Ecoacoustic Exploration of Bone Bolango Bamboo In The Tomini Bay Area For Polopalo Manufacturing As A Nusantara Cultural Heritage

Rahmawati Ohi

Lectures in Gorontalo State University, Indonesia
* Corresponding author:
Email : Ohan@ung.ac.id

Abstract.
This study aims to explore the physical-acoustic characteristics of talilo huidu bamboo from Bone Bolango, Tomini Bay area, in the production of Polopalo, while formulating geometric standards to preserve local ecology and cultural heritage. Utilizing a qualitative method as the primary approach, this research integrates oral ethnoorganological studies with sound analysis via Fast Fourier Transform in Audacity as supporting data, alongside the sound philosophy concepts of the Gorontalo community. The results successfully formulate precise geometric standards for the Polopalo blade: a base length of 154 mm and a wall thickness of 10–12 mm with a proportional resonator hole to maintain traditional sound accuracy. Psychoacoustically, the mechanical structure of the instrument (Bulango and Elenggengo) is proven capable of emitting sound pressure that propagates effectively across 3 to 6 kilometers in open space as an agricultural communication tool. This physical standardization has been archived so that the instrument's revitalization process provides cultural-economic incentives for the community to ecologically preserve mountainous bamboo groves in the Tomini Bay area.
Keywords: *Ekoakustik, Bambu, Teluk Tomini and Polopalo.*

I. INTRODUCTION

The raw material for making Polopalo a traditional musical instrument originating from the Gorontalo cultural sphere is not merely an artistic artifact or a static symbol of antiquity. Rather, it represents a vital space of collective identity for the people of Bone Bolango in the Tomini Bay area. In contemporary ethnomusicological and ecological discourse, this material must be actively developed as a crucial supporting resource for the advancement, protection, and preservation of the Polopalo as a cornerstone of Indonesian cultural heritage. The endemic bamboo species growing throughout the rugged terrains of Bone Bolango, functioning as an empirical product of a tightly intertwined natural-cultural ecology, reflects a profound and potential relationship between nature and human agency in maintaining socio-cultural community values.

For generations, the Bone Bolango region, which naturally interfaces with the expansive maritime and terrestrial ecosystem of the Tomini Bay area, has been widely recognized for producing bamboo with highly distinct physical characteristics. Local artisans look closely at its unique fiber structure, density, and naturally balanced moisture content. This empirical geographical fact provides an intriguing scientific premise regarding the specific type of bamboo harvested in making the traditional four-sound Polopalo: talilo huidu. This specific upland bamboo possesses the optimal internal characteristics to serve as an enduring raw material. Polopalo artisans strongly believe that these intrinsic physical characteristics namely the fiber alignment and natural moisture reduction process of the bamboo directly dictate the resonance, clarity, and overall quality of the resulting sound.

Ohi (2020) explains acoustic ethnoorganology as an integrated approach toward understanding the overarching ecological space of the Polopalo. She further elaborates that the bamboo selected for making Polopalo is highly specialized and acoustically bound to the deep-seated philosophical aspects of the Gorontalo community. The acoustics historically present in the traditional Polopalo encompass four core sonic concepts: moduloduo, moelenggengo, motoliyongo, and mobulongo. These four acoustic concepts, or primary sounds, are universally recognized as an endemic musical system of the community. However, a critical socio-cultural crisis currently emerging in modern society is that these four traditional acoustic concepts are beginning to be systematically forgotten, largely replaced by contemporary Polopalo variants manufactured from commercial wood utilizing a standardized western diatonic scale.

The gradual shift in Polopalo raw materials from authentic bamboo to industrial wood constitutes a problematic social action that threatens to destroy the very organic identity of the Polopalo itself. Furthermore, it directly undermines the localized environmental conservation efforts in Bone Bolango within the Tomini Bay area a geographic zone that historically guarantees raw material availability through its natural forests. Suriani (2017) explains that bamboo is a premier ecological material characterized by exceptional tensile strength, rapid adaptability, low erosion susceptibility, low embodied energy, and an innate capacity to structurally protect the surrounding ecosystem. This becomes highly compelling when viewed through an ecoacoustic lens: the Bone Bolango Tomini Bay area is not just an arena for voice or sound; it is a living template for the sustainable utilization of local materials. Therefore, the preservation of the Polopalo should serve as a cultural incentive to encourage the community to maintain and cultivate these native bamboo groves, which fundamentally serve as natural erosion control barriers and critical groundwater reservoirs.

