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RESEARCH

Traditional agroecological calendar, phenology, and biotic indicators among the Lepchas of Sikkim, Eastern Himalaya

Sangeeta Jha[1], Aranya Jha[1], D. Balasubramanian[2], Saibal K Saha[3] and Ajeya Jha[4*]

[1]Sikkim Manipal Institute of Technology, Sikkim Manipal University, Upper Tadong, Gangtok – 737136, Sikkim, India
[2]Faculty of Agriculture and Life Sciences, Arunachal University of Studies, Namsai – 792103, Arunachal Pradesh, India
[3]Depaertent of Commerce and Management, Xavier Business School, St. Xavier University, Kolkata-700016, West Bengal, India
[4]Arunachal University of Studies, Namsai – 792103, Arunachal Pradesh, India

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*Corresponding author
Ajeya Jha
E-mail ajha@arunachaluniversity.ac.in

Abstract

Traditional ecological knowledge plays a crucial role in understanding ecological processes, seasonal forecasting, and sustainable agroecosystem management among indigenous communities. The present study documents and analyzes the traditional agroecological calendar and biotic ecological indicators used by the Lepcha community of Sikkim in the Eastern Himalaya. Field investigations were conducted during 2024 in Lepcha-dominated areas of Pakyong district, Sikkim, using unstructured interviews, participant observations, and focused group discussions with knowledgeable community elders and local practitioners. The study primarily examined traditional seasonal calendars, floral and faunal indicators, insect activity, climatic observations, hydrological cues, and agricultural practices associated with seasonal transitions. The study documented twelve traditional Lepcha months synchronized with ecological rhythms rather than fixed calendrical systems. Seasonal progression and agricultural operations were regulated through detailed observations of flowering phenology, bird behaviour, insect emergence, amphibian vocalization, fish migration, atmospheric conditions, hydrological changes, and indigenous acoustic cues. Important floral indicators included *Bombax ceiba*, *Rhododendron arboreum*, *Clerodendrum infortunatum*, *Rosa macrophylla*, *Luculia gratissima*, and *Erythrina arborescens*, while faunal and insect indicators involved migratory birds, cicada choruses, frog breeding calls, dragonfly activity, moth swarming, and fish movements. Agricultural activities such as sowing, harvesting, food gathering, mushroom collection, honey harvesting, and tuber extraction were closely synchronized with these ecological indicators and seasonal environmental conditions. The findings reveal that the Lepcha seasonal calendar represents a highly integrated indigenous agroecological forecasting system developed through long-term interaction with Himalayan ecosystems. The study further highlights the ecological and cultural significance of indigenous phenological knowledge, soundscape ecology, and biotic forecasting systems in regulating traditional agricultural practices and livelihood adaptation. In the context of rapid socio-cultural transformation, biodiversity loss, and climate change, documentation of such indigenous ecological knowledge systems is essential for cultural preservation, biodiversity conservation, and sustainable mountain agroecosystem management in the Eastern Himalaya.

Keywords: biotic indicators, Eastern Himalaya, indigenous agroecological calendar, Lepcha community, seasonal ecological forecasting, traditional ecological knowledge

Introduction

Traditional ecological knowledge (TEK) has increasingly been recognized as an important component for sustainable natural resource management, biodiversity conservation, and resilience of agroecosystems. Although the concept remains broad and multidisciplinary, TEK generally refers to the cumulative body of knowledge, practices, beliefs, and observations developed by indigenous and local communities through long-term interaction with their surrounding environment (Agrawal 2014). Anthropologists further describe TEK as a dynamic system of knowledge evolving through generations and transmitted through oral traditions, cultural practices, stories, songs, rituals, and livelihood activities. It encompasses the relationships shared among living organisms, including humans within their socio-cultural settings, and the natural ecosystems they inhabit. Berkes (2012) emphasized that TEK possesses three major dimensions: (i) empirical knowledge of floral and faunal species and ecological processes, (ii) community practices associated with environmental management and subsistence activities, and (iii) cultural beliefs and value systems that regulate interactions between humans and nature.

In recent decades, TEK has attracted increasing attention from researchers, conservationists, policymakers, and nongovernmental organizations because of its potential contribution to sustainable development and effective natural resource management (Berkes et al. 2000; Huntington 2000; Prober et al. 2011). This growing interest has also been driven by concerns among indigenous communities regarding rapid environmental degradation, biodiversity loss, and erosion of traditional knowledge systems (Jackson and O'Leary 2006; Langton 1998; Luckert et al. 2007). Indigenous ecological knowledge is often geographically extensive and temporally deep because it is derived from continuous observations accumulated over generations in landscapes where livelihoods remain closely dependent on natural resources (Fraser et al. 2006). Consequently, TEK is increasingly being incorporated into ecological research, biodiversity conservation, climate adaptation studies, and sustainable resource management frameworks. Several studies have demonstrated the importance of indigenous ecological knowledge in natural resource management and subsistence adaptation among indigenous communities worldwide (Altman 1987; Buchanan et al. 2009; Chase and Sutton 1981; Ens et al. 2012; Horstman and Wightman 2001; Meehan 1981; Russell-Smith et al. 1997; Walsh 1990).

Among the diverse dimensions of TEK, biotic indicators and indigenous ecological forecasting systems constitute particularly important components of traditional environmental knowledge. Biotic weather forecasting indicators represent ecological cues derived from the behaviour, phenology, abundance, vocalization, migration, or reproductive activities of plants and animals that are used by indigenous communities to interpret seasonal transitions and predict weather variability (Shoko and Shoko 2012). Indigenous societies across the world have evolved sophisticated systems for interpreting such ecological signals to regulate agricultural operations, food gathering, fishing, hunting, and other subsistence activities. Numerous studies have highlighted the importance of biotic indicators in indigenous forecasting systems (Anju and Bonny 2019; Ayal 2017; Garteizgogeascoa et al. 2020; Iticha and Husen 2019; Magoro 2020; Mosime 2018; Nkuba et al. 2020; Radeny et al. 2019; Roque de Pinho 2020). Many avian, mammalian, reptilian, amphibian, and invertebrate species exhibit behavioural, physiological, and reproductive responses to climatic variability, which indigenous communities interpret as indicators of environmental change and seasonal progression. Ethno-zooindicators therefore represent an important component of indigenous ecological forecasting systems.

Closely related to indigenous ecological forecasting are traditional ecological calendars, which synchronize seasonal biological events with livelihood activities and environmental conditions. Traditional calendars based on flowering phenology, animal behaviour, hydrological changes, and climatic events have been documented among several indigenous communities worldwide (Faast et al. 2020; Franco 2015; Green et al. 2010; Múnera-Roldán et al. 2020; Nassar et al. 2020; Retnowati et al. 2014; Ryan 2013; Yang et al. 2019). Green et al. (2010) documented the significance of ecological calendars among Aboriginal communities through the expression: "We don't have a calendar. Bama story goes by the tree. The tree knows better than we do." Such observations illustrate the extent to which indigenous societies depend upon ecological rhythms rather than fixed calendrical systems for organizing subsistence activities. Interest in TEK-based ecological indicators has continued to grow because of their potential applications in forest management, biodiversity conservation, climate adaptation, and ecological forecasting (García-del-Amo et al. 2020; Kidemu et al. 2020; Sbragaglia et al. 2020; Sinthumule and Mashau 2020). Researchers have increasingly emphasized the importance of integrating TEK with scientific approaches to improve environmental management and climate resilience (Chambers et al. 2017; Eddy et al. 2017; Mantyka-Pringle et al. 2017; McMillen et al. 2017).

Sikkim, a small Himalayan state located in northeastern India, is situated within the Eastern Himalaya, one of the globally recognized biodiversity hotspots. Despite covering an area of only about 7,096 km^2, the state exhibits remarkable ecological heterogeneity because of its wide altitudinal gradient ranging from nearly 300 m above sea level to over 8,000 m. This extreme variation in altitude and climate has resulted in the occurrence of tropical, subtropical, temperate, sub-alpine, and alpine ecosystems within a relatively small geographical region. Consequently, Sikkim supports exceptionally rich biodiversity, including nearly 160 mammalian species (Agrawal 2000; Avasthe and Jha 1999), more than 500 bird species (Chettri 2000; Chettri et al. 2001), 78 reptilian species (Chettri et al. 2011; Jha and Thapa 2002), and 19 amphibian species (Jha and Thapa 2002).

Among the indigenous communities inhabiting the Sikkim Himalaya, the Lepchas are considered one of the oldest ethnic groups of the region. The Lepchas, who refer to themselves as Rong, primarily inhabit areas distributed along the southern and eastern slopes of Mount Kanchenjunga. Although several anthropological theories suggest migration from Tibet, Myanmar, or neighbouring Himalayan regions, the Lepchas traditionally regard Sikkim and adjoining Himalayan landscapes as their ancestral homeland. At present, they coexist with Bhutia and Nepali communities within Sikkim. According to the 2004 electoral records, the Lepcha population constituted approximately 8.46% of the total population of Sikkim.

The Lepchas possess rich TEK closely associated with the surrounding Himalayan environment. Their language contains extensive terminology describing local landscapes, mountains, rivers, forests, flora, and fauna. Previous studies have documented Lepcha nomenclature and ethnobiological knowledge associated with plants, food species, medicinal plants, mammals, birds, reptiles, and butterflies (Avasthe and Jha 1999; Hajra and Verma 1996; Jha et al. 2004a, 2004b; Jha and Jha 2012; Jha and Thapa 2002). Such detailed ecological knowledge reflects long-term interaction between the Lepcha community and the diverse ecosystems of the Eastern Himalaya.

Although several studies have documented ethnobotanical knowledge, medicinal plants, food plants, and biodiversity associated with the Lepchas, comprehensive studies focusing on traditional agroecological calendars and biotic ecological indicators remain limited. In particular, integrated documentation of floral phenology, faunal behaviour, insect activity, acoustic indicators, hydrological observations, and seasonal agricultural synchronization within a single indigenous ecological forecasting framework is largely lacking from the Eastern Himalaya. Considering the increasing threats posed by climate change, biodiversity loss, modernization, and erosion of indigenous knowledge systems, systematic documentation of such traditional ecological forecasting systems has become increasingly important.

Therefore, the present study aims to document and analyze the traditional agroecological calendar of the Lepcha community of Sikkim with particular emphasis on floral, faunal, insect, acoustic, hydrological, and climatic indicators used in seasonal forecasting, agricultural scheduling, food gathering, and livelihood adaptation in the Eastern Himalaya. The study further seeks to highlight the ecological, cultural, and conservation significance of indigenous agroecological knowledge systems in mountain ecosystems.

Materials and Methods

Study area

The study was conducted in the Himalayan state of Sikkim, located in the Eastern Himalaya biodiversity hotspot of northeastern India (Fig. 1). The region is characterized by remarkable ecological heterogeneity arising from steep altitudinal gradients, diverse climatic regimes, and varied vegetation types ranging from subtropical forests to alpine ecosystems. The study primarily focused on Lepcha-inhabited regions of Pakyong district, particularly Lower Gagyong and Amba Gram Panchayat Units, where a considerable proportion of the Lepcha population continues to maintain traditional ecological and agro-cultural practices.

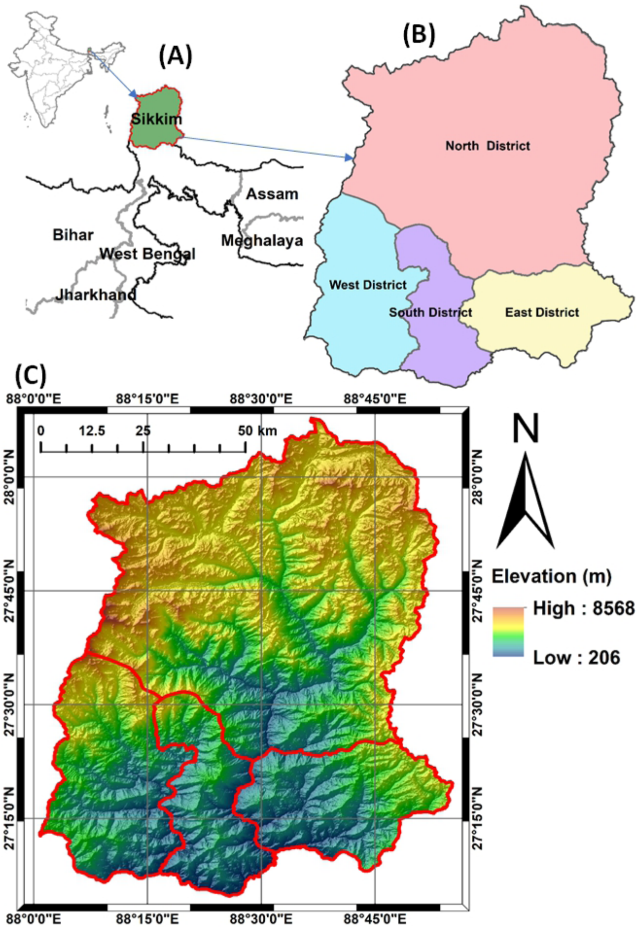

Fig. 1 Location study site. (A) Location of Sikkim within India, (B) districts in Sikkim and (C) Digital Elevation Model map of Sikkim (Source: ALOS-2, downloaded from https://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm).

