Phenology Probes: Exploring Human-Nature Relations for Designing Sustainable Futures

Phenology Probes

Shannon Rodgers*

Queensland University of Technology, Brisbane, shannon.rodgers@hdr.qut.edu.au

Bernd Ploderer

Queensland University of Technology, Brisbane, b.ploderer@qut.edu.au

Kellie Vella

Queensland University of Technology, Brisbane, kellie.vella@qut.edu.au

Margot Brereton

Queensland University of Technology, Brisbane, m.brereton@qut.edu.au

Understanding and relating with nature is increasingly important in design as we aim to address the risks posed by anthropogenic climate change. Design methods are often human-centered and provide us with opportunities to reshape existing methods to foreground nature. Inspired by phenology, the study of cyclic biological events, this paper presents phenology probes: a method to study the multifaceted relations between humans and nature and how they are manifested in a particular time and place. Our phenology probe kit consisted of 3 activities: spatial mapping, phenology snapshotting, and phenology wheels. In deploying these probes with 20 gardeners we identified key relations with nature: Personal historic, multisensory, emotional, global, and climate activist relations. We discuss how these relations help to bring nonhuman stakeholders and cyclic biological events to the design process and directions for future work to further enhance the agency of nonhumans in interaction design.

CCS CONCEPTS • Human-centered computing • Human Computer Interaction (HCI) • HCI design and evaluation methods

Additional Keywords and Phrases: Phenology, Posthumanism, Gardening, Probes, Sustainable HCI

1 INTRODUCTION

Anthropogenic climate change poses severe risks to human and natural systems, including biodiversity loss, rising sea levels with warmer and more acidic oceans, and loss of resources [36, 51, 56]. Even an intense change in societal adaption cannot eliminate future risks of anthropogenic climate change, but projections of

* Place the footnote text for the author (if applicable) here.

our risk by the end of the 21st century can be reduced significantly [51]. One of the most significant challenges is our collective inattentiveness to nature. Hence, we must harness technology design to raise people's attentiveness to their relations with nature. This also requires rethinking how we conduct design research where humans and nonhumans (animals, plants) share the center stage [75]. Engaging with nonhuman stakeholders in the design process is by no means trivial [62], because it requires going beyond human-centered ways of knowing, which are at the core of much design and HCI research. However, such a rethinking is essential if design research is to play a role in achieving sustainable development goals, such as promoting wellbeing, making cities and communities more sustainable, and taking urgent action on climate change [64].

In this paper, we explore how a well-established design method – probes [27] – can be harnessed to explore relations between humans and nonhumans. Probes are collections of objects and evocative tasks given to participants to create design insights for a specific, local setting [6, 27]. Design researchers have long used probes to gain rich qualitative insights into local cultures, to inspire design, and more broadly, to promote participation of human stakeholders in the design process [6, 18, 25, 29, 60, 69]. In our work, we are interested in how we can harness probes to gain insights into both local human culture and nature. We drew inspiration from HCI research on networks of relations between human and nonhuman stakeholders [16, 54, 70, 72]. We also looked at methods used by ecologists, specifically in the field of phenology. Phenology is the observation and study of cyclic biological events (also called phenophases) in local nature. In the case of plants, this might involve events such as leaf budburst, flowering, ripe fruit, etc. Phenophases commonly observed in animals include emergence from hibernation, mating, egg-laying, and migration [12, 31, 42, 52]. Climate change affects the timing and occurrence of such biological events, and observations of such shifts can provide indicators of the Earth's deterioration [53, 74]. Our work has been inspired by phenology methods to map and document events, particularly those used by educators, families, and nature enthusiasts.

This paper presents the design and deployment of Phenology Probes, a set of artifacts and activities to explore the interrelations between humans and nature in a particular context and to elicit interesting design opportunities. Our probe kit consisted of three artifactual activities: spatial mapping, phenology snapshotting, and a phenology wheel. The activities were created in a complementary manner to identify the nonhuman stakeholders and their locations, occurrence, and timing. We deployed the probes with 20 gardeners. Private gardens and backyards are often the most important place where people encounter local nature. Moreover, many gardeners have intimate knowledge of plant and animal lifecycles in their gardens and an awareness of the local impacts of anthropogenic climate change [4, 76]. Through discussing the probes with gardeners, we identified several key relations between humans and nonhumans in the local garden context: personal historic, multisensory, emotional, global, and climate activist relations.

Based on these findings, this paper offers two contributions: First, the paper highlights key relations between humans and local nature. We discuss the significance of these relations for designs that promote sustainable design. Second, this paper presents a new design method, phenology probes, to study human-nature relations in a local context. We discuss the experiences of deploying this method with gardeners and opportunities for future use of this method. Furthermore, we reflect on the limitations of this method and how it can be tweaked to further center nonhumans in the design process.

2 RELATED WORK

2.1 Sustainability and Phenology

A sustainable future involves maintaining the health and wellbeing of the Earth to sustain a viable future for future generations. In order to attain a sustainable future, Sustainable HCI (SHCI) has taken numerous directions to design and implement sustainable technologies. From earlier days, when Blevis [5] originated the term Sustainable Interaction Design and argued that stainability should be a central focus of interaction design, to the design of sustainable food systems [34, 49, 59, 77], reuse and management of waste [24, 61], water [43] and energy [41]. SHCI research promotes environmental sustainability through systems that persuade adopting sustainable living [20]. Dourish [21] asserts that by converting environmental action into a redirection of consumption patterns, it is self-limiting to take on the issue of environmental action as a personal moral issue.

Anggarendra et al. [2] argue that environmental HCI should also promote engagement with nature for enjoyment and appreciation and that a lack of such engagement could harm the environment. Researchers have explored sensors, IoT, cameras, and recorders to enable people to engage with nature and discover new species in the garden. For example, a motion-sensing camera such as My NatureWatch captures nature images, and a website teaches users how to create their own [26]. In addition, a wearable video-audio recorder enabled children to investigate and discover nature through play [14].

Engaging with nature is frequently accomplished in the personal space of one's garden. A garden is a place where people can learn about nature and is also a place for social skill-sharing [50]. Experiencing and exploring nature is imperative to forming nature connections [23]; there is an opportunity to explore relationships between humans and the nature they discover to design for sustainability.

Light et al. [44] suggest that we must pay attention to nature, the positives, and the discomforts we wish to avoid. Liu et al. [46] used photography to explore natureculture, exceeding the dualism of human/nature, describing how humans and nature are entangled. Photographing naturculture, e.g., vines growing on staircases and people subjectively experiencing snow, helps people to understand how humans and nature are interwoven and contribute to decentering the human in design and raises attention to more-than-humans. Four hundred photographs of natureculture were edited, organized, and reflected on how nature and culture are entangled. Natureculture was reflected in a multiplicity of forms, some including "subjective experiences," such as multisensory experiences in nature and the spatiotemporal movements of nature and culture.

The United Nations developed seventeen Sustainable Development Goals (SDGs) that address global challenges such as climate change, poverty, inequality, environmental destruction, peace, and justice [64]. Recent work reviewed SHCI literature from 2010-2019 [32], using the SDGs as an analytical lens to identify the goals of each piece of literature. Hansson, et al. [32] found a large body of SHCI work that could not be mapped to SDGs. Of the papers linked to SDGs, only five of the 17 SDGs were recognized as goals in the works. While it is important for SHCI to broaden its scope and cover goals we have not yet reached, SHCI work is not always relevant to SDGs.

Scuri et al. [63] took a holistic approach to systematically review SHCI literature, with the three pillars of sustainable development (environmental, social, and economic), by looking at how these transcend in SHCI. The authors argue that mainstream economic theory must be challenged and replaced with a more radical view that embraces nonhuman stakeholders while working in harmony with broader social and political contexts.

Tomitsch et al. [71] devised nonhuman personas as an adaption of personas that evaluate the needs of nonhumans and how they may be affected by design decisions. Rather than viewing nature as separate, nonhuman personas view humans and nature as interwoven. Nonhuman personas consist of four steps: identifying nonhuman stakeholders, creating nonhuman personas, forming coalitions (selecting a voice on behalf of the nonhumans), and finally employing nonhuman personas and the coalitions for design.

There is an opportunity to embrace nonhuman stakeholders; we can contribute to sustainable design by working closer to nature through the methods we use.

2.1.1 Phenology

Phenology is the study and observation of cyclic biological occurrences in nature. Occurrences in phenology include phenophases, the lifecycle stages of plants and animals defined by a start and endpoint; phenophases are controlled by the climate and last from a few days to weeks. The longest phenological record ever recorded is the cherry blossom flowering in spring in Kyoto, Japan, signifying the Japanese Cherry festival dating back to the ninth century [3, 52, 65]. In diaries dating back to AD 801 to 1400, there are descriptions of full bloom cherry blossom viewing parties in Kyoto, Japan [3].

