Avenues

6.2.1Understanding technologies of direct and indirect nature engagement

Diverse forms of indirect nature engagement offer possibilities for overcoming the extinction of experience, but also present distinct risks. This has raised concerns about dystopian futures in which people primarily engage with nature via simulation or mediated, ex situ technology experiences. Concerns about the limited sensory experiences offered by simulated and mediated nature [71,160] will inevitably be a focus for ongoing innovation, as research in extended and mixed reality (XR) technologies seeks to reduce the perceptual gap between physical and simulated spaces. There are risks also with abstracted nature experiences which entail representations of the natural world using data formats, categories and structures which codify specific perspectives on nature and are most commonly based in Western scientific ontologies. Interventions which require users to see the natural world through such a lens are especially problematic when they encounter indigenous ways of knowing which do not correspond to Western ontologies [166]. They may also inhibit the development of meaningful connections to natural places though embodied and social relationships, exploration and play [14,32,37]. There are further risks that mediated, abstract and simulated nature might replace the sensorially rich, embodied and culturally situated experiences of nature which are thought to be essential for the development of place attachment and environmental identity. Such concerns are voiced powerfully in the HCI literature reviewed, for example by Bidwell, Cumbo and Dema [14,32,37].

Evidence of diverse intersections and interplays between direct and indirect nature engagement points to the need for further investigation into the various ways these types of interaction might be configured. Building on research into the

use of digital media in zoos and museums, and the concept of "active indexing" [64,103], there is a need to investigate how multiple forms of engagement can be designed and used, in parallel or sequentially, to encourage meaningful interactions and relationships with nature. There are opportunities here to explore how such interplay might be designed to develop and maintain attachment to natural places in an era of high mobility, and to generate and strengthen environmental identity. To date, there has been little investigation into how a single intervention might be used through all stages of nature engagement, from initial "motivation" and "preparation" through "navigation to nature" and the direct experience of nature, to capturing, sharing and finally reflecting on the experience. We argue there is a need to adapt existing tools and instruments to study the impacts of nature engagement, accounting for the diversity of indirect engagement mechanisms and the interplay between direct and indirect interactions.

6.2.2Impacts of anticipated technology developments

Emerging technologies such as new forms of XR, head-mounted displays and drone-based interactions offer new opportunities for nature engagement which are amenable to analysis through the typologies that we propose. New augmented reality headsets which can be used outdoors will create the potential for interventions for *revealing and familiarising*, for *learning about nature* in the course of everyday life, and for *discovering and navigating nature sites*. These technologies will provide easier access to abstracted or mediated nature *in situ,* and the possibility of switching more rapidly between direct and indirect nature experiences, raising new concerns about the potential for technologies to disrupt and attenuate nature engagement.

On the near horizon, the anticipated use of virtual worlds or the metaverse for work, socialising and recreation presents new possibilities and risks for *nature on demand, experiencing nature from others' perspectives* and *learning about nature*. *Nature on demand* has been relatively less explored in HCI research, compared to the other roles we have identified, perhaps because it is closest to existing, non-interactive forms of vicarious nature experience, such as nature videos and television shows. However, as immersive, interactive virtual nature engagement looms as an important focus within the metaverse and XR market [67,130], there is a need to better understand the effects of habitual or repeated immersion in virtual nature upon people's attitudes and wellbeing, in themselves and relative to direct encounters. Our analysis points to the need for careful consideration and evaluation of choices relating to technology, design and usage.

6.2.3Design implications of new perspectives on human-nature relationships

Our review confirms the growing diversity of perspectives on nature engagement and human-nature relationships reflected in HCI research. Growing attention to notions from science and technology studies (STS) and related disciplines, such as more-than-human interactions, naturecultures, and socio-ecological relations presents new opportunities but also challenges for theorising and methodology in HCI. It is sometimes not clear, for example, how transdisciplinary perspectives might be deployed in the design of technologies to influence human behaviour and attitudes, or to integrate with domains such as education and health.