Study design and ethical approval

The present investigation was exploratory in nature and based on extensive field surveys undertaken during 2024. Although the broader field investigations originally focused on documenting various dimensions of Lepcha traditional knowledge, including food plants, medicinal plants, ethnobiological traditions, and cultural practices such as songs and dances, the present study specifically re-examined the collected information to identify and analyze indigenous agroecological knowledge systems, seasonal ecological indicators, and traditional agricultural calendars of the Lepcha community.

Prior to data collection, ethical approval for the study was obtained from the Institutional Ethics Committee of Sikkim Manipal Institute of Medical Sciences, Sikkim Manipal University (Approval No.: SMIMS/IEC/2024/2). Prior informed consent was obtained from all participants before interviews and discussions were conducted.

Data collection

The present study adopted an exploratory, participatory, and systematic qualitative inquiry to document and validate the traditional agroecological knowledge of the Lepcha community. The present investigation builds upon nearly three decades of anthropological, ethnobiological, and ecological research conducted among the Lepcha community by members of the research team (Avasthe and Jha 1999; Jha and Jha 2012; Jha and Thapa 2002; Jha et al. 2004). This long-term engagement provided an extensive body of primary observations and community interactions, forming the foundation for the present investigation.

To validate previously documented knowledge and fill remaining information gaps, six focus group discussions (FGDs) were conducted during 2024, with three FGDs held in each of the two selected Lepcha villages identified through purposive (judgment) sampling. Each FGD comprised approximately 10–12 participants, resulting in a total of 66 participants, with a balanced representation of men and women. Participants were intentionally selected because they were recognized within the community as knowledgeable holders of TEK. All participants were 55 years of age or older, primarily engaged in agriculture, and most possessed lifelong experience in farming, forest resource collection, and the use of wild food plants and other natural resources. The majority had resided in the study area throughout their lives, ensuring extensive familiarity with local ecosystems, seasonal cycles, and traditional livelihood practices (Table 1).

Each FGD began with an explanation of the study objectives, ethical considerations, confidentiality, and voluntary participation. Participants were first asked to review the traditional Lepcha calendar to establish a common understanding of the sequence and characteristics of the twelve indigenous months. Discussions then explored the criteria used to recognize seasonal transitions and any local variation in the calendar among villages.

Subsequently, each traditional month was discussed individually using a flexible thematic guide. Participants described seasonal climatic characteristics, flowering and fruiting patterns, bird and animal behaviour, insect emergence, amphibian activity, fish migration, hydrological changes, atmospheric phenomena, and indigenous weather forecasting indicators. Discussions also explored agricultural operations, including land preparation, sowing, transplantation, harvesting, and crop management, together with seasonal collection of wild vegetables, mushrooms, fruits, honey, fish, and other forest resources. Although discussions remained open-ended to encourage free expression of indigenous ecological knowledge, all FGDs followed these common thematic areas to ensure consistency and comparability across groups (Supplementary 1).

Data validation and analysis

Given the exploratory and qualitative nature of this study, the collected information was analyzed following a systematic qualitative inquiry approach aimed at documenting and preserving the indigenous ecological knowledge of the Lepcha community. Information obtained through unstructured interviews, participant observations, and focused group discussions was first organized according to the twelve traditional Lepcha months and subsequently categorized into major thematic components, including seasonal climatic conditions, floral phenology, faunal and insect indicators, hydrological observations, acoustic ecology, agricultural activities, food gathering, and associated cultural practices.

To enhance the credibility and reliability of the findings, information was continuously cross-validated through repeated interactions with participants and comparisons among individual interviews and different FGDs. Community consensus was established by identifying ecological observations and traditional interpretations that were consistently reported by multiple knowledgeable participants. Where differing interpretations or recollections emerged, these were discussed further with community elders and experienced knowledge holders until a broadly accepted consensus was achieved. Information that could not be adequately verified across respondents was interpreted cautiously and excluded where appropriate.

Potential recall bias, an inherent limitation of studies relying on long-term oral knowledge, was minimized by conducting group discussions that encouraged collective recollection and mutual verification of seasonal events, species behaviour, and agricultural activities. Because the documented knowledge represents cumulative intergenerational

Table 1 Demographic characteristics of study participants

Characteristic	Category	Number (*N*)
Total participants	-	66
Focus group discussions (FGDs)	-	6
Participants per FGD	-	10–12
Gender	Male	36
	Female	30
Primary occupation	Farming	Majority
Secondary livelihood	Collection of wild food resources	Majority
Residency	Long-term residents of study villages	Majority

observations that continue to guide contemporary livelihood practices, discussions were primarily directed toward recurring seasonal patterns rather than isolated historical events, thereby improving the consistency of the recorded information.

The validated information was subsequently synthesized into month-wise matrices and integrated ecological frameworks describing the relationships among floral phenology, faunal behaviour, insect activity, hydrological processes, weather indicators, seasonal soundscapes, and agricultural operations. Data were interpreted using thematic analysis to identify recurring ecological patterns and the interconnections between indigenous environmental observations and seasonal livelihood strategies. This systematic qualitative approach enabled the development of an integrated representation of the Lepcha agroecological calendar while preserving the ecological and cultural context of the indigenous knowledge system.

Results

Traditional Lepcha agroecological calendar

The present study documented a traditional Lepcha agroecological calendar comprising twelve seasonal months synchronized with ecological rhythms, climatic conditions, and subsistence activities rather than fixed calendrical systems (Table 2, Fig. 2). Seasonal transitions were identified through integrated observations of flowering phenology, bird behaviour, insect emergence, hydrological changes, atmospheric conditions, and characteristic acoustic cues. These ecological indicators regulated agricultural operations, food gathering, and other livelihood practices throughout the year.

The spring months extending from Karnyt to Ting (January–May) were characterized by increased flowering activity, emergence of butterflies and cicadas, bird courtship and nesting behaviour, and initiation of agricultural activities. Flowering of species such as *Bombax ceiba*, *Rhododendron arboreum*, *Clerodendrum infortunatum*, and *Euphorbia sikkimensis* served as major floral indicators of seasonal progression from winter toward warmer conditions (Table 3, Fig. 2). Concurrently, migratory bird arrival, nest building, courtship displays of Himalayan Monal pheasants, and upstream fish migration were recognized as important faunal indicators. Agricultural practices during this period included field preparation, sowing of millet, maize, ginger, and dry paddy, along with collection of leafy vegetables and tubers from surrounding forests.

The monsoon period from Numtsam to Purvim (May–September) exhibited the highest ecological productivity and biological activity within the annual cycle. This phase was associated with flowering of moisture-loving plant species such as *Bauhinia vahlii*, *Rosa macrophylla*, *Iris hookeriana*, *Hydrangea* spp., and *Erythrina arborescens*. Heavy rainfall, overflowing rivers, waterfalls, cloud-covered hills, and humid atmospheric conditions dominated the landscape. Faunal indicators included frog breeding calls, spawning migration of Golden Mahsir, reduced avian vocalization after breeding, and moulting behaviour among birds (Table 4, Fig. 2). Insect abundance also increased substantially, including dragonflies, cicadas, crickets, beetles, and butterflies (Table 4). Agricultural activities primarily involved transplantation and weeding of paddy and millet crops, harvesting of early rice varieties, cardamom processing, and extensive collection of mushrooms, wild fruits, edible shoots, leafy vegetables, and honey from forests.

The post-monsoon and winter months extending from Glu to Mar (September–January) were characterized by declining rainfall, migration of birds, reduced insect activity, flowering of winter-associated species, and preparation for winter agriculture. Floral indicators included *Millettia extensa*, *Aconitum ferox*, *Luculia gratissima*, and *Clerodendrum* spp. (Tables 2, 3). Faunal observations included migration of summer birds, formation of mixed-species bird flocks, communal roosting of Himalayan Monal pheasants, and local migration of Blood Pheasants to lower elevations (Table 3). Weather conditions during this period were marked by clear skies, starlit nights, dew formation, lunar halos, winter rainfall, and snowfall at higher elevations. Agricultural practices included harvesting and storage of rice, pulses, ginger, oranges, and fruits, sowing of barley and winter rice, field preparation, and maintenance of agricultural tools and houses. Thus, the Lepcha agroecological calendar is closely associated with sustainable mountain agriculture, ecosystem conservation, and resilience-building in the Eastern Himalaya, thereby supporting several sustainable development goals (SDGs), particularly SDGs 2, 13, and 15 (Fig. 3).

Floral indicators in the Lepcha agroecological calendar

Flowering phenology constituted one of the most reliable ecological indicators used by the Lepchas to identify seasonal transitions and regulate agricultural activities (Table 3). The onset of spring was marked by flowering of *B. ceiba* during Karnyt, followed by blooming of orchids, *Oberonia* spp., and *R. arboreum* during Kursong. These flowering events coincided with increasing temperatures, bird activity, and initiation of agricultural operations. Progression toward pre-monsoon conditions was further indicated by flowering of *C. infortunatum* and *E. sikkimensis* during Thon and Ting, respectively (Table 3).

Monsoon months were characterized by flowering of moisture-associated plant species including *B. vahlii*, *R. macrophylla*, *I. hookeriana*, *Hydrangea* spp., and *E. arborescens*, which were closely associated with humid conditions, overflowing rivers, and intensive agricultural activity

Table 2 Traditional agroecological and phenological knowledge system of Lepchas of Sikkim

Modern calendar	Lepcha-month	Floral indicators	Faunal indicators	Insect indicators	Agricultural activities	Weather	Community consensus level[a]
January-February	Karnyyt	*Tun-Glu Rip* (Red flowers of *Bombax ceiba*)	Towards the end of the month birds begin territory calls and courtship gestures	Great Effigy, Himalayan fritillary; Indian Tortoise Shell	*Kashyox Buk, Katching Buk* (Tubers)	*Cut* (wind without noise)	High
February-March	Kursong	*Oberonia Parvala*; Flowers of *Etok* (*Rhododendron arbereum*) flower *Kursong Rip* (An orchid flower)	Nest building begins on a serious note; Upward fish migration of some cold-water fish like *sun-ru no*	Great Windmill (Lugblo Sungchit)	Dry season rice cultivated, Millets (Savi) sown; Kunangbi, Kanthebi (Green leaf vegetables); Singnok buk (Tubers)	Tuk Nyil (Rushing gales and thunder)	High
March-April	Thon	Kum bal Rip (Flowers of *Clerodendrum infortunatum*) begin to bloom in this month	Eggs are laid by birds; Parent birds adopt hostile attitude towards anyone moving near their nests. Dance of Ta Ryok Pho (Monal pheasants). Snakes and bears avoided now	Tailed Jay (Rummchhot Thamblyok), Red Lacewing (Num Chang Thamblyok); Sam-si, La-gek (Species of cicadas) can be heard singing)	Winter rice harvested, Kin-rtsong sown, Barley harvested; Raburbi (Green leaf vegetables); *Zo Nyot So-Tap-Nun Nal* (cultivation destroyed by hails)	(So Tap) Hail storms, Nun Kun Nydn Bam (Trees bend with wind)	High
April-May	Ting	Sun Grryon rip (*Euphorbia sikkimensis*) begin to bloom	Arrival of migratory cuckoo (Indian cuckoo, himalayan cuckoo, and brain fever bird)	Jungle Glory (Lavo Thamblyok); La yen, Tunjor (Species of cicadas) can be heard singing	Kin-rtsong (sharung) sown; Rongzilit, Kushyulit; Green leaves availed now are *Kanchyel bi, Kuntong bi, Prongchyot bi and Tungtok bi.*	bop (rivers are muddy); *Hlo Pum-Byon-Nu Nup-Non* - the hill is overspread with clouds	Moderate
May-June	Numtsam	Tatkal flowers (Sal tree); Pa Gun Rip (Flower of *Bauhinia vahlii*) Blossom	Hills and valleys reverberate with calls of great Assam Barbet piercing, monotonous wailing calls Kunyoo-Kunyoo repeated over and over again	Ling-Doll-Tibbu (a kind of a beetle perched on sal trees; Stately Nawab (Uungling Thamblyok)	Kuzu Sarong, Chokle Bi, Kanyong Bi (Green leaf vegetables); Tumong Dorbi, Tarnong Dorbi, Gninchung, Sanong Dorbi, Tabat Dorbi (Mushrooms); Kandyom Dong (Young shoots); Mektap Pat, Phampat (Fruits); Thakchyong Muk (Others)	*kat-ta* (Hot and Humid weather); *Pum-Byon Gryom Tuk Di* the clouds rise and overcast the horizon	High
June-July	Blung	*Kun din Rip* (Pink flowers of *Rosa macrophylla*) bloom	Birds encourage young-ones to fly out. Bird-parents attack creatures far larger than them, *Chapling Pho* (Magpie) eats of young babies, second attempts to breed *Ta-luk, Da ri, Din gal tik, Luk pak,* (Species of frogs) begin croaking to mark breeding season	Northern Jungle Queen (*Mayel Pundi Thamblyok*); *Ta nak, Ta rel* (Species of cicadas) can be heard singing	*Kin-tsong* (Sharung) harvested, *Dambra* rice harvested; *Robit-dong, Po-dong* (Young shoots); Pashyen (Others); Honey (*hu fu*) is collected	So *gydn-nd gydn-nd* (Heavy Rains); *Klya-la ti* river in the rains when it has risen to its utmost height	High
July-August	Num-kum	*Iris hookeriana*; Kumbal Rip (flowers of *Clerodendrum infortunatum*) disappear; and Tun Dyar Rip, (Flowers of *Hydrangea* species) bloom	Cuckoos migrate back (mon ta-ryum-ma -Hills are silent); Bird lings take to wings and nests are left empty; Breeding season of *no-lam saa* (Golden Mahsir, a migratory fish)	*Koyeng-tungi* (a cricket); Yellow Dryad (*Rungkun Jom Thamblyok*), Green Commodore (*Aaom Thamblyok*); *Un sun vo* (Dragon-fly) seen flying around	Monsoon rice sown, Dry season rice cultivated, Kin-rtsong harvested; Pogurhip, Perfecdung (Others); Tu (Honey is collected)	*Klya* (When rivers continue to be full and flowing); *tuk syol or aa gyun* (Waterfalls)	Moderate