Phenology is closely linked with climate change [12, 36]. The timing and occurrence of phenophases are affected by climate change since temperature influences lifecycles (e.g., climate impacts when flowers bloom). As a result of climate change, nature is shifting, disrupting, and changing (such as spring arrival and growing season length, day and night length, temperature, animal hierarchy, and behavior [42]). Anthropogenic climate change contributes significantly to such shifts. Kassam et al. [40] illustrate how traditional ecological knowledge from phenological observations and climate science have worked together to inform local and international populations about climate change drivers and effects. We need to rethink the concept of time to anticipate climate change (e.g., considering time in relational terms rather than the Gregorian calendar, whereby a blooming flower indicates thawing ground). Adapting to climate change through a relational interpretation of time can assist us in a wide range of activities, including farmers growing crops.

Increasingly, phenology-related knowledge is being studied, which can contribute to designing technologies that focus equally on humans and nature. Observing and drawing phenological relations can also provide an opportunity to preserve knowledge that otherwise may be lost. Older adults often have an increased traditional ecological knowledge because of age and a loss of experience in younger generations. Okui et al. [55] found that most people who utilize natural resources (i.e., wild fruits in Awaji Island, Japan) were taught by elders during childhood, and this knowledge survived into adulthood. Similarly, Shanahan et al. [66] describe how Australian children spend less time playing outdoors than maximum-security prisoners.

Citizen science projects illustrate how phenology and technology play a role in contributing to climate research. BudBurst is a citizen science project where the general public upload images of plant phenophases, contributing to a larger dataset utilized by researchers and scientists in their climate research [39].

Smith et al. [67] discuss the use of Phenology clocks [38] to illustrate observations of the cyclical nature of biological occurrences in nature over time in localized settings. For instance, these observations may include when plants are blooming, fruiting, animals are hibernating, etc. A graph-like format is used to input citizen scientists' and volunteers' data into the phenology clock. There could also be opportunities to upload personal data to find interlinkages between phenophases of interspecies and climate to learn a relational interpretation of time. Besides Smith et al.'s initial exploration, HCI researchers have not articulated how phenology could

inform methods used to design technologies for humans and nature on equal footing and construct a relational interpretation of time for mitigating climate change impacts.

2.2 Relational Methods and Subjectivity

Scholars in HCI have employed relational methods in various contexts, from relations with nature [45, 72] and places [60], to relations within families [54]. Understanding our relations for design is imperative as we design for a sustainable future that seeks equality for all. When we understand the relations between things, we create important points for design where technologies can be embedded through the relations.

Itinerant Probes elicited relations and rich histories between people and public spaces through dynamic events, finding personal events that occurred in places, and the emotions attached to histories [60]. Camera traps in urban garden settings enabled researchers to understand the implications for relations between humans and nature [72], also finding care relations through viewing recorded data on camera traps and participants' desires to take action of pro-environmental behaviors for local species. Moreover, Suchman [70] identifies that the design of technologies should be evaluated in connection to the unique settings where they are intended for use. We begin to understand the unique setting and all it encompasses through design, including the network of relations that the technology is intended for, the lived experiences, and practices the site encompasses. Relatedly, Dema, et al. [16] designed in the 'network of relations' for the conservation of endangered species by connecting remote communities via the Wonglilaa Birdhouse. An ambient mode played local birdcalls in both audio and video format at specified intervals, while an interactive mode displayed spectrograms and bird images along with quizzes regarding whether the endangered heron was present. Notably, the Wonglilaa Birdhouse became embedded within the relations of the community.

Further, Position Exchange Workshops enabled the use of positions [30] to understand relationships within families of parents and adult children who live out of home by making positions explicit. A co-design process that reimagines and renegotiates positions leads to a design that considers everyone's perspective [54]. The human experience is trans-personal. In any situation, many perspectives and experiences surface relations and can contribute to design in sustainable ways when we begin to process our relations with all living matter.

2.2.1 Relational subjectivity

HCI researchers have begun to question the implicit centralization of humans in the design process (i.e., through posthumanist views). Previous work has argued for decentering humans from the design of technologies for cohabitation with nature [47, 67]. Phenology in design methods can lead us to design technologies that equally consider nonhuman stakeholders; however, how can we design for both humans and nonhumans through a human lens? Critical posthumanism describing the notion of decentering the human and abandoning human subjectivity and autonomy, plays a vital role in enabling us to focus on our multifaceted relationalities with the Earth while rejecting self-centeredness [8]. Furthermore, posthuman theory enables us to reconsider the standard reference point for humans in the Anthropocene.

Braidotti [7] speaks of critical posthumanism, illustrating, *"Posthuman subjectivity reshapes the identity of humanistic practices, by stressing heteronomy and multifaceted relationality, instead of autonomy and self-referential disciplinary purity."* That is, we can reshape the identity of design methods (a humanistic practice) by encouraging thinking beyond a human calculation and engaging humans in focusing on their multifaceted relationalities with the Earth and its health and wellbeing; this will raise not only attentiveness to nature relations

but a shift in how we design with nature. A second question arises: how can relationalities be researched for design inspiration? Fox et al. [22] illustrate, *"matter is to be studied not in terms of what it is, but in terms of what it does."* In terms of human-nature relations, that is to learn, how does nature affect us, and how do we affect nature? What are the consequences of such interactions? Humans are not autonomous, we are not a separate entity from the ecosystem, and we are always in relation. Learning about how matter affects matter identifies those relations [15]. Using posthuman subjectivity (relational) as a lens for designing with nature is essential. Our roles as researchers and designers are shifting. In order to understand humans and nature as relational via affects, we must challenge the humanistic lens through which we research and design.

Additionally, HCI research has incorporated noticing practices and strategies to gain multiple perspectives on technology design, often decentering humans [48]. For instance, Dew et al. [19] cultivated design with natural materials within a tiny house construction project. In the tiny house construction project, natural materials were emphasized to foster appreciation and relation to nature's histories and futures beyond human-centered calculations and used in design. Noticing practices within research that decenter humans often describes the temporal dimensions of nature's past, present, and future. Notably, Liu, et al. [45] devised dimensions for noticing, including the "scope" (level of attention), "temporal trajectory" (time/space relating to nature), and familiarity of a nature interaction (how common such interactions are for an individual). Practices and strategies for noticing can assist humans in moving beyond a human/nature divide and seeing nature as relational as we aim to grasp a relational subjectivity.

2.3 Development of Probes in HCI

Probes were first introduced in the Presence Project in 1993 [28], dedicated to exploring how technology could increase presence of older adults in their local communities. Cultural Probes have been widely used in HCI [13, 37, 57, 58, 68, 73] in various contexts since their introduction by Gaver, et al. [25] to obtain meaningful insights into older adults' lives in retirement homes. Probes are kits of ambiguous materials, such as postcards, maps, cameras, and crafts, deployed with participants for a period and designed to collect meaningful responses from diverse groups to inspire design by understanding culture. This method enables participants to reflect on their day-to-day lives in creative, inspiring, and meaningful ways within a distance from the researcher.

Since the introduction of probes, scholars have continued to refine, develop, and challenge the use of probes in design work. Technology Probes, a popular approach introduced by Hutchinson et al. [35], describes any adaptable technology deployed with participants for a time, in-situ. Technology Probes collect data from users' participation, enabling more than design inspiration, including data collection and analysis. Further, Cross-Cultural Dialogical Probes [68] describe the importance of co-presence of both the researcher and participant in the probe participation process to create opportunities for co-creation and dialogue. Probes are often deployed and left unsupervised with participants to generate responses with materials from the kits that enable meaningful reflection. However, Cross-Cultural Dialogical Probes were created with the intention of dialogue and co-creation between researcher and participants, fostering trust. For example, a researcher may be present during a mapping activity, discuss the map with the participant, and act as a co-creator through discussion.

In addition, Rosner, et al. [60] introduced Itinerant Probes that consider the spatial dimensions of their placement. These probes were experiences to enliven a person's memories and relationships with public spaces. For instance, one probe consisted of light sticks placed in dark public spaces where people passing by would move the sticks to where they perceived necessary to provide light. Itinerant probes were not

standardized artifacts, but 'dynamic events' shared in public spaces. Probes are a well-established human-centered method; there is an opportunity to reshape the use of probes for a relational approach with nature.

3 METHOD

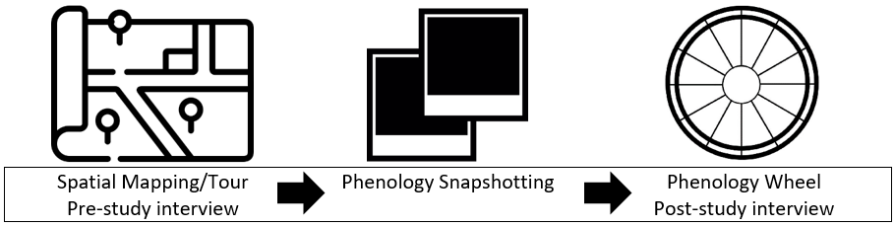

Figure 1: Phenology Probes study design.

Phenology probes have two main aims through raising attention to nature relations:
1) To address the social science goal of understanding how people pay attention to their relations with nature.
2) To address the design goal of providing inspiration to designers for technologies that support a sustainable future.
In order to explore relations between humans and nature, phenology probes consist of three design artifacts (see Figure 1).

