



Traditional Ecological Knowledge and Animal Bioindicators in Weather and Seasonal Forecasting: Evidence, Cultural Practices, and Emerging Perspectives from Maharashtra, India

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Abstract

Traditional ecological knowledge (TEK) represents cumulative, place-based knowledge developed through long-term interaction between communities and their surrounding environments. In many agrarian societies, observations of animal behaviour, plant phenology, atmospheric conditions and other environmental signals have historically been used to anticipate rainfall, seasonal transitions and short-term weather changes. This review examines the conceptual basis, documented evidence, cultural dimensions and contemporary relevance of animal bioindicators within traditional weather and seasonal forecasting, with particular attention to Maharashtra, India. The review uses an integrative narrative approach, drawing on peer-reviewed literature, Indian traditional-knowledge inventories, institutional reports and relevant scholarly sources identified through literature searching. The evidence indicates that birds, amphibians, insects and other animals have been incorporated into local forecasting systems, often in combination with wind direction, cloud appearance, plant phenology, astronomical observations and seasonal calendars. Maharashtra-specific documentation includes indigenous forecasting practices reported from Vidarbha and tribal areas, including observations of bird vocalization, ant activity and other environmental cues. These observations should not be treated as uniformly validated meteorological predictors: their interpretation is context dependent, culturally transmitted and potentially affected by ecological change, land-use change and changing climate patterns. Nevertheless, animal behaviour can provide locally available ecological information because many organisms respond to humidity, temperature, rainfall, pressure, resource availability and other environmental conditions. The review argues that traditional animal-based indicators are best understood as complementary local observations rather than substitutes for modern meteorological forecasting. Future research should combine ethnobiology, behavioural ecology, phenology, meteorology and participatory methods to test locally documented indicators while protecting community rights, knowledge sovereignty and cultural context. A carefully designed knowledge-braiding framework could improve the documentation of local environmental observations and strengthen locally relevant climate services without reducing traditional knowledge to a collection of unverified forecasting claims.

Keywords: traditional ecological knowledge; indigenous knowledge; animal bioindicators; ethnozoology; weather forecasting; rainfall prediction; seasonal forecasting; Maharashtra; monsoon; climate adaptation

1. INTRODUCTION

Weather variability has direct consequences for agriculture, livestock production, fisheries, water management and rural livelihoods in India. The southwest monsoon is particularly important because the timing, distribution and intensity of rainfall influence sowing, crop establishment, water storage and a wide range of livelihood decisions. India now possesses sophisticated meteorological observation and forecasting systems, including short- and medium-range forecasts, extended-range products and seasonal monsoon outlooks issued by the India Meteorological Department (IMD). At the same time, rural communities continue to observe local environmental signals that may be interpreted as indications of approaching rainfall or seasonal change. These practices belong to broader knowledge systems that are commonly described as traditional ecological knowledge, indigenous knowledge, local ecological knowledge or indigenous technical knowledge, depending on disciplinary and cultural context (Berkes et al., 2000; Alexander et al., 2011). Traditional ecological knowledge is not simply a collection of isolated beliefs. It can be understood as a dynamic body of observations, practices, values, ecological relationships and intergenerational learning that develops through repeated interaction with particular landscapes. Berkes et al. (2000) emphasized the role of traditional knowledge in interpreting ecological feedbacks, responding to uncertainty and supporting adaptive management. Similarly, Alexander et al. (2011) argued that indigenous and scientific knowledge systems can provide complementary information when their differences in evidence, scale, purpose and knowledge ownership are respected.

Within this broad field, animal bioindicators occupy a distinctive position. Communities may notice changes in bird calls, nesting behaviour, amphibian activity, insect emergence, ant movement, livestock behaviour or other animal activities before or around changes in weather. The scientific plausibility of some observations arises from the sensitivity of animal physiology and behaviour to environmental variables.

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Temperature, humidity, atmospheric pressure, rainfall, wind, food availability and reproductive conditions can influence activity patterns. The ethnozoological literature has therefore described animals used by communities as indicators of weather and climate, while cautioning that the meaning and reliability of individual indicators vary geographically and ecologically (Alves & Barboza, 2018).

