Designing Participatory Sensing with Remote Communities to Conserve Endangered Species

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Figure 1: The existing monitoring form used by local support members (left), Design probe revealing the critically endangered White-bellied Heron in its habitat (center), and children playing guessing game using audio and spectrogram visuals of local species (right)

ABSTRACT

The increasing loss of species globally calls for effective monitoring tools and strategies to inform conservation action. The dominant approach to citizens engagement has been smart phone and platform-centric, tasking crowds to collect and analyze data. However, many critically endangered species inhabit remote areas, characterized by sparsely populated communities with poor internet connectivity. Approaches need to garner high engagement relative to population size, with data collection and knowledge synthesis suited to the local context. We conducted a field study in remote communities to understand how to enhance conservation of Bhutan's critically endangered White-bellied heron by exploring existing monitoring practices and trialing acoustic sensing technologies. We found that knowledge about the species is partial, heterogeneous, situated within and across communities and rooted in cultural beliefs. Sensors, acoustic interfaces, and playful probes provided new ways for the community to 'see' and discuss their local environment fostering them to share and grow their knowledge together. We contribute a synthesis of key considerations for designing effective participatory sensing to conserve species in remote communities.

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CCS CONCEPTS

• **Human-centered computing** → **Field studies**; • **Social and collaborative computing**;

KEYWORDS

Conservation technologies; remote communities; participatory sensing; endangered species; social computing.

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1 INTRODUCTION

Environmental degradation and species loss are pressing global issues. Our planet is losing species at an unprecedented rate every year with higher risk of extinction of endangered species [20, 43, 59]. Several ecological studies highlight the significance of community participation in conservation endeavors for achieving successful conservation outcomes (e.g., [11, 34, 57]). However, these works shed little light on how to guide technology design for fostering community participation in conservation. Notably, a few recent studies in the HCI and CSCW communities [1, 13] have emphasized the need for broader interdisciplinary investigations on environmental protection, the role of technology, and whose agency is being strengthened by various forms of intervention.

The dominant technology used for citizen science targeting environmental conservation are either smartphone-based participatory sensing (e.g. eBird [58]) or online crowd sourcing platforms that facilitate the crowd to gather data or take part in cataloguing instances of data (e.g. Zooniverse [12]). We argue such open participation approaches are focused on wide spatial coverage of data through dispersed individuals submitting or analyzing data. They are therefore unsuitable for critical species conservation in remote settings due to the sensitivity and rarity of endangered species [35] and the remoteness of their habitat. In most cases, remote settings also have a sparse human population and poor internet connectivity. Thus, understanding design of suitable technology for enhancing conservation of endangered species in remote communities requires its own investigation.

This study aims to (1) understand existing monitoring practices and community participation for conservation of the critically endangered White-bellied Heron in remote communities of Bhutan; (2) explore design opportunities to enhance conservation practices and community participation by using acoustic sensing devices and probes [47]. We carried out a series of interviews, participant observations, and focus group discussions with various stakeholders (local support members, villagers, foresters, ecologists and staff at the conservation NGO, and local leaders) across five communities where the species inhabits. Further, we undertook participatory fieldwork and design sessions using acoustic sensors and probes with members of different communities.

We found several ways in which new socio-technical approaches can enhance conservation practices, awareness within communities, and effort by multiple stakeholders. First, while people had varying contextual knowledge of species and its habitat in the local environment, there was a lack of communal knowledge sharing across and within communities, thus as a result knowledge is disconnected and the opportunity to build a more comprehensive picture is neglected. Second, we found that conservation is rooted in the cultural practices and beliefs within the community. However, currently there is a lack of collective knowledge and action within the communities. The few local support members were over time dissatisfied with the paper-based monitoring which was limited to data entry of sightings; lacking further means to learn or share more about the species and environment. In our fieldwork trialing acoustic sensing devices and probes, we observed emergent participation and collaborative knowledge building among the stakeholders as the locals use their situated knowledge to figure sensor deployment sites; engage in joint interpretation of soundscapes; and share anecdotal knowledge and beliefs about the local species and environment in fun ways within communities.

Diverging from the dominant participatory sensing paradigms, our findings alert us to design for enhancing deeper engagement within communities for species conservation. This may help to widen our focus towards tools and interventions that create spaces for seeding interest and participation through playful interaction, collaborative learning and generation of awareness through joint interpretation of data within communities; rather than tasking people to submit data or to analyse data in disembodied manner. As such, shared agency will be promoted for conserving species among different stakeholders.

Our work contributes a synthesis of key considerations for designing new human-machine configurations for conservation of species in remote communities -

(1) Design must support assembling heterogeneous local knowledge of community members and pay attention to their local beliefs and social practices that influence conservation
(2) Engagement should entice, educate and grow interest within communities as opposed to tasking and reviewing data in disembodied manner (situated learning and exploration)
(3) The agencies of all actors in conservation must be understood and designed for.
(4) Conservation tools and decision support systems must leverage environmental sensor data and local knowledge synergistically to generate awareness and local action.

2 STUDY CONTEXT

85 percent of all species described in the IUCN's Red List are either "Threatened" or "Endangered" [20]. There exist only 60 individuals of the critically endangered, White-bellied Heron on earth, with a severe risk of extinction. 28 to 30 inhabit across dispersed wetland areas of Bhutan. Bhutan plays a pivotal role in protecting the critically endangered species in its natural habitat [46]. Monitoring strategies and tools

need to be unobtrusive and practical considering the solitary nature and critical status. Since 2003, the Royal Society for Protection of Nature (RSPN) has prioritized conservation of this flagship species in the country and has initiated a heron monitoring support group. The group consists of 13 local support group (LSG) members across distributed communities where the species is known to inhabit. The LSG members report sightings of the species using a paper-based monitoring form (Figure 1, left), which is periodically consolidated by the NGO conservation office. To date, no studies have been conducted to investigate how technology can enhance monitoring practices and participation of various stakeholders (including wider community members) in this work. Our study aims to understand existing practices of various stakeholders and seek to gain design insights for enhancing conservation participation within remote communities.