For the modern people of Bone Bolango, instilling this deep understanding can provide vital economic value to preserve natural bamboo forests rather than aggressively converting the land for industrial or agricultural monotypic uses, which ultimately degrades regional soil quality and destroys biodiversity. Fascinating research regarding the reciprocal relationship between music and the environment has been heavily presented by Kolar (2018) as well as Taylor and Hurley (2020) using an archaeacoustics approach. This framework opens distinct opportunities to study material culture and traditional artifacts as fundamental elements of spatial acoustics and environmental soundscapes.

Presently, the manufacturing of the Polopalo remains dominantly reliant on fluid oral traditions, leaving a profound lack of clear, rigorous scientific studies explaining why Bone Bolango bamboo in the Tomini Bay area possesses such a uniquely resonant sound profile. Furthermore, the distinct lack of empirical technical exploration regarding the precise manufacturing methods and sound characteristics needed to comprehend its acoustic nature poses an engaging challenge to modern researchers. Scientifically, modern organological concepts regarding bamboo can be utilized to revitalize the regional ecosystem space. Several prior studies note that land rehabilitation and soil conservation aimed at knowledge inheritance, soil fertility, and restoring degraded land can be effectively carried out by the government through target bamboo preservation. Due to its dense root architecture and physical growth characteristics, bamboo is capable of mitigating degraded land by up to 76% and increasing localized water discharge by 10% (Raka, Wiswata, Budiasa; 2011).

II. METHODS

Adopting the comprehensive framework established by Creswell (2014), the method applied in this research is a mixed-methods design that strictly prioritizes qualitative ethnography and ethnoorganology as the primary paradigm, while positioning quantitative digital signal processing as a secondary corroborative tool. This choice of methodology emphasizes the relevance of empirical acoustic measurements within their deep socio-cultural contexts, ensuring that mathematical numbers do not strip away the human and spiritual dimensions of the instrument. Before analyzing the sound from a purely mathematical perspective, one must meticulously dissect the human 'source' of the sound: the oral history, harvesting rituals, and sensory intuition surrounding the Bone Bolango Tomini Bay bamboo.

The qualitative phase of the methodology relied on two primary pillars: In-depth Interviews and Field Observations. In-depth interviews were systematically conducted through open-ended, narrative discussions with recognized musical Maestros and elderly perajin (artisans) in Gorontalo, most notably Mr. Karto, who has maintained this lineage since 1970. The focus of these interviews was to map how they 'hear' matured bamboo, how they classify acoustic properties using ancient vernacular terms, and how they evaluate the material based on touch, weight, and visual tone. Field observations involved directly engaging in the physical harvesting process within the deep mountain forests of Bone Bolango. This allowed the research team to document the localized rituals, seasonal timing, and specific local wisdom that may influence acoustic quality, such as the exact correlation between the bamboo's growth position relative to mountain slopes and its orientation toward the morning sun. The geographic identification covered both the

coastal fringes and the deeper mountainous terrains of Tomini Bay to isolate the ideal habitat for talilo huido bamboo groves.

The quantitative phase was subsequently deployed as an objective framework for data validation and triangulation (confirming the validity of oral claims). The procedures involved: (1) Geometric Measurement: Documenting the structural dimensions, including the total length of the blade, wall thickness, and internode length using precise mechanical calipers; (2) Acoustic Recording: Recording pristine sound samples of the Polopalo instruments in a controlled environment with low-reflection acoustics, utilizing a calibrated omnidirectional microphone placed at a standardized distance of 50 cm from the instrument; (3) Fast Fourier Transform (FFT): Executing signal processing via Audacity software to convert time-domain acoustic waveforms into frequency-domain spectrum graphs. This computational method was used exclusively to isolate and determine the exact Fundamental Frequency (f0) of each Polopalo blade; and (4) Harmonic Overtone Analysis: Performed to mathematically dissect the overtone structure of the instruments. High-quality Polopalo features harmonious overtones that do not generate disruptive, stray frequencies (noise), a characteristic that was cross-examined with the qualitative 'blind test' evaluations conducted by the local maestros to verify if human aesthetic preferences matched mathematical harmonic alignment.

