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Ecological Sensemaking as a Recursive Process of Indigenous Climate Adaptation: Evidence from the Santal Community of Bangladesh

Sourav Paul Chowdhury[1], Syed M. Ali Reza[2], M. Nasim Reza[3], Dhanno Saha[4], Md. Solaiman Chowdhury[5]

[1] MPhil Fellow, Institute of Environmental Science, University of Rajshahi, Rajshahi
& Professor, Department of Management, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Email address: sourav@hstu.ac.bd
[2] Professor, Department of Management Studies, University of Rajshahi, University of Rajshahi, Bangladesh-6205, Email: syedreza@ru.ac.bd
[3] Professor, Department of Management Studies, University of Rajsahi, Bangladesh,
Email: nasimreza981@yahoo.com
[4] Lecturer, Department of Business Administration, Varendra University, Rajshahi.
Email address: dhanno@vu.edu.bd
[5] Associate Professor, Department of Management Studies, University of Rajshahi, Rajshahi-6205, Bangladesh
Email: schowdhury@ru.ac.bd

Correspondence: Syed M. Ali Reza. Email: syedreza@ru.ac.bd

Abstract
Climate adaptation research has focused more on adaptive capacity, technological innovation, and resilience, and less on the interpretive processes that lie before adaptive action. In this study, ecological sensemaking is investigated as a factor influencing agricultural decision-making among the Santal indigenous community in Barind region, which is prone to drought in Bangladesh. The research employed an interpretivist paradigm using thematic analysis of 25 semi-structured interviews. The findings indicate that adaptation starts with the ongoing process of interpreting ecological cues in a way that is negotiated through indigenous ecological knowledge, lived experience, scientific information, and social interaction. Four interrelated themes account for the process of the construction of ecological meanings, their translation to agricultural and livelihood practices, and how they are constrained by structural conditions. The study goes beyond organizational contexts to describe and explain ecological sensemaking, reconceptualizing indigenous ecological knowledge as a process of environmental meaning-making, and proposes a process-based conceptual model for climate adaptation in the face of ecological uncertainty. The study extends Weick's Sensemaking Theory by conceptualizing ecological sensemaking as a recursive, relational, and structurally mediated process operating within Indigenous socio-ecological systems, thereby offering a theoretically grounded understanding of climate adaptation beyond organizational settings.

Keywords: Ecological Sensemaking, Indigenous Ecological Knowledge, Climate Adaptation, Santal community, Barind Region

1. Introduction

Climate change is transforming agricultural systems globally, jeopardizing rural livelihoods, food security, and environmental sustainability by increasing temperatures, unpredictable rainfall, extended dry periods, and more extreme weather events (IPCC, 2023). These effects are especially strong on smallholder and subsistence farmers who rely on ongoing interactions with the local ecosystem for their livelihoods, rather than just technological and institutional interventions (Morton, 2007; Wheeler & von Braun, 2013). Therefore, the nature of the relationship between farming communities and environmental change, and how this relationship is translated into decisions for adaptation has become a key issue in the study of climate adaptation.

While there has been considerable research and knowledge building around adaptive capacity, resilience, technological innovation, and institutional responses to climate adaptation, less work has been undertaken on the interpretive processes that precede adaptation (Adger, 2003; Folke et al., 2010; Smit & Wandel, 2006). Farmers react to climatic events, but not directly. They react to the meanings they give to the changing ecological conditions, which they continually observe and evaluate as they watch the rainfall, soils, water availability, vegetation and seasonal change. Adaptation is not only a behavioral or technological way of reacting to the environment, but also an interpretive process whereby observations of the environment gain meaning before they suggest action.

The interpretive dimension is particularly relevant in indigenous communities, where ecological knowledge has been developed over many generations, through intimate contact with the local environment. Indigenous ecological knowledge is an aggregate of insights about weather, soils, water, biodiversity, and seasonal cycles which are constantly refined by lived experience, collective learning and environmental practice (Berkes, 2018). It is now recognized as dynamic, adaptable, and socially negotiated process that allows communities to adjust to new ecological conditions and incorporate new experiences and knowledge systems (Dorji al., 2024; Fernández-Llamazares et al., 2021; Tengö et al., 2017). While this acknowledgment has been made, current research has tended to emphasize indigenous knowledge and the adaptations they are using, and less on how ecological meanings are actively created, negotiated, and realized in daily agricultural decisions (Ford et al., 2020; Whyte, 2013).

Sensemaking is the process by which people and groups make sense of situations, make shared meaning, and then act on that meaning (Maitlis & Christianson, 2014; Weick, 1995). Recent research on ecological sensemaking also highlights the interplay between persons and ecosystems, moving beyond the focus on ecological events to ecological sensemaking processes that make ecological change meaningful and actionable (Hahn et al., 2022; Whiteman & Cooper, 2011). Empirical studies on ecological sensemaking have, however, been limited to organizational and environmental governance contexts, and there is little knowledge of how environmental interpretation is lived in indigenous agricultural communities where it is part of people's daily living practices (Whiteman & Cooper, 2011; Wright et al., 2013).