3.1 Research Context and Positionality

Author 1 is a HCI design researcher with a theoretical perspective grounded in critical posthuman theory and new materialism, who intends to design technology that supports a more-than-human future by designing for noticing human-nature relations more critically. In addition, author 1 is an avid gardener and a neighbor to three participants in this research who have expanded the author's knowledge on sustainability in the garden over the years of living near each other. Being much younger than the older adult participants in this study, the first author sought to learn from the older adults' experiences and observations through dialogue and co-creation in the comfort of their own gardens to which the participants have strong attachment and connection. All research activities (data collection, analysis, and reflection of the probes) are based on the first author working hands-on with gardeners. The co-authors are interested in gardening and nature engagement and provided guidance in the study design, analysis, and write-up.

3.2 Participants

Table 1: Participant table identifying two groups of gardeners who participated in the phenology probes

Group	Participants	Demographics	Participation
1	GF1-GF8 (F = Face to face, individual)	Ages 55-78; 3 female, 5 male	Physical phenology probes, pre and post-study interviews
2	GO9-GO20 (O = Online, communal)	Ages 23-54; 8 female, 4 male	Communal phenology wheel workshop, snapshotting group

We chose to work with two groups of gardeners (Group 1: 55-78 year old older adults, Group 2: 23-54 year old gardeners). We chose to work with these groups because gardeners, especially experienced gardeners, have the potential to draw upon their regular experience of nature over several decades. In addition, gardeners are a beneficial starting point for research on human-nature relations, as many gardeners are already familiar with species' lifecycles. Many gardeners are aware of the unpredictable growing seasons due to anthropogenic climate change and have adapted their routines to cope with such shifts [4, 76].

All gardeners in Group 1 but GF3 were retired. GF1-GF3 live on the same street as the first author. Located in the Midwest region of the USA, across Illinois and Michigan, Group 1 completed non-digital versions of the probes. With group 2, GO9-GF20, who lived in both hemispheres, we used online, communal forms of phenology snapshotting and phenology wheels. Participants were recruited by personal contacts in the first author's neighborhood, ads in online nature communities, and snowball sampling.

3.3 Probe Design

Phenology probes are inspired by Cultural probes [25] and later iterations [60, 68]. We draw inspiration from the art of noticing and its integration in HCI [19, 45, 48] by offering different ways of noticing the garden through probes that explore spatial and temporal dimensions of nature by situating phenology in the design process. Observing nature in terms of time and space reveals how humans and nature affect one another and enables us to notice nature’s timings concerning space, which can influence our capacity to adapt to climate change.

We explore the attitudes and experiences of humans in nature just as Gaver, et al. [25] used mapping to inspire design based on their exploration of participants' attitudes towards their environment. Researchers and participants use spatial mapping during pre-study interviews to build context on the space in nature and how it illustrates human and nonhuman life affecting one another. Spatial mapping also reveals the nonhuman stakeholders known to the participant. Through discussion with gardeners, we found that gardeners are avid sharers of plants, seeds, and produce. Therefore we provided the gardeners with an opportunity to illustrate sharing through the spatial maps to understand how sharing might be part of human-nature relations.

Phenology snapshotting is designed to prompt the observation of spatiotemporal events in the garden, focusing on the noticeable changes over a period. Snapshotting was influenced by the works of Itinerant Probes [60] and their exploration of familiar spatial dimensions in probes. Snapshotting was also influenced by previous works in HCI that incorporated photography as a tool to reflect on natureculture [46]. Nonhuman stakeholders may be identified through snapshots due to the temporal dimension snapshotting encompasses.

Phenology wheels provide the context to a human's interactions with nature and how those relations have changed and expanded over time (e.g., worrisome climate shifts have led to the development of sustainable practices like composting). Phenology wheels also elicit interrelationships between nature and humans.

Cross-Cultural Dialogical Probes primarily influenced dialogue, co-presence, and co-creation in phenology probes [68]. We were interested in the relations between humans and nature and how people communicate with others about their nature observations. Several approaches were considered in the development of the phenology wheel, including the Phenology Clock Project [38], perspectives on cohabitation [67], formats for nature journaling, ecological calendars [11, 40], traditional ecological knowledge from anthropology and ecology, and nature and culture being interwoven, natureculture [33, 46]. According to Bulbulshoev et al. [10], concepts of time reveal ecological and socio-cultural values of individuals who use such calendar systems. Various human-phenological calendars have been implemented over the centuries [1, 10, 11, 40] to understand

the impacts of nature on humans, the drivers that are shifting the climate, and how we may adapt, often by using relational interpretations of time.

3.4 Phenology Probe Deployment Procedure

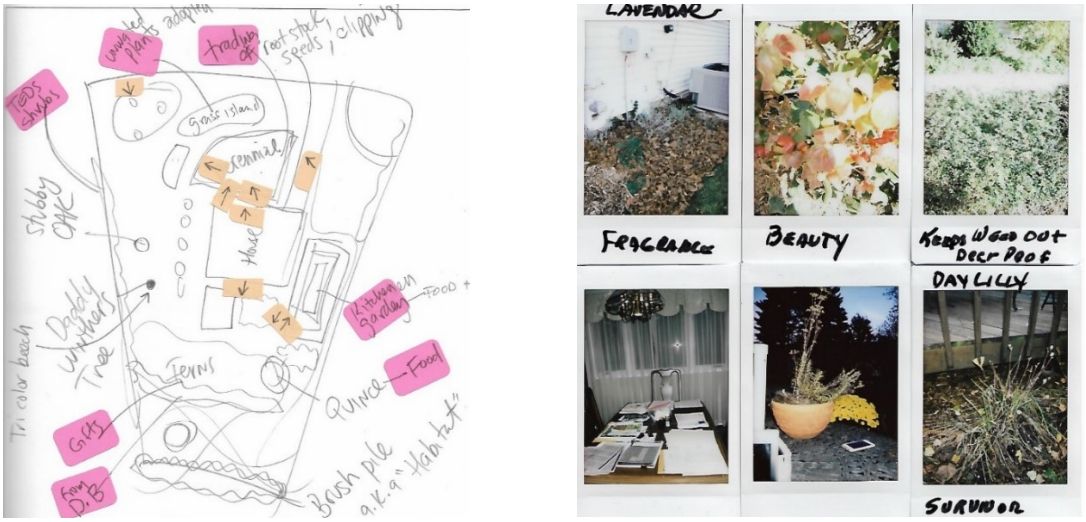

Figure 2: GF4's spatial map (left), GF1's phenology snapshots (right).

This section describes the phenology probe deployment procedure: Spatial mapping, Phenology snapshotting, Phenology wheels. Pre-study interviews included an introduction to phenology and phenophases, explained in terms of species' lifecycles and stages (plants, animals) and their linkages with other species and climate.

3.4.1 Spatial mapping

During the pre-study interview (Group 1), mapping was conducted where humans and nature coexist (gardens). Group 1 mapped their gardens and subsequently placed pink stickers on their maps to signify plants that had been shared (e.g., propagated plants). Gardeners conducted tours of their gardens to provide further context about the space. Some gardeners preferred to remain seated during the mapping probe and complete the tour afterward, while others used paper and pencil while touring the garden. This cyclic mapping activity required participants to revisit their maps to add orange stickers at the locations where they completed the subsequent phenology snapshotting. A completed spatial map is located in Figure 2.

3.4.2 Phenology Snapshotting

The second probe provided was phenology snapshotting; participants were tasked with taking photographs in their garden throughout a two- to three-week study. Group 1 was provided an instant camera, film, and instructions upon the conclusion of their pre-study interview. The snapshots were discussed in the post-study interview once the snapshotting probe had been completed. Group 1 was asked to write a thought or emotion around the instantly printed photo in the white space. Group 2 was added to a social media group to upload their snapshots. Instructions were to take photographs of phenophases in the garden whenever the gardeners felt compelled to. Within their posts to the social media group, Group 2 were asked to provide their location,

gardening zone, plant/animal species, comments about phenophase, and any general observation comments. Both groups were unsupervised in their pursuits of capturing images of phenophases in the garden. A set of phenology snapshots completed by GF1 is in Figure 2.

3.4.3 Phenology wheels

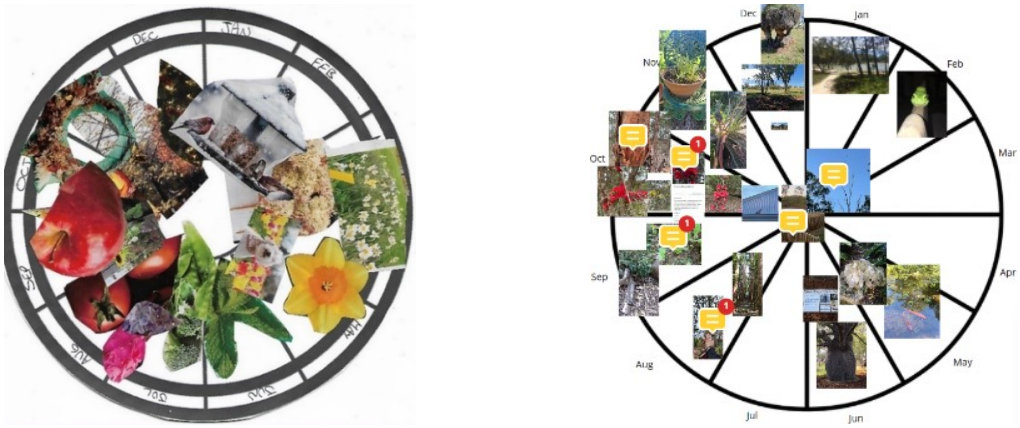

Figure 3: GF1's phenology wheel (left), GO16 and GO17's online phenology wheel (right)

The final probe in the set was a phenology wheel created to explore how people observe and relate to cyclic, biological events in nature across 12 segments (1 per month). Group 1 completed this probe in paper format, completed in one-on-one in-person post-study interviews (1-1.5 hours). With magazines, seed catalogs, scissors, and glue, Group 1 participants cut out images that they felt represented their relations with nature throughout the year and collaged them into their chosen months. During these recorded sessions, the researcher helped the participant cut out images. When necessary, the researcher prompted nature discussions but let the participant lead. Group 2 was presented the wheel in digital format using Miro, an online collaborative whiteboard, during a communal, co-creative Zoom workshop that encompassed a natural flow of dialogue between researcher and multiple participants (1-1.5 hours). An example of both versions of the phenology wheels is illustrated in Figure 3.