III. RESULT AND DISCUSSION

Physis Caharacteristic and Acoustic Bamboo Talilo Huidu

The primary raw material for manufacturing the Polopalo idiophone (*waditra*) in the Tomini Bay area, specifically within the Bone Bolango region, heavily depends on the physical-ecological characteristics of local upland bamboo. Based on the integration of empirical field data and in-depth interviews with senior artisan Mr. Karto, who has dedicated himself to this instrument since 1970 the selection of high-quality material relies on three main macroscopic indicators while the bamboo is still standing: heavy weight, hard fiber texture, and a naturally yellowed appearance of the culm. Bio-acoustically, these physical attributes signify a dense concentration of cellulose fibers and an optimal, natural reduction in moisture content, both of which are highly crucial for generating loud acoustic wave transmissions without experiencing high internal damping. Ethnoorganologically, traditional artisans classify the anatomy and function of the Polopalo into three primary local nomenclatures that influence the performance structure, namely:

- **Bulango:** Functions as the enclosure or closing section of the instrument.
- **Elengenggo:** Functions as the opening or introductory sound section.
- **Peletoo:** Functions as the base structural part that carries or holds the instrument when played.

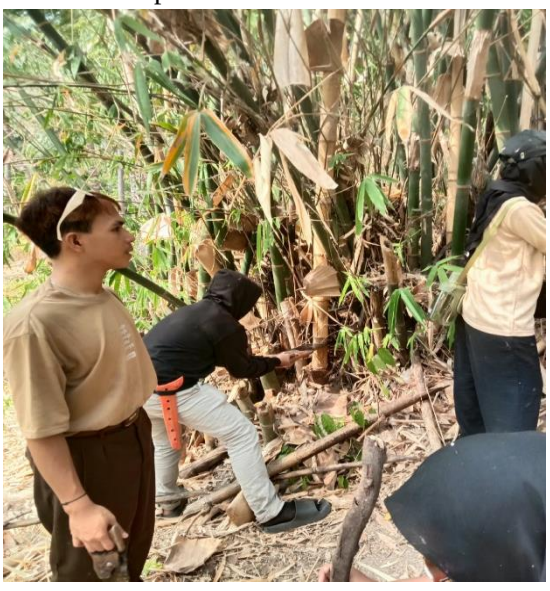


Fig. 1. Fieldwork Process for bamboo Materials
(Source : Ohi, 2026)



Fig. 2. Forum Group Discussion
(Source : Aan, 2026)

Exploration utilizing Fast Fourier Transform (FFT) analysis via Audacity software scientifically confirms that these traditional sound nomenclatures are divided into four distinct sounds organologically and further expanded into six sounds based on technical playing patterns. This scientific dimension aligns with the mapping of fundamental frequencies and distinct harmonic structures (Hermann & Baier, 2006; Feld, 2012). The sonic concept of *moelenggengo* represents the mid-high frequency range that serves as the initial melodic guide (opener), whereas *mobulongo* maps the clean lower frequency free of stray frequencies (*noise*). Interview data reinforces that the hardness and physical quality of the bamboo are directly proportional to the frequency amplitude; bamboo specimens fulfilling these premium criteria are proven to generate the highest decibels and the most resonant timbre, particularly within the Polopalo classifications (Pijanowski et al., 2011; Fletcher & Rossing, 1998)

Tabel 1. Research Prominent Frequency with Audacity

Sound of Polopalo	Prominent Frequncy (Hz)
Moelenggengo	517 Hz
Moduloduo	572 Hz
Mobulongo	600 Hz
Motoliyongo	643 Hz

Data indicate that in the scientific aspect of sound, the relationship among the four traditional Polopalo sounds possesses an intriguing character, wherein the conceptual intervals between each sound establish a microtonal space, thereby generating a rich inharmonic series profile. The investigation into the Polopalo sound also demonstrates that the thickness dimension of the bamboo tongue ranges between 10 and 12 mm.

