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The Bridge of Tradition and Learning Science: Mapping Ethnochemical Mental Models Based on the *Sasisen* and *Napnap* Mor Traditions of the Biak Ethnic, Papua, Indonesia

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ABSTRACT
In culturally rich regions such as Papua, Indonesia, formal science education is often disconnected from students' lived experiences, creating a gap between the abstract chemistry curriculum and the local ethnochemical knowledge embedded in ancestral traditions of the Biak ethnic group, particularly Sasisen and Napnap Mor. This study emphasizes the importance of integrating local wisdom to bridge this gap. This study aims to reconstruct the implicit ethnochemical knowledge within these traditions by mapping the community's mental models using Johnstone's Triangle multi-level framework, thereby connecting local knowledge with the formal chemistry curriculum. A qualitative approach was employed, using triangulation of data from in-depth interviews, participant observation, and document analysis. The data were analyzed based on Johnstone's three levels of chemical representation. The findings reveal culturally developed mental models (emics) among the Biak people that align empirically with modern chemical concepts (etics), especially in the use of natural materials related to the functions of secondary metabolites. This mapping confirms that the Sasisen and Napnap Mor traditions provide rich contextual foundations for chemistry learning. Integrating Biak traditions into the chemistry curriculum enhances the relevance of science education and students' scientific literacy while also contributing to cultural preservation and the decolonization of science education. This study offers a local wisdom-based pedagogical model that supports sustainable development.

KEYWORDS
Ethnochemistry; mental models; *Sasisen*; *Napnap* Mor; chemical representation.

INTRODUCTION

Incorporating indigenous knowledge into contemporary science curricula is increasingly recognized as an effective approach to enhancing the relevance, inclusivity, and depth of education, particularly in culturally diverse regions. This pedagogical shift enriches the educational experience by integrating local knowledge systems and cultural practices into formal instruction. Indigenous knowledge systems offer valuable perspectives and approaches that often align with modern scientific concepts, fostering a more comprehensive and culturally grounded understanding of science (Handayani et al., 2018). Historically, figures such as the Indian Rishis contributed significantly to various scientific fields, emphasizing careful observation, systematic experimentation, and holistic reasoning. Moreover, their teaching methods, including oral transmission and experiential learning, promoted critical thinking and creativity, addressing the fragmented and abstract tendencies often found in contemporary science education (Goyal, 2025; Yigit, 2017).

Research has shown that incorporating African indigenous knowledge into science education increases cultural relevance and strengthens student engagement (Kugara & Mdhluli, 2023; Omodan et al., 2024). These findings have supported the development of an integrated indigenous knowledge-based science education framework, which emphasizes teaching science in indigenous languages as a key step toward decolonizing education and empowering students (Aina, 2025). In addition, the inclusion of indigenous knowledge promotes intercultural learning and strengthens sustainability education by connecting traditional ecological knowledge with scientific inquiry, helping students better understand local ecosystems and encouraging sustainable thinking and practices (Ijatuyi et al., 2025; Nqabeni, 2024). This approach situates science within a culturally meaningful context for diverse learners, improves affective and emotional learning outcomes, and supports a deeper understanding of scientific concepts, ultimately encouraging student participation in addressing complex environmental and social challenges while fostering both global citizenship and respect for local wisdom.

Incorporating local wisdom into science education is a promising strategy to enhance scientific literacy while also supporting students' overall character development. By using culturally relevant content, this approach increases student engagement and highlights the meaningful value of scientific learning, leading to improved educational outcomes (Simbolon et al., 2025; Sevnarayan, 2022). Integrating indigenous knowledge systems not only strengthens students' understanding of fundamental scientific concepts but also builds a strong connection to their cultural heritage, contributing to both sustainable development and cultural preservation (Nwachukwu & Azuka, 2024). Previous studies support this perspective, showing that embedding local wisdom in science curricula significantly improves scientific literacy. Indigenous knowledge also provides a socio-scientific context that helps students connect abstract scientific ideas to real societal challenges, aligning closely with global sustainable development goals (Erman & Wakhidah, 2024; Ramírez-Montoya et al., 2025). Therefore, integrating local wisdom into science education helps bridge indigenous knowledge with

expected student competencies (Arjaya et al., 2024). Beyond cognitive benefits, this approach also promotes cultural awareness and character formation, as science learning grounded in local traditions can strengthen students' commitment to preserving cultural heritage and offer a meaningful pathway for heritage conservation and sustainable tourism. Moreover, character education grounded in local wisdom can be effectively cultivated through extracurricular activities, collaborative learning, and the meaningful use of local languages, thereby helping to prevent the erosion of ethical and moral values among students (Setya et al., 2024). The ancestral traditions of the Biak ethnic community in Papua Province, Indonesia, namely *Sasisen* and *Napnap Mor*, represent a compelling example of this form of local wisdom.