The Barind region of the Rajshahi division in the north-west of Bangladesh is a hotspot for drought-related issues due to its low groundwater table, irregular rainfall patterns and extended dry seasons (Rahman & Lateh, 2017; Shahid, 2010). The Santal people have ecological knowledge acquired over years of interaction with local environments, and have structural disadvantages such as limited access to land, financial resources, and institutional support (Chakma, 2010; Mohsin, 2002). This context is suitable for exploring the construction and translation of ecological meanings into adaptive agricultural practices in the context of ecological and social vulnerability.

In this context, this study examines the nature and role of ecological sensemaking in agricultural decision-making of the Santal community in the Barind region of Bangladesh. We conducted twenty-five in-depth interviews with Santal people using reflexive thematic analysis. This study makes three significant contributions. One, by expanding the concept of ecological sensemaking beyond organizational contexts; then, by rethinking the concept of indigenous ecological knowledge as a process of environmental meaning-making; and thirdly, by providing a process-oriented explanation of the emergence of ecological interpretations as adaptive practice. The study also

helps to build the theoretical foundation of the integration of ecological sensemaking, indigenous knowledge, and climate adaptation research.

2. Theoretical Framework

Climate change is creating uncertainty in agricultural systems as a result of rising temperatures, unpredictable rainfall, frequent extreme weather events, and longer periods of drought, which affect indigenous and other marginalized farming communities who are highly reliant on local ecosystems (Ford et al., 2020; IPCC, 2023; Whyte, 2020). Research on climate adaptation has produced many insights into climate vulnerability, resilience, adaptive capacity, and technological interventions, but has comparatively less work that focuses on the interpretive processes that link environmental observations to adaptive action (Adger et al., 2005; Folke et al., 2010; Smit & Wandel, 2006). Adaptation does not start with action, but rather with the way that people make sense of the changing ecological conditions and give meaning to environmental cues they experience in their daily lives (Nightingale, 2017).

Indigenous Ecological Knowledge (IEK) offers an important backdrop to the understanding of these interpretative processes. IEK is an accumulated body of knowledge, practices, beliefs, and skills acquired over time as a result of long-term engagement with local environments, which are learned through observation, participation, and experience (Berkes, 2018; Gadgil et al., 1993). Indigenous knowledge is now increasingly viewed as a dynamic knowledge system that is continually reconstructed through social interaction, ecological observation, and intergenerational learning, rather than as a static body of knowledge (Fernández-Llamazares et al., 2021; Whyte, 2020). Communities also combine indigenous knowledge and scientific advice, extension services, market information, and technological innovations, creating hybrid knowledge systems that enable locally appropriate adaptation (McMillen et al., 2017; Tengö et al., 2017). However, the majority of studies remain focused on what indigenous people know and how they use it, and on adaptive practices, instead of the active production, negotiation, and translation of ecological meanings into adaptive decisions (Dorji al., 2024; Hiwasaki et al., 2014; Reyes-García et al., 2016).

Sensemaking is the process of making sense of a situation that is open to multiple interpretations, of creating shared meaning or meanings, and of using those meanings or sense of that situation to inform their next actions (Maitlis & Christianson, 2014; Weick, 1995). Actors do not react directly to the objective environment but rather sense elements of it and respond to them based on their prior experiences and social interactions, which are continually modified as environmental situations change (Weick et al., 2005). The theory was first developed in the field of organizational studies but is increasingly being used in the study of environmental governance and sustainability, where interpretation plays a key role in the response to ecological uncertainty (Maitlis & Christianson, 2014).

Ecological sensemaking builds on this idea and highlights the interdependent nature between humans and ecological systems (Whiteman & Cooper, 2011; Whiteman et al., 2013). Central to this is the concept of ecological embeddedness, whereby people's interactions with landscape allow them to sense small changes in the environment and develop context-specific ecological meaning (Whiteman & Cooper, 2011). This is especially true for indigenous agricultural groups, where decisions about agriculture are made continuously in relation to the rainfall, soils, groundwater, vegetation and seasonal variability. The ecological meanings are thus not elicited by environmental cues per se, but by their interpretation within cultural, social and livelihood settings (Berkes, 2018; Whyte, 2020).

Adaptation research also shows that adaptation efforts that are effective in the face of climate change are not solely based on techno-fixes or resources. Institutions, governance, social capital, education, technology and financial resources affect adaptive capacity (Adger et al., 2005; IPCC, 2023), while the perception and interpretation of environmental change also influence adaptation (Adger et al., 2013; Eriksen et al., 2015). The adaptive strategies adopted by communities in similar climatic conditions vary as they have different experiences, identities, and knowledge systems through which they interpret their ecological observations (Nightingale, 2017). Ecological

sensemaking is not a substitute for the theory of adaptation, but rather a tool to help understand how and why people make sense of their environment and how they adapt to it (Folke et al., 2010; Maitlis & Christianson, 2014).