Table 2 Continued

Modern calendar	Lepcha-month	Floral indicators	Faunal indicators	Insect indicators	Agricultural activities	Weather	Community consensus level[a]
August-September	Pur-Vim	*Gya Se Rip* (Flowers of *Erythrina arborescens*) bloom in full glory	*Nyel Kun Zuk* Moulting in *Malcleph-Pho* (Redvented bulbul) and other birds	Green Duke (*Euezor klop Thamblyok*)	Millets (*Savi*) harvested; *Sungtok Bi* (Green leaf vegetables); *Tacheo Dorbi, Tachi Dorbi* (Mushrooms); *Puthu dong, Pro Dong, Purmum Dong, Parmyok Dong, Padyang Dong* (young shoots); *Kunu Pat, Koluk Pat* (Fruits); *Shyakukeyu Kung* (Others); *Tu* (Honey is collected)	Nup (Hills are covered with clouds)	High
September-October	Glu	Bru Dan Rip (White flowers of *Millettia extensa*) used for poisoning fish	A large number of migrating birds fly out, Spotted doves migrate partially	Swams of Moths arrive, Sup nan (Dragon Flies fly low)	Karhyopat, Kolpat, Takpopt (Fruits); Ginger is sown	(So Cet) Rains disappear, Gentle Moon; *So-Rin Tyer-Ra Tyer-Ra Bam* - a cloudless hot sky	High
October-November	Ayit	*Lun Ji Rip* (Flowers of *Aconitum forex*) bloom in this month	*Sura Dum Purbo* (white capped redstart) and *Rang-Fung-Pho* (Hoopoe) arrive from colder climes to tropical Sikkim); *Fa-Nok-Kyok* (long-billed thrush) Birds begin to have mixed groups of species. Snakes go into hibernation	Common awl (*Hasora badra*); arrival of large number of moths	Monsoon rice harvested, Shamben (Fruits)	Brilliant and blue sky (*Ka-Glyo-La*), Starlit night (*Par-Jit-La*)	High
November-December	Ra	*Simbrang Rip* (Flowers of *Luculia gratissima*) bloom at their best	*Kanpaha* (Night Jar) vocal with Bright moon-phase; Mixed grouping behaviour begins; *Sa Mo Fo* (Blood pheasant) shifts to lower elevations	Common earl (*Pungeu Thamblyok*)	Barley sown	*Kul* (Halo around moon), *So-Gi Pot Nan* (Dew on leaves and flowers)	High
December-January	Mar	A *Rot Rip* (Flowers of *Clerodendrum* sp) begin to bloom	Large mixed species groups seen, *Ta Ryok Pho* (monal pheasants) roost in large numbers	*Tun Bun Hu* (Bees) sleep inside *Lyan* (honey comb with honey); *Heliophorus brahma*; *Athyma inara*	Winter rice sown; *Sarong Nok* (Green leaf vegetables); *Kombo Dorbi* (Mushrooms); *Solat Pat, Sanong Pat, Sitnam Pat, Tanghil Pat, Tangrhil Nok, Kushyu Pat, Kushyutarol, Kathor Pat* (Fruits); *Pajok Buk, Kantuw Buk, Pkee Buk* (Tubers); *Hin* (Ginger) is harvested; *Sa Lum Pot* (Oranges) harvested; *Cam Nyo/Cam Nyot*	(*Sa-Tsuk-Tan*) Short days of winters, Month of intense cold, (*So-Zan*) Winter rains welcomed to break dry spell; *Sa-Non*, snow at higher reaches	High

[a]Consensus level: *High* = consistently reported across multiple focus group discussions and interviews; *Moderate* = reported by several respondents but with minor variations in interpretation.

MODERN CALENDAR	LEPCHA MONTH	FLORAL INDICATORS	FAUNAL INDICATORS	INSECT INDICATORS	AGRICULTURAL ACTIVITIES	WEATHER
January–February	Karnyyt	Tun-Glu Rip (Red flowers of *Bombax ceiba*)	Birds begin territory calls and courtship gestures	Great Effigy; Himalayan fritillary; Indian Tortoise Shell	Kashyox Buk, Katching Buk (Tubers)	Cut (Wind without noise)
February–March	Kursong	*Oberonia parvula*; Etok (*Rhododendron arboreum*); Kursong Rip (Orchid flower)	Nest building begins; upward fish migration of cold-water fish	Great Windmill (Lugblo Sungchit)	Dry season rice cultivated; millets (Savi) sown; Kuangbi, Kanthebi (green leafy vegetables);	Tuk Nyil (Rushing gales and thunder)
March–April	Thon	Kum bal Rip (Flowers of *Clerodendrum infortunatum*)	Birds lay eggs; parent birds hostile near nests; dance of Monal pheasants; snakes and bears avoided	Tailed Jay; Red Lacewing; cicadas (Sam-si, La-gek)	Winter rice harvested; Kin-rtsong sown; barley harvested; Barbul (green leafy vegetables)	(So Tap) hail storms; Nun Kun Nydn Ban (Trees bend with wind)
April–May	Ting	Sun Grryon Rip (*Euphorbia sikkimensis*)	Arrival of migratory cuckoos (Indian cuckoo, Himalayan cuckoo and brain fever bird)	Jungle Glory (Lavo Thamblyok); cicadas (La yen, Tunsor)	Kin-rtsong (Sharung) sown; Rongzilit, Kushyulit; green leaves: Kanchyel bi, Kuntong bi,	Bop (Rivers are muddy); Hlo Pum-Byon-Nu Nup-Nyon (the hill is
May–June	Numtsam	Tatkal flowers (Sal tree); Pa Gun Rip (Flower of *Bauhinia vahlii*)	Hills and valleys echo with calls of the Great Assam Barbet (Kunyoo-Kunyoo)	Ling-Doll-Tibbu (beetle on sal trees); Stately Nawab (Ungling Thamblyok)	Kuzu Sarong, Chokle Bi, Kanyong Bi (green leafy vegetables); mushrooms; young	Kat-ta (Hot and humid weather); Pum-byon Gryom Tuk Di (Clouds
June–July	Blung	*Rosa macrophylla* (pink flower indicator)	Birds encourage young ones to fly; magpie preys on babies; frogs begin croaking for breeding	Northern Jungle Queen (Mayel Pundi Thamblyok); cicadas (Ta nak, Ta rel)	Kin-tsong (Sharung) harvested; Dambra rice harvested; young shoots; others; honey (hu fu)	So gydn nd gydn-nd (Heavy rains); Klya-la e i river in rains at utmost
July–August	Num-kum	*Iris hookeriana*; Tun Dyar Rip (Flowers)	Cuckoos migrate back; birdlings take wing; breeding season of Golden Mahsir (fish)	Koyeng-tungi (cricket); Yellow Dryad; Green Commodore; dragon-fly (Un sun vo)	Monsoon rice sown; dry season rice cultivated; Kin-rtsong harvested; others; honey (Tu)	Klya (Rivers full and flowing); Tuk syo lu ar gyun (Waterfalls)
August–September	Pur-Vim	Gya Se Rip (Flowers of *Erythrina arborescens*)	Moulting in Red-vented bulbul and other birds	Green Duke (Euezor klop Thamblyok)	Millets (Savi) harvested; green leafy vegetables; mushrooms; young shoots; fruits; others;	Nup (Hills are covered with clouds)
September–October	Glu	Bru Dan Rip (White flowers of *Millettia extensa*)	Many migrating birds fly out; spotted doves migrate partially	Swarms of moths; dragon flies (Sup man) fly low	Karhypat, Kolpat, Takpopt (Fruits); ginger is sown	(So Cet) Rains disappear; Tendle Moon; So-Rin Tyer-Ra Tyer-Ra
October–November	Ayit	Lun Ji Rip (Flowers of *Aconitum ferox*)	White-capped redstart and Hoopoe arrive; long-billed thrush present; snakes hibernate	Common awl (Hasora bada); many moths arrive	Monsoon rice harvested; Shamben (Fruits)	Brilliant blue sky (Ka-Gly-La); star-lit night (Par-Jit-La)
November–December	Ra	Simbrang Rip (Flowers of *Luculia gratissima*)	Night Jar vocal with bright moon; mixed grouping begins; Blood pheasant shifts lower	Common Earl (Pungeu Thamblyok)	Barley sown	Kul (Halo around moon); So-Pi Pot Nan (Dew on leaves and flowers)
December–January	Mar	A Rot Rip (Flowers of *Clerodendrum sp.*)	Large mixed-species groups; Monal pheasants roost in large numbers	Bees (Tun Bun Hu) sleep in honeycomb; Heliophorus brahma; Athyma niara	Winter rice sown; Sarong Nok (green leafy vegetables); mushrooms; fruits; others	Frost (So Gi); So-Gi Pot Nan (Dew on leaves and flowers)

● Floral indicators ● Faunal indicators ● Insect indicators ● Agricultural activities ● Weather

Fig. 2 Integrated Lepcha ecological calendar showing seasonal relationships among floral phenology, faunal behavior, insect emergence, agricultural activities, and weather indicators across traditional Lepcha months in the Eastern Himalayan region. The scientific interpretations presented in this study are based exclusively on field observations, interviews, focus group discussions, and documented species records rather than on the graphical illustrations.

(Table 3, Fig. 2). The transition toward autumn and winter was marked by flowering of *M. extensa*, *A. ferox*, *L. gratissima*, and *Clerodendrum* spp., coinciding with declining rainfall, reduced insect activity, and onset of colder conditions. Several of these species additionally possessed medicinal, ritual, and nutritional significance within Lepcha society, thereby integrating plant phenology with subsistence and cultural practices.

Faunal and insect indicators in the Lepcha agroecological calendar

Faunal and insect indicators formed an integral component of the Lepcha indigenous ecological forecasting system (Table 4). Bird behaviour represented one of the most important seasonal indicators. Increased vocalization, territorial calls, courtship displays, and nest-building activities during Karnyt and Kursong signified the transition from winter toward spring. Arrival of migratory cuckoos during Ting and courtship displays of Himalayan Monal pheasants during Thon were considered important indicators of seasonal progression and ecological renewal (Table 4, Fig. 2).

Monsoon months were associated with major changes in faunal activity, including frog breeding calls, upstream migration and spawning of fishes, reduced avian vocalization after breeding, and moulting behaviour among birds. During Numkum, Lepchas described the landscape as "Mon Ta-Ryum-Ma," meaning the hills had become silent following departure of migratory cuckoos and dispersal of juvenile birds. Post-monsoon and winter periods were characterized by migration of summer birds, formation of mixed-species bird flocks, increased vocalization of Night Jars, and communal roosting behaviour of Himalayan Monal pheasants (Table 4). These behavioural changes were interpreted as ecological responses to declining temperature and changing seasonal conditions.

Insect indicators also exhibited pronounced seasonal variation. Emergence of butterflies after winter dormancy during Karnyt and Kursong represented one of the earliest signs of ecological rejuvenation. Butterfly species such as Great Windmill, Tailed Jay, Jungle Glory, Northern Jungle Queen, Green Duke, Yellow Dryad, and Common Earl appeared sequentially across different months and functioned as indicators of seasonal progression (Tables 2, 4). Continuous cicada vocalization during spring and monsoon months was associated with increasing humidity and crop maturation, while dragonfly abundance during Numkum indicated sustained monsoon conditions (Table 4, Fig. 2). Post-monsoon moth swarming around artificial lights and winter dormancy of bees further reflected seasonal climatic transitions.