Maharashtra provides an important context for reviewing this subject because the state contains contrasting agro-climatic regions, including the Konkan coast, the Western Ghats, the Deccan plateau and the semi-arid areas of Marathwada and Vidarbha. Rain-fed agriculture remains important in several regions, and local knowledge of rainfall has historically been incorporated into agricultural decision-making. An ICAR inventory records weather forecasting knowledge among Korku communities in Amravati district, including observations of a bird's vocal activity, ant movement, tree phenology and wind direction (ICAR, 2021). A study from Akola district also documented farmers' knowledge and adoption of indigenous weather forecasting practices and highlighted concerns about the erosion of orally transmitted knowledge under changing climatic and social conditions (Jadhav et al., 2018).

The purpose of this review is therefore not to establish the forecasting accuracy of individual animal signs in Maharashtra. Rather, it is to synthesize the available literature, clarify the conceptual and ecological basis of animal bioindicators, identify documented Maharashtra-specific evidence, examine opportunities and limitations, and propose a research framework for future validation. This distinction is important because a review based on secondary sources should not be presented as if it were a field-based ethnobiological survey.

2. REVIEW METHODOLOGY

This article adopts a narrative integrative review design. Literature was identified through scholarly searching of peer-reviewed journal articles, academic book chapters, institutional documents and Indian traditional-knowledge inventories relevant to traditional ecological knowledge, indigenous weather forecasting, rainfall prediction, animal behaviour, ethnozoology and climate adaptation. Particular attention was given to publications addressing India and Maharashtra, while international literature published was used to establish broader conceptual and methodological context.

Sources were included when they contributed at least one of the following: (i) a conceptual definition or

framework for TEK and local knowledge; (ii) documentation of traditional or indigenous weather and rainfall forecasting; (iii) evidence concerning animals or biological indicators; (iv) Maharashtra- or India-specific examples; or (v) guidance on integrating local knowledge with scientific climate services. Sources that merely repeated unsupported claims without identifiable provenance were not treated as independent evidence. The synthesis is thematic rather than statistical because the literature is heterogeneous in design, geographic scale, indicator definitions and methods of validation. A key interpretive principle of this review is to distinguish between a culturally reported indicator and a scientifically validated predictor. A community may consistently report that a particular animal behaviour precedes rain, but that observation alone does not establish causal or predictive accuracy. Accordingly, the terms 'reported', 'documented', 'interpreted as', and 'potential indicator' are used where appropriate, while stronger terms such as 'validated predictor' are reserved for evidence supported by systematic testing.

3. Traditional Ecological Knowledge and Environmental Forecasting

Traditional ecological knowledge is place based, cumulative and adaptive. It develops through observation, experimentation, memory, communication and practical decision-making. Berkes et al. (2000) described traditional knowledge systems as capable of interpreting environmental feedback and responding to ecological uncertainty. Gadgil et al. (1993) similarly emphasized the depth of ecological understanding that can arise from long-term resource use and repeated observation of local environments. These perspectives are useful for understanding weather forecasting because local forecasts are often embedded in broader ecological calendars rather than functioning as isolated meteorological rules.

Local forecasting systems may combine multiple classes of indicators. These can include atmospheric signs such as clouds, wind and humidity; astronomical signs; plant phenology; animal behaviour; soil and water conditions; and culturally transmitted seasonal calendars. Indian reviews of indigenous rainfall prediction describe both biotic and abiotic indicators and show that farmers frequently combine several observations before making a decision (Bheemappa et al., 2022; Duttarganvi et al., 2022). The use of multiple signals is important because an individual indicator may be ambiguous, whereas several coincident signals may increase confidence within the local knowledge system.

The term 'bioindicator' requires careful use. In ecology, a bioindicator can mean an organism or biological response used systematically to infer environmental conditions. In traditional forecasting, however, an animal may function as an indicator because its behaviour is culturally interpreted as a sign of an approaching event. Alves and Barboza (2018) proposed the term 'climate ethnozooinicator' for animals used

within human cultural systems to anticipate weather or climate events. This concept helps connect ethnozoology with behavioural ecology while retaining the cultural dimension of the observation.

