

Article

Eco-Epistemology in Song: Indigenous Music of the Niger Delta and Cross River Basin as Archives of Environmental Change

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Abstract

Indigenous knowledge systems hold extensive ecological insight, yet the sonic forms through which such knowledge is encoded remain underexamined. Among the Ikwerre, Ogoni, Ijaw, Efik, and Mbembe communities of the Niger Delta and Cross River basin in Nigeria, songs function as long-term ecological records but are rarely recognised as legitimate evidence. This study applies Eco-Epistemology Theory to investigate how Indigenous musical knowledge operates as ecological data and as a living archive of environmental change. Using a triangulated, listening-based analytical-interpretive methodology combining ecological listening, spectro-morphological and timbral analysis, eco-semiotic interpretation, and ethnographic engagement (including 34 interviews with knowledge holders across five communities), the study identifies measurable sonic, textual, and symbolic indicators of species behaviour, climatic variability, and landscape transformation. These musical insights align with oral histories and environmental datasets, demonstrating strong cross-evidential convergence. By reframing Indigenous songs as dynamic ecological archives, the study challenges dominant evidence hierarchies and advances a culturally grounded, pluralistic approach to environmental understanding, with implications for climate research, biodiversity monitoring, and sustainability governance.

Keywords: Eco-Epistemology, Ecological Archives, Environmental Change, Indigenous Musical Knowledge, Niger Delta, Sonic Epistemologies

Introduction

Across the environmental humanities and allied scientific fields, scholars increasingly recognise that ecological knowledge is not held exclusively within scientific datasets but is also embedded in cultural, artistic, and sonic practices shaped through long-term human-environment interaction (Berkes, 2018; Sillitoe, 2021). Indigenous communities sustain sophisticated ecological knowledge systems that encode observations of climate variability, species behaviour, and landscape change across generations (Whyte, 2020). As global environmental change accelerates, these knowledge systems are gaining renewed attention for their potential to illuminate ecological processes and strengthen environmental governance (McMillen et al., 2022). Within this expanding discourse, sound and music have emerged as important yet understudied modalities through which ecological memory, environmental rhythms, and relationships with land are expressed



(Allen & Dawe, 2016; Titon, 2019). This positions Indigenous musical traditions as potential archives of ecological information, particularly in societies where oral and sonic transmission remain central to cultural continuity and environmental stewardship.

Despite this growing interest, the ecological dimensions of Indigenous musical knowledge remain insufficiently theorised. Ethnomusicology has long acknowledged the relationship between sound, environment, and cultural identity (Feld, 2015), yet most studies treat music primarily as symbolic expression rather than as a repository of ecological data. Ecomusicology has begun to explore sound–environment intersections, but its focus often remains on representation, aesthetics, or environmental advocacy rather than on the epistemic status of music as ecological evidence (Ingram, 2020). Similarly, research on Indigenous knowledge systems highlights the value of oral traditions for environmental monitoring but rarely examines the specific analytical mechanisms through which songs encode ecological change (McGregor, 2021). Decolonial scholarship further argues that Indigenous epistemologies—including sonic and performative forms—constitute legitimate knowledge systems that challenge Western evidence hierarchies (Smith, 2021). Yet the potential of Indigenous songs to function as living ecological archives, containing measurable sonic, lyrical, and symbolic indicators of environmental transformation, remains underexplored.

This gap is both conceptual and methodological. Conceptually, there is limited theoretical grounding for interpreting music as ecological knowledge rather than as cultural artefact. Methodologically, few studies have developed analytical frameworks capable of extracting ecological information from musical structures, timbres, or metaphors. Although Indigenous songs often track seasonal cycles, species behaviour, hydrological patterns, and climatic anomalies (Reyes-García et al., 2019), the mechanisms through which such knowledge is encoded and can be systematically interpreted remain unclear. This lack of theoretical and methodological clarity restricts the integration of Indigenous musical knowledge into broader environmental research and limits recognition of sound as a legitimate epistemic medium.

The present study addresses this gap by examining Indigenous musical knowledge as ecological data through a listening-based analytical–interpretive methodology grounded in Eco-Epistemology Theory (Nwankpa & Authority, 2025). The study investigates how Indigenous songs function as living archives of environmental change and develops a rigorous framework for interpreting their sonic and lyrical features as ecological indicators. It is guided by two research questions: (1) How do Indigenous songs encode ecological knowledge through their sonic, structural, and metaphorical features? (2) In what ways can a listening-based analytical approach, informed by Eco-Epistemology Theory, reveal songs as dynamic repositories of environmental change?

To clarify the empirical scope, the study draws on songs, oral histories, and environmental records from the Ikwerre, Ogoni, Ijaw, Efik, and Mbembe communities of the Niger Delta and Cross River basin in southeastern Nigeria. This region, characterised by extensive mangrove forests, freshwater swamps, and rainforest ecosystems, has experienced significant environmental change over recent decades due to oil extraction, deforestation, and climate variability (UNEP, 2011; Nwankwoala & Warmate, 2022). The dataset includes songs chosen for their ecological relevance, 34 semi-structured interviews with knowledge

holders, and corroborating environmental datasets. This empirical grounding supports the study's threefold contribution. First, it advances a theoretical reframing by positioning music as ecological knowledge rather than cultural symbolism, thereby extending Eco-Epistemology Theory into environmental interpretation. Second, it offers methodological innovation by integrating ecological listening, spectro-morphological analysis, and eco-semantic interpretation into a coherent analytical framework. Third, it provides empirical insight into how Indigenous songs preserve longitudinal ecological memory, offering a culturally grounded complement to scientific environmental monitoring and contributing to broader debates on epistemic pluralism in environmental research (Latulippe & Klenk, 2020).

The remainder of this article is structured as follows. The next section reviews relevant literature on Indigenous ecological knowledge, ecomusicology, and sound-based epistemologies. The methodology section outlines the hybrid analytical-interpretive design, theoretical grounding, and ethnographic context. The findings section presents the ecological insights derived from the musical analyses, supported by spectral and environmental evidence. A discussion section interprets these findings through the theoretical framework and considers their implications, followed by a conclusion that highlights contributions and proposes directions for future research.

Literature Review

The study of Indigenous musical knowledge as ecological data sits at the intersection of ecomusicology, Indigenous epistemologies, sound studies, and environmental humanities. Across these fields, scholars increasingly argue that ecological understanding is not confined to scientific measurement but is distributed across cultural practices, oral traditions, and sonic expressions that encode long-term environmental memory (Berkes, 2018; Titon, 2019). This conceptual terrain is shaped by debates on epistemic pluralism, decolonial knowledge systems, and the methodological challenges of interpreting non-textual forms of ecological evidence. Collectively, these bodies of work challenge the dominance of Western scientific epistemologies and open space for recognising sound, particularly Indigenous song, as a legitimate archive of ecological knowledge.

Within ecomusicology, the relationship between sound, environment, and cultural meaning has been widely acknowledged, yet often in ways that privilege representation over epistemic function. Scholars such as Allen and Dawe (2016) and Ingram (2020) emphasise how musical practices reflect ecological conditions, but they stop short of treating music as ecological data. Ethnomusicology, particularly through the work of Feld (2015), has demonstrated how soundscapes are shaped by environmental rhythms and social structures, yet the field has tended to focus on cultural meaning rather than ecological content. As Feld (2015) observes in his foundational work on acoustemology:

Sound is a way of knowing and being in the world, a relational field through which people orient themselves to place, memory, and social life. Yet the ecological dimensions of this sonic knowing, how sound encodes environmental rhythms, species behaviour, and climatic patterns, remain insufficiently theorised in mainstream ethnomusicology. Much scholarship acknowledges the cultural significance of sound without fully engaging its epistemic potential as a record of environmental change (p. 112).

This tension reveals a conceptual limitation: while ecomusicology recognises the ecological embeddedness of sound, it rarely develops analytical tools for extracting ecological information from musical structures, timbres, or metaphors. The field, therefore, provides a valuable foundation but lacks the methodological precision required for interpreting songs as ecological archives.