Table 3 Phenological floral indicator matrix of the Lepcha agroecological calendar in the Eastern Himalaya

Lepcha month	Floral indicator (local name)	Scientific name	Growth form	Phenological event	Ecological significance	Agricultural significance	Cultural/ethnomedicinal importance	Associated season	Community consensus level[a]
Karnyt	*Tun-Glu Rip*	*Bombax ceiba*	Tree	Flowering onset	Indicates end of winter and ecological rejuvenation	Initiation of field preparation and forest food gathering	Flowers used for medicinal tea against constipation and gynecological disorders	Winter–Spring	High
Kursong	*Etok & Kursong Rip*	*Rhododendron arboretum & Oberonia* spp.	Tree & Epiphytic orchid	Peak flowering	Signals warming conditions and early spring & Confirms onset of spring	Agricultural preparation activities & Millet sowing and field cleaning	Culturally important spring flowering species	Spring	High
Thon	*Kum Bal Rip*	*Clerodendrum infortunatum*	Shrub	Flowering	Associated with increasing humidity and insect emergence	Sowing of millet and ginger	Leaves and roots used against fever and snakebite	Spring	High
Ting	*Sun Grryon Rip*	*Euphorbia sikkimensis*	Herb	Flowering	Indicates pre-monsoon transition	Maize sowing and buckwheat harvesting	Traditional medicinal importance	Pre-monsoon	High
Numtsam	*Pa Gun Rip*	*Bauhinia vahlii*	Climber	Flowering	Indicates onset of humid monsoon conditions	Wet rice transplantation	Nutritional and medicinal value	Early monsoon	Moderate
Blung	*Kun Din Rip*	*Rosa macrophylla*	Shrub	Flowering	Associated with peak monsoon conditions	Paddy transplantation and millet harvesting	Fruits and flowers used for nutritional and medicinal purposes	Monsoon	High
Numkum	*Tun Dyar Rip*	Hydrangea spp.	Shrub	Peak flowering	Indicates sustained rainfall and cloud cover	Rice weeding and honey collection	Medicinal value	Monsoon	High
Purvim	*Gya Se Rip*	*Erythrina arborescens*	Tree	Flowering	Marks transition toward late monsoon	Millet harvesting and cardamom processing	Bark decoction used as anthelmintic	Late monsoon	High
Glu	*Bru Dan Rip*	*Millettia extensa*	Climber	Flowering	Indicates monsoon withdrawal	Rice harvesting and ginger sowing	Roots used traditionally for fish poisoning and insect repellence	Post-monsoon	Moderate
Ayit	*Lun Ji Rip*	*Aconitum ferox*	Herb	Flowering	Signals onset of colder autumn conditions	Harvest-related activities	Highly poisonous; ritual and medicinal significance	Autumn	High
Ra	*Simbrang Rip*	*Luculia gratissima*	Shrub	Flowering	Indicates early winter conditions	Barley sowing and crop storage	Fragrant ornamental and culturally valued species	Early winter	High
Mar	*A Rot Rip*	*Clerodendrum* spp.	Shrub	Flowering initiation	Indicates peak winter	Winter field preparation	Traditionally used against diabetic symptoms	Winter	High

[a]Consensus level: *High* = consistently reported across multiple focus group discussions and interviews; *Moderate* = reported by several respondents but with minor variations in interpretation.

Table 4 Seasonal faunal and insect indicator matrix in the Lepcha agroecological calendar of the eastern Himalaya

Lepcha month	Faunal/insect indicator (local name)	Taxonomic group	Observed behaviour/ occurrence	Ecological interpretation	Agricultural/ seasonal significance	Cultural importance	Community consensus level[a]
Karnyt	Great Effigy, Himalayan fritillary, Indian Tortoiseshell	Butterfly	Emergence after winter dormancy	Indicates ecological rejuvenation and warming	Beginning of field preparation	Indicator of seasonal transition	High
	Migratory cuckoos, Green Magpie	Bird	Arrival and territorial calls	Early spring onset	Preparation for cultivation	Associated with seasonal renewal	High
Kursong	Sun-ru no	Fish	Upstream migration	Increased stream flow and early rains	Sowing season	Traditionally trapped for food	High
	Great Windmill (*Lugblo Sungchit*)	Butterfly	Increased emergence and flight activity	Rising temperature	Agricultural initiation	Spring ecological indicator	High
Thon	Himalayan Monal (*Ta rhyak Pho*)	Bird	Courtship dance	Breeding season onset	Crop sowing period	Sacred and auspicious bird	High
	Sam si and La-gek	Cicada	Loud singing	Increasing humidity and temperature	Millet maturation	Acoustic seasonal indicator	High
Ting	Cuckoos	Bird	Loud calls across hills	Pre-monsoon transition	Intensification of farming	Seasonal forecasting cue	High
	Jungle Glory (*Lavo Thamblyok*)	Butterfly	Reappearance in forests	Increasing vegetation productivity	Crop growth phase	Ecological transition indicator	High
Numtsam	Great Assam Barbet	Bird	Repetitive vocalization	Increasing humidity	Wet rice transplantation	Associated with folklore	High
	Ling-doll-tibbu	Beetle	Emergence on Sal trees	Monsoon onset	Forest resource collection	Indicator of humid weather	High
Blung	Ta-luk, Da ri, Din gal tik, Luk pak	Frog	Breeding croaks	Peak monsoon rainfall	Paddy cultivation season	Traditionally hunted for protein	Moderate
	Northern Jungle Queen	Butterfly	Increased abundance	Peak monsoon ecological productivity	Rice transplantation	Monsoon ecological indicator	High
Numkum	Golden Mahsir (*No-lam saa*)	Fish	Upstream breeding migration	Sustained monsoon river flow	Monsoon continuation	Important riverine indicator	High
	Dragonflies (*Un sun vo*)	Insect	Flying low in large numbers	Persistent humidity and rainfall	Rice field management	Monsoon indicator	High
Purvim	Red-vented Bulbul	Bird	Moulting behaviour	Seasonal renewal	Late monsoon transition	Ecological transformation indicator	High
Purvim	Green Duke	Butterfly	Large-scale emergence	Moist environmental conditions	Harvest preparation	Late monsoon indicator	High
Glu	Moths	Insect	Swarming around lights	Post-monsoon atmospheric change	Harvest period	Seasonal transition indicator	High
Ayit	White-capped Redstart, Hoopoe	Bird	Arrival from colder regions	Autumn onset	Rice harvesting season	Hoopoe associated with arrival of guests	Moderate
	Common Awl	Butterfly	Increased visibility	Dry post-monsoon conditions	Harvest activities	Autumn ecological marker	High
Ra	Mixed-species bird flocks	Bird community	Formation of feeding flocks	Winter adaptation	Crop storage period	Indicator of cold season	High
	Common Earl	Butterfly	Seasonal appearance	Early winter transition	Reduced agricultural activity	Winter seasonal indicator	High
Mar	Himalayan Monal	Bird	Communal roosting	Peak winter conditions	Dormant agricultural phase	Sacred winter indicator	High
	Bees (*Tun bun hu*)	Insect	Dormancy within honeycombs	Low temperature conditions	Minimal farming activity	Indicator of winter dormancy	High

[a]Consensus level: *High* = consistently reported across multiple focus group discussions and interviews; *Moderate* = reported by several respondents but with minor variations in interpretation.

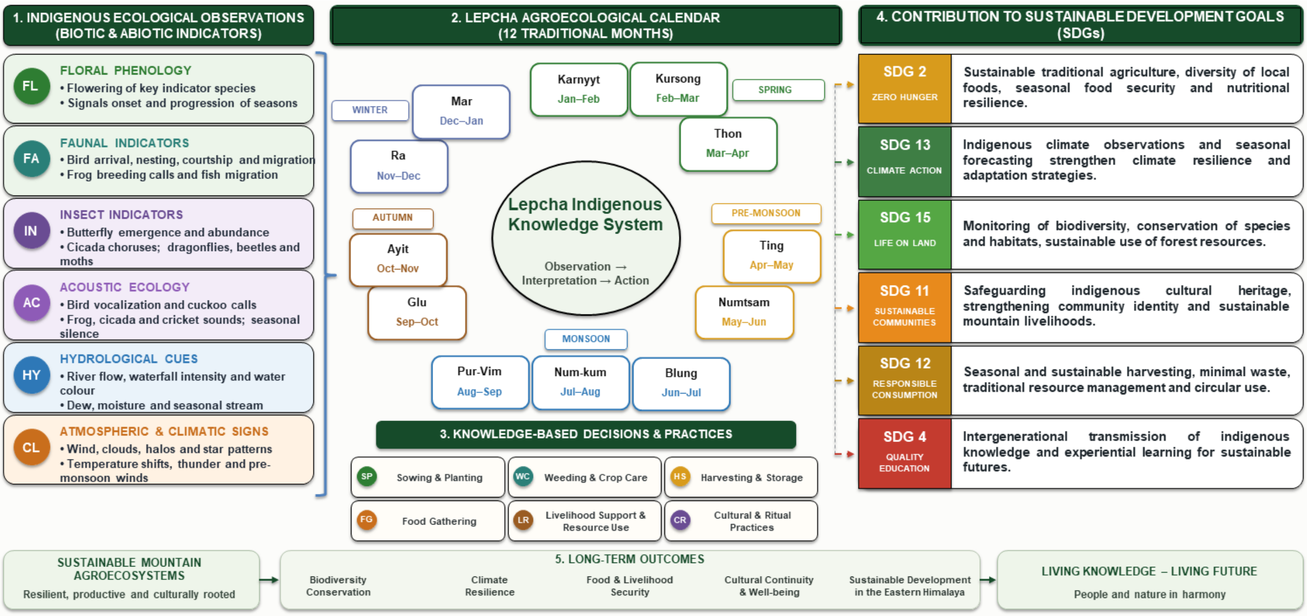

Fig. 3 Conceptual framework illustrating the contribution of Lepcha agroecological knowledge systems to biodiversity conservation, climate adaptation, and sustainable mountain livelihoods. The scientific interpretations presented in this study are based exclusively on field observations, interviews, focus group discussions, and documented species records rather than on the graphical illustrations.

Seasonal synchronization between ecological indicators and agricultural activities

The study revealed a highly integrated relationship between ecological indicators, climatic conditions, and agricultural practices within the Lepcha traditional knowledge system. Flowering phenology, bird migration, amphibian breeding, insect emergence, hydrological changes, and acoustic signals collectively functioned as ecological cues regulating sowing, harvesting, food gathering, and seasonal livelihood activities. Agricultural operations including cultivation of millet, maize, paddy, barley, and ginger were closely synchronized with seasonal ecological changes (Fig. 2). Simultaneously, collection of mushrooms, wild fruits, leafy vegetables, tubers, shoots, and honey formed an important supplementary subsistence strategy, particularly during monsoon periods when cultivated food resources were relatively limited. The findings demonstrate that the Lepcha agroecological calendar represents a sophisticated indigenous ecological forecasting system developed through long-term interaction with Himalayan ecosystems (Fig. 2). The calendar integrates phenological observations, faunal behaviour, soundscape ecology, climatic interpretation, and subsistence practices into a unified seasonal knowledge framework regulating traditional mountain agriculture in the Eastern Himalaya.

Seasonal acoustic ecology and indigenous environmental forecasting

The Lepcha agroecological calendar additionally incorporates a highly refined system of acoustic ecology based on seasonal variation in bird vocalization, cicada choruses, frog breeding calls, cricket sounds, and broader environmental soundscapes (Table 4, Fig. 4). These acoustic signals functioned as important ecological indicators for identifying seasonal transitions, onset and progression of monsoon conditions, breeding periods, and timing of agricultural activities. Seasonal changes in sound intensity, frequency, and composition were closely monitored and interpreted as indicators of environmental change, climatic variation, and ecosystem productivity.

Spring and pre-monsoon months were characterized by increased bird vocalization, territorial calls, cuckoo songs, and continuous cicada activity, reflecting rising temperatures and enhanced biological productivity (Table 4). During Thon and Ting, vocalization of cicadas and migratory cuckoos formed important seasonal indicators associated with crop sowing and approaching rainfall. Peak monsoon periods were dominated by intense frog croaking, cricket sounds, flowing rivers, waterfalls, and heavy rainfall, collectively creating distinct monsoon soundscapes interpreted by the Lepchas as indicators of high moisture availability and ecological abundance (Table 4, Fig. 2).

A particularly significant observation was recorded during Numkum, when the departure of migratory cuckoos and decline in bird vocalization led to a phenomenon locally described as "*Mon Ta-Ryum-Ma*," meaning "the hills have become silent." This seasonal silence was recognized as an important ecological indicator marking the transition toward mature monsoon conditions (Table 4). Post-monsoon and winter soundscapes were characterized by reduced insect activity, increased Night Jar vocalization, and gradual decline in biological acoustic intensity under colder climatic conditions. The findings demonstrate that the Lepchas possess a sophisticated indigenous sound-

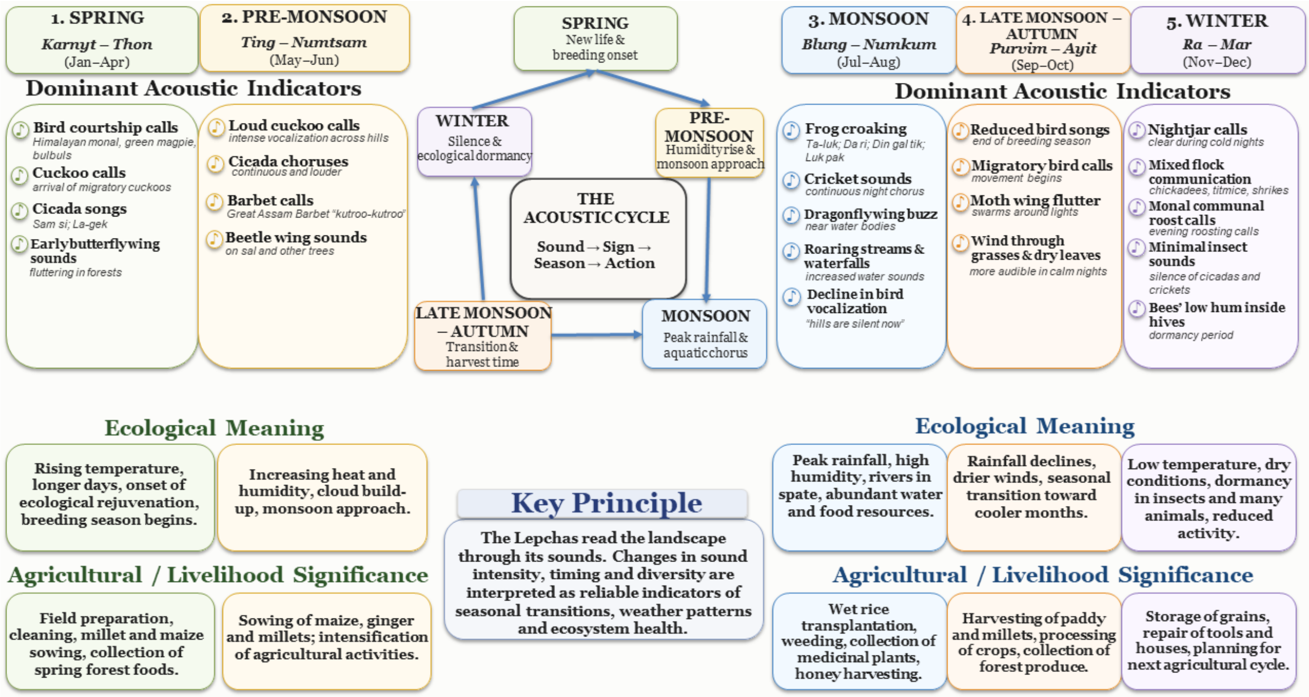

Fig. 4 Seasonal acoustic ecology framework in the Lepcha agroecological calendar of the Sikkim, Eastern Himalaya. The scientific interpretations presented in this study are based exclusively on field observations, interviews, focus group discussions, and documented species records rather than on the graphical illustrations.

scape-based environmental forecasting system integrating acoustic signals with seasonal ecology, climatic interpretation, and agricultural decision-making in the Eastern Himalaya (Table 4, Fig. 2).