Although there have been substantial developments, there are gaps to be addressed. First, there is a lack of focus on research on climate adaptation that explains adaptive outcomes, instead of the interpretative processes that lead up to them (IPCC, 2023; Smit & Wandel, 2006). Second, indigenous ecological knowledge is often seen as a resource of the environment, not as a continuous process of ecological meaning making (Berkes, 2018; Whyte, 2020). Third, ecological sensemaking has received limited attention in indigenous communities, particularly in agriculture, where it is part of everyday life, whereas it has been applied mostly in organizational contexts (Hahn et al., 2022; Whiteman et al., 2013). There has also been limited attention so far to how structural inequalities such as access to land, water, finance, technology and institutions affect the connection between ecological knowledge and adaptive action (Eriksen et al., 2015).

In this study, climate adaptation, indigenous ecological knowledge and ecological sensemaking are therefore combined in a single theoretical framework. It sees adaptation as a dynamic and iterative process of noticing, understanding, translating, and reconfiguring ecological signals in the light of indigenous and scientific knowledge, and with the ongoing impact of structural conditions and new environmental experiences (Berkes, 2018; Weick, 1995; Whiteman & Cooper, 2011). It brings ecological sensemaking into play as an analytical link between environmental observation and adaptive practice, extends sensemaking theory beyond organizational contexts, reframes IEK as a process of meaning making and provides a process-oriented explanation of climate adaptation in the face of ecological uncertainty and structural inequality.

3. Methodology

In this study, we used an interpretivist paradigm to investigate the Santal understanding of ecological change and the ways in which they make sense of that understanding when they make agricultural and livelihood choices. Interpretivism holds that reality is not an objective phenomenon, but rather one which is socially constructed by lived experience and interaction (Creswell & Poth, 2018; Schwandt, 2014). An interpretivist approach was deemed most suitable as ecological sensemaking is about the understanding of environmental change, not the measurement of climatic variables (Maitlis & Christianson, 2014; Weick, 1995). With this in mind, the study was designed as a qualitative study with an interpretive orientation, aiming to understand the participants' lived experiences of climate variability, in their daily experiences of farming (Creswell & Poth, 2018; Van Manen, 2016).

This research was carried out in the Barind area of the north-west of Bangladesh in a few Santal villages of Tanore Upazila, Rajshahi District which is suffering from dry condition. The Barind is one of the most environmentally vulnerable agriculture areas in Bangladesh due to the scarcity of groundwater resources, irregularity of rainfalls, long dry seasons and increasing climatic variability (IPCC, 2023; Shahid, 2010; Rahman & Lateh, 2017). The Santal community was chosen because of their long history of dependence on agriculture, their indigenous ecological knowledge and their ongoing experience of socioeconomic marginalization, which created a theoretically informative context for the study of ecological sensemaking under climate uncertainty (Berkes, 2018; Chakma, 2010; Mohsin, 2002).

Participants were purposefully sampled to include those who are experienced in farming, environmental change, and indigenous ecological knowledge with information-rich cases (Patton, 2015). To reflect a range of ecological viewpoints, 25 Santal participants, across different age groups, gender, occupations and community roles, including farmers, teachers, community leaders, women, elders and young adults, were interviewed. Sample adequacy was assessed on the basis of the principle of information power which was used to recruit participants until there was enough conceptual depth to meet the research objectives, and not to meet the requirements of statistical representativeness (Braun & Clarke, 2021; Malterud et al., 2016).

The composition of the sample is summarized in Table 1.

Table 1: summarizes participant characteristics.

Participant Code	Gender	Age	Educational Level	Livelihood Role	Village / Upazila (Barind Tract)
P01	Male	58	Primary (Grade 4)	Senior Farmer / Traditional Knowledge Keeper	Godagari, Rajshahi
P02	Female	42	No Formal Education	Agricultural Day Laborer & Seed Keeper	Godagari, Rajshahi
P03	Male	31	Higher Secondary (HSC)	Youth Farmer / Techno-Hybrid Adapter	Tanore, Rajshahi
P04	Male	64	No Formal Education	Village Elder (*Manjhi*) / Traditional Farmer	Tanore, Rajshahi
P05	Female	36	Primary (Grade 5)	Homemaker & Livestock/Homestead Farmer	Nachole, Chapainawabganj
P06	Male	49	Secondary (SSC)	Commercial Crop Farmer	Nachole, Chapainawabganj
P07	Male	27	Bachelor's Degree	Educated Youth / Diversified Farmer	Niamatpur, Naogaon
P08	Female	51	No Formal Education	Wage Laborer & Traditional Seed Conservator	Niamatpur, Naogaon
P09	Male	45	Primary (Grade 3)	Rainfed Rice & Vegetable Farmer	Godagari, Rajshahi
P10	Male	62	Primary (Grade 2)	Indigenous Knowledge Elder / Herbalist	Tanore, Rajshahi
P11	Female	29	Secondary (SSC)	Wage Laborer & Homestead Cultivator	Godagari, Rajshahi
P12	Male	38	High School Dropout	Borind Deep Tube-Well (DTW) User / Farmer	Nachole, Chapainawabganj
P13	Female	47	Primary (Grade 5)	Seed Manager & Seasonal Laborer	Niamatpur, Naogaon
P14	Male	53	No Formal Education	Traditional Paddy Farmer	Tanore, Rajshahi
P15	Male	33	Higher Secondary (HSC)	Youth Agribusiness / Input User	Godagari, Rajshahi
P16	Female	39	Primary (Grade 4)	Homestead / Small Livestock Farmer	Nachole, Chapainawabganj
P17	Male	67	No Formal Education	Senior Farmer / Oral History Custodian	Niamatpur, Naogaon
P18	Male	41	Secondary (SSC)	Mixed Crop Farmer	Tanore, Rajshahi
P19	Female	25	Higher Secondary (HSC)	Educated Youth / Family Farm Assistant	Godagari, Rajshahi
P20	Male	55	Primary (Grade 3)	Traditional Rice Farmer	Nachole, Chapainawabganj
P21	Male	30	Diploma/Vocational	Agro-Tech User & Youth Farmer	Niamatpur, Naogaon
P22	Female	44	No Formal Education	Agricultural Laborer & Seed Custodian	Tanore, Rajshahi
P23	Male	60	Primary (Grade 1)	Senior Farmer / Soil Cues Observer	Godagari, Rajshahi