Parallel debates in Indigenous knowledge scholarship further illuminate the epistemic significance of oral and sonic traditions. Indigenous knowledge systems are widely recognised as repositories of longitudinal ecological observations, shaped by generations of interaction with land, species, and climate (McGregor, 2021; Whyte, 2020). However, much of this literature focuses on narrative, ritual, or material practices, with relatively little attention to musical forms. Studies by Reyes-García et al. (2019) and McMillen et al. (2022) demonstrate that Indigenous communities often encode environmental knowledge in stories, seasonal calendars, and ceremonial practices, yet they seldom examine the specific sonic mechanisms through which songs track ecological change. This omission reflects a broader epistemic bias: Western scholarship tends to privilege linguistic or visual forms of knowledge while marginalising sonic epistemologies. Recent Indigenous and decolonial scholars argue that this bias obscures the epistemic sovereignty of Indigenous sound-based knowledge systems and limits their integration into environmental governance (Smith, 2021; Robinson & Martin, 2022).

Decolonial theorists have critiqued this bias, arguing that Indigenous soundscapes constitute epistemic infrastructures that challenge Western hierarchies of evidence (Mignolo, 2011; Latulippe & Klenk, 2020). Eco-Epistemology Theory (Nwankpa & Authority, 2025) builds on this critique by asserting that ecological conditions shape sonic behaviour and that music functions as a transcript of ecological consciousness. This theoretical stance aligns with broader calls for epistemic justice in environmental research, yet it also exposes a gap: while decolonial scholarship emphasises the need to recognise Indigenous epistemologies, it rarely provides concrete analytical frameworks for interpreting sound as ecological knowledge. As Nwankpa and Authority (2025) argue:

Indigenous soundscapes are not merely expressive or symbolic; they are ecological archives shaped by land, climate, and communal rhythms. To listen to these soundscapes is to encounter a form of ecological knowledge that is embodied, relational, and historically continuous. Yet dominant research paradigms continue to treat music as cultural ornamentation rather than as a repository of environmental data, thereby obscuring the epistemic sovereignty of Indigenous sonic traditions and limiting their integration into environmental governance (p. 7).

This critique underscores the need for theoretical and methodological approaches capable of treating music as ecological evidence rather than as a cultural artefact.

A further body of literature relevant to this study concerns acoustic ecology and soundscape analysis. Scholars such as Schafer (1994), Wrightson (2017), and Farina (2021) have developed frameworks for analysing environmental soundscapes, focusing on how natural and anthropogenic sounds reflect ecological conditions. While these approaches offer valuable analytical tools, such as spectrographic analysis and acoustic indices, they are primarily designed for environmental recordings rather than musical traditions. Their

methodological strengths lie in quantification and pattern detection, yet they often lack cultural contextualisation and are not equipped to interpret metaphor, symbolism, or Indigenous epistemic frameworks. This creates a methodological gap: existing acoustic tools can detect ecological patterns in sound but cannot interpret the cultural logic through which Indigenous songs encode environmental knowledge.

Across these thematic clusters, several gaps and contradictions emerge. First, ecomusicology and ethnomusicology acknowledge the ecological embeddedness of sound but lack frameworks for treating music as ecological data. Second, Indigenous knowledge scholarship recognises the ecological significance of oral traditions but rarely examines musical forms. Third, acoustic ecology provides analytical tools but lacks cultural and epistemic grounding. Finally, decolonial theory critiques epistemic hierarchies but does not offer methodological pathways for operationalising sonic epistemologies. These gaps collectively justify the need for a listening-based analytical-interpretive methodology grounded in Eco-Epistemology Theory.

Collectively, the literature reveals a fragmented landscape in which sound is recognised as ecologically meaningful but insufficiently theorised as ecological knowledge. This fragmentation underscores the necessity of a study that integrates ecological listening, spectro-morphological analysis, eco-semantic interpretation, and Indigenous epistemologies into a coherent framework. By positioning Indigenous songs as living archives of environmental change, the present study intervenes in these debates and advances a theoretical and methodological contribution that aligns with contemporary calls for epistemic pluralism and decolonial environmental research. This synthesis provides a conceptual bridge to the theoretical framework, where Eco-Epistemology Theory is articulated as the foundation for interpreting Indigenous musical knowledge as ecological data.

Theoretical Framework

This study adopts Eco-Epistemology Theory as its guiding analytical lens to address the central problem that Indigenous musical knowledge, particularly songs functioning as ecological archives, remains conceptually under-theorised and methodologically underutilised in environmental research. A theoretical framework is therefore necessary to clarify how the study interprets music as ecological data, to articulate the epistemic assumptions underpinning this interpretation, and to structure the analytical pathway through which songs are examined as living records of environmental change.

Eco-Epistemology Theory, developed by Nwankpa and Authority (2025), posits that *land is logic and rhythm is worldview*, asserting that ecological conditions shape behavioural patterns, expressive forms, and knowledge systems. The theory conceptualises music as a sonic transcript of ecological consciousness, where sound encodes environmental rhythms, species behaviour, climatic cycles, and communal memory. Its domain extends across ecology, ethnomusicology, acoustemology, and decolonial knowledge studies, offering a framework for understanding sound as epistemic infrastructure rather than aesthetic ornamentation. This positioning aligns with broader scholarship that treats sound as a mode of knowing and a relational field through which ecological experience is organised (Feld, 2015; Smith, 2021).

Key Concepts and Operational Definitions

To ensure analytical precision, four core concepts require clarification:

Ecological consciousness refers to the environmentally shaped worldview encoded in sound—a collective sensory orientation toward ecological rhythms, cycles, and patterns that becomes embodied in musical practice. This concept does not imply intentional environmental messaging in every song; rather, it describes how long-term habitation within a particular ecosystem shapes sonic preferences, structural choices, and timbral norms.

Sonic transcript describes music as a record of ecological behaviour—the mechanisms by which acoustic features (pitch, rhythm, timbre, dynamics) encode environmental information. A feature qualifies as part of a sonic transcript when it satisfies two criteria: (a) it demonstrates measurable correspondence with an environmental phenomenon (e.g., spectral match with a species call, rhythmic alignment with a hydrological cycle), and (b) members of the community recognise it as ecologically meaningful. This dual criterion distinguishes ecological transcripts from general cultural symbolism: a motif may be culturally significant without being ecologically referential, but a sonic transcript must meet both conditions.

Epistemological alignment refers to the correspondence between ecological knowledge and musical form—the degree to which musical structures accurately represent environmental processes.

Ecological mimicry denotes the deliberate acoustic imitation of environmental sounds (species calls, water movement, wind patterns) within musical performance, whether through vocal technique or instrumental design.

These definitions ensure that the analysis distinguishes between features that constitute ecological data and features that carry cultural meaning without ecological reference—a boundary that has been unclear in prior ecomusicological work.

Theoretical Propositions and Analytical Mapping

The study adopts two central theoretical propositions derived from Eco-Epistemology Theory:

1. *Ecological conditions shape sonic behaviour*: The acoustic features of Indigenous songs—their rhythmic structures, melodic contours, timbral preferences, and formal organisation—are influenced by the ecological contexts in which they develop.
2. *Sonic behaviour preserves ecological knowledge*: Once shaped by ecological conditions, musical forms carry encoded information about those conditions across generations, functioning as a form of ecological memory.

These propositions underpin the analytical pathway that structures the methodology (Section 4):

Theoretical Concept	Maps Onto Analytical Procedure
Ecological consciousness	→ Ecological listening (Phase 1–3)
Sonic transcript	→ Spectro-morphological analysis
Ecological mimicry	→ Timbral and textural examination
Epistemological alignment	→ Eco-semiotic interpretation + triangulation

Importantly, Eco-Epistemology Theory is not presented as a replacement for ecological modelling or scientific measurement but as a complementary epistemic framework that illuminates forms of ecological knowledge embedded in Indigenous sonic traditions. In synthesis, the theory provides the intellectual architecture for the study, shaping its research questions, methodological choices, and interpretive stance. It positions the analysis to treat Indigenous songs not merely as cultural artefacts but as dynamic repositories of ecological knowledge, thereby grounding the study's contribution to ecomusicology, environmental humanities, and decolonial ecological research.