3 BACKGROUND

Technology trends for nature conservation

There is growing interest in and adoption of new technology that can gather data at large spatio-temporal scale to support conservation work (such as camera-traps, drones, and acoustic sensors) [41]. However, this raises the need for appropriate data collection and analytic approaches. Citizen science and crowdsourcing approaches are considered to have great potential and power to expand ecological research [37, 42, 43]. Broadly, there are two kinds: i) participatory sensing using handheld sensors and smart phone apps; (ii) crowdsourcing platforms to curate and analyse large-scale environmental data. Most apps are focused on enabling distributed individuals to collect biodiversity data in the form of photos, audio and video clips (e.g. eBird [57], iSpotNature [50]. Notably, the rapid growth and interest in smartphone apps is highlighted in a recent survey that reports 36,304 apps in the Google play store that are related to nature themes; out of which 6301 apps were identified as closely tied to nature conservation activity such as surveys, sightings, field guides and gaming apps [21, 33]. Alternatively, in a recent study report of Snapshot Serengeti (a conservation project hosted on the Zooniverse crowdsourcing platform that engages distributed people to categorize and identify animals from instances of a huge number of camera-trap images), the authors proposed a more holistic approach to truly understand the ecosystem to inform conservation of species. Other crowdsourcing engagement strategies involve online gamification and game design [5]. Recently, advanced smartphone-based citizen sensing apps [61] have incorporated machine learning functionality. While these smart devices are designed with automated detection features, their usefulness in terms of distributed instances of data contribution is dependent on where and for how long people were there. Thus, most of these approaches consider biodiversity monitoring and conservation as a by-product of human mobility. Notably, Moran et al (2014) conducted a smartphone-based citizen sensing to monitor critically endangered cicadas in a UK forest reported the inappropriateness of such an approach for sensitive species as many people were out in the habitat area of a critically endangered species, potentially causing disturbance while searching for the species [35]. Therefore, although designing around the mobile phone is a well-considered alternative in rural technology design due to its ubiquity and ownership by a large population, it is often recommended for its use as a medium to provide people with useful text information and as a communication medium (e.g., farming practices [40], market information [60]. Moreover, most existing participatory sensing studies presume there are enough keen and motivated people who are interested to participate in data collection and analysis, with technology design targeted for specific keen communities such as birdwatchers [10]. While there are a large number of stand-alone web and mobile apps targeted for learning species identification, in most cases learning is considered to be a modular activity that is not particularly integrated into other aspects of participation and community context. Our study seeks to explore new design opportunities to enhance conservation participation within communities that share the environment with endangered species. Acoustic sensors are gaining popularity as a non-invasive monitoring approach for various environmental studies [4, 31], however in most studies, the devices are used as a data gathering tool and how this new sensing technology might support existing practices of species monitoring and conservation by various stakeholders and how it can potentially enhance community participation remains understudied.

Environmental sensing research in HCI

Environmental conservation and sustainability research in HCI has largely focused on individual or household consumption practices of water and energy and focused on use of persuasive technology e.g., [14, 15, 48]. More recently, a growing body of work has focused on environmental monitoring and data work in HCI. Sensor technologies of different capacities are used to gather and discuss environmental data of different kinds (such as air, water, and energy). Kim et al (2010, 2013) reported on how visual tools to monitor indoor air quality using hand held devices helped raise awareness and reflection of participants about air pollution. Further, their creek watch study [26] investigated the quality and usefulness of the water quality data gathered by citizens and how that is used by managerial stakeholders. The study recommended that design of useful data for end users is as important as designing the user interface. Similarly, Aoki et al (2009) through their street sweepers design field work investigated how to facilitate public awareness of environmental conditions by working with government, private, and public stakeholders. Recently, the authors investigated citizen's motivations for participation in local air monitoring where they argued that citizen science design investigation must look beyond data protocols to reduce human variability [12]. Most works have focused on urban environmental data that are scientifically more explored such as air pollutants and water contaminants [23]. Design investigation to enhance conservation practices in remote community context is currently understudied, as is exploration of environmental sound data and wilderness contexts. To the best of our knowledge, there are no interventions that focus on investigating human-environmental sound data interactions to inform design of processes and technology to support species conservation. Moreover, environmental soundscape representations that can be navigated as reams of acoustic scenes (see Figure 2) over a long duration have not been studied for conservation design. Details on how the environmental soundscapes are generated from long duration recordings is reported in [54]. Sensors of different forms and capacities have been used for various individual purposes and social applications to build a network of devices and human connections in varying contexts (e.g., for family connection over distance [7], light sensors in the garden [49], smart cities [32]). We believe there is a need to better understand how to configure the use of sensing devices considering existing human practices, the capacities and limits of sensing devices and the environment in which they are used. Notably, Gaver et al explored a ludic approach through a curious system to explore technology design opportunities for encouraging environmental awareness in domestic spaces [17, 18]. Kutnetsov et al (2011) investigated practices of people who used both traditional and digital sensing technologies to understand living organisms (e.g., gardeners and beekeepers) and found that innovative technology design can teach new ways of understanding local ecosystem processes. However, few investigations have explored environmental sensing from a broader practice and design lens. Our study will investigate how sensing technologies might support conservation practices and participation in remote communities.

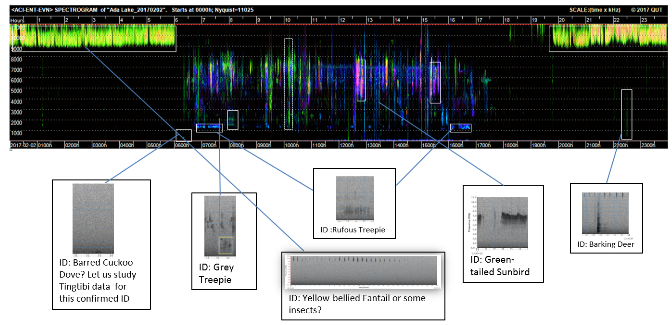

Figure 2: A 24 hours soundscape representation from Site 2 lake side (dated: 2^{nd} Feb 2017) that was jointly annotated after listening to the audio by local support member, forester (P16) and ecologists (P2, P18).