P24	Male	35	Secondary (SSC)	Mango Orchard / Crop Diversifier	Nachole, Chapainawabganj
P25	Female	50	Primary (Grade 4)	Indigenous Seed Keeper / Laborer	Niamatpur, Naogaon

Data were gathered through semi-structured, in-depth interviews, non-participant observation, and reflexive field notes. Semi-structured interviews allowed participants to describe their ecological observations, indigenous knowledge, agricultural decision-making, livelihood adaptations, and experiences of climate variability in their own words, while giving the interviewer flexibility to probe emerging issues (Kvale & Brinkmann, 2015; Patton, 2015). Interviews were conducted face-to-face in Bangla, at locations chosen by participants.

Because many participants expressed concerns about privacy, safety, and the possible misuse of recorded voices, none of the interviews were audio-recorded; this preference was respected as an ethical priority (Orb et al., 2001). Instead, detailed field notes were written immediately after each interview, while conversations remained fresh in memory, capturing participants' narratives as comprehensively as possible alongside contextual observations, key expressions, remembered non-verbal cues, and preliminary analytical reflections. Notes were subsequently expanded, reviewed, and translated into English for analysis, with care taken to preserve participants' intended meanings and culturally specific expressions (Emerson et al., 2011; Temple & Young, 2004).

The interviews were done by the first author in Bangla, which is the language that was used by the participants to communicate naturally. Detailed expanded field notes were produced after each interview and these field notes were the main data source for analysis. The first author then translated the expanded field notes into English, maintaining the intended meanings of participants, culturally specific expressions and the ecological terms. Translation was done in parallel with the repeated reading of field records to ensure that the meaning and context of the texts did not become distorted during the analysis process. This iterative process facilitated the consistent interpretation process during the coding and theme development in the interpretivist approach (Braun & Clarke, 2021; Temple & Young, 2004; van Nes et al., 2010).

Non-participant observation complemented the interview field notes by documenting agricultural landscapes, irrigation practices, household environments, and visible ecological conditions, supporting richer contextual interpretation through methodological triangulation (Patton, 2015).

Data were analyzed using Reflexive Thematic Analysis (RTA) as described by Braun and Clarke, which treats themes as interpretive patterns actively produced through the researcher's engagement with the data rather than as categories simply discovered within it (Braun & Clarke, 2021). Analysis proceeded through six iterative phases: familiarization with the data, inductive coding, and generation of candidate themes, theme review, theme definition, and report production (Braun & Clarke, 2006, 2021). It was considered appropriate to use manual analysis because it allowed for an ongoing interpretive analysis of the expanded field notes and allowed for building up of meaning throughout the analytical process (Braun & Clarke, 2021). Coding was recursive and not linear; early coding is revisited as new insight occurs throughout the data set. Participants' explicit accounts were captured using semantic coding, and the underlying meanings were captured using latent coding (Braun & Clarke, 2021). Through repeated comparisons between participants the conceptual related codes were modified to become candidate themes (Braun & Clarke, 2021). These themes were then analyzed for their internal coherence, conceptual distinctiveness and explanatory power and subsequently revised to make them more clearly defined (Braun & Clarke, 2006, 2021). In the analysis, contradictory and deviant cases were intentionally included to deepen the analysis and not considered as anomalies (Patton, 2015; Tracy, 2010). The final thematic framework was then explored via boundary case analysis, rival explanation analysis and reflexive memo writing, which was then incorporated into the study's conceptual model and theoretical contribution (Charmaz, 2014; Tracy, 2010).

Expanded interview field notes, observation notes, and reflexive memos were read repeatedly to build familiarity before inductive coding began (Braun & Clarke, 2021). Codes were compared across the dataset to identify overarching patterns, and themes were refined through constant comparison to strengthen conceptual clarity and consistency (Nowell et al., 2017). Themes were first generated inductively and then read against the theoretical

framework of ecological sensemaking, with data and theory informing one another in an abductive process (Timmermans & Tavory, 2012).