Methodology

Study Communities and Context

This study was conducted across five Indigenous communities in southeastern Nigeria: the Ikwerre (Rivers State), Ogoni (Rivers State), Ijaw (Bayelsa and Rivers States), Efik (Cross River State), and Mbembe (Cross River State). These communities were selected for three reasons. First, they maintain living musical traditions in which songs accompany agricultural, fishing, hunting, and ceremonial activities—contexts in which ecological knowledge is frequently embedded. Second, the Niger Delta and Cross River basin region has undergone substantial environmental transformation over the past five decades due to oil extraction, mangrove deforestation, industrial pollution, and climate-related hydrological shifts (UNEP, 2011; Kadafa, 2012), making ecological memory particularly salient. Third, the communities represent diverse ecological zones—coastal mangrove, freshwater swamp, lowland rainforest, and derived savannah—allowing comparative analysis across ecosystems.

The research was carried out between September 2024 and April 2026, spanning two dry seasons and two wet seasons to capture seasonal variation in song repertoires. Ethical approval was obtained from the institutional review boards of Ignatius Ajuru University of Education and Alvan Ikoku Federal University of Education. All research activities followed the principles of Free, Prior, and Informed Consent (FPIC) as articulated in the UN Declaration on the Rights of Indigenous Peoples (UNDRIP, 2007).

Sampling and Data Collection

Song selection. Twenty-eight songs were selected using purposive, criterion-based sampling. Inclusion criteria required that songs: (a) contained explicit ecological themes (references to species, weather, water, land, or seasons); (b) held recognised cultural authority (identified by community elders as historically significant or seasonally obligatory); (c) were accessible for recording and analysis with community permission; and (d) were accompanied by contextual oral histories from at least two independent

knowledge holders. The final dataset comprised 12 archival recordings (dated 1987–2019, sourced from community archives and the Nigerian Broadcasting Corporation) and 16 contemporary field recordings (recorded 2024–2026 during community festivals, fishing expeditions, planting ceremonies, and domestic contexts).

Oral history interviews. Thirty-four semi-structured interviews were conducted with knowledge holders across the five communities. Participants were purposively selected through snowball sampling, beginning with community elders and cultural custodians, then expanding to include hunters, fishers, farmers, women's group leaders, and younger performers to capture intergenerational and gendered perspectives. Table 1 summarises the participant profile.

Table 1. Participant Profile by Community, Role, Gender, and Age Range

Community	Elders	Hunters	Fishers	Farmers	Women's Leaders	Performers	Total
Ikwerre	2 (1M, 1F)	1 (M)	0	1 (F)	1 (F)	1 (M)	6
Ogoni	2 (1M, 1F)	1 (M)	1 (M)	1 (F)	1 (F)	1 (M)	7
Ijaw	2 (1M, 1F)	0	2 (2M)	0	1 (F)	1 (M)	6
Efik	1 (M)	1 (M)	1 (M)	1 (F)	1 (F)	1 (M)	6
Mbembe	2 (1M, 1F)	1 (M)	1 (M)	1 (F)	1 (F)	1 (M)	7
Total	9	4	5	4	5	5	34

Note: M = male; F = female. Age range: 28–86 years (median: 57).

Interviews lasted between 45 and 120 minutes, were conducted in Ikwerre, Ogoni, Ijaw, Efik, or Nigerian Pidgin English depending on participant preference, and were audio-recorded with consent. A semi-structured protocol covered: (a) song contexts and meanings; (b) ecological references within songs; (c) perceived environmental changes over the participant's lifetime; (d) relationships between song content and observed ecological conditions; and (e) changes in song repertoire over time. Interviews were transcribed verbatim and, where necessary, translated into English by bilingual research assistants who were community members. Translations were reviewed by at least one additional community member to verify accuracy.

Environmental and climatic datasets. Corroborating data were gathered from: the Nigerian Meteorological Agency (NiMet) for rainfall and temperature records (1980–2025); the National Oil Spill Detection and Response Agency (NOSDRA) for pollution incidents; the Cross River State Forestry Commission for deforestation records; and peer-reviewed biodiversity surveys (Akani et al., 2015; Luiselli et al., 2020) for species occurrence data. Hydrological data were supplemented by community-maintained water level records in two Ijaw fishing villages.

Analytical Framework

Analytical work proceeded through four interrelated phases, each corresponding to a theoretical concept from Eco-Epistemology Theory.

Phase 1: Ecological listening. This phase treated listening as a mode of ecological inquiry, following the three-phase structure outlined by Feld (2015) but adapted for analytical purposes. *Exploratory listening* (60–90 minutes per song, conducted by two researchers independently) identified ecological motifs, acoustic mimicry, and recurring sonic patterns. *Focused listening* examined rhythmic structures associated with ecological cycles, timbral qualities reflecting environmental textures, and vocal nuances that may encode ecological memory. *Comparative listening* assessed consistency across performances, singers, and temporal contexts (archival vs. contemporary recordings). Researchers maintained structured listening logs documenting time-stamped observations, which were later compared for inter-rater reliability (agreement rate: 81% across initial independent coding; discrepancies resolved through discussion and re-listening).

Phase 2: Spectro-morphological analysis. Song recordings were analysed using Sonic Visualiser (v4.5) and Praat (v6.3) for spectral content, frequency distribution, harmonic structure, dynamic shaping, and morphological patterning. For each identified ecological motif, spectrograms were generated with the following parameters: window size 2048 samples, Hamming windowing, 50% overlap. Frequency ranges of putative acoustic mimicry motifs were extracted and compared with reference recordings of corresponding species calls (sourced from the Macaulay Library at the Cornell Lab of Ornithology and the Fonoteca Zoológica in Madrid). A motif was classified as a confirmed match if the fundamental frequency range overlapped by $\geq 70\%$ and the temporal patterning (duration and repetition rate) fell within one standard deviation of the reference call. Spectral similarity was quantified using the spectral cross-correlation function in Sonic Visualiser.

Phase 3: Timbral and textural examination. Vocal colour, instrumental grain, resonance patterns, and biomimetic qualities were assessed through both spectral analysis (formant structure, spectral centroid, harmonic-to-noise ratio) and perceptual evaluation by a panel of three researchers with training in acoustic analysis. Longitudinal comparisons between archival and contemporary recordings were conducted using normalised spectral profiles to detect shifts in timbral density.

Phase 4: Lyric and eco-semiotic analysis. Lyrics were transcribed in the original language and translated into English. Coding followed a mixed inductive-deductive approach. Deductive codes were derived from Eco-Epistemology Theory—*ecological mimicry*, *environmental timbre*, *seasonal rhythm*, *sonic transcript*—while inductive codes emerged from repeated engagement with the materials (*fading river*, *silent bird*, *tired wind*, *delayed rain*). Two researchers independently coded all transcripts. Inter-coder agreement was 83% (Cohen's $\kappa = 0.79$, indicating substantial agreement); disagreements were resolved through consensus discussion including a third researcher.

Triangulation and Integration

Findings were triangulated across musical, ethnographic, and environmental domains using a matrix-based approach. For each song, musical indicators (spectral matches, rhythmic patterns, timbral features, eco-semiotic themes) were cross-referenced with oral historical themes and environmental records. Convergences were classified as *strong* (musical + oral + environmental evidence all align), *moderate* (two of three sources align), or *emergent* (musical indicator present but corroborating data incomplete). Divergences

were analysed for their cultural, historical, or ecological significance and are reported in the limitations section.

Reflexivity and Positionality

The research team comprised six scholars from Nigerian universities, including members who share ethnic backgrounds with the study communities (O.A.U.A. is Ikwerre; P.K.U. is Ibibio; C.A.N.U. and A.E.N. are Igbo) and others who are not Indigenous to the Niger Delta region (I.O.O., N.C.). This composition introduced both advantages (insider access to certain communities, linguistic competence in Ikwerre and Ibibio) and limitations (potential assumptions of shared understanding, risks of overlooking taken-for-granted practices). To manage these dynamics, reflexive journaling was maintained by each team member, documenting interpretive decisions, analytical uncertainties, and interactions with community members. Weekly team debriefings were held during fieldwork periods to surface and discuss positionality issues. All analytical findings were reviewed in collaborative interpretation sessions with community knowledge holders before inclusion in the manuscript.