4. Traditional Weather Forecasting in India

Traditional weather forecasting has a long history in South Asia. Historical agricultural and astronomical traditions included observations of rainfall, clouds, winds, celestial phenomena and seasonal cycles. Reviews of Indian knowledge systems describe the continuing presence of indigenous rainfall forecasting based on biological and non-biological observations (Bheemappa et al., 2022; Duttarganvi et al., 2022). Such knowledge has practical value when decisions must be made at a local scale and when formal weather information is unavailable, delayed or too spatially coarse for a particular farm or settlement.

Traditional forecasting should not be positioned in opposition to contemporary meteorology. The India Meteorological Department (IMD) provides short- and medium-range forecasts, extended-range guidance and seasonal monsoon outlooks. The appropriate research question is whether local ecological observations can add place-specific information to formal forecasts, rather than whether one knowledge system should replace the other.

5. Animal Bioindicators in Weather and Seasonal Forecasting

5.1 Birds

Birds are among the most frequently reported animal groups in traditional weather forecasting. Vocal activity, timing of calls, nesting location, migration, flocking and unusual changes in activity may be interpreted as signs of approaching rainfall or seasonal transition. Their visibility, conspicuous calls and strong seasonal responses make them particularly accessible to rural observers. The ethnozoological literature indicates that birds are widely represented among animals used as weather indicators (Alves & Barboza, 2018).

In Maharashtra, the ICAR inventory records a Korku practice from Amravati district in which intense calling of the kokila or black cuckoo at night is interpreted as an indication of rainfall on the following day (ICAR, 2021). The same inventory records bird nesting position as one component of a wider indigenous weather knowledge system in Maharashtra. These examples demonstrate that bird behaviour can have a forecasting role within a cultural knowledge system, but they should be treated as locally reported indicators rather than generalized predictors for the whole state.

5.2 Amphibians

Frogs and toads are frequently associated with rainfall in traditional ecological knowledge because their activity is strongly linked to moisture, temperature and breeding conditions. In many cultural systems, increased calling or emergence of amphibians is interpreted as a sign of

approaching rain. The relationship has an ecological basis in that many amphibians respond rapidly to changes in humidity and surface moisture. Nevertheless, the timing of calling may vary among species, habitats and seasons, so a culturally recognized association should not automatically be interpreted as a universal rainfall forecast.

5.3 Insects

Insects can provide conspicuous environmental signals because many species respond rapidly to humidity, temperature, wind and rainfall. Ant movement, emergence of winged forms, termite activity, dragonfly abundance and other insect phenomena have been reported in indigenous forecasting systems. The ICAR inventory documents a Korku practice in Amravati in which rapid ant movement is interpreted as indicating rain within a short period (ICAR, 2021). Indian reviews similarly identify insects among biotic indicators used in traditional rainfall prediction (Bheemappa et al., 2022; Duttarganvi et al., 2022).

From a behavioural-ecology perspective, insect

responses may sometimes provide mechanistic clues. Changes in humidity can affect flight, foraging and emergence, while rainfall changes soil conditions and resource availability. However, the same environmental response may be influenced by several variables simultaneously. Consequently, the observed association between an insect event and rainfall requires local validation before it can be treated as a forecasting rule.

5.4 Mammals and livestock

Mammals and domestic animals also appear in local weather knowledge, although their indicators are often less standardized than those involving birds or insects. Changes in feeding, resting, movement, vocalization or shelter-seeking behaviour may be interpreted as signs of environmental change. Ethnozoological studies show that communities can hold detailed knowledge of animal behaviour and use it for a variety of purposes, including omen interpretation and weather forecasting (Baral & Dahal, 2010). For scientific investigation, livestock observations may be particularly valuable because animals are observed repeatedly by farmers and herders, allowing long-term local records to be reconstructed.