Methodological rigor was assessed against Lincoln and Guba's (1985) criteria of credibility, transferability, dependability, and confirmability. Because interviews were not audio-recorded, field notes were written immediately after each interview to minimize recall loss and preserve contextual detail — a practice recognized as appropriate when recording is not culturally or ethically acceptable (Emerson et al., 2011; Phillippi & Lauderdale, 2018). Credibility was further supported by methodological triangulation, extended engagement with the community, iterative interviewing, and reflexive practice (Lincoln & Guba, 1985; Patton, 2015). Transferability was supported through rich description of the study setting and participants (Creswell & Poth, 2018). An audit trail documented data collection and analytical decisions to strengthen dependability, and confirmability was supported by grounding each theme in illustrative excerpts drawn from field notes and analytical memos, presented in the Findings below (Finlay, 2002; Nowell et al., 2017).

The interpretivist approach to research, which sees knowledge as socially constructed through interaction between the researcher and the participants (Crotty, 1998; Lincoln et al., 2018) was adopted in this study. Interviews were carried out by the first author, who also prepared the extended field notes, translated the data set and did the analysis. Reflexivity was supported by ongoing memo writing and re-reading of the data to reflect on interpretations that were emerging throughout the research process, and to prevent early theoretical closure (Berger, 2015; Braun & Clarke, 2021; Charmaz, 2014). While Weick's Sensemaking Theory was used as a sensitizing device, analytical decisions were based largely on what the participants said and the themes were inductively developed before being interpreted theoretically (Blumer, 1986; Charmaz, 2014). To increase interpretive credibility and transparency, contradictory cases and alternative interpretations were intentionally included throughout the analysis (Lincoln & Guba, 1985; Tracy, 2010).

The study was conducted in accordance with ethical standards for qualitative research with human participants. Ethical approval was obtained prior to fieldwork from Department of Management, Hajee Mohammad Danesh Science and Technology University, Dinajpur with reference number HSTU/MGT/2026/56. Participants were informed about the purpose of the study, gave informed written or verbal consent as appropriate to their preference and literacy, and were told they could withdraw at any time without consequence (Orb et al., 2001; Tracy, 2010). Pseudonyms and participant codes were used throughout to protect confidentiality, and all participants preferred that interviews not be audio-recorded, a preference that was fully respected (Orb et al., 2001; Tracy, 2010). Consistent with ethical engagement with an indigenous community, the research emphasized cultural sensitivity and reflexivity throughout, treating participants as collaborators in knowledge generation rather than as sources of data (Braun & Clarke, 2021; Tracy, 2010).

4. Findings and Discussion

Analysis generated four interrelated themes describing how Santal participants perceive, interpret, and act on ecological change. *Table 2* summarizes these themes before they are discussed in turn, with illustrative excerpts included to ground each theme in participants' own accounts.

Theme	Focus	Key sub-processes
1. Reading a Living Landscape under Ecological Change	Participants recognize ecological change through multisensory observation, accumulated experience, bodily engagement, more-than-human relationships, and emerging digital information. This theme represents the cue extraction stage of sensemaking and extends Weick by showing cue extraction as	Embodied Ecological Observation; More-than-Human Ecological Communication; Temporal Ecological Disruption; Emerging Digital Ecological Attention

Theme	Focus	Key sub-processes
	ecological, embodied, relational, and culturally situated.	
2. Making Sense of Ecological Change through Multiple Interpretive Worlds	Participants transform ecological observations into meaningful understandings of climate change through overlapping interpretive worlds shaped by culture, livelihood, gender, education, institutions, and experience. This theme explains how ecological observations become socially meaningful before action is taken.	Relational and Moral Ecological Worlds; Practical Agricultural Risk; Technological and Commercial Interpretations; Household Ecologies of Care; Political and Structural Interpretations
3. Translating Ecological Meanings into Agricultural and Livelihood Practices	Participants enact ecological meanings by modifying farming practices, managing water resources, changing crop varieties, diversifying livelihoods, adjusting planting calendars, and adopting new agricultural techniques. These responses are continuously revised as ecological conditions evolve, demonstrating that adaptation is an ongoing process of practical sensemaking rather than a one-time behavioral response. This theme represents the enactment stage of ecological sensemaking. It demonstrates that ecological interpretations acquire significance only when translated into concrete agricultural and livelihood decisions.	Adaptive Crop and Farming Decisions; Water Management and Resource Adjustment; Livelihood Diversification under Climate Uncertainty; Learning through Agricultural Experimentation; Collective Adaptation and Community Practice
4. Negotiating Ecological Agency under Structural Constraints	Although participants demonstrated sophisticated ecological knowledge and adaptive intentions, their responses were shaped by unequal access to land, irrigation, financial resources, institutional support, markets, technology, and political influence. Ecological agency therefore emerged as relational and structurally mediated rather than simply a product of individual knowledge or motivation. This theme reveals that ecological sensemaking cannot be understood independently of broader social, economic, and institutional contexts.	Resource Constraints and Adaptive Capacity; Institutional Opportunities and Barriers; Economic Vulnerability and Livelihood Decisions; Negotiating Agency through Collective Action; Hope, Persistence, and Future-Oriented Adaptation