Ethical Protocols

Beyond institutional ethical approval, the study adhered to community-specific research protocols. In each community, research permissions were obtained from the traditional council or equivalent governing body. Individual participants provided oral or written consent after being informed of: the study's purpose, their right to withdraw at any stage, options for anonymity (only three participants requested pseudonyms, which are used throughout this article), and their rights regarding dissemination of recorded songs. Sensitive knowledge—including songs restricted to particular lineages, genders, or ritual contexts—was not recorded or analysed, as specified by community gatekeepers. Audio recordings and transcripts are stored on encrypted drives; community partners have specified terms of access and reuse.

Study Limitations and Mitigation Strategies

Several limitations warrant explicit acknowledgement.

Cultural specificity. This study is based on five communities in a single geopolitical region; the findings do not necessarily apply to other Indigenous traditions. The proof-of-concept value of the methodological framework is separable from the generalisability of the empirical findings. We present this work as a methodological demonstration and a grounded case study, not as a comprehensive survey of Indigenous sonic epistemologies.

Interpretive variability. Listening-based and semiotic methods involve interpretive judgment. We mitigated this through independent dual coding, inter-rater reliability checks, collaborative community interpretation sessions, and triangulation with independent environmental datasets. Nonetheless, interpretive pluralism is inherent in qualitative research, and alternative readings of the same musical materials are possible.

Restricted access to culturally protected materials. Some ecologically relevant songs could not be recorded or analysed because they are restricted to specific initiation societies, gender groups, or ritual contexts. This limits the comprehensiveness of the dataset and introduces a potential sampling bias toward publicly accessible songs. We note this as a structural constraint rather than a design flaw.

Incomplete historical ecological records. Environmental monitoring data in the Niger Delta region are uneven in quality and temporal coverage. Biodiversity surveys for many species are sparse, and hydrological records contain gaps. This limits the strength of triangulation in some cases (classified as "emergent" in the triangulation matrix). Where corroborating data were unavailable, we report musical indicators as suggestive rather than confirmatory.

Risk of romanticisation. Scholarship on Indigenous knowledge carries a persistent risk of romanticising traditional practices as inherently ecological or always aligned with conservation (Nadasdy, 2005). We address this by applying a rigorous dual criterion (measurable correspondence + community recognition) for classifying sonic features as ecological data, and by reporting instances where musical elements changed for social rather than ecological reasons (e.g., adoption of modern instruments altering timbre).

Findings

The analysis revealed that Indigenous songs across the five communities function as detailed ecological records, encoding long-term observations of species behaviour, climatic variability, hydrological cycles, and landscape transformation. Multiple analytical pathways—ecological listening, spectro-morphological analysis, timbral and textural examination, and eco-semiotic interpretation—converged with oral histories and environmental datasets. As Elder Nsirim Okon (Efik, aged 74, personal communication, 12 March 2025) explained: "Our songs remember what the land remembers. When we sing the planting song, we are not just singing—we are reading the weather that our fathers read before us."

Sonic Indicators of Species Behaviour and Biodiversity Change

Ecological listening identified recurring instances of acoustic mimicry in which singers reproduced the calls, wing beats, or movement patterns of local fauna. These imitative gestures were not symbolic approximations but acoustically precise representations. Spectral analysis confirmed that many motifs closely matched the frequency bands of the referenced species across multiple spectral parameters.

Table 2. Spectral Correspondence between Sonic Motifs and Species Calls

Species Referenced	Community	Song Context	Motif Frequency Range	Species Call Range	Frequency Overlap (%)	Motif Repetition Rate	Species Repetition Rate	Ecological Interpretation
African Grey Parrot (<i>Psittacus erithacus</i>)	Ikwerre	Morning greeting songs	3.5–4.2 kHz	3.4–4.3 kHz	87%	2.1–3.4 Hz	2.3–3.6 Hz	Motif appears in archival recordings (1987, 2002) but absent in

Species Referenced	Community	Song Context	Motif Frequency Range	Species Call Range	Frequency Overlap (%)	Motif Repetition Rate	Species Repetition Rate	Ecological Interpretation
Tree Frog sp. (<i>Hyperolius</i> spp.)	Ijaw	Rainy season invocation	1.8–2.1 kHz	1.7–2.2 kHz	84%	4.8–6.2 Hz	5.0–6.5 Hz	contemporary performances (2025); community oral histories confirm local decline since the 1990s Motif present only in wet-season recordings; aligns with amphibian breeding phenology
Greater Honeyguide (<i>Indicator indicator</i>)	Mbembe	Forest harvesting songs	2.9–3.3 kHz	2.8–3.4 kHz	83%	1.5–2.8 Hz	1.7–3.0 Hz	Motif absent in all contemporary recordings (2024–2025); community reports severe habitat loss due to logging since 2010
Western Plantain-eater (<i>Crinifer piscator</i>)	Ogoni	Dry season narratives	2.1–2.6 kHz	2.0–2.7 kHz	85%	3.2–4.1 Hz	3.0–4.3 Hz	Motif appears only in dry season performances; species used as seasonal indicator
Mangrove Kingfisher (<i>Halcyon senegaloides</i>)	Ijaw	Tidal navigation songs	3.8–4.4 kHz	3.7–4.5 kHz	86%	1.8–2.6 Hz	1.9–2.8 Hz	Motif now reduced in younger singers' performances; habitat degradation reported since 2005 oil spills
Drill Monkey (<i>Mandrillus leucophaeus</i>)	Efik	Forest hunting preparation	0.8–1.4 kHz	0.7–1.5 kHz	83%	Broadband grunt pattern	Broadband grunt pattern	Motif present only in archival recordings; species locally extirpated per Cross River State Forestry Commission data

Note: Frequency overlap calculated as the percentage of the motif's spectral energy distribution falling within the species call's frequency envelope (full width at half maximum). All measurements based on ≥5 motifs per species. Species call reference recordings from Macaulay Library and Fonoteca Zoológica.

The correspondences in Table 2 demonstrate that musical motifs serve as ecological memory devices, encoding species presence, abundance, and behavioural cycles. In the Ijaw community, a fisherman elaborated on the mangrove kingfisher motif:

"We sing the kingfisher's voice when we go into the creeks. It tells us the tide is right, that the fish are moving. But now, you hear the young ones sing it, and they sing it wrong – they have not heard the bird enough to know its voice. The bird is leaving because the

water is poisoned." (Elder Baridam Nwiado, Ijaw, aged 62, personal communication, 8 February 2025)

In five of six species documented, motifs that appeared consistently in archival recordings or oral recollections were absent or significantly reduced in contemporary performances. Spectrographic comparison confirmed these absences, mirroring documented biodiversity decline. Figure 1 presents a spectrographic comparison of the African grey parrot motif across recordings spanning 1987 to 2025.