Table 1. Major categories of animal-associated weather indicators reported in the literature

Animal group	Observed cue	Commonly interpreted signal	Evidence interpretation	Key sources
Birds	Calls, nesting, flocking, migration, unusual activity	Rainfall onset, seasonal transition	Documented widely; Maharashtra examples recorded in ICAR inventory	Alves & Barboza, 2018; ICAR, 2021
Amphibians	Calling, emergence, movement toward wet habitats	Rainfall or increased moisture	Ecologically plausible but strongly species- and habitat-dependent	Alves & Barboza, 2018
Insects	Ant movement, emergence, swarming, dragonfly activity	Short-term rain or seasonal change	Reported in India; local validation required	Bheemappa et al., 2022; ICAR, 2021
Mammals/livestock	Movement, vocalization, feeding/resting changes	Weather disturbance or seasonal change	Less standardized; often embedded in broader local observation systems	Baral & Dahal, 2010; Alves & Barboza, 2018

6. Evidence and Cultural Practices in Maharashtra

The Maharashtra evidence base indicates that indigenous weather forecasting has been documented in several parts of the state, especially among farming and tribal communities. The strongest directly relevant source located for this review is the ICAR Inventory of Indigenous Technical Knowledge in Agriculture, which includes a weather-forecasting entry from Korku communities in Amravati district. The inventory records several signs interpreted in relation to rainfall, including profuse leafing of salai, intense night calling of the kokila or black cuckoo, continuous wind from south to north, particular cloud patterns, rapid ant movement and a sound associated with ant hills (ICAR, 2021). Because the inventory records these observations as indigenous knowledge rather than as meteorological experiments, the entries should be read as documentation of community knowledge. A separate study conducted in Akot Panchayat Samiti, Akola district, investigated farmers' knowledge and adoption of indigenous weather

forecasting practices and highlighted the vulnerability of orally transmitted knowledge to social and climatic change (Jadhav et al., 2018). This is particularly relevant to Maharashtra because the state's agricultural environments are heterogeneous and local forecasting knowledge is likely to be adapted to specific landscapes. An indicator that is meaningful in a semi-arid interior district may not have the same ecological relationship in the humid Konkan region or in the higher-rainfall Western Ghats.

The Maharashtra literature therefore supports three cautious conclusions. First, animal and other biological observations form part of documented local forecasting systems. Second, such observations are commonly combined with non-biological indicators rather than used in isolation. Third, the existing literature is much stronger in documenting knowledge than in quantitatively validating predictive accuracy. This distinction represents an important research gap and should be central to future studies.

7. Ecological and Behavioural Basis of Animal Indicators

Animals are not weather instruments in the technological sense, but their behaviour is shaped by environmental variables. Temperature affects metabolic rate and activity; humidity influences water balance and the performance of many ectotherms; rainfall changes food availability and habitat conditions; atmospheric pressure and wind can influence flight and movement; and seasonal photoperiod interacts with temperature and resource availability to regulate reproduction and migration. These responses can create observable behavioural patterns that communities learn to associate with weather events (Alves & Barboza, 2018).

The ecological mechanism, however, is not equivalent to predictive accuracy. An animal may respond to a change that occurs shortly before rainfall without that response being sufficiently consistent to forecast rainfall across seasons. For example, insect emergence may be influenced by soil moisture as well as temperature, while bird vocalization may respond to breeding condition, territoriality, food availability or social interactions. A scientifically meaningful validation study must therefore record the indicator and the target weather variable simultaneously and account for alternative environmental explanations.

The concept of phenology is useful in this context. Phenological observations concern recurring biological events and their timing relative to environmental conditions. Ecological calendars can integrate such observations into a broader seasonal framework, allowing communities to connect animal and plant events with expected periods of rainfall, agricultural activity and resource availability (Meadows et al., 2019). This suggests that animal bioindicators may be more informative when treated as components of multi-indicator ecological calendars rather than as isolated forecasting devices.

8. Evidence, Reliability and Scientific Validation

The literature reveals a substantial difference between documentation and validation. Many studies document what farmers or local knowledge holders report, but relatively few compare those indicators prospectively against standardized meteorological observations over multiple years. Bheemappa et al. (2022) explicitly noted that traditional rainfall-prediction knowledge is often based on accumulated experience and oral transmission, while much of the available documentation lacks scientific validation. Duttarganvi et al. (2022) likewise emphasized the relevance of indigenous weather knowledge while identifying opportunities for improving its use and documentation.

A robust validation framework should include a clearly defined indicator, a measurable outcome, a specified lead time, repeated observations and a pre-established statistical test. For example, if an animal behaviour is said to predict rain within 24 hours, researchers should record the occurrence and non-occurrence of the behaviour daily and compare it with objectively measured rainfall. Sensitivity, specificity, positive predictive value, false-alarm rate and lead time can then be estimated. Where an indicator is intended to forecast seasonal onset rather than individual rainfall events, a different design is required, using long-term phenological and meteorological series.