It was found that ecological sensemaking in the Santal community is a recursive, socially constructed process of interpreting, negotiating and translating the process of environmental change into adaptation strategies for agriculture. Through the lived experience, Indigenous ecological knowledge, intergenerational learning and emerging institutional information, participants continually reconstructed ecological meanings rather than reacting to climate change with traditional knowledge or just technical answers. This process is described in 4 interconnected themes.

Reading a Living Landscape under Ecological Change

The landscape was not only a physical environment, but also a dynamic source of ecological information, as described by the participants. Environmental changes were detected by several environmental indicators such as irregular rainfall, prolonged heat, falling groundwater levels, irregular flowering patterns, lower soil moisture, and bird, insect, livestock and wild plant behavior. These changes were interpreted in terms of long-term farming experience by participants P09 and P12, and by adding information from agricultural extension services by P10. Younger participants, especially P21, more often used digital weather information as well as local weather information. These stories seem to indicate that ecological attention is not necessarily constant, and is continually modified by experience and shifting information sources. In line with Weick's (1995) idea of cue extraction, participants actively picked out and interpreted signals that were ecological, relational and embedded in local socio-ecological contexts, not in organizational contexts.

Making Sense through Multiple Interpretive Worlds

There was not a single definition of ecological change among the participants. Rather, there were several ways of interpreting. Some participants knew about climatic uncertainty from Indigenous knowledge passed on from generation to generation, while others integrated local knowledge with scientific guidance, government agricultural initiatives, or digital weather forecasts. The use of seeds was a frequent topic among female participants, as was household food security, and water management as well as the younger farmers' focus on technological information and market conditions were also frequently mentioned. The various interpretations show that ecological sensemaking is not a personal process, but a social one. Instead of supplanting the knowledge of Indigenous peoples, scientific and technological knowledge was used in selective ways and blended with the existing knowledge system to make hybrid forms of ecological interpretation. This discovery goes beyond the realm of cognitive interpretation of the environment and shows that meaning is formed through the interplay of cultural knowledge, institutional factors and farmers' daily lives.

Translating Ecological Meanings into Agricultural and Livelihood Practices

Adaptive decisions were made based on ecological interpretations, such as crop variety, planting dates, water conservation, and livelihood diversification and decreasing reliance on climate-sensitive agriculture. Adaptation was repeatedly defined as a process of experimentation, not as a process of pre-planned strategies. For instance, P11 and P25 discussed the changes in the previous farming methods to deal with the growing climate uncertainty, while P21 highlighted collective responses based on community cooperation and agricultural learning. These results suggest that ecological sensemaking is performed in the form of ongoing, real-time decisions. In this sense sensemaking acts as an iterative process in which the making of sense of the environment is connected to adaptive action, as in the focus on enactment in Weick's account, but with the emphasis on the role of Indigenous ecological knowledge in influencing the adaptation to agriculture.

Negotiating Ecological Knowledge and Agency under Structural Constraints

While participants exhibited a fairly high level of ecological knowledge, the need for adaptive action was always linked to structural conditions. They were constrained in their ability to undertake preferred adaptation strategies by limited access to irrigation, declining groundwater, financial insecurity, land scarcity, institutional inequalities, and limited government support. Participants thus differentiated between knowledge of ecological change and the resources needed to act in a way that is effective. Simultaneously, ecological knowledge was negotiated in intergenerational, gendered, and educationally diverse ways, and through institutional encounters. Younger participants were more likely to integrate Indigenous knowledge with technological information, while women were a significant part of the seed conservation, adaptation of the household and transmission of knowledge. The results show that ecological agency is not only contextualized by personal knowledge or motivation, but also by socially-embedded relationships.

The results indicate that ecological sensemaking is a recursive process where the observation, interpretation, adaptive practice and construction of ecological knowledge continuously shape and are shaped by each other. The study does not depict Indigenous knowledge as a fixed or the process of adaptation to climate change as a linear series of behaviorally-based adaptation responses, but rather shows that ecological meanings are continually reconstructed as lived environmental experiences, and are influenced by structural opportunities and constraints. This builds on Weick's (1995) Sensemaking Theory by placing sensemaking not just in the human or human-made world, but within Indigenous socio-ecological systems, where the environmental relationships, collective knowledge, and institutional inequalities all shape the ways in which ecological disruptions are understood and responded to. Climate adaptation thus becomes not just a technical solution to climate change, but a continuously evolving process of meaning making as communities work out how to deal with the uncertainties of the environment, the need to maintain cultural identity, and the opportunities for future livelihoods.