4 METHODOLOGY

Our study took a pragmatic approach aiming to understand practices, knowledge, and perceptions in relation to conservation of the White-bellied Heron across remote communities and to explore opportunities for enhancing participation and creation of new conservation practices using acoustic sensor technologies. As Schwartz (2013)'s, referring to Idhe (1978)'s non-neutrality of technology remarked, *"the matter of design should not be the artefact in isolation, but the co-evolution of the artefacts and the social practices in which they are embedded"* [48]. For this reason, our research investigates human-machine configurations [53], a term that we use to describe the broader context in which humans interact with each other and machines as well as detailed interactions with interfaces. This includes considerations such as who will use devices and interfaces, what skills they have, what kinds of social relations exist, where devices might be placed, how information and stories might be shared - in person or via machine, and the ways in which agency is distributed across humans and machines. In small remote communities, in particular, the context of technology use must be understood. To begin, we conducted a series of contextual interviews and observational studies with multiple stakeholders across communities and at the NGO conservation office. By forming a team of interested locals led by the forester in the region, a nesting site was located based on situated knowledge of local people in the community. After the deployment of sensors, contextual inquiries and focus group discussions were conducted with the team members to gain their perspective and motivation for participation. The full list of participants and sites for the study is shown in Table 1.

Based on the outcome of the initial study, a seed technology probe [19] was designed. The probe was designed to play bird media to audiences of different sizes. It consisted of local bird stills, calls, videos of birds vocalising, call spectrograms, and clues in the form of anagrams of bird names in local language, stored on a R-Pi computer. Media could be played through a built-in small screen, on a larger screen or projected on a wall. Games were made up on the spot, playing only sound or revealing further clues (anagram, video, spectrogram) encouraging participants to identify and discuss bird sounds. Probes were used as instruments for eliciting participation and to engage more deeply in the design exploration process [22,51,55]. Rather than interviewing people about their knowledge of birds, the probe served as an engaging talking point, encouraging reflection and sharing knowledge of local birds. It also served to elicit design insights on possible technologies for community engagement in conservation. The probe was used with different community members to engage and trigger discussions during community social gatherings, with groups of children in the village and schools, villagers at home, and teacher groups across different sites (Figure 3b). The design and mode of interaction with the probe at this point was left very open-ended so that it was appropriable to different community groups and social settings. Acoustic sensing is a non-invasive approach to monitor species and the environment. All the sensor recordings from the sites are hosted on a web-based acoustic workbench [55]. The key features of the system are that it allows navigation and visualization of the long duration (days, months to even years) audio recordings across multiple sites. With summarised sound representations (referred to as soundscapes), a day of sound can be seen on a single screen or as an interpretable image on an A3 sheet of paper. We used summarized and standard visual representations of sound and played the associated sounds at points of interest identified by the participants from inspecting the visual representations. We sought to understand whether participants found these representations of value, how they discussed them, and what the requirements were for interface technologies that might incorporate the soundscapes and foster collaborative analysis and discussion of environmental data. We emphasize that the system that generates these soundscapes was not designed for rural community use. Thus we used paper visualisations or facilitated on-screen use, in order to understand how the community might use the visualisations and how to design with that in mind, rather than trying to evaluate the existing system in this context. A sample soundscape visualization is shown in Figure 2. Several collaborative investigations into the data were carried out using both low-fidelity paper prototypes and high-fidelity prototypes of soundscape representations. These were used to understand how people can find target species, make sense of and interpret the environmental soundscape data as well as to understand how stakeholders engage with each other through sensor data interpretation. We also participated in local events and informal social gatherings (e.g., annual ceremonies, community gatherings) in the village to gain deeper understanding of their socio-ecological associations and practices around the species habitat area. All interviews, focus-group discussions, and design sessions were audio recorded and transcribed and the field discussions notes were summarized. Altogether, this resulted in more than 15 hours of recordings. Most interviews were conducted in the local language, Dzongkha, which was later translated to English by the first author. We used thematic analysis, a widely used qualitative approach to identify key themes across a set of data [6]. Thematic analysis revealed themes that helped us to identify key related sub-themes around existing monitoring practices and socio-ecological relations in each community context. It also revealed opportunities for fostering community participation and conservation awareness of local environment and species using sensed data probes within communities. Next, we discuss our findings.

Figure 3: Use of probe (right) and sensor deployment by local support member at Site 5

5 FINDINGS

Our analysis discovered key findings related to:

(1) people's knowledge and perceptions about the endangered species,
(2) current monitoring practices of multiple stakeholders and the opportunities and challenges arising,
(3) the need for a bigger picture approach incorporating broader socio-ecological practices

Our fieldwork using acoustic sensing technologies and design probes in communities provided insights into how we might be able to (a) enhance participation by seeding interest socially within communities and (b) support collective discourse and knowledge sharing through new interfaces to the environment.

PERCEPTIONS, CONTEXTUAL FACTORS & EXISTING MONITORING PRACTICES

Distributed and heterogeneous local knowledge. People across sites had different perspectives and contextual knowledge about the species. In some communities, only a few people were familiar with the species' behavioral aspects (such as its flight direction and nest trees) with various speculations about its existence in their areas. For instance, the local person at Site 3 who lives near the feeding areas knew little about the species calls, but a lot about its feeding behaviour and arrival time. Likewise, at site 1, the nest is on a steep cliff across a big river and because the heron is visible to a few local household residents when it flies in and out of the nest,