In keeping with broader HCI trends, there is a substantial thread in research we review which reflects on human-technology-nature interactions in their sociocultural context, and as part of broader practices and routines of organisational, family and community life. These papers describe interventions which are oriented primarily towards *pooling knowledge* and *learning about nature*, but may well have important contributions to make to *nature on demand*, with a view to contributing to human wellbeing. While several interventions are motivated by both ecological aims (such as promoting conservation or pro-environmental attitudes) and humanistic aims (such as promoting wellbeing through nature contact), there is the opportunity for stronger connections with theories and approaches that account for the interrelatedness of

humans and ecosystems. One such approach is offered by the notion of socio-ecological systems, which reflects strong interconnections between society and ecosystems, integrating knowledge from social sciences and natural science [173]. Another approach is offered by the notion of One Health, an integrated approach to understanding and optimising the health of people, animals and environment [52].

6.3 HCI and other disciplines in human-nature engagement

The decision to focus our review on work in HCI was based on the belief that these HCI studies collectively offer distinctive perspectives and methodologies that are worthy of examination in themselves. However, it must be acknowledged that much relevant research on technology-supported human-nature engagement exists in other disciplines, such as psychology and environmental social sciences. We turn now to consider opportunities for HCI to expand its horizons and connect with a broader body of thinking and evidence. Many of the publications surveyed here demonstrate the value of interdisciplinary connections and provide valuable models to follow. Some demonstrate, for example, how relevant theory on human-nature relations can be enhanced through the recognition and re-imagining of natural elements - plants, animals and ecosystems - as stakeholders in interaction design, e.g. [15,158]. Other endeavours in Participatory Design and ACI aim to empower diverse human users and non-human animals in design activities.

Many of the HCI studies we reviewed focus their contribution on novel designs for natural situations, with a promise of positive impact. There is often little formal evaluation of their medium- or long-term effects, or even of the abilities of technology interventions to engage people sufficiently and for sufficiently long periods of time to achieve desired outcomes. This is an understandable limit for work that faces the challenges of designing and deploying technologies in natural environments, needing to overcome barriers such as remoteness, access and inhospitability. However, there is a need to establish methods for evaluation to understand how design choices impact knowledge, attitudes and behaviour. This can be aided by connecting with expertise and theories developed in other disciplines, including measures of biospheric values, place attachment and environmental identity.

Equally, HCI has much to offer neighbouring disciplines working on human-nature engagement though technology. It can bring to bear its tradition of critiquing technology proposed as a simple fix to complex problems, and the authenticity of grounding in human and other concerns. The value of HCI approaches will increase as an expanding range of technologies are deployed by non-technology researchers working in various settings. More broadly, HCI research on nature engagement is well placed to support global efforts to address the ecological crisis. While the crisis is deeply rooted in larger arenas of politics, human history and culture, it nevertheless hinges on human-nature-technology relations. In tandem with neighbouring disciplines, the work reviewed here offers the seeds of a contribution to address this larger challenge.

7 CONCLUSION

Through a scoping review, we present an analysis of HCI research on human-nature engagement over the past 25 years. We highlight the deeper themes in this body of work and offer two typologies for classifying this work: one concerning modes of engagement with nature, the other concerning the roles of technology deployed for this purpose. Collectively, the work surveyed demonstrates the potential for digital technologies to play a role in motivating, fostering, enabling and reflecting upon nature engagement, and shows that technologies can offer diverse forms of direct and indirect nature experiences, including experiences where nature is very distant from the user.

While we have promoted a view of these studies as coalescing around a coherent topic, we also report how the work has arisen in multiple isolated pockets with different theoretical and methodological orientations. These pockets of research

appear to have arisen independently at different times and places and tend not to cite nor gain inspiration from each other. They share the challenge of conducting research in natural environments, and a need to develop methods and approaches for more rigorously evaluating the medium and longer term impacts of designed interventions.

We find that HCI research addressing human-nature interrelatedness and separation has been significantly influenced by certain developments in other disciplines but has given less attention to others. By mapping these, we highlight valuable avenues for further exploration including place attachment, environmental identity and values, and approaches such as One Health and social-ecological systems. We conclude that there is an important and ongoing role for HCI to conceptualise, design and evaluate the role of technologies in human-nature engagement.

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