Reliability should also be considered at multiple levels. Ecological reliability concerns whether the animal response is consistently associated with a measurable environmental change. Cultural reliability concerns whether knowledge holders consistently interpret the signal in the same way. Operational reliability concerns whether the observation is sufficiently conspicuous and timely to support a decision. These dimensions should not be conflated.

Table 2. Suggested framework for evaluating traditional animal-based weather indicators

Evaluation component	Recommended approach	Reason
Indicator definition	Precisely define species/group, behaviour, intensity and timing	Avoid vague descriptions such as 'unusual activity'
Target event	Define rainfall amount, onset, storm, dry spell or seasonal transition	The forecast target must be measurable
Lead time	Record expected interval between indicator and event	Use fixed categories such as 6, 12, 24 or 48 h where appropriate
Replication	Observe across sites, seasons and years	Single-season observations are insufficient
Meteorological comparison	Pair observations with rain gauges and relevant weather variables	Use objective measurements
Statistical validation	Estimate accuracy and uncertainty	Include false alarms and missed events
Local interpretation	Document who observes, interprets and acts on the indicator	Retain cultural context
Climate-change sensitivity	Test whether the indicator-event relationship changes over time	Avoid assuming historical relationships remain stationary

9. Integrating Traditional Knowledge with Modern Climate Services

The appropriate relationship between traditional ecological knowledge and scientific meteorology is one of complementarity and knowledge co-production rather than simple substitution. The IPCC (2022) recognizes

that Indigenous and local knowledge can enrich understanding of climate risks and adaptation, while emphasizing the importance of context, participation and recognition.

For Maharashtra, a practical model would combine community observations with IMD weather

information. A local forecasting project could maintain a community ecological calendar in which animal activity, plant phenology, wind direction and other locally recognized indicators are recorded alongside rainfall, temperature, humidity and official forecasts. The objective would not be to prove or disprove cultural knowledge in a single experiment, but to identify which observations have reproducible environmental associations and under what conditions.

Such a system could be particularly relevant to agricultural advisory services. Farmers make decisions at field and village scales, whereas many formal forecasts are communicated at larger spatial scales. Local ecological observations may provide information about micro-environmental conditions or very short-term changes that are difficult to represent in broad forecasts. Conversely, meteorological forecasts provide information beyond the immediate local environment and can supply quantitative estimates and uncertainty ranges. A hybrid system could therefore use each knowledge source for the scale at which it is most informative.

10. Climate Change, Knowledge Erosion and Changing Indicator Reliability

Climate change introduces an important complication: the environmental relationships on which traditional indicators are based may themselves be changing. Altered rainfall timing, temperature regimes, land-use change, habitat fragmentation and declining biodiversity can change animal behaviour and seasonal phenology. Consequently, an indicator that historically coincided with a rainfall event may become less reliable if the ecological mechanism or seasonal context changes.

At the same time, TEK can contribute to climate adaptation because it contains long-term place-based observations that may capture environmental changes not represented in short instrumental records. Research from India and other regions demonstrates that local communities observe changes in seasonality, species behaviour and resource availability and may adapt practices accordingly (Ingty, 2017; Parmentier et al., 2018). The challenge is to preserve the observational record while also testing whether historical interpretations remain appropriate under current climate conditions.

Knowledge erosion is another concern. Oral transmission can weaken when younger generations leave farming communities, when local languages and practices decline, or when environmental changes reduce opportunities to observe the species involved. The Akola study illustrates concern about the loss of indigenous forecasting knowledge through disruption of traditional communication channels (Jadhav et al., 2018). Documentation should therefore be undertaken with community participation and should respect intellectual and cultural ownership rather than extracting knowledge solely for external scientific use.

11. Ethical and Epistemological Considerations

Research on traditional ecological knowledge requires more than technical validation. Knowledge is embedded in social relationships, language, customary practice and community identity. Researchers should therefore avoid presenting community observations as anonymous raw data when the source communities can and should be acknowledged. Knowledge holders should be involved in decisions about what is recorded, how it is interpreted and how findings are disseminated.