Table 1: List of participants and monitoring sites

Sites	Participants (Experience in terms of number of years)	Contextual inquiry (CI), Focus group (FG), Design sessions, Field work(FW), Interview
NGO Conservation Central office	P1-ecologist (12 years), P2- ecologist and avid birder (5 years), P3 & P4- ecologist field expert and communication officer (9 and 4 years respectively)	CI, FGs
NGO Conservation Central office	P5, Environmental scientist and Manager (3 years)	Interview
NGO Conservation Central office	P6- local person (non-LSG), P7- local person (non-LSG), P8- local person (non-LSG), P9- local student intern (non-LSG)	FGs, Design sessions
(Site 1) First pilot study	P10- Forester, P11- local person, P12- local person, P13- local person, P14- student, P15- community conservation officer (all participants are non-LSG members), P18 âĂŞ conservation scientist and avid birder (non-LSG)	CI, FG, FW
Unsure sightings, old nesting site (Site 2)	P16- Forester (LSG member) P17- local leader (non-LSG),P18 & P19-LSG, P20 & P30 -Village farmer and business man (non-LSG)	CI, FG, FW
Unsure sightings, old nesting site (Site 2)	Student groups and village social events	Design sessions
Regular feeding site sighted for many years (Site 3)	P25- local villager, LSG member, P26, P27, P28 (local villagers)	CI, FG, and FW
Regular feeding site sighted for many years (Site 3)	P29- environmental Science teacher, birder	CI and Design session
Regular feeding site sighted for many years (Site 3)	Student groups and teacher groups	Design sessions
Potential site sighted for feeding (Site 4)	P20 & P21 (local residents), P16, P22, P23 & P24 (foresters), P15 & P18	CI, FG, and FW
Most pristine habitat area (Site 5)	P16 - forester, P18, P17, P19 (local villager, LSGs)	CI, FG, and FW

Participants P1-P3 from the NGO conservation office and P15 (Conservation Biologists and avid birder) has been involved in guiding field work and connecting us to their local support members. Participants who were local residents but were not currently part of Heron conservation Local Support Group are referred as non-LSG)

they knew more about the bird's nesting behaviour than most other people in their community. Participant, P12 had rich contextual stories to share from his situated observations over the past three years. He knew the bird stayed put in the nest all day long during rainy days and called for the whole night from early February to March. He further narrated more in depth observations:

"I have observed the species for more than three years...The nest has been here for many years now. The permanent resident is just one bird but after the breeding season, there is a visitor, presumably the male heron. I understand that the female bird is nesting, and the male bird is a visitor, seen only during the day. Once they hatch eggs, they take turns to feed the chick...but I have not heard the chicks call since we are far across the river..." - P12, non-LSG volunteer

However, this was not common knowledge among other community residents from the same area as P12. One commented: *"I did not have any information about this species, White-bellied heron and after learning it is globally and critically endangered, I was determined to to work in the team even though it demanded us to walk for hours searching for a suitable sensor deployment site ...which we figured out by asking households living nearby the species habitat"* - P13, non-LSG volunteer

Our findings suggest that knowledge about an endangered species, like the white-bellied heron, is often incomplete, partial, and situated; such that it needs assembling and sharing within and across communities.

Existing Local Support Group Monitoring Practices. The existing human observation-based species monitoring has been carried out for more than 15 years across distributed sites by a small group of conservation staff and local support group members (one or two villager or foresters) in each community. The LSG work mainly involves recording their daily observations of species in the nearby sighting areas in a monitoring book. Periodically, the book is collected by one of the staff from the conservation head office, who enters and consolidates the data using Excel.

Most LSG members found the paper-based form easy enough to follow and convenient in allowing them to negotiate human resources and time by sharing the work with others.

"Sometimes when I am busy with other work, my wife does the monitoring work for me. Ocassionally, other village people inform me on my way to check the species arrival for feeding if they sighted the species" - P25, LSG member

Likewise, at Site 5 (a sparsely populated community), the team of foresters and elephant caretakers narrated how they take turns to do the task over different months, sometimes relying on the opportunistic sightings of the species made by local elephant caretakers during their routine work of elephant feeding. However, currently only a few local community members participate and they are limited to filling out the forms on a regular basis. Some participants remarked that often what they neglect within the community is to bring together their observations and experiences.

We observed a clear lack of coordination and communication among LSG members who are doing similar work. Some of the local participants (especially participants who are part of different institutional organizations) expressed dissatisfaction with the current data-reporting task and raised concerns over data ownership and sharing, and where sharing the data would lead, indicating concerns about a loss of control and further action. Moreover, participants shared their perspectives on the limited 'view' and potential human biases in the routine monitoring work.

"I think it is not effective since if people are not sincere, then the observation info is flawed in terms of count and timing. As it is only submitted at the end." - P25, LSG member

He further elaborated, *"It is actually boring since it is from 7 am to 6:30 pm for 5 continuous days of observation Also, I believe there are some biases as we can only record during the daylight and we still do not know much of what happens at the nest and night time."* - P25, LSG member

Ecologist and Managerial Perspectives. Ecologists and managers view this situation more delicately. Although they worry about issues of timeliness, data trust, and efficiency, they believe overall that paper-based monitoring is what works best for the current situation. Confounding issues are illiteracy, the need to raise awareness about the species, rural people's lack of time to carry out continuous monitoring work, and that people's time dedicated for monitoring has to be compensated with a minimum wage. Another important issue is the data trust factor. While most participants fill out the monitoring form daily, there are cases where they may have missed a few days, and in such situations, the conservation staff mentioned that unexpected observations occasionally appeared. However, at present, aside from patterns of past records and their own field knowledge, there is no means to verify observations.

Lack of bigger picture may lead to complacent thinking. Keeping relevant stakeholders and community members abreast through collective knowledge can mobilise their urgency to act. However, our participants across different sites had varying understanding of the species population and status leading to complacency. Often, in places with decreasing sightings of the species over the years, they simply assumed the species might be healthier in other places. P25 thinks his place is losing the species but believes that sites 3 and 4 have a healthier habitat. On the other hand, P18 thinks the overall species population in the country must have increased a lot considering the healthy habitat in his locality. He thinks the species population that was said to be around 28 a few years back must now be about 40 individuals in Bhutan. Complacent hope that the species and habitat is healthy elsewhere might miss the opportunity to utilise in-depth local accounts to inform conservation strategies.

Broader socio-ecological practices that influence conservation. Community social practices and beliefs have a strong influence on local conservation strategies and needs. Each site has different local practices and beliefs. At site 2, people worship the lake (species feeding and old nesting site) as a local deity and try to protect the area. Over the years, the shifts in people's living income and social practices has changed annually conducted rituals at the lakeside to more frequent ritual activities, which may possibly disturb the species. In addition, there is a keenness to open eco-tourism and expand farmroads in the local community area to promote local development. These changes in the community social structure and practices might significantly affect conservation of the species habitat area. However, it is no longer known if the species has completely stopped visiting the lake or if it is still roosting there when no one is around. These findings highlight the need for more effective accounts to understand species behavior and to engage communities to discuss the impact of changing social practices. At site 5, social practices are likely to be supporting the species habitation because religious beliefs encourage the villagers to conserve the habitat, mainly the roosting tree. During our fieldwork, the LSG member and a potential volunteer who is also a farmer in the nearby village shared their knowledge of species roosting behavior and habitat usage patterns.