Organological Science: Manufacturing Methodology Transition and Blade Geometry Formulation research successfully documents a technological and methodological transition in the production process of Polopalo in Bone Bolango. In the past, the process of acoustic perforation or creating holes on the bamboo body was conducted intuitively using heated iron nails. Today, artisans have migrated to mechanical technology utilizing manual drills and three types of specialized blades, where each knife has a specific function in the sequential stages of establishing the instrument's acoustic dynamics (cutting, body-shaping, and tip-finishing). Adopting the mixed-methods framework by Creswell (2014), these intuitive parameters derived from communal experience are quantified into a precise standard formula for blade geometry.

Based on the artisans' standard operational procedures, the initial raw material cutting process must take a geometric reference length of 15 cm from the nodes or internodes of the bamboo. From this cutting baseline, the material's wall thickness is kept constant at approximately 1 cm. This minimum thickness restriction is mechanically proven to prevent the material from becoming too thin, which could otherwise make it easily fragile or prone to breaking.

The most crucial aspect determining the fundamental frequency and the accuracy of the traditional pentatonic scale is the diameter of the resonance hole. Artisans apply the law of geometric proportionality:

- If the bamboo specimen is small, the acoustic hole is sized approximately to a standard small ABC battery.
- If the bamboo specimen is large, the acoustic hole is measured scalarly larger than the size of an ABC battery.

The standardization of these geometric parameters (Length of 15 cm, Thickness of 1 cm, and Proportional Hole Scale) ensures pitch stability of the pentatonic scale for digital archiving needs and the establishment of a Digital Sound Bank.

Psychoacoustics and Frequency Range within the Eco-Cultural Space

The integration of oral data reveals a massive spatial psychoacoustic dimension of the Polopalo idiophone (*waditra*), which is highly relevant to the regional ecoacoustic study. The acoustic characteristics of the Polopalo are examined not only through its internal harmonic structure but also through its wave propagation performance in the open air of Tomini Bay. Mr. Karto outlines the spatial sound range parameters generated by the Polopalo's geometric structure as follows:

- Elenggengo Sound Character (Open Condition): Generates a timbre that tends toward the mid-high frequencies with a radial propagation pattern. This sound character is capable of propagating effectively in open environments up to a radius of 2 to 3 kilometers. Sociologically, this propagation performance functions as a position marker or a sound carrier (*mambawa bunyi*) between agricultural regions.
- Bulango Sound Character (Enclosed Condition): The enclosure structure on the instrument triggers air compression inside the resonator tube, producing a lower fundamental frequency with a significantly higher Sound Pressure Level (SPL). This characteristic grants the *bulango* sound an extraordinarily strong acoustic penetration against environmental barriers (such as foliage friction and coastal air humidity), rendering it audible up to a distance of 5 to 6 kilometers.

This phenomenon proves the existence of a highly mature traditional acoustic mechanics system. Through this mechanical duality wherein *bulango* acts as a wind barrier (*penahan angin*) while *pelyongo* acts as a wind carrier (*pembawa angin*) the Polopalo functions as an environment-based communication tool (ecoacoustics). The capability of sound propagation spanning up to several kilometers reinforces why the use of thick, high-quality bamboo from the highlands of Bone Bolango is absolute. Substituting the raw material with wood or utilizing thin bamboo will fail to reproduce the mechanical elasticity required to generate a sound pressure capable of reaching up to 6 kilometers.