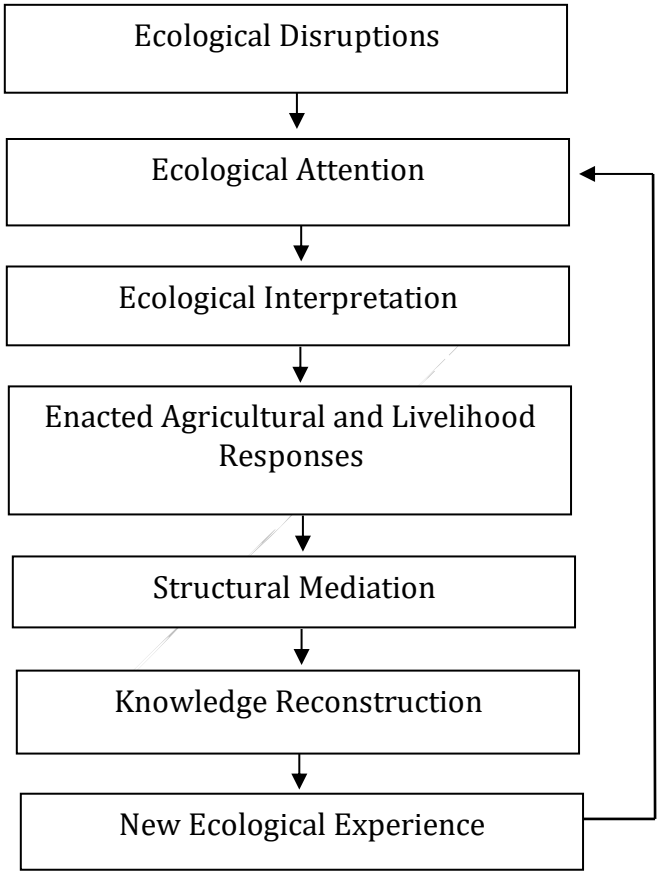

Figure 1: Recursive Conceptual Model

The study suggests that ecological sensemaking is not linear, but rather recursive, as Indigenous farmers are continually reinterpreting shifts in environmental conditions by interacting with their socio-ecological context again and again. The process starts with disruptions in the ecology, e.g., unpredictable rainfall, falling groundwater levels, rising temperatures, or evolving seasonal cycles, that disrupt existing farming practices, and raise ecological concern. Farmers then involve themselves with ecological interpretation, using their Indigenous ecological knowledge, their experiences, social engagement and new external knowledge, to bring meaning to these environmental changes. Such interpretations are then translated into enacted agricultural and livelihood responses (such as changes in cropping pattern, irrigation strategies, livelihood diversification and household adaptation strategies). These responses are not in isolation, however, but are continually influenced by structural mediation, such as access to land, water, financial resources, institutions, technologies, and wider socio-political context that either facilitating or hindering adaptive action. The consequences of these adaptive responses then create new ecological experiences that shape knowledge reconstruction as individuals and communities revisit previous knowledge in the context of the new environmental realities. This reconstructed knowledge, in turn, guides future

ecological attention and interpretation, establishing a continuous feedback loop to drive the evolution of ecological sensemaking over time. Therefore, the model sees climate adaptation as a process of recursive, socially negotiated, ongoing meaning-making that is constantly reproduced, refined and translated into practice in the face of persistent climate uncertainty and structural constraint, with Indigenous ecological knowledge always being reproduced, refined and translated into practice.

5. Conclusion

While technologies, institutions, and adaptive outcomes are frequently portrayed as climate adaptation, the results of this study suggest that climate adaptation starts with the perception of environmental change. Based on an interpretivist qualitative approach and Reflexive Thematic Analysis of interviews with Santal farmers in Barind region, Bangladesh, the study examined how indigenous farmers interpret ecological changes and how they make these interpretations manifest in their farming and livelihood strategies. The results show that adaptation is a continuous and dynamic process of ecological sensemaking that involves ongoing interpretation, negotiation and enactment of observations of rainfall, groundwater, soils, seasonality, and daily environmental experiences amidst climate uncertainty.

The main theoretical implication of this study is that ecological sensemaking is an iterative process, one in which the processes of observing environments, interpreting them, adapting to them, and reconstructing knowledge are continuously influenced and informed by the structural environment and by Indigenous knowledge systems. The study shows that sensemaking is not an organizational or mainly cognitive process, but a process that is continuously generated by a dynamic interplay between the changes in the environment, cultural practices, institutional influences, and learning for the future. This approach extends the sensemaking theory to Indigenous communities in climate-sensitive environments and provides a more socially grounded approach to adaptation in an uncertain environment.

The results also have significant implications for practice. Climate adaptation actions often focus on a technical solution without considering the interpretation work involved in the understanding of environmental changes. The findings indicate that adaptation policies should consider the active role of indigenous communities as knowledge holders and decision makers, explore the possibility of dialogue between indigenous and scientific knowledge systems, increase participation of communities in adaptation planning, increase access to locally relevant climate information, and tackle structural constraints like groundwater scarcity, insecure livelihoods, and limited institutional support. This kind of strategies are more likely to result in effective and socially legitimate adaptation strategies.