"We have heard the calls. It sounds like a wild animal. It is from that tree out there. It is our local deity..., It is a tree that we preserve and worship as a deity. We believe that the tree has spiritual power, and no one disturbs that area. The bird usually nests on one of the two big trees. In fact, our village people believe that anyone who cuts down branches or disturbs that area will fall sick." - P25 (LSG member), P26 and P27 (educated farmers at Site 5 who are non-LSG)

Conservation practices in this case are rooted in their social practices and beliefs. The indirect associations between community practices and species habitat selection are important conservation indicators that must be carefully understood in each context. At another site, participants indicated that local people both benefit and are disadvantaged by sharing corridors with a critically endangered species. P17 remarked that they have shared resources, including fishing which was a common local practice in the past, but that new practices and regulations have reduced access.

These findings suggest that design interventions must reach beyond technical feasibility to broader understanding of the network of actors and relations within each community.

EXPLORING SENSOR & SOUNDSCAPE INTERFACES

Discussions about the existing practices and perceptions of different stakeholders led us to then discuss how acoustic sensing technologies and environmental interfaces might be used to support conservation practices and community participation.

Local strategies and situated knowledge to figure monitoring sites. Our participants guided sensor deployment in the wild using their situated knowledge of the species and the place. *"It was not hard to understand how to deploy and maintain the sensors every 2 weeks. The most important aspect of deployment was that we pick a site, which is not too low where the river sound is dominant and deploy it when the bird is not in the nest...I think it would be even better if the same box could also capture videos"* - P12, local volunteer

Furthermore, he suggested the team try to get better data and was keen to take initiative and support.

"After the first month of deployment, we listened to the recordings and could mostly hear only river sound and that no bird calls were captured. I was very disappointed with myself and I suggested that we change the deployment site for the second month... I think we should also put it back for much longer duration till July so that we might also capture the calls of the chicks after the egg hatches." - P12, local volunteer

Likewise, at site 5, the elephant caretaker provided a local rationale for suitable monitoring sites there. Getting useful data is a situated and participatory process, beginning with people's existing knowledge about the species and the place, and configuring what and how far sensors can capture based on existing knowledge of different people and the technological capacities and limits of the sensor. People's contentious views on species habitation and recent sightings were brought up during the focus group discussions on where and how the acoustic sensors might be used to monitor the species, with views being much more contentious in places where the species is no longer sighted than in existing species habitat. Notably, there was organic and emergent participation in each community site that was built through the trail of a local face to face social network of people possessing knowledge of the species. The fieldwork in this sense goes beyond training locals to deploy and maintain sensors to mutual learning and collaborative problem solving in the wild. As such, it promotes shared agency between ecologists, foresters and local stakeholders to conserve and act.

Ecologists' hopes for acoustic sensing technologies. Ecologists have high expectations about how acoustic sensing might help to inform conservation and better understand the species. Participant P1, a senior ecologist who has over 12 years of field knowledge and survey experience of the target species in the wild stated: *"We are hopeful that the acoustic sensors can detect the presence or absence in our speculated and potential heron habitats. Considering the rugged terrains, it is hard to reach all the potential sites of heron for visual survey. We hope acoustic sensors will be of great use in detecting and monitoring species through its call."* - P1, Conservation ecologist

P2 and P3 echoed P1 in their perspective. They commented that it was hard for humans to monitor continuously in the field and that getting to know the species activity on a continuous basis will be an effective approach to learning more about it. Another conservation ecologist (P18) commented that this would provide acoustic baseline data for others to learn to listen to environmental sound. He thinks that he will also be able to use the acoustic sensors to discover and learn new insights about other species of interest. *"I am hopeful that this approach will provide a semantically rich nature acoustic collection as we cover more areas in different parts of the country."* - P18, Conservation ecologist

Collaborative investigation of species through soundscapes. New interfaces to the environment served as focal points through which our participants discussed their partial, situated knowledge and brought to fore different lines of inquiry.

People relate to their knowledge of the bird's behavior and place as they read the patterns in the data; this helps them to search and understand data representations. For instance, P12 (our key volunteers from site 1) interprets soundscape patterns of sensor data from the bird's nesting site by relating it to his own knowledge that the bird calls from the nest from between 5 to 6 A.M, then leaves the nest to feed, only returning at about 3 P.M. Participants ground their interpretation of data in their experiential knowledge of the species over time and the place. The soundscape visual interface served as an alternative way of 'seeing' the environment. This triggered participants to explore, learn and inquire about both the target species and other kinds of distinctive environmental acoustic patterns that are being revealed. Further instances highlight moments of excitement, curiosity and speculative guesses in collaborative and collective sensemaking of soundscape data.

Instance 1: *Learning about target species through acoustic patterns.* Our participants were able to detect species presence in the visual soundscape representations. Once people learned and localized the heron calls on the soundscape interfaces (24 hour soundscape representation), they then focused on the localized region looking for broader patterns to detect its calling behavior. In addition, it allowed them to explore other dominant or similar acoustic patterns in the environment at the habitat during the peaks, gaps, and dominant patterns of activity on the interface. One participant asked the field expert, "Will the heron call 30 times in an hour?" P2 responded, "That is a lot of calls in an hour? We usually hear it call once in 3 to 4 minutes but if the calls are more frequent. It seems both parents are together, or something is happening. We don't know yet."

Instance 2: *Exploring the local environment through soundscape.* P1 navigates to a red pinkish pattern and listens to 8:54 AM in the morning) and then learns that it was raining for few hours in the morning. Following that he checks the blue strikes and confirms that it is wind and another participant confirms, "yes that is a windy place, especially in the winter months I know". P3 then requested the group to check the pinkish pattern in the mid-region, which P3 thought was a Striated Prinia (a bird species), but which, P1 after listening a while, reckoned to be a green-backed tit. Upon listening again, both agreed on the species. Likewise, they explored how long other birds species (Whistling thrush and Drongo) were calling at the heron nesting site.