3.5 Analysis

Proceeding each contact with a participant (interviews, workshop), a mind map was created to visually understand the discussions accompanying the probes. Following a thematic analysis format [9], the recordings were transcribed and iterated to gain familiarity with the data. We subsequently found and iterated through patterns of humans and nature affecting one another to generate codes such as "familiar nature generates eye-catching phenophases," "memorializing humans through planting," and "ecological knowledge derived from experiences in nature" to further theorize and categorize the interview and workshop data into high-level themes (human-nature relations). Themes and codes were consistently reviewed as we obtained data. Images of completed Phenology Probes were simultaneously placed in mind maps and sections of the transcriptions to identify which probe elicited which discussion point throughout the iterations of all data, as well as coded. Snapshots were compared to search for underlying relational themes to support dialogue. Affinity diagrams of human-nature relations were created to understand how they are tightly woven and overlap. We embraced a

relational subjectivity, specifically unpacking the layers of relations, understanding that each theme and code consisted of the intertwinement of humans and nature that make the relations possible.

4 FINDINGS

Each probe in this paper worked together to piece together the types of human-nature relations present in the participants' gardens; no human has a single relation with nature, relations are multifaceted. Specifically, we found the following relations: personal histories of each participant that lead them to their attentiveness to nature; multisensory relations formed through experiencing nature in a multiplicity of senses; emotional relations through and with the garden; global relations that are formed through the digital phenology wheel resulting in the attentiveness to and care for nature across the globe; and climate relations that are actions derived from witnessing the shifts of the climate and the impact that has on local species and spaces. Whilst we have separated these relations in the presentation of our findings, these relations were often tightly interwoven. For example, personal histories were also entangled with sensory and emotional experiences, leading to care for nature exhibited through climate activism.

4.1 Personal Historic Relations

Gardeners often cited their personal histories, especially stories related to nature experiences from their childhood and cultural heritage, to illustrate nature's importance. Many gardeners had not thought about their experiences with nature throughout their lifetime in greater detail before. The engagement with the probes and the dialogue with the researcher elicited a new thought process for them, allowing them to attend to particular plants and animals that surround them and to reflect on their personal significance. The process of mapping was beneficial to bring out personal histories. Four of the participants in this study grew up on farmland. These participants showed a concentrated interest in growing food, the phenology of such plants, and what could be salvaged in winter. For example, GF2 (F, 62, IL USA), who grew up on farmland, illustrated while sketching her vegetable garden into a spatial map, *"I like picking fresh tomatoes. Especially tomatoes and cucumbers. There's nothing like a fresh tomato out of the garden. They just don't compare to the ones in the store… My mother grew up in the 30s to 40s depression era. So if you didn't have a garden, you didn't get a lot of fresh vegetables,"* contextualizing the history of her early experiences in nature and why she now has a vegetable and fruit garden. GF2 expanded while mapping out her garden, *"I'll can tomatoes. I'll make sauce. I'll make juice. I'll can the squash up. We make zucchini bread, and we will freeze the zucchini bread. We can pull that up throughout the year."* GF2's mother was an avid gardener who shared this passion with GF2 throughout her childhood.

Snapshots offered discussion points for understanding why a particular phenophase or species received attention, which also often led to discussions about personal histories. GF1 (F, 77, IL USA) lives in a once farmland county that has developed around her over the past four decades. As illustrated in Figure 2, GF1 captured a last-standing Day Lily after the year's first frost. GF1 labeled the snapshot as 'survivor' and took the researcher during the post-study interview to the garden area where the Day Lilies once grew. This participant was particularly fond of last-standing plants after the first frost, describing a personal historic relation to nature through her upbringing being influential towards her behavior of salvaging herbs and vegetables when possible. In the pre-study interview, GF1 salvaged and repotted herbs after the first frost at the table in her garden while the interview began (illustrated in Figure 2). GF1 stated, *"when I have time, I dry them [herbs] and use them during the winter… [my parents] didn't waste anything. I never wasted anything."* She continued to describe her

Italian heritage and parents from Italy who used overripe fruits to make tiramisu, *"the original had fruits that were going a little too ripe when it was getting late in the season for them, and they weren't quite as good... They didn't waste anything, so they made this layered tiramisu."* It became clear that the underlying fascination of plant survivors derived from her personal historic relation to nature. That is, GF1's heritage, upbringing and childhood nature experiences created attentiveness to plant survivors, and nature that could be salvaged.

4.2 Multisensory Relations

Gardeners often described rich sensory relationships with their gardens, such as experiencing the scents and colors of individual plants, feeling when a fruit is ripe, and preparing family meals from the harvest. The garden tour and spatial mapping allowed the researcher and participant to explore the gardens together and experience multisensory relations. For example, GF1 highlighted several sensory relations during her garden tour and invited the researcher to experience them. The first thing GF1 said was: "*This is rosemary. Smell it. It's very good on chicken. Squeeze some lemon in it. We'll throw the lemon in the cavity and put one of these [rosemary] inside,"* GF1 continued with her herbs, highlighting both their taste and feel and indicating her Italian heritage: *"Thyme is very peppery. Run your fingers on that. You'll get that in a lot of Italian type dishes."*, GF1's relations with nature were primarily through the senses, even relating to her peace and creativity, bringing positive psychological effects to the fore, *"[seeing] the colors [in nature], it gives me peace, peace and connection to creation. I've read things even with therapy and it says, it's good to get your hands in the Earth!"*

Phenology snapshots and phenology wheels enabled us to expand on these relations and explore how these relations changed throughout the year. For example, in winter, the multisensory relations highlighted were the experiencing of feeling cold and building structures out of snow. During the harvesting season, on the other hand, gardeners highlighted how the senses were involved in preparing food and sharing it with friends and family. GF2 and GF3 have rhubarb in their garden, GF2 described her love for rhubarb, *"I really love rhubarb, I make rhubarb pie and rhubarb sauce,"* GF2 shares her pies and sauce with neighbors, friends, family members, and even baked a rhubarb and apple pie for the first author. The rhubarb highlights a multisensory relation, through harvesting to bake goods for friends, family, neighbors, and gatherings, and clippings that are shared to expand the plant into numerous locations among family and friends. Gardeners, family, and friends nurture this plant. It is a source of expanding and strengthening relationships between humans, and human to nature.

4.3 Emotional Relations

The garden is not just a space that surrounds homes; it is a place that is often nurtured and evokes rich emotions. For some, these emotions were attached to personal histories and memories of loved ones. For others, emotions were a response to the sensory experiences in the garden and a source of joy and relief from the demands of everyday life. Some participants compared their emotional relations to the garden with their family, where they treated plants as beings that were part of the family and part of the daily routine. Touring the gardens and discussing spatial maps elicited emotional connections with and through nature, prompting dialogue about the origins of these relationships. Snapshots provided discussion points surrounding emotion towards nature, while phenology wheels drew out how gardeners relate to nature emotionally year-round through experiences that contribute to the emotional relations.

Many gardeners view the nature around them as beings and care for them as family members. For example, GF4 (F, 55, MI USA) is an avid sustainable gardener; she described her father's death and how it influenced

sharing and her garden. “The daddy [surname]'s tree, my former coworkers sent me the money and said, would you buy a tree, plant a tree memorial to your dad.” GF4 illustrated her father’s memory living on through the oak tree (Figure 4), her coworkers knew that GF4 was an avid gardener and comforted her with a plant to encapsulate the memories of her father. Moreover, a reoccurring theme was GF4’s relationship with her garden, through naming areas such as ‘Grass Island.’ GF4 demonstrated that she treats nature similar to how she would treat a human; she brings nature to the foreground in her everyday life and has formed an emotional relation through the effects of daily nature experiences. When GF4 completed a phenology wheel, she placed hikers in the center and told her story of hiking every day of the year, even when it’s snowing. GF4 uses these hikes to immerse herself in nature and pay close attention to the nature changes she observes year-round. While GF4 placed hikers in the center of her wheel, she explained*, “the same pleasures that I get out of gardening, I get out of hiking - observing nature. At the State Park there's forest. There's foredune, there's a lot of different sort of micro climates. So there's something new every month.”*

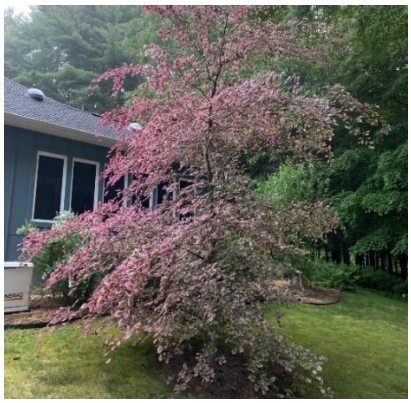

Figure 4: Memorial tree planted by GF4.