Discussion

Traditional agroecological calendars as indigenous ecological knowledge systems

The present study demonstrates that the Lepcha community maintains a highly integrated agroecological calendar that synchronizes seasonal climatic variation, flowering phenology, faunal behaviour, insect activity, hydrological changes, and agricultural practices into a unified indigenous ecological knowledge system (Fig. 2). Rather than relying on fixed calendar dates, seasonal transitions are recognized through ecological signals that guide sowing, harvesting, food gathering, and other livelihood activities. This close coupling between biodiversity, climate, and agriculture illustrates how long-term environmental observations have been translated into practical ecological forecasting, enabling local communities to adapt to the dynamic mountain environment of the Eastern Himalaya (Armatas et al. 2016; Ullmann et al. 2022; Yang et al. 2019). Furthermore, the Lepcha agroecological calendar contributes to sustainable mountain agriculture, biodiversity conservation, and climate resilience, aligning closely with SDGs 2, 13, and 15 (Fig. 3).

These findings support the concept of TEK proposed by Berkes (1993), whereby ecological knowledge, cultural practices, and environmental observations are accumulated through generations and continually refined through interaction with local ecosystems. Similar indigenous seasonal calendars have been documented among Aboriginal and other indigenous communities worldwide, where phenological events and animal behaviour are used to regulate resource management and agricultural activities (Bulbulshoev et al. 2011; D'Arcy and Kuan 2023; Prober et al. 2011; Ullmann et al. 2022). However, comprehensive studies integrating floral phenology, faunal behaviour, insect indicators, hydrological observations, and acoustic ecology within a single agroecological framework remain scarce in the Eastern Himalaya. The present study therefore fills an important regional knowledge gap by documenting a comprehensive indigenous ecological forecasting system.

A notable feature of the Lepcha calendar is its multidimensional interpretation of ecological indicators. Flowering of key plant species is closely synchronized with bird migration, amphibian breeding, insect emergence, seasonal weather, and agricultural operations, demonstrating that ecological indicators are interpreted collectively rather than independently. This holistic perspective is characteristic of indigenous knowledge systems, where ecological, cultural, and livelihood dimensions are inseparable (Boillat and Berkes 2013; Caillon et al. 2017; Pretty 2011). The integrated seasonal wheel and acoustic ecology framework developed in this study further illustrate these ecological linkages and provide a conceptual representation of the Lepcha environmental knowledge system.

Beyond agricultural scheduling, the Lepcha agroecological calendar also encompasses ethnomedicinal knowledge, food gathering, ritual practices, and environmental ethics, highlighting the multifunctional role of indigenous ecological knowledge in sustaining both livelihoods and cultural identity. As climate change increasingly alters phenological patterns and ecological processes in mountain ecosystems, such locally adapted knowledge systems provide valuable complementary information for biodiversity monitoring, climate adaptation, and sustainable resource management (Kassam et al. 2018; Turner and Reid 2022; Ullmann et al. 2022). Consequently, the Lepcha agroecological calendar represents not only a repository of traditional knowledge but also a living framework for understanding and responding to environmental change in the Eastern Himalaya.

The Lepcha agroecological calendar also shares important characteristics with indigenous seasonal calendars documented in other mountain regions of the world, including the Pamir Mountains of Central Asia and the Andes of South America, where seasonal ecological knowledge is similarly derived from long-term observations of plant phenology, animal behaviour, climatic variability, and agricultural cycles (Kassam et al. 2010; Mathez-Stiefel 2014; Ullmann et al. 2022). However, the Lepcha system is distinguished by its integration of floral, faunal, hydrological, and acoustic indicators within a single agroecological framework adapted to the exceptionally diverse environmental gradients of the Eastern Himalaya. This multidimensional ecological interpretation highlights the unique biocultural heritage of the Lepcha community while demonstrating the broader relevance of indigenous mountain knowledge systems for ecological research and sustainable resource management.

Phenological indicators and indigenous seasonal forecasting

Flowering phenology emerged as one of the most reliable ecological foundations of the Lepcha agroecological calendar (Table 3). Sequential flowering of species such as *B. ceiba*, *R. arboreum*, *C. infortunatum*, *B. vahlii*, *R. macrophylla*, and *L. gratissima* provided consistent cues for recognizing seasonal transitions and regulating agricultural activities. Rather than following fixed calendar dates, the Lepchas synchronize field preparation, sowing, transplantation, harvesting, and forest resource collection with recurrent phenological events, reflecting a long-term indigenous environmental monitoring system developed through continuous observation and intergenerational knowledge transmission (Ruelle et al. 2022; Yang et al. 2019; Zeiger et al. 2024).

The close synchronization between flowering phenology, climatic conditions, and agricultural practices demonstrates a strong ecological coupling within the Himalayan socio-ecological system. For example, flowering of *B. ceiba* and *R. arboreum* coincides with increased bird activity, butterfly emergence, and initiation of agricultural preparation, whereas flowering of moisture-associated species such as *B. vahlii* and *Hydrangea* spp. corresponds with monsoon onset, wet-rice transplantation, and intensified forest food gathering. These observations indicate that the Lepcha seasonal calendar is based on ecosystem processes rather than chronological time, enabling agricultural activities to remain closely aligned with seasonal environmental conditions.

Such reliance on local phenological indicators is particularly important in the Eastern Himalaya, where steep altitudinal gradients create substantial spatial variation in temperature, precipitation, and growing seasons. Similar use of plant phenology for seasonal forecasting has been documented among indigenous communities in alpine, Arctic, and tropical mountain ecosystems (D'Arcy and Kuan 2023; Prober et al. 2011; Reyes-García et al. 2016; Ullmann et al. 2022). However, the present study provides one of the few comprehensive accounts from the Eastern Himalaya integrating flowering phenology with faunal behaviour, hydrological observations, agricultural practices, and indigenous environmental forecasting within a single agroecological framework.

Beyond seasonal forecasting, Lepcha phenological knowledge also incorporates ethnomedicinal uses, food gathering, ritual beliefs, and environmental ethics, illustrating the multifunctional role of biological indicators in indigenous livelihood systems. Species such as *A. ferox* and *M. extensa* are interpreted not only as seasonal markers but also through their medicinal, toxicological, and cultural significance. This multidimensional interpretation reflects the holistic character of TEK, in which ecological observations are inseparable from cultural values and resource management (Li and Han 2022; Ludwig and Poliseli 2018; Sterling et al. 2017). The continued relevance of this indigenous phenological system is particularly evident under contemporary climate change. Shifts in flowering phenology, rainfall patterns, and species distributions may alter the reliability of traditional seasonal indicators and disrupt long-established ecological synchrony. Nevertheless, long-term indigenous phenological observations provide valuable complementary information for biodiversity monitoring, climate adaptation, and sustainable management of mountain ecosystems, highlighting the importance of documenting and preserving such knowledge systems.

Faunal and insect indicators as ecological forecasting tools

The present study demonstrates that faunal and insect indicators constitute a fundamental component of the Lepcha agroecological calendar, functioning as reliable tools for seasonal forecasting and agricultural decision-making. The Lepchas closely monitor changes in bird migration, courtship and nesting behaviour, amphibian vocalization, fish migration, butterfly emergence, cicada choruses, dragonfly abundance, and moth activity to recognize seasonal transitions and guide agricultural operations. These observations illustrate a sophisticated indigenous ecological monitoring system developed through long-term interaction with the Himalayan environment.

Bird behaviour emerged as one of the most important ecological indicators within the Lepcha seasonal calendar. Increased bird vocalization, territorial displays, and nesting activity marked the transition from winter to spring, whereas migratory species such as cuckoos, White-capped Redstarts, and Hoopoes signalled successive seasonal changes. Similarly, the courtship displays of the Himalayan Monal during Thon reflected reproductive phenology associated with spring. Comparable use of bird behaviour as seasonal indicators has been reported among indigenous communities in different ecological regions, where migration and breeding patterns are closely linked with climatic variability and resource availability (Carey 2009; Morelli et al. 2017; Ortega-Álvarez and Casas 2023).

Amphibians and insects also played important roles in environmental forecasting. Frog breeding calls coincided with the onset of monsoon conditions and paddy cultivation, while continuous cicada vocalization reflected increasing temperature, humidity, and crop maturation. Likewise, the seasonal abundance of dragonflies, butterflies, and crickets provided additional indicators of moisture availability and monsoon progression. These observations are consistent with ecological studies demonstrating the sensitivity of amphibians and insects to temperature, rainfall, and humidity (Bonnefond et al. 2020; Ficetola and Maiorano 2016; Neff et al. 2022).

One of the most distinctive findings of this study is the incorporation of acoustic ecology into the Lepcha agroecological calendar. Seasonal soundscapes created by birds, frogs, cicadas, crickets, flowing rivers, and even periods of environmental silence were interpreted as ecological signals reflecting seasonal progression and ecosystem dynamics. The locally recognized phenomenon "*Mon Ta-Ryum-Ma*" ("the hills have become silent") during *Numkum*, following the departure of migratory cuckoos and decline in bird vocalization, represents a particularly sophisticated example of indigenous soundscape-based environmental interpretation. This finding complements the growing field of soundscape ecology, which recognizes biological and environmental sounds as valuable indicators of ecosystem condition and biodiversity dynamics (Darras et al. 2019; Farina 2018; Müller et al. 2023).

The close synchronization between faunal behaviour and agricultural activities further demonstrates the ecological sophistication of the Lepcha seasonal calendar. Fish migration, amphibian breeding, insect emergence, and seasonal changes in bird activity consistently coincided with crop sowing, rice transplantation, harvesting, and other agricultural operations, indicating that animal behaviour is interpreted collectively with climatic and hydrological cues rather than in isolation. Such integration reflects the holistic character of indigenous ecological knowledge systems and reinforces the role of biodiversity as an important source of environmental information for mountain communities (Castagnetti et al. 2021; Ullmann et al. 2022).

As climate change increasingly alters migration patterns, breeding phenology, insect emergence, and seasonal acoustic patterns, the reliability of traditional ecological indicators may also be affected. Nevertheless, indigenous faunal knowledge provides valuable long-term ecological observations that complement scientific biodiversity monitoring and enhance understanding of ecological responses to environmental change in Himalayan ecosystems. Consequently, documenting such knowledge is important not only for preserving biocultural heritage but also for informing future biodiversity conservation and climate adaptation strategies.

Indigenous weather forecasting and seasonal synchronization

The present study demonstrates that the Lepcha agroecological calendar functions not only as a seasonal classification system but also as a sophisticated indigenous weather forecasting framework. Rather than relying on individual environmental signals, the Lepchas interpret seasonal weather through the combined observation of flowering phenology, faunal behaviour, insect activity, hydrological changes, cloud formation, atmospheric conditions, and characteristic soundscapes. This integrated approach enables accurate recognition of seasonal transitions and guides agricultural operations within the environmentally heterogeneous landscapes of the Eastern Himalaya.

Weather prediction is closely linked with biological and hydrological indicators. Increased cicada activity, cuckoo vocalization, frog breeding calls, and low-flying dragonflies signal increasing humidity and the approach of the monsoon, whereas upstream fish migration and rising river discharge indicate intensifying seasonal rainfall. Hydrological observations, including changes in river colour, stream flow, waterfall activity, and valley cloud accumulation, further assist in predicting rainfall and determining suitable periods for crop cultivation. Such ecological associations are consistent with studies demonstrating that many plant and animal species respond sensitively to changes in temperature, humidity, atmospheric pressure, and precipitation (Boillat and Berkes 2013; Chanu et al. 2019; Kom et al. 2024).