Instance 3: *Curiosity generated through ambiguous patterns.* P5 was intrigued to know what was tracing the "dominant pattern at night" that looked like a night view of a fortress. They explored various ambiguous soundscape patterns to each time discover the individuals or assemblage of species that collectively make those patterns.

In these discussions, we saw that new environmental visualisations create new ways of 'seeing' and trigger collective discourse about the environment. In addition to bringing to the fore individual's local or experiential knowledge, the collaborative process of exploring soundscapes yields new insights and confirms existing knowledge through a rich mix of speculative interpretations and hypotheses on the data.

Bridging knowledge gaps through human-sensor work. Interesting knowledge gaps are bridged through assimilation of sensor data and human's interpretative and experiential knowledge. For instance, the bird at site 1 was not observed during the population survey by LSG members however the sensor captured vivid calls at night. Upon presenting the sensor readings to the core working group at the conservation office, initially they wanted to seek further evidence and verification as it did not tally with the existing records made during the population survey. These observations pointed us to how acoustic sensor devices can supplement existing practices and engage locals to contribute better in conservation efforts. This nest site was found in an emergent way through much relaying of knowledge and referrals between local people which enabled the team to find the nest; the nest had been abandoned for a few years and therefore, was missed during the survey. Another instance illustrates how the bird was seen to be nesting but the recorder had no record of its call for a certain duration at Site 3. This triggered stakeholders to question, why no calls were captured during the breeding season this year? It led to questioning other environmental factors that could have influenced the bird's calling pattern and made the team seek reasons on the ground. The local support member (P17) who does the regular monitoring discovered that the nest had been destroyed by a windstorm and that the species was taking time to rebuild its nest, thus delaying it from making breeding calls. These examples indicate how human observations and sensor records complement each other to bridge knowledge gaps and trigger further actions.

PROBING COMMUNITIES

Next, we discuss our findings on using probes with different members of the communities.

Seeding interest through fun forms of interaction. We observed that socialization opportunities as a community are an important space for engagement. In a local community event at Site 2 where 50 individuals from different household families were gathered. As part of the social event, we asked if they were interested to explore and guess local species. We played bird calls and showed their sound patterns (i.e. audio spectrograms), prompting them to guess and share if they knew the species. We then showed video recordings of several local birds. [Bird call 10 was White-belled Heron. People wait to

listen to the calls and there was no murmuring]
We can only hear the river sound...it does not call? does it?
Researcher, R:*Does anyone know the calls of Chubja Phowkarp (local name of White-bellied Heron)?*
[People trying to remember...]
R: *Has anyone seen the bird?*
[Most people respond yes]
We used to see at the lake-side but it is not sighted lately
R: *Do we not have the species here anymore? Why do you think so?*
A villager responds: *Before we used to hear the call around evening time near Chazam. Now we don't have the species in our village.*
Another elderly villager man added: *No, I disagree. I think it is still here. A little higher above our village. I think it has moved up as it is much quieter. Early morning, we see it flying to the lake side and flies back to Tshekha chu (upper village) around 5 to 6 pm before dark.*
Another villager questions: *How recent was the sighting? This triggers to people to query each other for more evidence of his sighting. It is just about one month ago. It needs to be in a quiet habitat, so it moved away from here. It is very sensitive to human activities. In Tsekha, I also saw its faeces when I went cow herding.* In such a social setting, the interaction was enthusiastic, rich and full of anecdotes and laughter. People paid attention to listen, guess and then identify the local species by their calls and appearance. They were fully engaged in sharing more stories about the local birds and environment, their encounters, beliefs and values. While elders who knew birdsongs sang to the crowd and elaborated the associations of the local species, youngers enjoyed listening to tales and songs. We observed enthusiasm as a community to engage in sharing stories of their encounters, anecdotal tales and songs that relate to nature; and to discuss and probe each other to share their experiential knowledge and impressions of local soundmarks. Although perhaps only 10 of the 40 who were gathered spoke, the remainder was also clearly engaged as legitimate peripheral participants [28]. People's enthusiasm to share and discuss in social settings inspires us to conceive of interfaces and tools that can enhance learning and sharing about local environment and species in fun and social ways within communities. It alerts us to opportunities to create fun forms of interaction in domestic and community spaces through which people of different age groups are engaged; to promote collective stewardship to save species. seeding interest and curiosity of other members. One important observation was how such social discourse triggers participation of new volunteers to support conservation. For instance, after the event, a member from the nearby village called one of the local participants in our research to report that they had sighted the endangered species near their village river confluence towards evening and suggested to deploy one sensor there.

Situated learning and reflections in a social context. Generating conservation awareness is a key aspect of conservation. However current approaches are limited to sensitization meetings and workshops delivered by the conservation office staff through periodic visits. We observed opportunities for designing technologies that can trigger situated learning within households and small community groups. Some participants lamented that no-one ever taught them bird calls. In another session using the design probe with a small group of seven high school teachers, our participants demonstrated how they are reflective of their habits.

"I think I don't know much because I am always wearing earphones outdoors whereas Dorji knows a lot as he gets up early by 4 am in the morning." - teacher participant 1 at Site 5. *"I know most of these calls as I grew up in the village. Also, I am a early riser, so these bird calls are familiar to me."* - teacher participant 2, Site 5. As they played call identification in fun ways, participants expressed a sense of accomplishment. *"I am already learning some birds from today's experience and I would love to use it in the evening time based on what we noticed or explored. Usually I only look for Ja phokarp as it is considered lucky to sight it."* - teacher participant 3 at Site 5.

Emotional links to local soundscape. Another village person (P30) visiting, who has now lived in the city for more than 20 years, mentioned the popular species in the village and narrated how the sounds of local species remind him of his childhood in the village.