There are a number of limitations in this study. It is based on a single community from amongst the indigenous communities of the Barind, which area is characterized by drought conditions, and thus does not aim for analytical generalization based on statistics. Further, the results presented are derived from a qualitative account gathered in one phase of the fieldwork. Comparative studies with indigenous communities in other regions could expand this work, as could the use of longitudinal designs to explore how ecological interpretations change over time, and mixed methods to further examine the links between ecological sensemaking, adaptation, and environmental governance.

The study concludes that besides resources and/or technologies, the processes by which environmental change becomes meaningful before it becomes actionable are also key to effective climate adaptation. The experiences of the Santal community demonstrate how adaptation is embedded in an ongoing process of interpretation, negotiation and action in everyday life, which is based on ecological knowledge. This study provides a process-based approach that connects the process of observing the environment to adaptive practice, thereby advancing the understanding of indigenous climate adaptation and emphasizing the need to build locally informed ecological sensemaking to inform culturally responsive, socially legitimate and sustainable adaptation policy.

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Informed Consent Statement/Ethics Approval: This study adhered to internationally accepted ethical standards for social science research involving human participants. As the research involved minimal risk and consisted of interviews with adult participants, informed consent was obtained from all respondents prior to participation, and confidentiality and anonymity were strictly maintained in accordance with institutional research ethics guidelines.

Data Availability Statement: The qualitative data supporting the findings of this study are not publicly available because they contain information that could compromise the privacy and confidentiality of research participants from the Santal community. De-identified data may be made available by the corresponding author upon reasonable request and subject to ethical considerations and participant consent.

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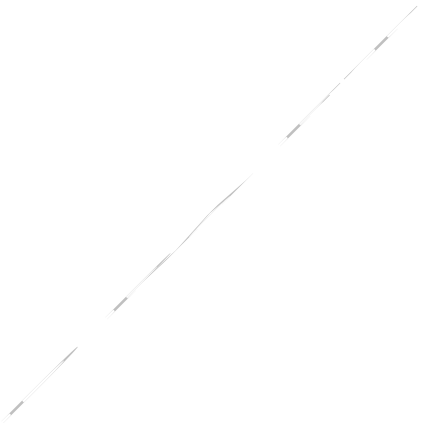

Appendix-1

Interview Guide

Project Title: Ecological Sensemaking as a Recursive Process of Indigenous Climate Adaptation: Evidence from the Santal Community of Bangladesh

1. Could you tell me the story of how you became involved in farming/working on this land? What are your earliest memories of walking through these fields as a child?

2. If you were to describe your relationship with the earth (*Ot*) and the sky (*Serma*) to someone who has never been to the Barind region, how would you describe it?

3. Walk me through a typical, intense day of work during the peak cultivation or harvesting season. What are the physical demands, and what keeps you motivated through the day?

4. When you stand in your field or courtyard at the start of a season, how do you know *exactly* when the weather is about to turn?

5. Have you noticed any changes in the behavior of local plants, trees (e.g., *Sal*, *Mahua*, *Palash*), birds, insects, or field animals over the last few years? What are these living things trying to tell you?

6. Traditional calendars used to dictate exactly when to plant and harvest. Do those dates still work today? If not, what specific signals from nature have you had to look for instead?

7. Do you look at your mobile phone or digital weather forecasts before making decisions? How do those digital numbers compare to what you see and feel when standing on your land?

8. People talk a lot about "climate change" or the weather behaving strangely. When the rain delays for weeks or a sudden heatwave burns the crops, how do you explain *why* this is happening?

9. How does it feel inside when you look at a cracked, dry field or an empty tube-well pump? How does this environmental unpredictability affect your peace of mind and your sense of stability?

10. Is there a deeper, spiritual, or ancestral meaning behind these harsh environmental changes? How do traditional rituals (like agricultural festivals) help the community make sense of these disruptions?
11. Do you view these changes as a technical problem that can be fixed with modern machinery, irrigation, and fertilizers, or is it something deeper that technology cannot resolve?

12. When the rains are highly erratic, walk me through the mental debate you have before buying seeds. How do you decide whether to stick to traditional rainfed rice or pivot to something else (like mango orchards or vegetables)? What risks are you weighing?

13. When water becomes scarce, how do you manage and prioritize its use? How do you decide how much water goes to the main crop fields, versus the household garden (*Bari*), versus the livestock?

14. If the environment makes it impossible to farm, how do you decide it's time to stop working the land and pivot to day labor or urban construction? What does losing that connection to the soil mean to you?

15. Think about the agricultural wisdom you use every day. Who taught you how to read the soil, select seeds, and predict the weather? How was that knowledge shared with you?

16. Do you feel the younger generation reads the landscape the same way the elders do? Where do you see disagreements or friction between ancestral wisdom and modern farming practices?

17. What are you teaching your own children about this landscape? What kind of future do you imagine for them on this land? Do you want them to remain farmers in the Barind, or do you hope they find a life completely detached from agriculture?

18. How does the changing weather affect your daily life?