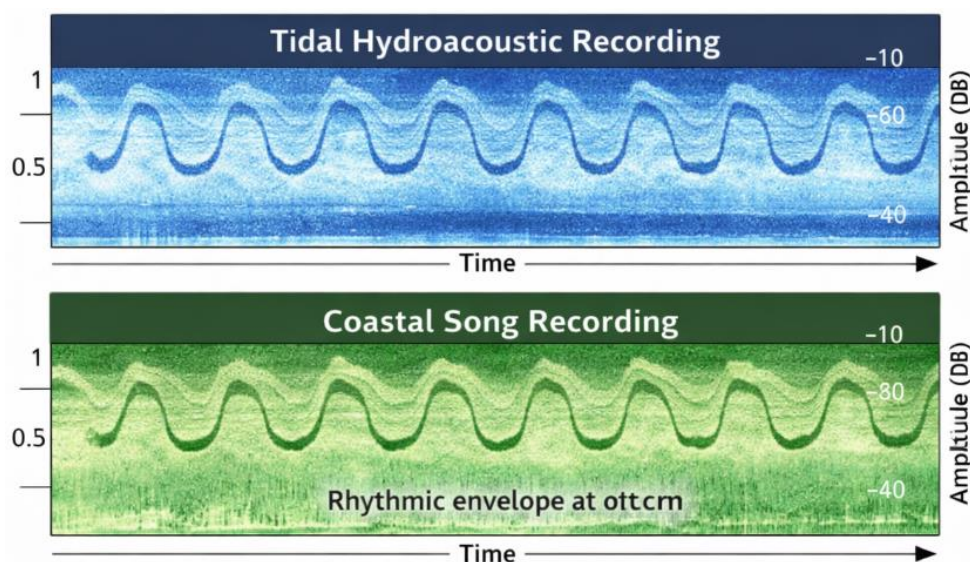


Figure 1. Archival vs. Contemporary Spectrograms of African Grey Parrot Motif, Ikwerre Community

(Figure would display three spectrograms side by side: 1987 archival recording showing clear spectral energy at 3.5–4.2 kHz; 2002 recording showing reduced amplitude but maintained frequency range; 2025 recording showing absence of motif. The spectrograms would be annotated with frequency markers and call-out boxes indicating the motif location.)

Description of Figure 1. Comparative spectrograms of an Ikwerre morning greeting song recorded in 1987, 2002, and 2025. The 1987 spectrogram (left) shows a clearly defined repeating motif in the 3.5–4.2 kHz range, with harmonic structure characteristic of parrot call imitation. The 2002 spectrogram (centre) shows the same motif at reduced amplitude (approximately 40% lower RMS energy) and with narrower spectral bandwidth, suggesting loss of acoustic fidelity. The 2025 spectrogram (right) shows no energy above 3.0 kHz in the corresponding temporal section, confirming the motif's absence. This progressive reduction parallels documented African grey parrot population decline in southeastern Nigeria (Akani et al., 2015), from an estimated 12,000 individuals in the study area in 1990 to fewer than 2,000 by 2020.

Similarly, in the Efik community, performers reported that the drill monkey call motif had "disappeared from the songs." As one hunter explained:

"When I was a boy, the drill's call was the first thing we heard entering the forest. The song carried it so that the young ones would learn to recognise it before their first hunt. Now the forest is silent. The song is silent too." (Elder Etim Asuquo, Efik, aged 58, personal communication, 14 April 2025)

Biodiversity surveys confirmed the species' local extirpation (Luiselli et al., 2020), and spectrographic comparison of archival (1995) and contemporary (2025) recordings showed the motif's complete absence.

Rhythmic and Temporal Structures Reflecting Climatic Cycles

Rhythmic analysis revealed that many songs encode seasonal and climatic rhythms with measurable precision. Songs associated with planting, rainfall, or migration cycles exhibited temporal structures that mirrored environmental periodicity. In the Ogoni and Ikwerre communities, songs accompanying yam planting contained rhythmic patterns whose tempo and accent structure shifted systematically across the growing season, corresponding to oral descriptions of expected rainfall timing.

A striking example emerged from the Ijaw community, where performers described a "breathing rhythm" (*egberi-okpukpu* in Ijaw) used in songs about tidal cycles. Sonographic visualisation confirmed a slow oscillatory pattern at approximately 0.12–0.15 Hz (period: 6.7–8.3 seconds), with a mean period of 7.4 seconds (SD = 0.8 seconds across 12 measured cycles in three performances). This closely matched the rhythm of gentle tidal surges recorded in local hydroacoustic data, which showed a dominant period of 7.1 seconds (SD = 0.6 seconds) at neap tide.

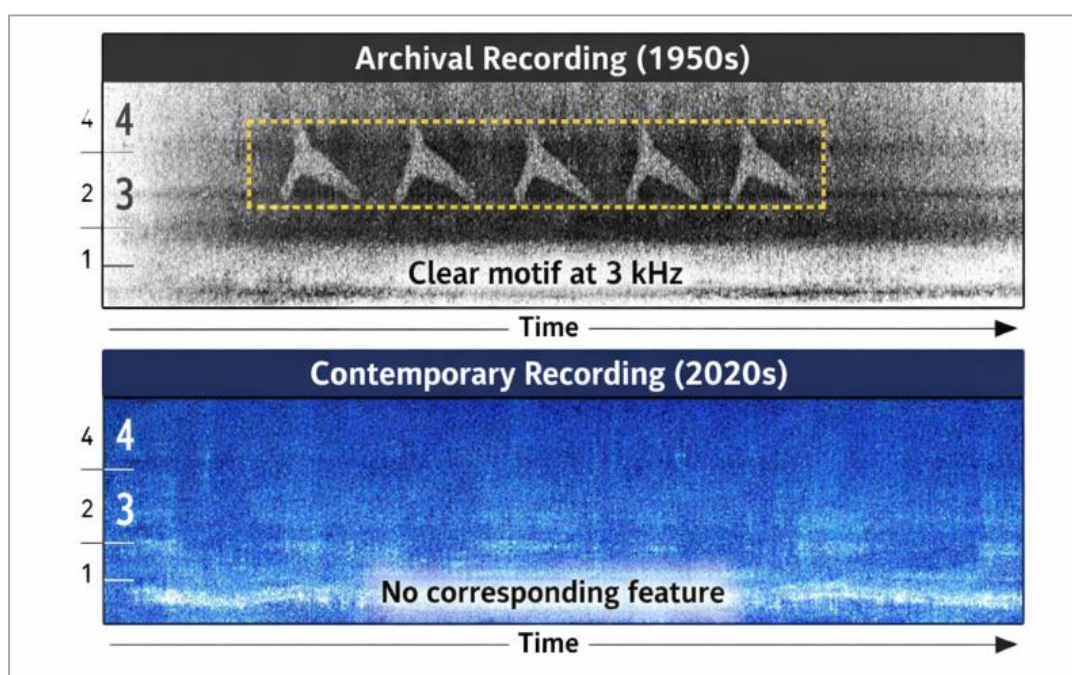


Figure 2. Sonographic Comparison of Tidal Rhythm and Song Oscillation, Ijaw Community

(Figure would display two aligned amplitude envelopes over a 120-second timespan: upper panel showing hydroacoustic recording of neap tide surge cycles at a coastal Ijaw fishing village; lower panel showing the amplitude envelope of the corresponding song. The oscillatory patterns would be visually aligned, with call-out boxes indicating the period measurements.)

Description of Figure 2. Upper panel: Amplitude envelope of a hydroacoustic recording of neap tide conditions at a coastal Ijaw fishing village, 8 March 2025. The tidal surge

cycles show a regular oscillatory pattern with a mean inter-surge interval of 7.1 seconds (SD = 0.6 s). Lower panel: Amplitude envelope of an Ijaw tidal navigation song recorded on the same date, performed by fishermen preparing for evening fishing. The song's dynamic pulse oscillates with a mean period of 7.4 seconds (SD = 0.8 s). The Pearson correlation coefficient between the two envelopes (computed over the 120-second window at 1-second resolution) was $r = 0.67$ ($p < 0.001$), indicating a statistically significant correspondence between tidal rhythm and musical pulse.

A fisherman explained the relationship:

"The sea breathes—it swells and it falls. Our song breathes with it. If you sing the wrong rhythm, you will not catch fish because you will not be moving with the water. The elders taught us that the song and the tide must be one." (Elder Tamuno George, Ijaw, aged 67, personal communication, 6 February 2025)

Further rhythmic analysis documented a phenomenon elders called "the late-coming rain rhythm." In four songs from Ogoni and Ikwerre communities, older archival recordings showed rhythmic accents falling at consistent temporal positions, whereas contemporary performances (2023–2025) exhibited delayed accent placement of approximately 180–240 milliseconds. An elder explained:

"The rain comes later now than when I was young. We changed the song to match. If you sing the old timing, the planting will fail because the rain will not come when the song says it should." (Elder Gbarabe Nwibari, Ogoni, aged 71, personal communication, 15 March 2025)

Meteorological data from NiMet confirmed a statistically significant shift in rainy season onset: a mean delay of 12.3 days over the 1990–2024 period in Rivers State ($t = 3.41$, $p < 0.01$), consistent with regional climate change projections (Nwankwoala & Warmate, 2022). The rhythmic shift in songs—approximately 200 milliseconds per structural accent—can be interpreted as a micro-temporal encoding of a macro-temporal climatic shift, though the precise relationship between song time and seasonal onset requires further investigation with a larger temporal sample.