P: *Our special bird sounds are 'terroo' and 'serp juroo' and they are both considered good omen by our folks.*

R: *If you can hear something from your village, what would that be?*

P: *I want to hear Kaew Kaew...Kaew. I want to hear Ja kaw kaw (bird kaw kaw)...it sounds like kaw kawww kawwww. I have not sighted the bird but people say it is a small bird with short tail. It reminds me of home. It reminds of long hot days and its time when the stock finishes by this time of the year. It is a melancholic reminder of my village. However, this has an emotional linking to my country.*

Motivations for participation. People's motivation to participate varies. In most cases, we found that our volunteers would rely on their existing social networks in the village. People enjoy the collective action and learning opportunities for a common cause. *"My personal experience is that although it was a challenging task without prior knowledge, I was happy to be able to take part and learn a lot about the bird by working in a team..."* - P13, local volunteer.

For other participants it was curiosity to discover more about the species behavior, although they were unsure in the beginning how sensing technology might help and wanted to use it to explore night time activities at known nesting areas. Other participants such as P12 were enthusiasts of new technology and keen to explore what technologies could help to find. Other stakeholders such as conservation managers/ecologists were motivated to gather good acoustic baseline data and to discover new insights about species population and behavior and its sensitivity to environmental changes through use of sound.

Technological implications of disjointed human activities. Our interviews revealed some potential negative consequences of technologies. One participant who is an avid birder reported endangered species disturbance caused due to a sighting being posted on social media. *"Whenever there is a threatened bird post, others are keen to know where it is found, and they try to get a shot of it as well. There is much more attention on rare or threatened birds... Around September, me and my friend saw the rare red necked farrow. Someone posted about this species sighting... I took some pictures. Soon, there were so many cameras and then tomorrow morning, when I went there, the bird was not found there anymore..."* - P29

Adverse effects of technology enabling people (i.e. novice birders and enthusiasts) to disturb species were raised in our interviews. The growing practice of using call playback through mobile phones in the field to attract birds to photograph points to technology's impact on practices. To some extent, disjointed tasking approaches encourage individuals to be more focused on finding and claiming species for their collection rather than conserving species.

6 DISCUSSION

Our discussion themes reflect on current participatory sensing paradigms and suggest design considerations for new forms of human-machine configurations to support conservation practices and participation in remote communities.

Designing tools and interfaces for sharing and assembling contextual knowledge

"Humans are highly tuned learners and actors whose internal form is constantly changing to refine their ability to act on the world" [25]

Technology support for conservation must go beyond typical tasking models for opportunistic data collection and analysis to enabling people to learn, share, and advocate for conservation of local species and the environment more collaboratively. Our findings point out the narrowing limits and unsuitability of considering generic tools (such as data gathering apps and crowdsourcing platforms used for biodiversity surveys) to solve critical conservation problems. Moreover we reveal the problems created when distributed individuals act in their individual interests when tasked to catalogue data. Recent studies using camera traps over large-scale environments [36, 50] mostly focus on crowd-sourcing interested people to analyse or catalog data in a disembodied manner. We argue that technology design for supporting conservation in remote areas must go beyond tasking to engaging communities more deeply and collectively within the context of the broader goals and interest of communities. Citizen science is struggling with issues around sustaining participation and maintaining data stream and quality over time [24, 30]. Here, we argue that we need to think of conservation participation more broadly than viewing people as data collectors - treating volunteers beyond being '...a pack of mules...' to gather data [1]; instead to create more opportunities for data interpretation and collective discourse among various stakeholders to share contextual knowledge. As Kidd remarked,

"...the valuable marks are on the knowledge worker rather than on the paper or on the electronic file and suggest how computer support for knowledge work might be better targeted on the act of informing rather than on passively filing large quantities of information in a *'disembodied'* form." pg. 1 in [25].

Sensing technologies and new ways of 'seeing' the environment can help stakeholders bring to the fore their partial, situated knowledge and through joint interpretations and inquiries generate new knowledge and awareness. People are more likely to take informed action based on their collective knowledge and interpretations which otherwise remain incomplete and disconnected. Moreover, a much higher rate of participation may be needed in small sparse populations than in larger ones that are addressing environmental matters of other sorts. Furthermore, design needs to take into account cultural and traditional values of different communities. Importantly, we found that conservation practices are inherently intertwined with their culture. In most communities, there was an inherent respect for and historical practice of worshiping lakes and preserving specific parts of the forest where the species inhabits. However, we also found that there are shifts in community practices with the rise in people's income. High social connectedness in small remote communities of nuclear families and small overall population offer different design opportunities for engagement. These contextual factors play a pivotal role is shaping and sustaining conservation. Light-weight interfaces, ideally, locally appealing tangibles might work like Sangeet Swara (which relies on community interaction and choices of local cultural content e.g. songs and jokes [56]) or OLO Radio [39] to engage communities to explore and share about the environment and environmental soundscape in fun ways.

Designing interactions for seeding interest and participation

Building on the premise that conservation is a social construct [3], we believe that promoting awareness and affinity of community members towards local species and environment might be better supported by integrating fun, collaborative and social ways of learning and sharing in their everyday life rather than relying on traditional top-down awareness workshops; or typically expecting people to use and learn from modularized mobile or web-apps. We argue that learning is better supported informally as part of social process [28]. Furthermore, awareness creation is not a dyadic and periodic communication between experts and local community members, rather it is weaved within heterogenous and complex socio-ecological beliefs and practices. Awareness creation is better supported by situating it as communal activity with appropriate technology that triggers attention, conversation, and interactions within. In this spirit, it is important for design interventions to understand and create spaces that might support seeding interest and participation of community members; beyond the design of interfaces [45]. We observed a richer interaction among participants of different age-groups, bearing different levels of interest and knowledge about the local environment with opportunities for legitimate peripheral participation [28]. These findings inspire us to rethink technologies as situated dialogical probes [52] that continuously support and prompt collaborative learning and sharing in fun ways. Probes can be designed for the household or community level triggering participation, knowledge sharing and knowledge building. A sensor-based probes study on domestic security in rural Kenya [8] showed how it fostered neighborhood cohesion and contextualization of the technology. The design of situated probes can be evolutionary such that their use and content are triggered both by environmental phenomena detected in the sensor data as well as through interactions of locals or family members. We envision that new forms of interfaces, possibly tangible ones like [7, 51], can be tailored to fit into the routines of sub-communities (such as schools and households) through fun forms of engagement to discover, learn, and share about endangered species and other local species. Understanding motivations for participation is key for designing sustainable citizen science [38]. Previous studies have explored motivational factors of participants in online citizen science and crowdsourcing platforms [1, 38, 44]. In a remote context, we found that locals' interest in socialization opportunities, collective action, and their existing affinity and associations to environmental sound and species were fertile design sites. Some of these are distinct features that are contextual to remote communities and their environment, differentiating them from the way we conceive and design participatory sensing in urban settings [1, 23].