A second consideration concerns epistemological pluralism. Indigenous and local knowledge should not be treated merely as an incomplete version of Western science waiting for validation. Contemporary scholarship emphasizes that knowledge systems may have different purposes, methods of transmission and criteria of usefulness (Alexander et al., 2011; IPCC, 2022). Scientific validation can be valuable for a specific forecasting claim, but it does not determine the cultural value of the knowledge system as a whole.

Finally, researchers should distinguish between empirical ecological observations and symbolic or spiritual interpretations. Both may be culturally important, but they represent different kinds of claims. A review article should describe these dimensions accurately without either dismissing cultural meanings or presenting symbolic interpretations as experimentally established meteorological mechanisms.

12. Research Gaps and Future Directions

The literature points to several priorities for future work in Maharashtra. First, there is a need for district-level inventories of animal-associated weather indicators, especially in rain-fed agricultural and tribal regions. Second, species identification should be standardized because local names can refer to different species in different linguistic regions. Third, prospective monitoring should replace retrospective recollection wherever possible. Fourth, animal observations should be paired with meteorological measurements to distinguish genuine environmental responses from coincidental associations.

Future studies should also examine seasonal and spatial variation. Maharashtra's environmental heterogeneity makes it unlikely that a single indicator will perform uniformly across the state. Comparative studies between Vidarbha, Marathwada, the Deccan plateau, Western Ghats and Konkan could determine whether the same animal response has similar predictive meaning in different climatic contexts.

Modern technologies could strengthen documentation without replacing community observation. Mobile applications, georeferenced photographs, acoustic recording, automated weather stations, camera traps and citizen-science platforms could create synchronized datasets of animal behaviour and meteorological conditions. Machine-learning approaches may eventually identify combinations of indicators associated with rainfall events, but such approaches

should be used transparently and should not obscure the cultural provenance of the underlying observations. A final priority is the development of community-owned ecological calendars. Such calendars could record locally meaningful animal, plant and atmospheric observations alongside instrumental measurements and official forecasts. The resulting system would preserve traditional knowledge while enabling empirical evaluation and potentially supporting locally relevant agricultural advisories.

13. Synthesis and Implications for Maharashtra

The reviewed evidence indicates that animal behaviour forms a meaningful component of traditional ecological forecasting in India and is specifically documented in Maharashtra. Bird calls, bird nesting, ant movement and other biological observations occur within broader systems that also consider plants, winds, clouds and seasonal timing. The strongest regional evidence currently available is documentary rather than experimental: the literature establishes that communities use and transmit these observations, but it does not justify a blanket claim that particular animal signs reliably predict rainfall across Maharashtra.

This distinction strengthens rather than weakens the case for research. Traditional ecological knowledge offers hypotheses about locally observable relationships between biological behaviour and environmental change. Behavioural ecology and meteorology provide tools for testing those hypotheses. Ethnobiology provides the methods for understanding how the indicators are named, remembered, interpreted and used in decisions. Together, these disciplines can produce a more complete understanding than any one perspective alone.

14. CONCLUSION

Traditional ecological knowledge provides a valuable record of how communities observe and interpret environmental change. Within this knowledge system, animals can function as culturally recognized bioindicators of rainfall, seasonal transition and short-term weather change. The evidence reviewed here shows that such practices are documented across India and have clear regional representation in Maharashtra, including indigenous forecasting knowledge recorded among communities in Amravati and farmer knowledge documented in Akola.

The review also demonstrates that documentation should not be confused with scientific validation. Animal behaviour is influenced by multiple environmental and biological variables, and the reliability of an indicator is likely to depend on species, habitat, season and local ecological conditions. Consequently, future research in Maharashtra should use prospective, replicated and participatory designs that combine ethnobiological documentation with meteorological measurements.

Rather than replacing modern meteorological services, traditional animal-based observations may be most useful as complementary local ecological information. A respectful approach that brings community knowledge into dialogue with scientific research could help preserve cultural knowledge, generate testable ecological hypotheses and improve the local relevance of climate-risk information. Such an approach is consistent with the broader scientific recognition that Indigenous and local knowledge can contribute to climate adaptation when it is treated as context-specific knowledge and when communities retain an active role in its interpretation and use.

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