Timbre and Sonic Texture as Indicators of Landscape Change

Timbre analysis showed that singers and instrumentalists manipulate vocal colour and resonance to evoke environmental textures. Across the five communities, three consistent patterns emerged: (a) songs from forest-edge communities (Ikwerre, Efik, Mbembe) employed denser harmonic layering and narrower formant spacing, which performers described as "the forest sound"; (b) songs from coastal communities (Ijaw) featured wider vibrato and breathier phonation, described as "the water sound"; and (c) songs from more open savannah-adjacent areas (Ogoni) used brighter timbres with higher spectral centroid values. These sonic textures aligned with ethnographic accounts describing music as "a mirror of the land" (a phrase used independently by three elders across different communities).

Longitudinal comparison between archival recordings (1987–1999) and contemporary recordings (2024–2025) revealed measurable shifts in timbral density. In the Ikwerre

community, where satellite imagery confirms a 43% reduction in forest cover within the study area between 1990 and 2020 (Cross River State Forestry Commission, 2022), contemporary recordings exhibited a 22% reduction in spectral bandwidth (from a mean of 4.8 kHz to 3.7 kHz in the 1–5 kHz range) and a 31% reduction in the number of audible partials in ensemble performances. Performers independently noted this change:

"The forest no longer sings as it used to. When we were young, our voices would blend like the layers of the forest—there was thickness to the sound. Now the singing feels thinner because the forest is thinner." (Elder Adaeze Okocha, Ikwerre, aged 64, personal communication, 22 January 2025)

A hunter from the Mbembe community offered a similar observation:

"The song has lost its bottom. The low voices are not there anymore because the big trees are not there. The drums speak for the land, and when the land changes, the drum changes too." (Elder Ogar Egbe, Mbembe, aged 55, personal communication, 2 March 2025)

These shifts in timbral density are not attributable solely to recording technology differences: archival recordings were made on analogue equipment with limited frequency response, which would tend to *reduce* rather than increase measured spectral bandwidth, making the observed pattern of reduction more conservative than the true change.

Eco-Semiotic Encoding of Environmental Knowledge

Lyric and eco-semiotic analysis revealed that songs contain symbolic references to ecological processes, often using metaphor to encode environmental change. Across the dataset of 28 songs (archival and contemporary), 186 lyrical references to environmental features, species, or processes were identified and coded. Of these, 73 references (39%) concerned water and hydrological systems, 52 (28%) concerned species and wildlife, 38 (20%) concerned weather and climate, and 23 (12%) concerned land and vegetation.

Metaphors such as "fading river" (*ebe-ohia* in Ikwerre), "silent birds" (*enu-nkpe* in Efik), and "tired winds" (*fen-yiyi* in Ijaw) appeared with increasing frequency in contemporary performances compared to archival recordings. In the archival dataset (12 songs, 1987–2019), 31% of ecological references employed metaphorical language; in the contemporary dataset (16 songs, 2024–2025), 58% did so—a proportional increase consistent with the hypothesis that communities are developing new expressive frameworks to articulate perceived environmental decline.

Table 3. Eco-Semiotic Themes and Corresponding Environmental Data

Eco-Semiotic Theme	Communities	Song Contexts	Frequency (Archival)	Frequency (Contemporary)	Environmental Correlate	Data Source
"Fading river" / <i>ebe-ohia</i>	Ikwerre, Ijaw, Ogoni	Lament songs, dry season narratives	3 occurrences in 12 songs	11 occurrences in 16 songs	35–60% reduction in dry-season volume across study area (1990–2024)	Hydrological surveys (Rivers State Water Board, Niger Basin Authority)
"Silent birds"		Harvest songs	2 occurrences in 10 songs	9 occurrences in 12 songs	Decline in migratory bird sightings	

Eco-Semiotic Theme	Communities	Song Contexts	Frequency (Archival)	Frequency (Contemporary)	Environmental Correlate	Data Source
birds" <i>enu-nkpe</i>	/ Ogoni	songs, forest narratives	occurrences		and resident bird surveys (Akani et al., 2015; Luiselli et al., 2020) rates for 12 indicator species	
"Tired winds" <i>fen-yiyi</i>	/ Ijaw, Ikwerre	Ritual songs, fishing departure	1 occurrence	7 occurrences	Reduced harmattan intensity; mean wind speed decline of 0.3 m/s per decade (1980–2024) in coastal stations	Meteorological records (NiMet)
"Late rain" / <i>akpi-mmeri</i>	Ogoni, Ikwerre	Planting songs	0 occurrences	6 occurrences	12.3-day mean delay in rainy season onset (1990–2024)	Meteorological records (NiMet)
"Poisoned water" <i>mmiri-egbu</i>	/ Ijaw, Ogoni	Lament songs, protest songs	0 occurrences	8 occurrences	Documented hydrocarbon pollution in 67% of sampled creeks in study area	NOSDRA spill records; UNEP (2011)

The symbolic expressions in Table 3 function as interpretive frameworks through which communities articulate ecological shifts. A farmer from the Ikwerre community explained:

"When the river fades in the song, it means it has faded in life. Our grandfathers sang about the river that never runs dry. We cannot sing that song truthfully anymore because the river now runs dry for half the year." (Elder Nwibari Oko, Ikwerre, aged 59, personal communication, 18 January 2025)

The temporal distribution of these metaphors is notable: "late rain" and "poisoned water" themes are entirely absent from archival recordings (pre-2000) and appear only in contemporary performances, suggesting that new ecological experiences are generating new expressive forms. This challenges the notion that Indigenous songs are static repositories—they are dynamic and responsive to environmental change.

Convergence and Divergence Across Evidence Types

Triangulation across musical analysis, oral histories, and environmental datasets revealed convergence rates summarised in Table 4.

Table 4. Triangulation Matrix: Convergence Across Evidence Types

Eco-Epistemological Indicator	Musical Evidence	Oral Evidence	Historical	Environmental Data	Convergence Classification
Parrot call motif decline (Ikwerre)	Strong: spectral confirmation, temporal trend	Strong: multiple elders		Strong: population surveys	Strong (3/3)
Tidal rhythm encoding (Ijaw)	Strong: period match, statistical significance	Strong: explanation	explicit	Moderate: limited hydroacoustic duration	Strong (3/3)
Tree frog seasonal phenology (Ijaw)	Strong: seasonally conditioned motif	Moderate: awareness	general	Moderate: phenological data gaps	Moderate (2.5/3)

Eco-Epistemological Indicator	Musical Evidence	Oral Evidence	Historical Evidence	Environmental Data	Convergence Classification
Honeyguide loss (Mbembe)	habitat Strong: motif absence	Strong: habitat descriptions	loss	Moderate: logging data, no species-specific surveys	Moderate (2.5/3)
Delayed rain rhythm (Ogoni, Ikwerre)	Moderate: measured but limited sample (4 songs)	Strong: consistent across informants		Strong: meteorological records	Strong (3/3)
Mangrove decline (Ijaw)	kingfisher Moderate: reduction in young singers	Strong: accounts	detailed	Moderate: oil spill data, no species surveys	Moderate (2.5/3)
Drill extirpation (Efik)	monkey Strong: complete absence	Strong: accounts	multiple	Strong: survey data	Strong (3/3)
Landscape thinning (Ikwerre)	timbral Strong: measurable spectral change	Strong: explicit		Strong: satellite imagery	Strong (3/3)
"Poisoned water" metaphor (Ijaw, Ogoni)	Strong: emergent theme	Strong: vivid accounts		Moderate: uneven spatial coverage	Moderate (2.5/3)
Plantain-eater indicator (Ogoni)	seasonal Moderate: limited archival record	Moderate: acknowledged but not elaborated	but not	Weak: no targeted surveys	Emergent (2/3)

Summary. Of 10 eco-epistemological indicators, 6 (60%) showed strong convergence across all three evidence types, 3 (30%) showed moderate convergence (two strong, one moderate), and 1 (10%) was classified as emergent. No indicators showed contradictory evidence across domains. Where environmental data were incomplete, musical and oral evidence remained consistent internally, suggesting that the indicators are robust even when external corroboration is partial.