Atmospheric observations provide additional forecasting cues within the Lepcha knowledge system. Dew formation during Ra is associated with dry winter conditions, while lunar halos are interpreted as indicators of impending snowfall or rainfall. Likewise, increasing cloud accumulation over mountain slopes during Numtsam and Pur-Vim signals the onset and progression of monsoon conditions. Similar use of atmospheric and hydrological phenomena for seasonal prediction has been reported among indigenous communities in diverse mountain environments (Kijazi et al. 2013; Vedwan 2006), highlighting the widespread importance of locally derived weather knowledge for subsistence agriculture.

A distinctive feature of the Lepcha forecasting system is that weather predictions are rarely based on a single indicator. Instead, multiple ecological signals—including flowering of moisture-associated plants, increased insect activity, frog choruses, river swelling, cloud development, and acoustic changes—are interpreted collectively to assess seasonal progression. This systems-based interpretation closely synchronizes agricultural activities such as sowing, transplantation, harvesting, food gathering, and storage with prevailing environmental conditions, thereby enhancing the resilience of mountain farming systems under highly variable climatic conditions (Castagnetti et al. 2021; Kassam et al. 2018; Ullmann et al. 2022).

The continued relevance of this indigenous forecasting system is particularly important under ongoing climate change. Altered rainfall regimes, rising temperatures, and shifting phenological patterns may weaken the synchrony between traditional ecological indicators and seasonal agricultural activities. Nevertheless, the long-term environmental observations embedded within the Lepcha agroecological calendar provide valuable complementary information for climate adaptation, biodiversity monitoring, and sustainable management of Himalayan mountain ecosystems. Preserving this knowledge therefore contributes not only to safeguarding indigenous cultural heritage but also to strengthening locally adapted strategies for responding to environmental change.

Biocultural relationships and adaptive livelihood strategies

The present study demonstrates that the Lepcha agroecological calendar represents a comprehensive biocultural knowledge system in which ecological observations, agricultural practices, food gathering, ethnomedicinal knowledge, and cultural beliefs are closely interconnected. Seasonal environmental changes are interpreted not merely as ecological events but as components of a broader socio-ecological system that guides livelihood decisions, resource use, and community practices. This holistic relationship between people and nature is a defining characteristic of many indigenous knowledge systems (Berkes et al. 2000; Rist and Dahdouh-Guebas 2006; Rozzi et al. 2023).

Many floral and faunal indicators documented in this study possess ecological, medicinal, and cultural significance simultaneously. Species such as *B. ceiba*, *C. infortunatum*, *B. vahlii*, and *A. ferox* function as seasonal markers while also serving medicinal, nutritional, or ritual purposes. Likewise, animals including the Himalayan Monal, Hoopoe, and Great Assam Barbet are embedded within local beliefs, folklore, and symbolic traditions, illustrating how ecological observations reinforce cultural identity and facilitate intergenerational transmission of knowledge. Such multifunctional use of biodiversity highlights the close integration of ecological understanding with ethnobiological traditions (Hosen and Nakamura 2020; Kassam et al. 2010).

Seasonal food gathering further strengthens the adaptive capacity of the Lepcha livelihood system. During periods when cultivated food resources become limited, particularly during the monsoon, communities increase their reliance on wild edible plants, mushrooms, fruits, tubers, honey, fish, and other forest resources. This seasonal diversification reduces dependence on cultivated crops and enhances resilience to environmental variability, a strategy widely recognized among indigenous communities inhabiting mountain ecosystems (Dhyani and Dhyani 2016; Ghosh-Jerath et al. 2021; Lu et al. 2023).

Agricultural practices are similarly synchronized with ecological conditions. Timing of sowing, transplantation, harvesting, and storage is guided by biological and climatic indicators rather than fixed calendar dates, allowing farming activities to remain closely aligned with seasonal environmental variability. Combined with practices such as mixed cropping, organic nutrient management, and sustainable use of forest resources, this adaptive strategy contributes to both livelihood security and maintenance of agroecosystem diversity (Altieri et al. 2015; Barthel et al. 2013; Witharana et al. 2025).

Beyond agriculture, the seasonal calendar also structures community life by determining periods suitable for social gatherings, marriages, weaving, repair of agricultural tools, and other collective activities. Consequently, the Lepcha calendar functions as an ecological, economic, and cultural institution that strengthens community cohesion while regulating interactions between people and their environment. However, this knowledge system faces increasing pressures from modernization, changing livelihood aspirations, youth migration, agricultural intensification, and climate change, all of which threaten the continuity of intergenerational knowledge transmission. Documenting the Lepcha agroecological calendar is therefore important not only for preserving indigenous cultural heritage but also for supporting biodiversity conservation, climate adaptation, and sustainable mountain development. As a long-term repository of environmental observations, the Lepcha calendar provides valuable complementary knowledge that can inform future ecological research and conservation planning in the Eastern Himalaya (Kassam et al. 2018; Ullmann et al. 2022; Yang et al. 2019).

Relevance of indigenous agroecological calendars under climate change

The present study highlights the continued relevance of the Lepcha agroecological calendar as a locally adapted environmental monitoring and climate adaptation system in the Eastern Himalaya. Built upon long-term observations of flowering phenology, animal behaviour, hydrological changes, atmospheric conditions, and seasonal soundscapes, the calendar enables communities to synchronize agricultural activities with changing environmental conditions. Such knowledge is particularly valuable in mountain regions, where steep altitudinal gradients and high climatic variability strongly influence ecosystem processes and agricultural productivity (Gerlitz et al. 2017; Kassam et al. 2018).

However, climate change poses significant challenges to the reliability of traditional ecological indicators. Shifts in flowering phenology, migration timing, insect emergence, and rainfall regimes have been widely documented across mountain ecosystems and may disrupt the ecological synchrony upon which indigenous forecasting systems depend (Inouye 2022; Parmesan 2007; Vitasse et al. 2021). In the Lepcha calendar, seasonal transitions are interpreted through multiple interacting indicators, including flowering of moisture-associated plants, cicada vocalization, frog breeding, fish migration, cloud formation, and river dynamics. Alterations in the timing or intensity of these ecological processes may reduce the accuracy of traditional seasonal forecasting and affect agricultural planning.

Despite these challenges, the present study demonstrates that indigenous ecological knowledge remains an important source of fine-scale environmental information. The long-term phenological, behavioural, hydrological, and acoustic observations maintained by the Lepcha community provide valuable complementary evidence for understanding ecological change in data-deficient mountain regions. Increasingly, global assessments recognize that integrating indigenous and local knowledge with scientific approaches strengthens biodiversity conservation, ecosystem management, and climate adaptation strategies (Brondízio et al. 2021; McElwee et al. 2020; Tengö et al. 2017).

A particularly novel contribution of this study is the documentation of indigenous acoustic ecology as part of climate-relevant environmental monitoring. Seasonal variation in bird vocalization, frog choruses, insect sounds, and periods of environmental silence were interpreted as indicators of ecological change and seasonal progression. These observations complement recent advances in soundscape ecology, which recognize acoustic patterns as sensitive indicators of biodiversity status and ecosystem functioning (Oestreich et al. 2024; Stowell and Sueur 2020). The integration of soundscape observations with phenological and climatic indicators broadens our understanding of indigenous environmental forecasting and provides new opportunities for interdisciplinary ecological research.

An important contribution of the present study is the establishment of a comprehensive qualitative baseline for future ecological research in the Eastern Himalaya. The twelve-month Lepcha agroecological calendar documented here provides a locally derived seasonal framework that can serve as a hypothesis-generating tool for quantitative investigations. Future studies may integrate these indigenous seasonal indicators with long-term meteorological records, remote sensing products, satellite-derived vegetation phenology, and biodiversity monitoring datasets to evaluate shifts in flowering phenology, species behaviour, monsoon timing, and ecological synchrony under changing climatic conditions. Such interdisciplinary approaches would facilitate rigorous assessment of climate-induced ecological change while simultaneously validating and strengthening indigenous ecological knowledge systems in data-deficient mountain environments.

Nevertheless, the continuity of this knowledge system is increasingly threatened by socio-economic transformation, modernization, changing agricultural practices, climate change, and declining intergenerational knowledge transmission. Documenting indigenous agroecological calendars such as that of the Lepchas is therefore essential not only for safeguarding biocultural heritage but also for supporting locally adapted climate resilience, biodiversity conservation, and sustainable mountain development.

Conservation significance and future perspectives

The present study demonstrates that the Lepcha agroecological calendar is more than a traditional farming calendar; it represents a dynamic biocultural knowledge system that integrates ecological observation, sustainable resource use, and cultural practices. Through continuous monitoring of plant phenology, animal behaviour, hydrological changes, and seasonal climatic variation, the Lepcha community has developed an adaptive framework that supports agricultural planning, biodiversity conservation, and sustainable management of mountain ecosystems. Such holistic relationships between people and nature are increasingly recognized as fundamental to ecosystem stewardship and resilience (Berkes et al. 2000; Brondízio et al. 2021).

The documented dependence on wild edible plants, mushrooms, medicinal species, fish, and other forest resources further highlights the importance of surrounding forest ecosystems in sustaining food security, livelihood diversification, and cultural continuity. Consequently, conserving forest biodiversity is inseparable from conserving the TEK upon which indigenous livelihoods depend. The

Lepcha agroecological calendar therefore provides an important example of how biodiversity conservation and cultural heritage are mutually reinforcing within mountain socio-ecological systems.

Beyond its cultural significance, the Lepcha calendar represents a valuable repository of long-term environmental memory. Generations of observations on seasonal phenology, species behaviour, hydrological processes, and climatic variability provide locally relevant ecological information that complements conventional scientific monitoring, particularly in data-deficient mountain regions (Kassam et al. 2018; Rozzi et al. 2023). Integrating such indigenous knowledge with contemporary ecological research can improve biodiversity monitoring, ecosystem management, and climate adaptation planning.

Future research should evaluate the relationships between traditional ecological indicators and contemporary climatic and phenological datasets to better understand climate-driven changes in seasonal synchrony across the Himalaya. Comparative studies among indigenous communities of the Eastern Himalaya would further reveal regional similarities and differences in ecological forecasting systems. The indigenous acoustic indicators documented in this study also provide promising opportunities for interdisciplinary research linking ethnobiology, soundscape ecology, biodiversity monitoring, and environmental assessment.

Despite its ecological and cultural importance, the continuity of Lepcha Indigenous Ecological Knowledge is increasingly threatened by modernization, changing livelihood patterns, market-oriented agriculture, and declining intergenerational knowledge transmission. Younger generations are becoming progressively less familiar with traditional seasonal indicators and ecological forecasting practices. Therefore, systematic documentation, revitalization, and incorporation of indigenous ecological knowledge into conservation, education, and community-based resource management initiatives are urgently needed. Preserving traditional agroecological calendars such as that of the Lepchas will not only safeguard an important element of intangible cultural heritage but also contribute to sustainable mountain development, biodiversity conservation, and climate-resilient ecosystem management in the Eastern Himalaya.

Conclusions

The present study documents the traditional agroecological calendar of the Lepcha community of Sikkim and demonstrates that it represents a highly sophisticated indigenous ecological knowledge system linking biodiversity, seasonal forecasting, agriculture, and livelihood adaptation in the Eastern Himalaya. The Lepchas utilize a diverse range of floral, faunal, insect, acoustic, hydrological, and climatic indicators to recognize seasonal transitions, regulate agricultural activities, anticipate weather variability, and organize seasonal food gathering. These observations reflect long-term ecological experience accumulated through continuous interaction with mountain ecosystems. Flowering phenology forms the primary ecological basis of the Lepcha seasonal calendar, while bird behaviour, fish migration, amphibian vocalization, insect emergence, and environmental soundscapes function as complementary ecological forecasting tools. The documentation of indigenous acoustic ecology further reveals a previously underexplored soundscape-based environmental monitoring system in which seasonal changes in biological sounds and environmental silence serve as indicators of ecosystem dynamics and seasonal transitions.

The Lepcha agroecological calendar also illustrates the close interdependence between ecological knowledge, subsistence practices, ethnomedicinal traditions, folklore, and social organization. Agricultural operations, forest food gathering, seasonal labour allocation, and cultural activities are closely synchronized with ecological rhythms, thereby strengthening adaptive resource management and livelihood resilience within the environmentally heterogeneous landscapes of the Eastern Himalaya. At a time when climate change is altering phenological patterns, biodiversity, and seasonal climatic variability, indigenous ecological knowledge provides valuable fine-scale environmental observations that can complement scientific monitoring, particularly in data-deficient mountain ecosystems. However, rapid socio-economic transformation, modernization, changing livelihood aspirations, and weakening intergenerational knowledge transmission increasingly threaten the continuity of this knowledge system, highlighting the urgency of its documentation and preservation.