Technological Evolution of Organology and Digital Preservation Challenges

This study also records a technological shift in work tools when transforming local wisdom into physical artifacts. The practice of Polopalo manufacturing has experienced a technological transition from the traditional phase toward the manual drill:

- Traditional Thermal Perforation Technique: Resonator hole creation in the past relied on iron stakes or nails heated over glowing embers to gradually burn through the bamboo wall. Acoustically, this burning method leaves a carbon/charcoal layer on the inner rim of the hole, which indirectly increases the rigidity of the hole's perimeter and plugs the pores of the bamboo fibers, thereby generating a distinctive vibration damping characteristic.
- Modern Mechanical Perforation Technique: The use of modern manual drills accelerates production time and yields geometrically sharper, more precise hole edges. Although it increases hole size consistency (such as standardizing the hole to the size of an ABC battery), this mechanical technique can leave fine micro-fibers behind if the drill blade is not sharp, potentially triggering minor frequency deviations.

The physical fragility of bamboo material against weather fluctuations and long-term usage poses a major challenge to the preservation of this instrument. Any structural damage, even as minor as a hairline crack or a split on the blade body, will instantly alter the acoustic impedance and kill the resonance of the Polopalo sound. Although artisans possess emergency mitigation methods, such as gluing or mechanical rope binding, these actions alter the total mass of the blade and automatically shift the accuracy of its original pentatonic scale.

Therefore, the formulation of Blade Geometry Standardization and the creation of a Digital Sound Bank based on authentic Polopalo frequencies become highly crucial steps. Digital documentation not only locks the Prominent frequency (f_0) against extinction caused by the physical degradation of the bamboo but also archives the rich oral production techniques of elderly Gorontalo artisans into scientific parameters that can be replicated by future generations without losing their cultural identity.

Based on the video interview transcript with the second informant, vital new ethnoorganological data emerged to enrich your proposal analysis. The informant explained about *bambu talilo* (local rope bamboo), a specific material that exhibits dense and hard fiber characteristics if allowed to mature and dry naturally on its tree. Interestingly, the informant stated that coastal bamboo possesses less dense fibers and is of inferior quality; thus, artisans must specially order *bambu talilo* from deeper mountainous forest areas to guarantee the sound quality of the Polopalo.

One of the significant findings in both the sociocultural and technical aspects is the sensitivity of the material's acoustic durability. Mr. Karto explained that mechanical deformation, shape changes, or any physical damage no matter how minor to the bamboo tube structure will directly affect and degrade the purity of the Polopalo sound. Nonetheless, the local wisdom of the artisans includes a physical restoration mitigation system: a cracked or broken bamboo blade can be repaired by gluing it with a specialized adhesive or binding it tightly with rope to restore the compactness of the instrument's resonance chamber.

Modern challenges, marked by the widespread shift from bamboo base materials to wood as well as the transition toward the modern diatonic scale, not only threaten the preservation of Polopalo as an Intangible Cultural Heritage (ICH) but also negatively impact the environmental degradation of Tomini Bay. The interconnectedness between the preservation of the instrument and the ecosystem of *talilo huidu* bamboo in the highlands of Bone Bolango forms a mutualistic ecoacoustic chain. Conserving local bamboo groves to guarantee the raw material availability for Polopalo directly supports the restoration of buffer forest ecosystems.

IV. CONCLUSION

This study has successfully formulated an organological science standardization and identified the physical-acoustic characteristics of talilo huidu bamboo from Bone Bolango in the Tomini Bay area as the primary raw material for the Polopalo instrument. The standardized geometric formulation to maintain the traditional pentatonic pitch accuracy includes an effective blade length of 154 mm, a vibrating wall thickness of 10–12 mm, and a proportionally scaled acoustic resonator hole. Quantitative FFT analysis maps the fundamental frequency (f0) range of the instrument between 517 Hz and 643 Hz, characterized by a rich inharmonic series profile.

V. ACKNOWLEDGMENTS

The author wishes to express the highest gratitude to Universitas Negeri Gorontalo for funding this research and providing the necessary institutional support to complete this project. Deepest appreciation is also extended to the traditional Polopalo maestros and artisans in Bone Bolango, Tomini Bay area, for their invaluable cooperation and generosity in sharing their traditional knowledge, oral histories, and acoustic practices as the primary data sources for this study

REFERENCES

[1] UNESCO, Convention for the Safeguarding of the Intangible Cultural Heritage. United States of America: UNESCO Cultural Sector, 2003.