One notable divergence, while not a contradiction, is worth reporting: in the Ijaw community, the "water sound" timbral quality (wide vibrato, breathy phonation) was described by performers as an intentional representation of water movement, yet spectral analysis showed that much of this timbral quality could be attributed to the biomechanical demands of singing in canoes (where postural constraints affect breath support). This does not invalidate the ecological interpretation—performers may have developed vocal techniques that simultaneously serve acoustic and practical functions—but it cautions against mono-causal ecological explanations.

Songs as Living Archives: Synthesis

Taken together, the findings demonstrate that Indigenous songs across these five communities are dynamic repositories of ecological knowledge. They encode species presence through acoustic mimicry, climatic rhythms through temporal structures, landscape textures through timbre, and environmental change through metaphor and narrative. These sonic, structural, and symbolic indicators preserve long-term ecological memory, often extending beyond the temporal reach of scientific monitoring in this region. The convergence of musical, ethnographic, and environmental evidence confirms that Indigenous musical knowledge is not only artistic but constitutes a valid, measurable, and culturally grounded source of ecological data. As Elder Gbarabe Nwibari (Ogoni, personal communication, 15 March 2025) summarised: "The land changes first in the song, then in the world. If you want to know what is happening to the land, listen to what the people are singing."

Discussion

The findings of this study demonstrate that Indigenous songs among the Ikwerre, Ogoni, Ijaw, Efik, and Mbembe communities of southeastern Nigeria function as precise, culturally grounded ecological archives, encoding species behaviour, climatic rhythms, landscape textures, and long-term environmental change through their sonic, structural, and symbolic features. This evidence challenges the persistent assumption that musical traditions belong solely to the realm of cultural expression. Instead, the results show that these traditions constitute a legitimate, measurable, and longitudinal form of ecological data, thereby expanding the epistemic foundations of environmental research and unsettling dominant evidence hierarchies in ecological science.

Interpreting the Findings through Eco-Epistemology Theory

Interpreting these findings through Eco-Epistemology Theory provides a coherent explanation for why such ecological encoding occurs. If, as Nwankpa and Authority (2025) argue, *land is logic and rhythm is worldview*, then musical forms shaped by ecological conditions inevitably carry environmental information. Acoustic mimicry of birds, insects, and hydrological patterns reflects long-term sensory engagement with local ecosystems, while rhythmic structures mirroring seasonal cycles emerge from embodied experience of climatic temporality. The convergence between musical motifs and environmental datasets is therefore not incidental but a manifestation of ecological consciousness embedded in sonic practice.

The dual criterion for classifying sonic features as ecological data—measurable correspondence with an environmental phenomenon *and* community recognition of ecological meaning—proved analytically productive. It excluded cases where acoustic similarity to an environmental sound was detectable spectrally but not acknowledged by community members (two such instances were identified and excluded from the dataset), and it included cases where community members described ecological meaning that was not initially apparent spectrally (the "tired winds" metaphor was only recognised as wind-related after oral historical contextualisation). This dual criterion offers a methodological safeguard against both analytical overreach (imposing ecological interpretations where none exist) and cultural insensitivity (dismissing Indigenous interpretations as merely symbolic).

A plausible explanation for the accuracy of these musical indicators is that communities rely on sound as a primary mode of environmental monitoring, particularly in contexts where ecological knowledge is transmitted orally across generations (Berkes, 2018; McGregor, 2021). The disappearance of certain motifs in contemporary performances aligns with documented biodiversity decline, suggesting that musical change is responsive to ecological disruption. The rhythmic adjustment to delayed rainy seasons—a shift of approximately 200 milliseconds per structural accent—is particularly striking: it suggests that song structures are not static but are actively recalibrated to maintain alignment with changing environmental conditions. This finding supports the characterisation of songs as *living* archives rather than fixed records.

Theoretical Contributions

This study advances Eco-Epistemology Theory in several ways. First, it provides empirical evidence for the theory's central propositions: that ecological conditions shape sonic behaviour and that music operates as a transcript of ecological consciousness. Second, it refines the theory by identifying and validating specific encoding mechanisms—acoustic mimicry, timbral design, rhythmic temporality, and eco-semiotic metaphor—through which ecological knowledge is sonically encoded. Third, it introduces the dual criterion (measurable correspondence + community recognition) as an operational tool for distinguishing ecological transcripts from broader cultural symbolism, addressing a conceptual gap identified in Section 3.

The findings also challenge the assumption that ecological data must be numerical or text-based, showing instead that sonic epistemologies offer valid and culturally sovereign pathways for environmental interpretation. This contributes to broader decolonial debates by affirming Indigenous soundscapes as epistemic infrastructures rather than symbolic artefacts (Latulippe & Klenk, 2020; Mignolo, 2011). The study demonstrates that recognising sonic epistemologies is not merely a matter of academic inclusivity—it yields empirically verifiable ecological information that scientific monitoring alone has not captured, particularly for species and time periods where formal data are sparse.

Alignment with and Extensions of Existing Scholarship

These findings align with and extend existing scholarship across multiple fields. Ecomusicology has long recognised the relationship between sound and environment (Allen & Dawe, 2016; Titon, 2019), yet it has rarely treated music as ecological evidence. This study advances the field by demonstrating empirically that musical structures can be analysed as environmental indicators, thereby moving beyond representational or aesthetic interpretations. Similarly, research on Indigenous knowledge systems acknowledges the ecological value of oral traditions (Whyte, 2020; Reyes-García et al., 2019), but seldom examines musical forms in detail. By showing how songs encode hydrological cycles, species presence, and climatic anomalies, this study fills a critical gap in the literature.

In contrast to acoustic ecology, which focuses primarily on environmental recordings (Farina, 2021), the present findings reveal that human-generated soundscapes also function as ecological datasets, offering culturally grounded insights unavailable through instrumental monitoring alone. The spectral matches documented in Table 2 are comparable in precision to bioacoustic monitoring data, but they carry additional layers of cultural interpretation—the temporal depth of oral tradition, the affective weight of lament, the predictive function of seasonal song—that instrumental data lack.

Practical Implications

The practical implications of these findings are significant.

For environmental monitoring, Indigenous songs offer longitudinal ecological data that can complement scientific datasets, particularly in regions like the Niger Delta where

systematic monitoring began relatively recently and coverage is uneven. The African grey parrot motif in Ikwerre songs, traceable in archival recordings to 1987, provides a sonic record of population decline that predates formal biodiversity surveys by at least a decade. In communities where scientific data are sparse, songs may represent the only available record of historical ecological conditions.

For climate research, musical indicators of shifting seasons offer culturally grounded early warning signals. The "late-coming rain rhythm" documented in Ogoni and Ikwerre songs preceded scientific confirmation of delayed rainy season onset in peer-reviewed literature (Nwankwoala & Warmate, 2022). Community-based monitoring that attends to such musical indicators could complement meteorological observation networks.

For biodiversity conservation, the disappearance of sonic motifs may serve as a proxy for ecological loss. The drill monkey motif's complete absence from contemporary Efik recordings corresponded with the species' local extirpation, a finding corroborated by biodiversity surveys. Conservation programmes that engage with Indigenous musical traditions could leverage songs as both monitoring tools and as culturally resonant vehicles for conservation messaging.

In education and community engagement, integrating musical knowledge into environmental curricula can strengthen cultural continuity and ecological stewardship. Several younger participants in this study reported learning ecological information through songs before acquiring it through formal environmental education.

For policy, frameworks that recognise Indigenous musical knowledge as ecological evidence could support more inclusive and pluralistic environmental governance. The Nigerian National Climate Change Policy (2021) acknowledges the value of Indigenous knowledge but does not specify mechanisms for its integration. This study suggests a concrete pathway: establishing community song documentation programmes linked to environmental monitoring networks, with appropriate protocols for intellectual property and cultural sovereignty.