A recurring theme was how gardeners’ emotional states were affected through nature. For instance, GF5 (M, 66, MI USA) placed a sign within his garden with an arrow pointing in the direction of St. Louis, *“400 miles from St. Louis. My youngest son is in St. Louis.”* He described including a sign within the garden to symbolize his son, who moved out of the home. Each night GF5 walks through his garden with his wife to observe the changing nature. Throughout these walks, they also observe objects like the sign that encapsulates memories of their son and holds a part of him emotionally (in memory form) in the garden while he lives 400 miles away.

GF2 and GF3 (M, 63, IL USA) are married gardeners who live together; they propagated rhubarb from GF2’s deceased mother’s home 30 years ago. *“This original rhubarb plant was actually one of my mom's. It kept growing and growing, and then I shared it with my son too. So he’s got the rhubarb plant from his grandma.”* The plant is a memorial shared through four generations and affects the lives of the family who now remember their mother and grandmother through this plant; it is an emotional relation, a memory encapsulated within a plant species in the garden, and is the source of many family memories.

Gardeners also found that phenology wheels enabled them to reflect on their emotions in the garden. GF1 explained, *“It’s really helped me to reflect on why I garden, I’ve never done that before. Thinking about my parents gardening in Italy, the home grown tomatoes, the herbs and never wasting food growing up.”* GF1 described this reflection of gardening as she pasted a tomato cutout into her phenology wheel, as illustrated in

Figure 3. GF1 felt an overarching emotional relation to her garden; it is a central encapsulation and reminder of her human-nature relations, it is what keeps her in the garden.

4.4 Global Relations

Phenology wheels in online workshops revealed how gardeners globally relate to nature. The gardeners in these workshops exhibited curiosity in species and lifecycle events in opposite hemispheres, highlighting the potential of phenology probes to foster an awareness of nature beyond one's immediate surroundings.

Gardeners in Australia viewed images of snow from the Midwest region of the USA in awe, expressing their desire to experience the snow and view more observations of nature in a different climate. In contrast, gardeners in the Midwestern region of the USA wanted to jump into a warmer climate to experience and discover Australian wildlife. These were observations of nature in others' gardens that participants had not yet built relations with (i.e., some participants had not experienced snow in person, seen a kangaroo in person, or had ever heard of a certain type of plant before). There was a clear desire to explore and discover nature in new areas, and the ability to discuss the new nature prompted many conversations among the participants.

Viewing other people's nature observations in other continents created an added layer of appreciation for and relation to nature. In a tone of pure excitement, GF14 illustrated*, "she's [GF13] in a different season to us and I've never heard of this Camellia. Just seeing these other flowers, this is just fascinating. You're in Australia and I'm here [in IL, USA]."* GF14 questioned GF13 about Australian climate, *"When it's summer time because you live by the mountains. Is it dry heat? Or is it humid?"* GF13 responded, *"There's no ozone layer above Tasmania. So we have scorching heat… it's really dry."* Making global connections to other people and their gardens and having meaningful discussions is an important step toward collective action on climate change.

4.5 Climate Activist Relations

Finally, phenology probes helped surface climate activist relations. Firstly, gardeners reflected on observations of changes in their immediate environment. We found that gardeners pinpointed what was currently present in the garden through spatial maps and tours while sometimes describing what was 'missing' or had 'emerged.' Snapshots built context on gardeners' relations and thoughts about nature. Phenology wheels elicited dialogue about observations of temporal shifts where the timing of biological events had shifted throughout the years.

GF1 described the birds in her area as *missing*. Her Tina Crabapple tree was central to her climate relation to nature and tied to her concerns about bird migration. The Tina Crabapple tree symbolizes the action GF1 has taken through her climate relations as she has witnessed the bird migration in her area shift and the birds disappear over the last four decades around her home. GF1 has a firm belief that impacts on bird migration in her area are anthropogenic; she is confident that the bird feed people provide for the birds holds little nutritional value and has concerns about their sanitization. GF1 discussed how she now spreads the awareness that fruits and nuts are nutritious for birds and educates everyone about the threats to bird migration after witnessing her perceived extreme and worrying shifts in bird migration in her area. GF1 planted the Tina Crabapple tree to provide nutritious berries for the birds. When the first author of this paper moved into a house on the same street as GF1, GF1 deterred the author from placing a bird feeder and educated the author about planting fruits and nuts instead. GF1 labeled the Tina Crabapple snapshot as *'beauty',* explaining that beauty in itself is multifaceted; beauty in terms of aesthetics and providing for the local birds.

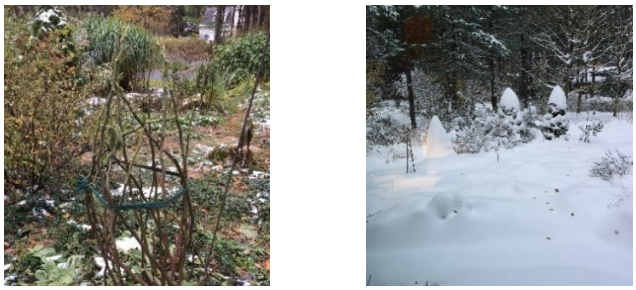

Figure 5: GF4's garden comparison, start to end of study (snapshots showing *"dramatic changes in weather"* – GF4)

Relatedly, GF4 spoke of feeling *"helpless and hopeless,"* when discussing dramatically quick weather changes viewed in her phenology snapshots from the study's beginning and end (Figure 5). Observing snapshots of weather changes prompted a discussion about other temporal shifts in GF4's mind. GF4 explained, *"In my short life I have seen the plovers and clams disappear from the beaches, the elms disappear from city street. Plastic crumbles appear in every shovelful of soil. My neighbors hire mosquito-spraying companies to fog their yards. Ever larger houses are popping up on every patch of undeveloped land."* With her thoughts about plastic emerging in the garden, undeveloped land being taken over, and species disappearing, she declared, *"In a nutshell, [I feel] frustration! Climate accords come and go with lots of wordy, carefully-framed promises, but action seems invisible"* GF4 firmly understands that humans and nature are interconnected. By completing the phenology wheel and dialogue with the researcher, it was clear that GF4 has advanced ecological knowledge. This ecological knowledge translates to her pro-environmental behaviors in choosing sustainability over ease.

Secondly, gardeners also reflect on their actions to mitigate the effects of climate change on their local environment. Most gardeners in this study cared deeply for nature and had already adopted pro-environmental behaviors. Through discussions surrounding the phenology wheel, we found that less experienced gardeners also desired to adopt pro-environmental behaviors. They benefitted from discussions with experienced gardeners during the co-creation of the wheel, and they left the workshop with plans to take action.

An example of climate activist relations was GO9, a novice gardener trying to adopt more environmentally sustainable practices by learning to preserve biodiversity. GO9 lived *"on acreage, there's a lot of wildlife here, I want to protect the wildlife. All of the land around me is now being built into houses and apartments, taking nature away. We have a Black Necked Stork, amazing bird that is nearly as tall as me. I want to protect that bird and the rest of the nature around me."* GO9 discussed growing tomatoes when she questioned if the phenology wheel could be an interface that included information to steer people into adopting pro-environmental behaviors, she asked *"can you have [information within a phenology wheel] that's got some natural pesticides? Rather than saying you need to be using this type of pesticide, pointing people into more environmentally friendly ways."* GO11 promptly replied, *"There's something that you can plant that will ward off something that will naturally eat the fruit."* Subsequently, GO12, an experienced gardener, placed a Marigold into the phenology wheel and illustrated, *"Marigold. It's the smell that wards off the butterfly that lays the egg."* GO12 educated novice gardeners about companion planting. Discussions throughout the wheel co-creation and critiques about potential features gardeners wanted added to a digital phenology wheel led to educational conversations, even resulting in planned action to adopt pro-environmental behaviors, *"I will be planting those marigolds with the tomatoes, and I'll give you an update later."* GO9 stated.

5 DISCUSSION

Inattentiveness to nature contributes to a lack of societal adaption to mitigate risks posed by anthropogenic climate change. Light, et al. [44] assert that we should design for attentiveness to more-than-humans and the parts of Earth that may make us feel uncomfortable. Phenology probes enabled gardeners to think more critically about their relations with nature, aiding gardeners to draw out new layers of their relations with nature. Instead of persuading people to become aware of the surrounding nature and climate shifts, we created phenology probes to raise attentiveness to their personal nature relations. This in turn led to people noticing nature's pleasures and what we can do when faced with uncomfortable aspects of nature, such as the beauty of birds but the dwindling bird numbers, and subsequently planting for healthy biodiversity. Our deployment of phenology probes achieved the social science aim of understanding how people pay attention to their human-nature relations, and the design aim by providing inspiration for design through the five key relations identified that have opened up spaces for design opportunity. Our own future work intends to design with these relations identified. Below we discuss the key human-nature relations identified, our reflections on the probe deployment, and directions for future work towards more than human-centered probes.