Enhancing collaborative situated analysis to generate environmental awareness

Data of any nature must be used in context and shaped through narratives that are created through a meaning-making process [16]. Such a process also questions the way the data is gathered, processed, represented and interpreted within specific contexts. Previous studies raised the issues of data reliability and quality and suggest design of standard protocols for citizens gathering data [9]. In the case of using sensing devices for monitoring species in its habitat areas, we propose that it is better to gather long duration data that creates a complete soundscape to understand the species and the wild environment in new ways. We propose that rather than standardizing protocols that might limit participation, it is better to support the locals to gather data with sensor devices and engage participants in collaborative analysis of the data in fun ways. Fundamentally, design interventions targeting conservation must engage people in the process and result in situated actions by communities. Sensor devices can gather terabytes of data. Currently, ecological data is typically either considered as raw material for automated processing through black-box intelligent systems [35] or it is analyzed by the distant crowd (e.g., such as in [22, 29]). Although this suits some problems, in our work, we observed that having the community-in-the-loop on how the data is gathered and represented will support extracting relevant insights and engender a much higher conservation impact. Scientific knowledge doesn't help if the people aren't engaged and don't care. Our findings show that people figure contextually where to deploy sensors using embodied knowledge of place and their existing or partial knowledge of species behavior; and show more interest in sharing and interpreting the data with others when they are actively involved in the process. In so doing they sensitize each other to learn both through the data and from each other better. Future design will integrate sensor data through light-weight interfaces to reveal environmental soundscape views or sporadic acoustic events that can engage locals to 'see' and connect through their environment [27]; thus, promoting community participation in conservation to better understand ecosystem and ecological conditions.

Agencies of actors in conservation design

Conservation strategies and appeals that are supported by both local people and conservation organizations are most likely to have impact. However, sometimes conservation strategies conflict with needs of local communities such timber harvesting, fishing and local development. In this case, the critical need to conserve species can be better supported by advocating through collective community knowledge. This can help in seeking government funding and finding support for compromises. New socio-technical approaches may bring about shifts in the ways that data and information is gathered, shared, and disseminated within communities, across communities, and across different institutional bodies. We need to carefully consider the agencies of various actors that are involved in this work. Foremost, it is important to make sure that data ownership and sharing is ethically conducted and acknowledged. Prior studies reported similar concerns over multi-stakeholder projects [1, 2]. Primarily, we must carefully understand the power dynamics of all actors including the species under study. It reminds us that our approaches must think beyond what a new and innovative technology can offer a world that is largely being configured for human species. Rather, we must seek to account for both the tensions and harmony in conservation and community practices that are contextual to each setting. Design interventions can explore how to create broader units of analysis for citizen's engagement within communities in conservation research such that they benefit species conservation as well as community recognition. E.g. Interactive and playful activities such as discovery games might engage young children with ecologists to explore soundscape data in fun ways and create local species songs that have broader reach.

Beyond monitoring to stewardship

As more and more sensor devices are being deployed, it is important to reconsider our imaginations and approaches towards "sensing the planet". Fundamentally, it is important to understand complexities of designing human-machine cooperatives as sensing might lead to irreversible damage or an asocial mechanically monitored world, both of which we seek to avoid. While there is rigorous effort to automate big data analysis using machine deep learning systems, we believe the benefits of such systems in comparison to what a relational human network can achieve are clearly distinct. Deep learning systems focus on training machine algorithms to gain optimal precision and recall in their detection performance, whereas a relational human network engaged to participate and interpret brings to the fore collaborative inquiry, knowledge sharing and an awareness network in the real world. The former approach digs deeper into the data to learn whilst the latter spreads wider into the world seeking associations and triggering human agents to learn. Rather than advocate for one or other approach, we believe that critical problems such as species and environment conservation require more integrative approaches where HCI researchers have an important role to provoke alternative perspectives and steer technology design directions. This study presents design challenges and opportunities to implement participatory community sensing for conservation of threatened species in remote contexts. While there are contextual issues of illiteracy and support member's lack of time to dedicate full monitoring jobs, the prospect of humans aided by long-term ongoing sensing and engaging community interfaces opens opportunities to seed and grow participation and social computing for conservation research. Interfaces must be fun, social and promote continual learning in order to engage people of different age groups in environmental conservation projects. Varying proportion of illiteracy, and specific community's oral communication practices are contextual factors to be taken in account in design of future technologies. Although this work explores monitoring of one critically endangered species is a particular setting, the design insights drawn from the study are applicable to wider sensing systems that are targeted for environmental monitoring and conservation work. We have sought to provide sufficient contextual detail, so that researchers considering another context can judge which aspects might be applicable to their own context.

7 CONCLUSION

This paper offers key considerations in designing new forms of human-machine configurations to enhance conservation practices and participation in remote communities. Primarily, we found that knowledge about the species is incomplete, partial, and situated; such that it needs assembling and sharing within and across communities. In contrast to the dominant participatory sensing paradigm, our study points out wider design opportunities for seeding interest by creating deeper engagement within communities to learn and share together; rather than tasking people to collect data in a disembodied manner. New sensing technologies and interfaces (such as soundscapes) can trigger curiosity and joint interpretations by multiple stakeholders; and thus engage people to 'see' and discuss the environment. Finally, design intervention must be sensitive to local, social practices and beliefs that influence conservation. Conservation technology design must account for power relations of all actors (the species, community, conservation agents, and technology innovators) such that it benefits the ultimate goal of saving endangered species. Our study offers opportunities to deepen the HCI community's understanding of conservation practices and technology design opportunities for enhancing participation in remote communities.

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