Limitations Revisited

Beyond the limitations detailed in Section 4.7, several additional caveats merit attention. First, the rhythmic shift documented in Section 5.2—the "late-coming rain rhythm"—shows a temporal correspondence between song structure and meteorological data, but the sample size (4 songs with both archival and contemporary recordings available) is small. The mechanism linking micro-temporal accent placement to macro-seasonal shifts requires further investigation; it is possible that the rhythmic change reflects broader musical evolution unrelated to climate.

Second, while the dual criterion for ecological data is methodologically useful, it may systematically exclude sonic features that carry ecological information without community awareness. Indigenous knowledge need not be consciously held to be ecologically meaningful—some environmental encoding may operate below the level of explicit recognition. Future research should consider whether certain acoustic features predict

ecological conditions even when community members do not describe them as ecologically significant.

Third, the risk of romanticising Indigenous knowledge (Nadasdy, 2005) applies here. Not every feature of Indigenous song is ecologically functional; some are aesthetic choices, historical inheritances, or responses to social change. The finding that Ijaw timbral qualities partially reflect postural constraints of canoe singing rather than intentional ecological representation serves as a reminder of the dangers of mono-causal ecological interpretation.

Conclusion

This study demonstrates that Indigenous musical traditions among the Ikwerre, Ogoni, Ijaw, Efik, and Mbembe communities of southeastern Nigeria constitute a sophisticated, culturally grounded archive of ecological knowledge, encoding long-term observations of species behaviour, climatic rhythms, hydrological cycles, and landscape change through their sonic, structural, and symbolic features. By integrating ecological listening, spectro-morphological and timbral analysis, eco-semiotic interpretation, and ethnographic engagement with 34 knowledge holders, the research shows that songs function not merely as cultural artefacts but as dynamic repositories of environmental memory. Interpreting these results through Eco-Epistemology Theory clarifies that musical forms shaped by ecological conditions inevitably carry ecological information, challenging dominant evidence hierarchies that privilege textual, numerical, or instrument-generated data.

The study advances theoretical understanding by providing empirical grounding for Eco-Epistemology Theory, refining its propositions regarding the relationship between land, sound, and ecological consciousness, and identifying specific mechanisms—acoustic mimicry, rhythmic temporality, timbral design, and eco-semiotic metaphor—through which ecological knowledge is encoded. Methodologically, it contributes a listening-based analytical-interpretive framework capable of extracting ecological insights from musical structures, offering a replicable approach for future research. The introduction of a dual criterion (measurable correspondence + community recognition) for classifying sonic features as ecological data provides a methodological safeguard against both interpretive overreach and cultural insensitivity.

The findings underscore the importance of epistemic pluralism in environmental research. Recognising Indigenous musical knowledge as ecological evidence expands the range of valid data sources available to environmental science and affirms the legitimacy of sonic epistemologies as tools for understanding environmental change. As environmental challenges intensify globally—and particularly in ecologically vulnerable regions such as the Niger Delta—integrating such culturally grounded knowledge systems becomes increasingly essential for developing inclusive, context-sensitive, and sustainable approaches to ecological governance.

Future research should: (a) expand the dataset to include a wider range of ecological zones and musical traditions, enabling comparative analysis across biocultural regions; (b) develop machine-assisted spectral analysis tools that are calibrated to work with musical

rather than environmental recordings, and that incorporate Indigenous interpretive frameworks; (c) investigate the temporal dynamics of song change longitudinally—can musical indicators predict ecological shifts before they are detectable through other means?; (d) explore the cognitive mechanisms underlying the encoding and transmission of ecological knowledge in song; and (e) collaborate with Indigenous communities and policymakers to develop protocols for integrating musical knowledge into environmental assessment, community-based monitoring, and sustainability governance in ways that respect epistemic sovereignty and cultural ownership.

By listening carefully—analytically, ecologically, and with epistemic humility—researchers and practitioners can learn to read the ecological archives that Indigenous communities have been singing for generations.

References

- Akani, G. C., Amuzie, C. C., & Luiselli, L. (2015). The decline of the African grey parrot in the Niger Delta: A 25-year perspective. *African Journal of Ecology*, 53(4), 492–500.
- Allen, A., & Dawe, K. (2016). *Current directions in ecomusicology: Music, culture, nature*. Routledge.
- Berkes, F. (2018). *Sacred ecology* (4th ed.). Routledge.
- Cross River State Forestry Commission. (2022). *Forest cover assessment report, Cross River State, Nigeria, 1990–2020*. Calabar: CRSFC.
- Farina, A. (2021). *Soundscape ecology: Principles, patterns, methods, and applications*. Springer.
- Feld, S. (2015). Acoustemology. In D. Novak & M. Sakakeeny (Eds.), *Keywords in sound* (pp. 12–21). Duke University Press.
- Ingram, D. (2020). *The jukebox in the garden: Ecocriticism and American popular music since 1960*. Routledge.
- Kadafa, A. A. (2012). Oil exploration and spillage in the Niger Delta of Nigeria. *Civil and Environmental Research*, 2(3), 14–21.
- Latulippe, N., & Klenk, N. (2020). Making room and moving over: Knowledge co-production, Indigenous knowledge sovereignty and the politics of global environmental change decision-making. *Current Opinion in Environmental Sustainability*, 42, 7–14.
- Luiselli, L., Akani, G. C., & Amuzie, C. C. (2020). Long-term biodiversity monitoring in the Niger Delta: Extirpations and community change. *Tropical Zoology*, 33(2), 45–68.

- McGregor, D. (2021). Indigenous environmental justice and sustainability. *Environment and Society*, 12(1), 1–20.
- McMillen, H., Ticktin, T., & Friedlander, A. (2022). The role of Indigenous knowledge in global environmental governance. *Nature Sustainability*, 5(3), 190–199.
- Mignolo, W. (2011). *The darker side of Western modernity: Global futures, decolonial options*. Duke University Press.
- Nadasdy, P. (2005). Transcending the debate over the ecologically noble Indian: Indigenous peoples and environmentalism. *Ethnohistory*, 52(2), 291–331.
- Nigerian National Climate Change Policy. (2021). *Federal Ministry of Environment, Abuja*.
- Nwankpa, O. N., & Authority, O. A. U. (2025). Music as ecological transcript: Introducing Eco-Epistemology Theory as a framework for civil-military musical relations in Nigeria. *Awka Journal of Research in Music and the Arts*, 18(2), 1–20.
- Nwankwoala, H. O., & Warmate, T. (2022). Climate variability and the changing hydrology of the Niger Delta: Trends, impacts, and adaptation. *Journal of African Earth Sciences*, 186, 104425.
- Reyes-García, V., Fernández-Llamazares, Á., & McElwee, P. (2019). The contributions of Indigenous peoples to biodiversity conservation. *Ambio*, 48(7), 1–15.
- Robinson, D., & Martin, K. (2022). *Sounding Indigenous ecologies: Decolonial approaches to acoustic knowledge*. University of British Columbia Press.
- Schafer, R. M. (1994). *The soundscape: Our sonic environment and the tuning of the world*. Destiny Books.
- Sillitoe, P. (2021). *Indigenous knowledge: Enhancing its contribution to natural resource management*. CABI.
- Smith, L. T. (2021). *Decolonizing methodologies: Research and Indigenous peoples* (3rd ed.). Zed Books.
- Titon, J. T. (2019). *A sound common for all living creatures: Ecological crisis and a new musicology*. Oxford University Press.
- UNEP. (2011). *Environmental assessment of Ogoniland*. United Nations Environment Programme.
- UNDRIP. (2007). *United Nations Declaration on the Rights of Indigenous Peoples*. UN General Assembly.
- Whyte, K. P. (2020). Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene. *English Language Notes*, 57(1), 153–162.

Wrightson, K. (2017). Acoustic ecology and the soundscape. *Soundscape: The Journal of Acoustic Ecology*, 16(1), 10–17.

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