5.1 Noticing Human-Nature Relations

A key strength of the phenology probes was that they invited gardeners to notice and reflect upon their diverse relations with nature. The art of noticing has been foregrounded in posthumanist HCI design work [19, 45, 48] and has focused on decentering the human. Through phenology probes, we drew out how people are both affected by nature and affect nature in a personal context, drawing closer to nature. Hence, phenology probes provide a practical response to Liu, et al. [48] calling for methods and principles for noticing required in HCI. Phenology probes aided participants in forming new understandings of how they are interconnected with nature through noticing phenophases and intertwining the observations with their own life experiences.

On one hand, we found that people notice and relate to nature in very personal ways, such as their histories and upbringing, rich sensory experiences, and emotional connection with people and places related to the garden. For instance, a snapshot of an oak tree (Figure 4) had a complex meaning; it was gifted by coworkers and planted in a mourning process to memorialize GF4's father. The emotional action of memorial planting and the tree's existence in its space reflects natureculture and identifies an emotional relation with nature for that gardener. Liu, et al. [46] explored the ways natureculture presents itself by using photography as a tool; they assert that the concept of natureculture, the idea that nature and culture are so intertwined that they cannot be separated, is helpful as we move away from the human-centered design. Each human-nature relation we found through the deployment of phenology probes embodied natureculture and reflected how it presents in our lives in personal ways. Phenology probes build on prior work that elicits personal histories in spaces [60] by foregrounding nature relations through time and space, and taking a holistic approach whereby histories are a segment, or a layer, in the scheme of relations that visualize not only the human aspects but how human and nonhuman life are intertwined. Earlier work has revealed how gardeners create personal spaces in the garden to express human relationships [50]. In our research, emotional relations extend beyond how gardens reflect human relationships; our work expresses how nature in gardens is intertwined with life. By memorializing through planting, gardeners expand mourning experiences and find ways to relate with and to the garden, creating not only "subjective experiences" but observing and creating experiences with "movements in space" and "time" [46], layers of human-nature relations that embody natureculture.

On the other hand, participants noticed how their garden was related to broader concerns, as highlighted in the global relations to gardens in other climates and the relations to climate activism. Human-nature relations extend through personal (local) and global relations with nature. Locally, gardeners reflected on the discomforts such as plastic propping up in the soil and how they respond to such negative shifts with pro-environmental behaviors. As Light, et al. [44] asserted that we should design for the parts of earth people avoid and do not feel comfortable about, phenology probes enabled gardeners to reflect on these matters, signifying their relations with nature, such as climate activist relations. By connecting gardeners globally, we found that technologies can assist in connecting gardeners to aid in building appreciation for nature outside of one's norm. Global relations are an opportunity for technologies that scale beyond local levels and enable people to share the possibilities of natureculture that are unfamiliar to some, and also create discussions about making informed sustainable decisions through their relations, such as companion planting instead of using chemicals.

Noticing such relations is an important step in a design process. As Tomitsch, et al. [71] highlighted, making human and nonhuman stakeholders visible through personas is critical for design processes that affect our environment. Phenology probes can aid in the generation of nonhuman personas by identifying the presence of species in our environment, as well as important details such as their phenophases. Phenology probes also provide an opportunity to advance nonhuman personas [71] by highlighting the relations and interdependencies between different human and nonhuman stakeholders.

5.2 Reflections on the Dialogical and Temporal Aspects of Deploying Phenology Probes

A key feature of our study was that insights into human-nature relations came largely through the dialogue while participants and researcher engaged with the probes, in particular with the spatial mapping and the phenology wheel. In this sense, phenology probes built on the idea of cross-cultural dialogical probes [69], where probes are not simply deployed and retrieved by researchers, but where the researcher's presence helps build trust and dialogue with participants to make probe-led discoveries. In our study, the first author's emotional involvement helped participants feel comfortable revealing their personal information, from family matters, health histories, and discomforts to cultural heritage and upbringing, all a part of how people experience and relate to their gardens in both personal and global ways.

At the same time, phenology snapshots were captured by participants in their own time, without the researcher present. This worked well because this activity was fast and bounded and required less discussion with the researcher [17]. The snapshots also followed a different pace, where participants needed to take photos of nature over time, ranging from daily to weekly photos. The older participants in group 1 responded well to using instant cameras for this task to take photos and to label their images with associated emotions and thoughts. Group 2 used their cameraphones, which allowed them to share the snapshots with the group online. The final interview and workshop allowed participants to reflect on these snapshots with the researcher.

The phenology wheels worked particularly well, because the structure of the wheel allowed participants to see phenophases over time in a simple manner, and could relate the timings in nature with their own life experiences. The researcher could elicit dialogue about human-nature relations while acting as a co-creator by helping the participants cut out their chosen nature images from magazines.

Finally, phenology probes achieved the initial aims of collecting data (social science goal) and providing sensibility to designers on opportunities for sustainable design (design goal). Looking back at the study, we see that another strength of phenology probes was in their participatory nature. As highlighted by Boehner, et al.

[6], probes can give voice to participants to reflect on their own practices. Phenology probes gave voice to the gardeners, the nonhuman stakeholders, and their interrelations (as perceived by the gardeners). By incorporating a relational worldview, phenology probes help to foreground nonhuman lives in design.

5.3 Future Use of Phenology Probes to Give More Prominence to Nonhumans

Our main motivation in this study has been to think how can go beyond traditional human-centered design practices to give more prominence to nonhumans in the design process. By taking a probe approach in dialogue with participants, our study has given preference to the voices and interpretations of humans, which have led to new insights into their connections and relations to nature. While these insights are an important starting point, we are interested in how we can give more prominence to nonhumans. Light, et al. [44] assert that the 'H' in HCI is the incorrect term; if we are to design technologies that all beings are to cope with, we need to design technologies in ways that consider all stakeholders on an equal field, not only human stakeholders.

In future work, we are interested in applying natural materials to better understand nonhumans for their histories and futures and how this plays a role in contributing to design. Dew, et al. [19] offered insights on designing with living materials as active collaborators through lumber in a woodshop. In their research, they attained close attention and appreciation for nature's agency and derived histories and futures of the living materials (i.e., trees) that contributed to design. Garden tours in phenology probes elicited different responses about subjective experiences and multisensory relations in comparison to the other probes, because the gardeners were physically close to nature. Phenology probes participants could practice foraging for natural materials before completing a phenology wheel (e.g., over several seasons) to then complete a wheel with natural materials to elicit inspiring responses about human-nature relations.

A second direction for future work involves the use of audio-visual recordings to supplement or accompany phenology snapshotting. For example, researchers have used audio and video cameras to observe nature we may not typically see [26, 72], and some of that research found an increase in attention to human-nature relations, especially regarding care and concern for nature.

6 CONCLUSION

This paper contributes a design method, phenology probes, which work as interventions to raise attentiveness to human-nature relations that include both the enjoyments and the discomforts in nature. We uncovered five key human-nature relations: personal historic, multisensory, emotional, global, and climate activist. Each relation revealed the ways gardeners in this study have begun to move towards rejecting a human/nature divide in a familiar place (their gardens). Although it is difficult to go beyond human ways of knowing, phenology probes are a step towards working closely with nature to understand the affects between humans and nature by bringing phenology to the design process and noticing nature in terms of multifaceted relationality through time and space. Our future work is set to design a technology to enable people to notice nature differently, intertwining with the layers of relations discovered through working with gardeners. Finally, we invite researchers and designers to go beyond the garden, to scale out and study the human-nature relations in various natural spaces with other groups interested in how their lives are intertwined with nature.

ACKNOWLEDGMENTS

This research has been supported by the Australian Research Council (DP190101647).

REFERENCES

[1] Rein Ahas, J. Jaagus and A. Aasa. 2000. The Phenological Calendar of Estonia and Its Correlation with Mean Air Temperature. *International Journal of Biometeorology* 44, 4, 159-166. https://doi.org/10.1007/s004840000069

[2] Riga Anggarendra and Margot Brereton. 2016. Engaging Children with Nature through Environmental Hci. *In Proceedings of the 28th Australian Conference on Computer-Human Interaction*. ACM, 310-315. https://doi.org/10.1145/3010915.3010981

[3] Yasuyuki Aono and Shizuka Saito. 2010. Clarifying Springtime Temperature Reconstructions of the Medieval Period by Gap-Filling the Cherry Blossom Phenological Data Series at Kyoto, Japan. *International journal of biometeorology* 54, 2, 211-219. https://doi.org/10.1007/s00484-009-0272-x

[4] Richard Bisgrove and Paul Hadley. 2002. Gardening in the Global Greenhouse: The Impacts of Climate Change on Gardens in the Uk. *The UK climate impacts Programme*.