Beyond its value as a repository of TEK, the Lepcha agroecological calendar should be recognized as a living knowledge system with practical applications for contemporary biodiversity conservation, climate adaptation, sustainable mountain agriculture, participatory ecological monitoring, and environmental education. To ensure its continued relevance, coordinated conservation actions are required, including systematic documentation and digital archiving of indigenous knowledge, integration of traditional seasonal calendars into educational programmes, active participation of Lepcha knowledge holders in community-based conservation and climate adaptation initiatives, establishment of long-term participatory ecological monitoring that combines indigenous observations with scientific phenological and climatic datasets, and promotion of collaborative research among indigenous communities, academic institutions, conservation organizations, and government agencies. Such an integrated Knowledge Conservation Action Plan will not only safeguard an invaluable element of

Lepcha biocultural heritage but also strengthen locally grounded strategies for biodiversity conservation, ecosystem resilience, and sustainable mountain development in the Eastern Himalaya.

Supplementary Information

Supplementary information accompanies this paper at https://doi.org/10.5141/jee.26.028.

Supplementary 1. Core question themes addressed in the unstructured interviews and FGDs.

Abbreviations

TEK: Traditional ecological knowledge
FGD: Focus group discussion
SDG: Sustainable development goal

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Authors' contributions

SJ: Conceptualization, Methodology, Resources, Data curation, Project administration, Writing – original draft. ArJ: Data curation, Investigation, Validation, Formal analysis, Methodology, Writing – original draft. DB: Data curation, Methodology, Visualization, Formal analysis, Validation, Writing – review & editing. SKS: Data curation, Methodology, Formal analysis, Resources. AjJ: Conceptualization, Investigation, Formal analysis, Data curation, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing. All authors read and approved the final manuscript.

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Availability of data and materials

The phytoplankton data and the distribution of water parameters are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

Agrawal A. Indigenous and scientific knowledge: some critical comments. Anthropology Indonesia. 2014;(55):1-9.

Agrawal VC. Taxonomic studies on Indian muridae and hystricidae (Mammalia: Rodentia). Kolkata: Zoological Survey of India; 2000.

Altieri MA, Nicholls CI, Henao A, Lana MA. Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev. 2015;35(3):869-90. https://doi.org/10.1007/s13593-015-0285-2.

Altman JC. Hunter-gatherers today: an Aboriginal economy in north Australia. Canberra: Australian Institute of Aboriginal Studies; 1987.

Anju R, Bonny BP. Biotic indicators as weather predictors in Wayanad district of Kerala. J Agrometeorol. 2019;21(1):114-8. https://doi.org/10.54386/jam.v21i1.219.

Armatas CA, Venn TJ, McBride BB, Watson AE, Carver SJ. Opportunities to utilize traditional phenological knowledge to support adaptive management of social-ecological systems vulnerable to changes in climate and fire regimes. Ecol Soc. 2016;21(1):16. https://doi.org/10.5751/es-07905-210116.

Avasthe R, Jha A. Mammals of Sikkim. WWF; 1999.

Ayal DY. Revisiting indigenous biotic and abiotic weather forecasting for possible integration with scientific weather prediction: a case from the Borana people of South Ethiopia. In: Venkatesan P, editor. Indigenous people. InTech; 2017.

Barthel S, Crumley C, Svedin U. Bio-cultural refugia—safeguarding diversity of practices for food security and biodiversity. Glob Environ Chang. 2013;23(5):1142-52. https://doi.org/10.1016/j.gloenvcha.2013.05.001.

Berkes F, Colding J, Folke C. Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl. 2000;10(5):1251-62. https://doi.org/10.1890/1051-0761(2000)010[1251:roteka]2.0.co;2.

Berkes F. Sacred ecology. 3rd ed. New York: Routledge, 2012.

Berkes F. Traditional ecological knowledge in perspective. In: Inglis JT, editor. Traditional ecological knowledge: concepts and cases. Ottawa: International Development Research Centre; 1993. p. 1-9.

Boillat S, Berkes F. Perception and interpretation of climate change among Quechua farmers of Bolivia: indigenous knowledge as a resource for adaptive capacity. Ecol Soc. 2013;18(4):21. https://doi.org/10.5751/es-05894-180421.

Bonnefond A, Courtois EA, Sueur J, Sugai LSM, Llusia D. Climatic breadth of calling behaviour in two widespread neotropical frogs: insights from humidity extremes. Glob Chang Biol. 2020;26(10):5431-46. https://doi.org/10.1111/gcb.15266.

Brondízio ES, Aumeeruddy-Thomas Y, Bates P, Carino J, Fernández-Llamazares Á, Ferrari MF, et al. Locally based, regionally manifested, and globally relevant: indigenous and local knowledge, values, and practices for nature. Annu Rev Environ Resour. 2021;46(1):481-509. https://doi.org/10.1146/annurev-environ-012220-012127.

Buchanan G, Altman JC, Arthur B, Oades D, Rangers BJ. "Always part of us": the socioeconomics of indigenous customary use and management of dugong and marine turtles—a view from Bardi and Jawi sea Country. Western Australia. Canberra: Centre for Aboriginal Economic Policy Research; 2009.

Bulbulshoev U, Kassam K, Ruelle M. Ecology of time: calendar of the human body in the Pamir Mountains. J Persianate Stud. 2011;4(2): 146-70. https://doi.org/10.1163/187471611x600369.

Caillon S, Cullman G, Verschuuren B, Sterling EJ. Moving beyond the human–nature dichotomy through biocultural approaches: including ecological well-being in resilience indicators. Ecol Soc. 2017;22(4): 27. https://doi.org/10.5751/es-09746-220427.

Carey C. The impacts of climate change on the annual cycles of birds. Philos Trans R Soc Lond B Biol Sci. 2009;364(1534):3321-30. https://doi.org/10.1098/rstb.2009.0182.

Castagnetti F, Bhatta J, Greene A. An offering of grain: the agricultural and spiritual cycle of a food system in the Kailash Sacred Landscape, Darchula, Far Western Nepal. Front Sustain Food Syst. 2021;5: 646719. https://doi.org/10.3389/fsufs.2021.646719.

Chambers LE, Plotz RD, Dossis T, Hiriasia DH, Malsale P, Martin DJ, et al. A database for traditional knowledge of weather and climate in the Pacific. Meteorol Appl. 2017;24(3):491-502. https://doi.org/10.1002/met.1648.

Chanu TA, Teron R, Singh OSK, Singh HT. Animals as weather-forecasting bio-indicators a case study of different communities of Bishnupur District, Manipur, NE India. Int J Adv Res. 2019;7(5):502-9. https://doi.org/10.5281/zenodo.3270443.

Chase A, Sutton P. Hunter-gatherers in a rich environment: aboriginal coastal exploitation in Cape York peninsula. In: Keast A, editor. Ecological biogeography of Australia. Springer Dordrecht; 1981. p. 1817-52.

Chettri B, Acharya BK, Bhupathy S. An overview of the herpetofauna of Sikkim with emphasis on elevational distribution pattern and threats and conservation issues. In: Arrawatia ML, Tambe S, editors. Biodiversity of Sikkim — exploring and conserving a global hotspot. Information and Public Relations Department, Government of Sikkim, Gangtok, India; 2011. p. 233-54.

Chettri N. Impact of habitat disturbances on bird and butterfly communities along the Yuksom-Dzongri Trail in Khangchendzonga Biosphere Reserve [Ph.D. dissertation]. India: North Bengal University; 2000.

Chettri N, Sharma E, Deb DC. Bird community structure along a trekking corridor of Sikkim Himalaya: a conservation perspective. Biol Conserv. 2001;102(1):1-16. https://doi.org/10.1016/s0006-3207(01)00092-1.

D'Arcy P, Kuan DDDW. Islands of hope: indigenous resource management in a changing Pacific. ANU Press; 2023.

Darras K, Batáry P, Furnas BJ, Grass I, Mulyani YA, Tscharntke T. Autonomous sound recording outperforms human observation for sampling birds: a systematic map and user guide. Ecol Appl. 2019;29(6): e01954. https://doi.org/10.1002/eap.1954.

Dhyani S, Dhyani D. Significance of provisioning ecosystem services from moist temperate forest ecosystems: lessons from upper Kedarnath valley, Garhwal, India. Energ Ecol Environ. 2016;1(2):109-21. https://doi.org/10.1007/s40974-016-0008-9.

Eddy IMS, Gergel SE, Coops NC, Henebry GM, Levine J, Zerriffi H, et al. Integrating remote sensing and local ecological knowledge to monitor rangeland dynamics. Ecol Indic. 2017;82:106-16. https://doi.org/10.1016/j.ecolind.2017.06.033.

Ens EJ, Finlayson M, Preuss K, Jackson S, Holcombe S. Australian approaches for managing 'country' using Indigenous and non-Indigenous knowledge. Eco Management Restoration. 2012;13(1):100-7. https://doi.org/10.1111/j.1442-8903.2011.00634.x.

Faast R, Clarke PA, Taylor GS, Salagaras RL, Weinstein P. Indigenous use of lerps in Australia: so much more than a sweet treat. J Ethnobiol. 2020;40(3):328-47. https://doi.org/10.2993/0278-0771-40.3.328.

Farina A. Ecoacoustics: a quantitative approach to investigate the ecological role of environmental sounds. Mathematics. 2018;7(1):21. https://doi.org/10.3390/math7010021.

Ficetola GF, Maiorano L. Contrasting effects of temperature and precipitation change on amphibian phenology, abundance and performance. Oecologia. 2016;181(3):683-93. https://doi.org/10.1007/s00442-016-3610-9.

Franco FM. Calendars and ecosystem management: some observations. Hum Ecol. 2015;43(2):355-9. https://doi.org/10.1007/s10745-015-9740-6.

Fraser DJ, Coon T, Prince MR, Dion R, Bernatchez L. Integrating traditional and evolutionary knowledge in biodiversity conservation: a population level case study. Ecol Soc. 2006;11(2):4. https://doi.org/10.5751/es-01754-110204.

García-Del-Amo D, Mortyn PG, Reyes-García V. Including indigenous and local knowledge in climate research. An assessment of the opinion of Spanish climate change researchers. Clim Change. 2020; 160(1):67-88. https://doi.org/10.1007/s10584-019-02628-x.

Garteizgogeascoa M, García-del-Amo D, Reyes-García V. Using proverbs to study local perceptions of climate change: a case study in Sierra Nevada (Spain). Reg Environ Change. 2020;20:59. https://doi.org/10.1007/s10113-020-01646-1.

Gerlitz J, Macchi M, Brooks N, Pandey R, Banerjee S, Jha SK. The Multidimensional Livelihood Vulnerability Index – an instrument to measure livelihood vulnerability to change in the Hindu Kush Himalayas. Clim Dev. 2017;9(2):124-40. https://doi.org/10.1080/17565529.2016.1145099.

Ghosh-Jerath S, Kapoor R, Ghosh U, Singh A, Downs S, Fanzo J. Pathways of climate change impact on agroforestry, food consumption pattern, and dietary diversity among indigenous subsistence farmers of Sauria Paharia tribal community of India: a mixed methods study. Front Sustain Food Syst. 2021;5:667297. https://doi.org/10.3389/fsufs.2021.667297.

Green D, Billy J, Tapim A. Indigenous Australians' knowledge of weather and climate. Climatic Change. 2010;100(2):337-54. https://doi.org/10.1007/s10584-010-9803-z.

Hajra PK, Verma DM. Flora of Sikkim (Vol. 1). Calcutta: Botanical Survey of India; 1996.

Horstman M, Wightman G. Karparti ecology: recognition of Aboriginal ecological knowledge and its application to management in northwestern Australia. Eco Management Restoration. 2001;2(2):99-109. https://doi.org/10.1046/j.1442-8903.2001.00073.x.

Hosen N, Nakamura H. Local knowledge for global actions: the role of traditional ecological knowledge in climate change adaptation. Environment-Behaviour Proceedings Journal. 2020;5(13):37-43. https://doi.org/10.21834/e-bpj.v5i13.2059.

Huntington HP. Using traditional ecological knowledge in science: methods and applications. Ecol Appl. 2000;10(5):1270-4. https://doi.org/10.1890/1051-0761(2000)010[1270:utekis]2.0.co;2.

Inouye DW. Climate change and phenology. WIREs Clim Chang. 2022;13(3):e764. https://doi.org/10.1002/wcc.764.

Iticha B, Husen A. Adaptation to climate change using indigenous weather forecasting systems in Borana pastoralists of southern Ethiopia. Clim Dev. 2019;11(7):564-73. https://doi.org/10.1080/17565529.2018.1507896.

Jackson S, O'Leary P. Indigenous interests in tropical rivers: research and management issues. Darwin: CSIRO Sustainable Ecosystems and Tropical Savannas CRC; 2006.

Jha A, Jha S, Suhag V. Ethnomedicinal plants of Lepchas of Dzongu area in Sikkim, India. Crop Research. 2004a;28:138-41.

Jha A, Rao A, Jha S, Suhag V. A preliminary survey of plants used as food by Lepchas of Dzongu area in Sikkim, India. Crop Research. 2004b;28(1/3):135-7.

Jha A, Thapa K. Reptiles and amphibians of Sikkim. Gangtok, India: WWF; 2002.

Jha V, Jha A. Ethno-ornithology of Lepchas of Sikkim. Readworthy Publications; 2012.

Kassam KA, Karamkhudoeva M, Ruelle M, Baumflek M. Medicinal plant use and health sovereignty: findings from the Tajik and Afghan Pamirs. Hum Ecol. 2010;38(6):817-29. https://doi.org/10.1007/s10745-010-9356-9.