[2] R. Ohi, 'Polopalo: Tinjauan Etnoorganologi Akustik,' ***Selonding Jurnal Etnomusikologi***, vol. 16, no. 2, pp. 125–138, 2020.

[3] R. Ohi, 'Ekologi Polopalo dalam Lihuta lo Polopalo di Bone Bolango,' ***Selonding: Jurnal Etnomusikologi***, vol. 19, no. 1, pp. 45–58, 2023.

[4] R. Ohi, 'Filosofi Bunyi Polopalo Pentatonik sebagai Karakter Keseimbangan Masyarakat Gorontalo,' ***Jurnal Penelitian Pembelajaran Matematika dan Sains***, vol. 8, no. 2, pp. 89–98, 2024.

[5] R. Ohi and A. N. Wijayanto, 'Transformasi Polopalo sebagai Media Hiburan Masyarakat Gorontalo di Lihuta Lo Polopalo,' Ideas: ***Jurnal Pendidikan, Sosial, dan Budaya***, vol. 9, no. 3, pp. 997–1004, 2023.

[6] E. Suriani, 'Bambu Sebagai Alternatif Penerapan Material Ekologis: Potensi dan Tantangannya,' Indonesian ***Journal of Architecture***, vol. 3, no. 1, pp. 45–56, 2017.

[7] M. A. Kolar, 'Archaeacoustics: Re-Sounding Material Culture,' Acoustics Today, vol. 14, no. 2, pp. 22–31, 2018.

[8] H. Taylor and A. Hurley, 'Music and environment: Registering contemporary convergences,' ***Journal of Music Research Online***, vol. 6, pp. 1–8, 2015.

[9] I. D. N. Raka, I. G. N. A. Wiswasta, and I. M. Budiasa, 'Pelestarian Tanaman Bambu sebagai Upaya Rehabilitasi Lahan dan Konservasi Tanah di Daerah Sekitar Mata Air pada Lahan Marginal di Bali Timur,' Agrimeta, vol. 1, no. 01, pp. 2–23, 2011.

[10] J. W. Creswell, Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 4th ed. Thousand Oaks, CA, USA: SAGE Publications, 2014.

[11] G. Baier and T. Hermann, 'Sonification: listen to brain activity,' in Music that works: Contributions of biology, neurophysiology, psychology, sociology, medicine and musicology, R. Haas and V. Brandes, Eds. Vienna, Austria: Springer, 2009, pp. 11–23.

[12] S. Feld, Sound and Sentiment: Birds, Weeping, Poetics, and Song in Kaluli Expression, 3rd ed. Philadelphia, PA, USA: University of Pennsylvania Press, 2012.

[13] B. C. Pijanowski, L. J. Villanueva-Rivera, S. L. Dumyahn, A. Farina, B. L. Krause, B. M. Napoletano, S. H. Gage, and N. Pieretti, 'Soundscape Ecology: The Science of Sound in the Landscape,' BioScience, vol. 61, no. 3, pp. 203–216, 2011.

[14] N. H. Fletcher and T. D. Rossing, The Physics of Musical Instruments, 2nd ed. New York, NY, USA: Springer, 1998.

[15] M. J. Kartomi, On Concepts and Classifications of Musical Instruments. Chicago, IL, USA: University of Chicago Press, 1990.

[16] A. V. Oppenheim and R. W. Schafer, Discrete-Time Signal Processing, 3rd ed. Upper Saddle River, NJ, USA: Prentice Hall, 2010.

[17] I. W. Sudana, 'Fungsi Seni Tradisional dalam Kehidupan Sosial Budaya Masyarakat Gorontalo,' Ideas: ***Jurnal Pendidikan, Sosial, dan Budaya***, vol. 8, no. 2, pp. 601–610, 2022.

[18] A. Smith and B. Arthur, 'The Mechanics of Bamboo Resonance: Internal Damping and Structural Acoustics,' ***Journal of Wood Science***, vol. 65, no. 4, pp. 312–325, 2019.

[19] A. P. Merriam, The Anthropology of Music. Northwestern Illinois, IL, USA: Northwestern University Press, 1964.