[5] Eli Blevis. 2007. Sustainable Interaction Design: Invention & Disposal, Renewal & Reuse. *In Proceedings of the SIGCHI conference on Human factors in computing systems*. 503-512. https://doi.org/10.1145/1240624.1240705

[6] Kirsten Boehner, Janet Vertesi, Phoebe Sengers and Paul Dourish. 2007. How Hci Interprets the Probes. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, New York, 1077-1086. https://doi.org/10.1145/1240624.1240789

[7] Rosi Braidotti. 2013. Posthuman Humanities. *European Educational Research Journal* 12, 1, 1-19. https://doi.org/10.2304/eerj.2013.12.1.1

[8] Rosi Braidotti. 2018. A Theoretical Framework for the Critical Posthumanities. *Theory, Culture & Society* 36, 6, 31-61. https://doi.org/10.1177/0263276418771486

[9] Virginia Braun, Victoria Clarke and Gareth Terry. 2012. Thematic Analysis. *APA handbook of research methods in psychology* 2, 57-71. https://doi.org/10.1080/17439760.2016.1262613

[10] Umed Bulbulshoev, Karim-Aly Kassam and Morgan Ruelle. 2011. Ecology of Time: Calendar of the Human Body in the Pamir Mountains. *Journal of Persianate Studies* 4, 2, 146-170. https://doi.org/10.1163/187471611X600369

[11] Philip A Clarke. 2009. Australian Aboriginal Ethnometeorology and Seasonal Calendars. *History and Anthropology* 20, 2, 79-106. https://doi.org/10.1080/02757200902867677

[12] Elsa E Cleland, Isabelle Chuine, Annette Menzel, Harold A Mooney and Mark D Schwartz. 2007. Shifting Plant Phenology in Response to Global Change. *Trends in ecology & evolution* 22, 7, 357-365. https://doi.org/10.1016/j.tree.2007.04.003

[13] Andy Crabtree, Terry Hemmings, Tom Rodden, Keith Cheverst, Karen Clarke, Guy Dewsbury, John Hughes and Mark Rouncefieldr. 2003. Designing with Care: Adapting Cultural Probes to Inform Design in Sensitive Settings. *OZCHI 2003*. ACM, 4-13.

[14] Bronwyn J. Cumbo and Tuck Wah Leongr. 2015. Wearable Audio-Video Recorders as a Tool for Investigating Child Play Experiences in Nature. *In Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction (OzCHI '15)*. ACM, Parkville, VIC, Australia, 618-622. https://doi.org/10.1145/2838739.2838822

[15] Gilles Deleuze and Félix Guattari. 1988. *A Thousand Plateaus: Capitalism and Schizophrenia*. Bloomsbury Publishing.

[16] Tshering Dema, Margot Brereton, Michael Esteban, Alessandro Soro, Sherub Sherub and Paul Roer. 2020. Designing in the Network of Relations for Species Conservation: The Playful Tingtibi Community Birdhouse. *In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1-14. https://doi.org/10.1145/3313831.3376713

[17] Eleanor Chin Derix and Tuck Wah Leong. 2019. Towards a Probe Design Framework. *In Proceedings of the 31st Australian Conference on Human-Computer-Interaction*. 117-127. https://doi.org/10.1145/3369457.3369467

[18] Eleanor Chin Derix and Tuck Wah Leong. 2020. Probes to Explore the Individual Perspectives on Technology Use That Exist within Sets of Parents. *In Proceedings of the 2020 ACM Designing Interactive Systems Conference*. 519-531. https://doi.org/10.1145/3357236.3395471

[19] Kristin N Dew and Daniela K Rosner. 2018. Lessons from the Woodshop: Cultivating Design with Living Materials. *In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1-12. https://doi.org/10.1145/3173574.3174159
[20] Carl DiSalvo, Phoebe Sengers and Hrönn Brynjarsdóttir. 2010. Mapping the Landscape of Sustainable Hci. *In Proceedings of the SIGCHI conference on human factors in computing systems*. 1975-1984. https://doi.org/10.1145/1753326.1753625
[21] Paul Dourish. 2010. Hci and Environmental Sustainability: The Politics of Design and the Design of Politics. *In Proceedings of the 8th ACM conference on designing interactive systems*. 1-10. https://doi.org/10.1145/1858171.1858173
[22] Nick J Fox and Pam Alldred. 2016. *Sociology and the New Materialism: Theory, Research, Action*. Sage,
[23] Lara S Franco, Danielle F Shanahan and Richard A Fuller. 2017. A Review of the Benefits of Nature Experiences: More Than Meets the Eye. *International journal of environmental research and public health* 14, 8, 864. https://doi.org/10.3390/ijerph14080864
[24] Eva Ganglbauer, Geraldine Fitzpatrick and Georg Molzer. 2012. Creating Visibility: Understanding the Design Space for Food Waste. *In Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia (MUM '12)*. ACM, Ulm, Germany, 1-10. https://doi.org/10.1145/2406367.2406369
[25] Bill Gaver, Tony Dunne and Elena Pacenti. 1999. Design: Cultural Probes. *Interactions* 6, 1, 21-29. https://doi.org/10.1145/291224.291235
[26] William Gaver, Andy Boucher, Michail Vanis, Andy Sheen, Dean Brown, Liliana Ovalle, Naho Matsuda, Amina Abbas-Nazari and Robert Phillips. 2019. My Naturewatch Camera: Disseminating Practice Research with a Cheap and Easy Diy Design. *In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, Glasgow, Scotland Uk, 1-13. https://doi.org/10.1145/3290605.3300532
[27] William Gaver, A. Dunne and E. Pacenti. 1999. Design: Cultural Probes. *Interactions* 6, 1, 21-29. https://doi.org/10.1145/291224.291235
[28] William H Gaver, Ben Hooker, Anthony Dunne and Paul Farrington. 2001. The Presence Project (Rca Crd Projects Series). *London: RCA Computer Related Design Research*, 21-52.
[29] William W. Gaver, Andrew Boucher, Sarah Pennington and Brendan Walker. 2004. Cultural Probes and the Value of Uncertainty. *Interactions* 11, 5, 53-56. https://doi.org/10.1145/1015530.1015555
[30] Alex Gillespie and Jack Martin. 2014. Position Exchange Theory: A Socio-Material Basis for Discursive and Psychological Positioning. *New Ideas in Psychology* 32, 73-79. https://doi.org/10.1016/j.newideapsych.2013.05.001
[31] Brian P Haggerty and Susan J Mazer. 2008. The Phenology Handbook. *University of California, Santa Barbara*, P41.
[32] Lon Åke Erni Johannes Hansson, Teresa Cerratto Pargman and Daniel Sapiens Pargman. 2021. A Decade of Sustainable Hci: Connecting Shci to the Sustainable Development Goals. *In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1-19. https://doi.org/10.1145/3411764.3445069
[33] Donna Jeanne Haraway. 2003. *The Companion Species Manifesto: Dogs, People, and Significant Otherness*. Prickly Paradigm Press Chicago,
[34] Sara Heitlinger, Rachel Clarke, Adrian K. Clear, Simran Chopra and Özge Dilaver. 2019. Co-Creating "Smart" Sustainable Food Futures with Urban Food Growers. *In Proceedings of the 9th International Conference on Communities & Technologies - Transforming Communities*. Association for Computing Machinery, Vienna, Austria, 114–120. https://doi.org/10.1145/3328320.3328399
[35] Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans and Heiko Hansen. 2003. Technology Probes: Inspiring Design for and with Families. *CHI 2003*. ACM, 17-24. https://doi.org/doi.org/10.1145/642611.642616
[36] Amy M Iler, Paul J CaraDonna, Jessica RK Forrest and Eric Post. 2021. Demographic Consequences of Phenological Shifts in Response to Climate Change. *Annual Review of Ecology, Evolution, and Systematics* 52. https://doi.org/10.1146/annurev-ecolsys-011921-032939
[37] Ole Sejer Iversen and Christina Nielsen. 2003. Using Digital Cultural Probes in Design with Children. *Interaction Design And Children: In Proceeding of the 2003 conference on Interaction design and children*. Citeseer, 154-154. https://doi.org/10.1145/953536.953564
[38] Natalie Jeremijenko, Jake M Richardson, Tega Brain and Blacki Li Rudi Migliozzi. 2018. Phenology Clock: Design and Concept. Retrieved 2021 from https://www.tegabrain.com/The-Phenology-Clock.