Kassam KAS, Ruelle ML, Samimi C, Trabucco A, Xu J. Anticipating climatic variability: the potential of ecological calendars. Hum Ecol. 2018;46(2):249-57. https://doi.org/10.1007/s10745-018-9970-5.

Kidemu M, Gebreyesus M, Semere M, Worku A, Anjulo A. Traditional ecological knowledge for climate change assessment and rainfall prediction: a case of Adami Tulu Jido Kombolcha District, Oromia Region, Ethiopia. Int. J Nat Resour Ecol Manag. 2020;5(2):43-8. https://doi.org/10.11648/j.ijnrem.20200502.12.

Kijazi AL, Chang'a LB, Liwenga ET, Kanemba A, Nindi SJ. The use of indigenous knowledge in weather and climate prediction in Mahenge and Ismani wards, Tanzania. J Geogr Reg Plann. 2013;6(7):274-9. https://doi.org/10.5897/jgrp2013.0386.

Kom Z, Nicolau MD, Nenwiini SC. The use of indigenous knowledge systems practices to enhance food security in Vhembe District, South Africa. Agric Res. 2024;13(3):599-612. https://doi.org/10.1007/s40003-024-00716-8.

Langton M. Emerging environmental issues for indigenous peoples in northern Australia. In: Masini EB, editor. Quality of human resources: gender and indigenous peoples. Encyclopedia of Life Support Systems (EOLSS); 1998. p. 84.

Li J, Han F. Strong ethics and flexible actions, the properties of traditional ecological knowledge (TEK), as key resources for socioecological resilience to the impacts of climate change: a case study of Baojiatun, Yunnan-Guizhou Plateau karst area, southwest China. Ecol Soc. 2022;27(4):31. https://doi.org/10.5751/es-13400-270431.

Lu M, Lu Y, Yang Z, Cili N, Ma M. Diverse subsistence strategies related to the spatial heterogeneity of local environments in the Hengduan Mountain Region during the Bronze Age. Front Earth Sci. 2023;11:1144805. https://doi.org/10.3389/feart.2023.1144805.

Luckert MK, Campbell BM, Gorman JT, Garnett ST. Investing in indigenous natural resource management. Darwin: Charles Darwin University Press; 2007.

Ludwig D, Poliseli L. Relating traditional and academic ecological knowledge: mechanistic and holistic epistemologies across cultures. Biol Philos. 2018;33(5):43. https://doi.org/10.1007/s10539-018-9655-x.

Magoro MD. An exploration of the role of indigenous weather and climate knowledge in crop production: the case of Lepelle Nkumpi municipality in Limpopo Province [Doctoral dissertation]. Potchefstroom: North-West University; 2020.

Mantyka-Pringle CS, Jardine TD, Bradford L, Bharadwaj L, Kythreotis AP, Fresque-Baxter J, et al. Bridging science and traditional knowledge to assess cumulative impacts of stressors on ecosystem health. Environ Int. 2017;102:125-37. https://doi.org/10.1016/j.envint.2017.02.008.

Mathez-Stiefel SL. Local environmental knowledge: a key input for the sustainable development of Andean mountain communities. 2014. https://boris-portal.unibe.ch/entities/publication/51465054-0d9b-41b3-997d-eec5ba17984f. Accessed 4 May 2026.

McElwee P, Fernández-Llamazares Á, Aumeeruddy-Thomas Y, Babai D, Bates P, Galvin K, et al. Working with indigenous and local knowledge (ILK) in large-scale ecological assessments: reviewing the experience of the IPBES global assessment. J Appl Ecol. 2020;57(9):1666-76. https://doi.org/10.1111/1365-2664.13705.

McMillen H, Ticktin T, Springer HK. The future is behind us: traditional ecological knowledge and resilience over time on Hawai'i Island. Reg Environ Change. 2017;17(2):579-92. https://doi.org/10.1007/s10113-016-1032-1.

Meehan B. Wetland hunters: some reflections. In: Haynes CD, Ridpath MG, Williams MAJ, editors. Monsoonal Australia: landscape, ecology and man in the northern lowlands. Rotterdam: A.A. Balkema; 1981. p. 197-206.

Morelli F, Møller AP, Nelson E, Benedetti Y, Liang W, Šímová P, et al. The common cuckoo is an effective indicator of high bird species richness in Asia and Europe. Sci Rep. 2017;7(1):4376. https://doi.org/10.1038/s41598-017-04794-3.

Mosime B. The use of traditional weather forecasting by agro-pastoralists of different social groups in Bobirwa sub-district, Botswana [Doctoral dissertation]. Botswana: University of Cape Town; 2018.

Müller J, Mitesser O, Schaefer HM, Seibold S, Busse A, Kriegel P, et al. Soundscapes and deep learning enable tracking biodiversity recovery in tropical forests. Nat Commun. 2023;14(1):6191. https://doi.org/10.1038/s41467-023-41693-w.

Múnera-Roldán C, Roux D, Colloff M, van Kerkhoff L. Beyond calendars and maps: rethinking time and space for effective knowledge governance in protected areas. Land (Basel). 2020;9(9):293. https://doi.org/10.3390/land9090293.

Nassar PEDLC, Bello Baltazar E, Muñoz LEA, Estrada Lugo EIJ, Arce Ibarra M, Barrios LEG. Traditional knowledge in the Colombian Amazon: tensions between indigenous territorial autonomy and environmental governance. In: Arce Ibarra M, Parra Vázquez MR, Bello Baltazar E, Gomes de Araujo L, editors. Socio-environmental regimes and local visions. Cham: Springer; 2020. p. 27-47.

Neff F, Korner-Nievergelt F, Rey E, Albrecht M, Bollmann K, Cahenzli F, et al. Different roles of concurring climate and regional land-use changes in past 40 years' insect trends. Nat Commun. 2022;13(1):7611. https://doi.org/10.1038/s41467-022-35223-3.

Nkuba MR, Chanda R, Mmopelwa G, Mangheni MN, Lesolle D, Kato E. Indigenous knowledge systems and indicators of rain: evidence from Rwenzori Region, Western Uganda. Weather Clim Soc. 2020;12(2): 213-34. https://doi.org/10.1175/wcas-d-19-0027.1.

Oestreich WK, Oliver RY, Chapman MS, Go MC, McKenna MF. Listening to animal behavior to understand changing ecosystems. Trends Ecol Evol. 2024;39(10):961-73. https://doi.org/10.1016/j.tree.2024.06.007.

Ortega-Álvarez R, Casas A. Biocultural salient birds: which biological and cultural factors define them? Front Conserv Sci. 2023;4:1215967. https://doi.org/10.3389/fcosc.2023.1215967.

Parmesan C. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Glob Chang Biol. 2007;13(9):1860-72. https://doi.org/10.1111/j.1365-2486.2007.01404.x.

Pretty J. Interdisciplinary progress in approaches to address social-ecological and ecocultural systems. Envir Conserv. 2011;38(2):127-39. https://doi.org/10.1017/s0376892910000937.

Prober SM, O'Connor MH, Walsh FJ. Australian Aboriginal Peoples' seasonal knowledge: a potential basis for shared understanding in environmental management. Ecol Soc. 2011;16(2):12. https://doi.org/10.5751/es-04023-160212.

Radeny M, Desalegn A, Mubiru D, Kyazze F, Mahoo H, Recha J, et al. Indigenous knowledge for seasonal weather and climate forecasting across East Africa. Climatic Change. 2019;156(4):509-26. https://doi.org/10.1007/s10584-019-02476-9.

Retnowati A, Anantasari E, Marfai MA, Dittmann A. Environmental ethics in local knowledge responding to climate change: an understanding of seasonal traditional calendar PranotoMongso and its phenology in karst area of GunungKidul, Yogyakarta, Indonesia. Procedia Environ Sci. 2014;20:785-94. https://doi.org/10.1016/j.proenv.2014.03.095.

Reyes-García V, Fernández-Llamazares Á, Guèze M, Garcés A, Mallo M, Vila-Gómez M, et al. Local indicators of climate change: the potential contribution of local knowledge to climate research. Wiley Interdiscip Rev Clim Change. 2016;7(1):109-24. https://doi.org/10.1002/wcc.374.

Rist S, Dahdouh-Guebas F. Ethnosciences—a step towards the integration of scientific and indigenous forms of knowledge in the management of natural resources for the future. Environ Dev Sustain. 2006;8(4):467-93. https://doi.org/10.1007/s10668-006-9050-7.

Roque de Pinho J. The year people helped zebras to stand up: climatic variability and extreme weather observed and portrayed by Kenyan Maasai pastoralists. In: Welch-Devine M, Sourdril A, Burke B, editors. Changing climate, changing worlds. Cham: Springer; 2020. p. 145-81.

Rozzi R, Álvarez R, Castro V, Núñez D, Ojeda J, Tauro A, et al. Biocultural calendars across four ethnolinguistic communities in Southwestern South America. Geohealth. 2023;7(4):e2022GH000623. https://doi.org/10.1029/2022GH000623.

Ruelle ML, Skye AJ, Collins E, Kassam KS. Ecological calendars, food sovereignty, and climate adaptation in Standing Rock. Geohealth. 2022;6(12):e2022GH000621. https://doi.org/10.1029/2022GH000621.

Russell-Smith J, Lucas D, Gapindi M, Gunbunuka B, Kapirigi N, Namingum G, et al. Aboriginal resource utilization and fire management practice in Western Arnhem Land, Monsoonal Northern Australia: notes for prehistory, lessons for the future. Hum Ecol. 1997;25(2):159-95. https://doi.org/10.1023/a:1021970021670.

Ryan JC. Toward a phen(omen)ology of the seasons: the emergence of the indigenous weather knowledge project (IWKP). Environment, Space, Place. 2013;5(1):103-31. https://doi.org/10.7761/esp.5.1.103.

Sbragaglia V, Cerri J, Bolognini L, Dragićević B, Dulćić J, Grati F, et al. Local ecological knowledge of recreational fishers reveals different meridionalization dynamics of two Mediterranean subregions. Mar Ecol Prog Ser. 2020;634:147-57. https://doi.org/10.3354/meps13193.

Shoko K, Shoko N. Indigenous weather forecasting systems: a case study of the abiotic weather forecasting indicators for wards 12 and 13 in Mberengwa District Zimbabwe. Asian Social Science. 2013;9(5): 285. https://doi.org/10.5539/ass.v9n5p285.

Sinthumule NI, Mashau ML. Traditional ecological knowledge and practices for forest conservation in Thathe Vondo in Limpopo Province, South Africa. Glob Ecol Conserv. 2020;22:e00910. https://doi.org/10.1016/j.gecco.2020.e00910.

Sterling EJ, Filardi C, Toomey A, Sigouin A, Betley E, Gazit N, et al. Biocultural approaches to well-being and sustainability indicators across scales. Nat Ecol Evol. 2017;1(12):1798-806. https://doi.org/10.1038/s41559-017-0349-6.

Stowell D, Sueur J. Ecoacoustics: acoustic sensing for biodiversity monitoring at scale. Remote Sens Ecol Conserv. 2020;6(3):217-9. https://doi.org/10.1002/rse2.174.

Tengö M, Hill R, Malmer P, Raymond CM, Spierenburg M, Danielsen F, et al. Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability. Curr Opin Environ Sustain. 2017;26-27:17-25. https://doi.org/10.1016/j.cosust.2016.12.005.

Turner NJ, Reid AJ. "When the wild roses bloom": Indigenous knowledge and environmental change in Northwestern North America. Geohealth. 2022;6(11):e2022GH000612. https://doi.org/10.1029/2022GH000612.

Ullmann AL, Haag I, Bulbulshoev U. Ecological calendars of the Pamir Mountains: illustrating the importance of context-specificity for food security. Geohealth. 2022;6(12):e2022GH000610. https://doi.org/10.1029/2022GH000610.

Vedwan N. Culture, climate and the environment: local knowledge and perception of climate change among apple growers in northwestern India. Journal of Ecological Anthropology. 2006;10(1):4-18. https://doi.org/10.5038/2162-4593.10.1.1.

Vitasse Y, Ursenbacher S, Klein G, Bohnenstengel T, Chittaro Y, Delestrade A, et al. Phenological and elevational shifts of plants, animals and fungi under climate change in the European Alps. Biol Rev Camb Philos Soc. 2021;96(5):1816-35. https://doi.org/10.1111/brv.12727.

Walsh FJ. An ecological study of traditional Aboriginal use of "country": Martu in the Great and Little Sandy Deserts, Western Australia. Proceedings of the Ecological Society of Australia 1990;16:23-37.

Witharana L, Chen D, Curio J, Burman A. Traditional ecological knowledge in High Mountain Asia: a pathway to climate resilience in agriculture amidst changing climates. Adv Clim Chang Res. 2025;16(1): 167-82. https://doi.org/10.1016/j.accre.2025.01.009.

Yang H, Ranjitkar S, Zhai D, Zhong M, Goldberg SD, Salim MA, et al.

Role of traditional ecological knowledge and seasonal calendars in the context of climate change: a case study from China. Sustainability. 2019;11(12):3243. https://doi.org/10.3390/su11123243.

Zeiger J, Chankin A, Selfa T, Rolnick R, Diemont SAW. Traditional knowledge complexity and climate change resilience: a case study of natural rainfall indicators of the Lacandon Maya. Agroecol Sustain Food Syst. 2024;48(6):807-20. https://doi.org/10.1080/21683565.2024.2341248.