[39] Katherine A Johnson. 2016. Real Life Science with Dandelions and Project Budburst. *Journal of microbiology & biology education* 17, 1, 115-116. https://doi.org/10.1128/jmbe.v17i1.1064
[40] Karim-Aly S Kassam, Morgan L Ruelle, Cyrus Samimi, Antonio Trabucco and Jianchu Xu. 2018. Anticipating Climatic Variability: The Potential of Ecological Calendars. *Human Ecology* 46, 2, 249-257. https://doi.org/10.1007/s10745-018-9970-5
[41] Cecilia Katzeff, Loove Broms, Li Jönsson, Ulrika Westholm and Minna Räsänen. 2013. Exploring Sustainable Practices in Workplace Settings through Visualizing Electricity Consumption. *ACM Transactions on Computer-Human Interaction (TOCHI)* 20, 5, 1-22. https://doi.org/10.1145/2501526
[42] Christian Körner and David Basler. 2010. Plant Science. Phenology under Global Warming. *Science* 327, 5972, 1461-1462. https://doi.org/10.1126/science.1186473
[43] Stacey Kuznetsov and Eric Paulos. 2010. Upstream: Motivating Water Conservation with Low-Cost Water Flow Sensing and Persuasive Displays. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1851-1860. https://doi.org/10.1145/1753326.1753604
[44] Ann Light, Alison Powell and Irina Shklovski. 2017. Design for Existential Crisis in the Anthropocene Age. *In Proceedings of the 8th International Conference on Communities and Technologies*. 270-279. https://doi.org/10.1145/3083671.3083688
[45] Jen Liu, Daragh Byrne and Laura Devendorf. 2018. Design for Collaborative Survival: An Inquiry into Human-Fungi Relationships. *In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1-13. https://doi.org/10.1145/3173574.3173614
[46] Szu-Yu Liu, Jeffrey Bardzell and Shaowen Bardzell. 2018. Photography as a Design Research Tool into Natureculture. *In Proceedings of the 2018 Designing Interactive Systems Conference*. 777-789. https://doi.org/10.1145/3196709.3196819
[47] Szu-Yu Cyn Liu, Shaowen Bardzell and Jeffrey Bardzell. 2019. Symbiotic Encounters: Hci and Sustainable Agriculture. *In proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, 317. https://doi.org/10.1145/3290605.3300547
[48] Szu-Yu Liu, Jen Liu, Kristin Dew, Patrycja Zdziarska, Maya Livio and Shaowen Bardzell. 2019. Exploring Noticing as Method in Design Research. *In Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion*. 377-380. https://doi.org/doi.org/10.1145/3301019.3319995
[49] Peter Lyle, Jaz Hee-jeong Choi and Marcus Foth. 2014. Designing for Grassroots Food Production: An Event-Based Urban Agriculture Community. *In Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures the Future of Design (OzCHI '14)*. ACM, Sydney, New South Wales, Australia, 362-365. https://doi.org/10.1145/2686612.2686666
[50] Hanuma Teja Maddali and Amanda Lazar. 2020. Sociality and Skill Sharing in the Garden. *In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1-13. https://doi.org/10.1145/3313831.3376246
[51] Alexandre K Magnan, Hans-Otto Pörtner, Virginie KE Duvat, Matthias Garschagen, Valeria A Guinder, Zinta Zommers, Ove Hoegh-Guldberg and Jean-Pierre Gattuso. 2021. Estimating the Global Risk of Anthropogenic Climate Change. *Nature Climate Change* 11, 10, 879-885. https://doi.org/10.1038/s41558-021-01156-w
[52] Annette Menzel. 2002. Phenology: Its Importance to the Global Change Community. *Climatic change* 54, 4, 379. https://doi.org/10.1023/A:1016125215496
[53] Annette Menzel and Tim Sparks. 2006. Temperature and Plant Development: Phenology and Seasonality. *Plant growth and climate change* 70, 95. https://doi.org/10.1002/9780470988695.ch4
[54] Diego Muñoz, Bernd Ploderer and Margot Brereton. 2019. Position Exchange Workshops: A Method to Design for Each Other in Families. *In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1-14. https://doi.org/10.1145/3290605.3300339
[55] Kaori Okui, Yoshihiro Sawada and Takehito Yoshida. 2021. “Wisdom of the Elders” or “Loss of Experience” as a Mechanism to Explain the Decline in Traditional Ecological Knowledge: A Case Study on Awaji Island, Japan. *Human Ecology* 49, 3, 353-362. https://doi.org/10.1007/s10745-021-00237-w
[56] Ariel Ortiz-Bobea, Toby R Ault, Carlos M Carrillo, Robert G Chambers and David B Lobell. 2021. Anthropogenic Climate Change Has Slowed Global Agricultural Productivity Growth. *Nature Climate Change* 11, 4, 306-312. https://doi.org/10.1038/s41558-021-01000-1
[57] Marieke Oumard, Diana Mirza, Juliane Kroy and Konstantinos Chorianopoulos. 2008. A Cultural Probes Study on Video Sharing and Social Communication on the Internet. *In Proceedings of the 3rd international conference on Digital Interactive Media in Entertainment and Arts*. 142-148. https://doi.org/10.1145/1413634.1413664

[58] Estelle Perry, Charlotte Baraudon and Stéphanie Fleck. 2018. Designing Hci for Education: Cultural Probes Interest to Better Know the Teacher-User. *In Proceedings of the 30th Conference on l'Interaction Homme-Machine*. Association for Computing Machinery, Brest, France, 186-194. https://doi.org/10.1145/3286689.3286706
[59] Ankita Raturi, Juliet Norton, Bill Tomlinson, Eli Blevis and Lynn Dombrowski. 2017. Designing Sustainable Food Systems. *In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 609-616. https://doi.org/10.1145/3027063.3027075
[60] Daniela K Rosner, Margaret E Morris, Ariel Duncan, Sarah E Fox, Kathi R Kitner, Ankur Agrawal and Mei J Chen. 2016. Designing for Movement in Public Life with Itinerant Probes. *In Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. 1072-1082. https://doi.org/10.1145/2901790.2901913
[61] Oliver Schneider, Bruno Fruchard, Dennis Wittchen, Bibhushan Raj Joshi, Georg Freitag, Donald Degraen and Paul Strohmeier. 2022. Sustainable Haptic Design: Improving Collaboration, Sharing, and Reuse in Haptic Design Research. *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. Association for Computing Machinery, New Orleans, LA, USA, Article 79. https://doi.org/10.1145/3491101.3503734
[62] Eric Schweikardt. 2009. Sustainably Ours User Centered Is Off Center. *interactions* 16, 3, 12-15. https://doi.org/10.1145/1516016.1516019
[63] Sabrina Scuri, Marta Ferreira, Nuno Jardim Nunes, Valentina Nisi and Cathy Mulligan. 2022. Hitting the Triple Bottom Line: Widening the Hci Approach to Sustainability. *CHI Conference on Human Factors in Computing Systems*. 1-19. https://doi.org/10.1145/3491102.3517518
[64] UN SDG. 2018. Sustainable Development Goals. *United Nations*.
[65] T Sekiguti. 1969. Historical Dates of Japanese Cherry Festivals since the 8th Century and Her Climatic Changes. *Tokyo Geogr. Pap* 13, 175-190.
[66] Danielle Shanahan and Richard Fuller. 2016. Averting the Extinction of Experience. *Wildlife Australia* 53, 2, 36. https://doi.org/10.3316/informit.163465501073785
[67] Nancy Smith, Shaowen Bardzell and Jeffrey Bardzell. 2017. Designing for Cohabitation: Naturecultures, Hybrids, and Decentering the Human in Design. *In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 1714-1725. https://doi.org/10.1145/3025453.3025948
[68] Alessandro Soro, Margot Brereton, Jennyfer Lawrence Taylor, Anita Lee Hong and Paul Roe. 2016. Cross-Cultural Dialogical Probes. *In Proceedings of the First African Conference on Human Computer Interaction*. ACM, Nairobi, Kenya, 114-125. https://doi.org/10.1145/2998581.2998591
[69] Alessandro Soro, Margot Brereton, Jennyfer Lawrence Taylor, Anita Lee Hong and Paul Roe. 2016. Cross-Cultural Dialogical Probes. *In Proceedings of the First African Conference on Human Computer Interaction*. ACM, 114-125. https://doi.org/10.1145/2998581.2998591
[70] Lucy Suchman. 1993. Working Relations of Technology Production and Use. *Computer supported cooperative work* 2, 1, 21-39.
[71] Martin Tomitsch, Joel Fredericks, Dan Vo, Jessica Frawley and Marcus Foth. 2021. Non-Human Personas: Including Nature in the Participatory Design of Smart Cities. *Interaction Design and Architecture (s)* 50. https://doi.org/10.55612/s-5002-050-006
[72] Kellie Vella, Bernd Ploderer and Margot Brereton. 2021. Human-Nature Relations in Urban Gardens: Explorations with Camera Traps. *In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1-13. https://doi.org/10.1145/3411764.3445438
[73] Frank Vetere, Martin R. Gibbs, Jesper Kjeldskov, Steve Howard, Florian "Floyd" Mueller, Sonja Pedell, Karen Mecoles and Marcus Bunyan. 2005. Mediating Intimacy: Designing Technologies to Support Strong-Tie Relationships. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, Portland, Oregon, USA, 471–480. https://doi.org/10.1145/1054972.1055038
[74] Marcel E Visser and Christiaan Both. 2005. Shifts in Phenology Due to Global Climate Change: The Need for a Yardstick. *In Proceedings of the Royal Society B: Biological Sciences* 272, 1581, 2561-2569. https://doi.org/10.1098/rspb.2005.3356
[75] Ron Wakkary. 2021. *Things We Could Design: For More Than Human-Centered Worlds*. MIT press.
[76] Eleanor Webster, Ross Cameron and Alastair Culham. 2017. Gardening in a Changing Climate.

[77] Ilaria Zonda, Dan Xu, Mick Jongeling and Gijs Huisman. 2019. Growkit: Using Technology to Support People Growing Food at Home. *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM, Glasgow, Scotland Uk, 1-6. https://doi.org/10.1145/3290607.3312834