Sasisen is a traditional temporary moratorium on the use of marine and terrestrial resources, intended to provide time for ecosystem regeneration, whereas Napnap Mor is the collective harvesting activity conducted after the Sasisen period ends. These practices function not only as effective conservation mechanisms but also as important means of transmitting ecological knowledge and ethnochemistry across generations, including implicit chemical concepts related to atmospheric cycles, material transformations, and nutrient recycling. However, the contextual chemical knowledge (emics) embedded in these traditions is often neglected in formal education, resulting in a disconnect between students' lived experiences and the abstract chemical content presented in schools.

Integrating local knowledge, particularly the *Sasisen* and *Napnap Mor* traditions, into science education is essential because these practices contain implicit ethnochemical concepts that can be systematically examined through Johnstone's Triangle framework (Gilbert & Treagust, 2009; Johnstone, 1993). Analyzing community mental models using this multi-level approach offers a pathway for meaningful knowledge reconstruction Treagust et al. (2002), yet a persistent disconnect remains between indigenous wisdom and the formal chemistry curriculum, especially in remote regions such as Papua. Previous studies have shown that incorporating indigenous knowledge enhances learning relevance and conceptual depth (Aikenhead & Ogawa, 2007; Zidny et al., 2020). However, three key gaps remain. First, there is a methodological gap, as few studies link ethnochemistry with multi-level mental model analysis across macroscopic, submicroscopic, and symbolic representations within Johnstone's framework. Second, there is an evidence gap concerning the specific chemical conceptualizations held by the Biak community, particularly within *Sasisen* and *Napnap Mor*. Third, a practical gap exists due to rapid sociocultural changes, including commercialization and reduced intergenerational transmission, which threaten the preservation of ethnochemical knowledge (Junaedi et al., 2022). Addressing these gaps is crucial for both cultural preservation and the development of a more culturally responsive chemistry curriculum.

To address this gap, this study examines ethnochemistry through the lens of the mental model framework. Mental models are internal cognitive representations shaped by experience and culture that individuals use to interpret their environment. In science education, mapping mental models is essential for identifying students' existing conceptions and reconstructing

them into more meaningful scientific understanding. This framework supports the translation of observable phenomena at the macroscopic level into submicroscopic explanations and symbolic representations in formal scientific language (Gilbert & Treagust, 2009). Although *Sasisen* and *Napnap Mor* have been widely studied from anthropological and conservation perspectives, research that explicitly integrates ethnochemistry, community mental models, and the three levels of chemical representation within the Biak context remains scarce. Therefore, this study aims to reconstruct the implicit ethnochemical knowledge embedded in the *Sasisen* and *Napnap Mor* traditions by mapping the Biak community's mental models using Johnstone's Triangle framework, thereby bridging indigenous knowledge with the formal chemistry curriculum. To accomplish this objective, the following research questions were formulated:

RQ1: What key ethnochemical concepts are embedded in the *Sasisen* and *Napnap Mor* traditions of the Biak ethnic group as observed at the macroscopic level?

RQ2: How are these ethnochemical concepts represented in the community's mental models at the submicroscopic and symbolic levels of chemical representation?

RQ3: What sociocultural and environmental factors influence the formation and preservation of these ethnochemical mental models within the Biak community?

RQ4: How can the mapping of these mental models provide a foundation for integrating indigenous knowledge into the formal chemistry curriculum?

METHODOLOGY

Sasisen is a traditional Biak practice that temporarily closes certain coastal areas to allow natural resources to regenerate, while *Napnap Mor* refers to the traditional knowledge of using specific marine and plant materials for preservation and medicinal purposes, and together these practices represent important expressions of Biak ethnochemistry.

Research design and units of analysis

This study employed a qualitative ethnographic design to explore the shared knowledge systems and cultural meanings embedded within the Biak ethnic community. Ethnography was selected to enable an in-depth understanding of the community's perspectives and practices. The unit of analysis consisted of ethnochemical mental models, defined as the internal cognitive representations of chemical phenomena related to the *Sasisen* and *Napnap Mor* traditions. To ensure rigorous analysis within chemical education, Johnstone's Triangle (1993) served as the primary theoretical framework. Rather than being used solely for post hoc classification, this framework functioned as an analytical lens to connect macroscopic traditional practices with submicroscopic chemical principles and symbolic representations, thereby maintaining focus on participants' cognitive structures concerning material transformations.

Participants and data collection

1. The primary data sources for this study consisted of 16 key informants purposively selected based on their roles in preserving Biak traditions. The participants included 11

customary leaders (Mananwir), one village head, one church leader, one district official, one community elder, and two NGO practitioners. Data collection followed a rigorous qualitative protocol to ensure depth, credibility, and objectivity.

2. Semi-structured interviews: Each interview lasted 45–60 minutes and was conducted in Bahasa Indonesia to ensure clear communication without translators. To build rapport and honor local emic principles, researchers followed the Manseren Mangun protocol by conducting preliminary visits and informal discussions with the Mananwir prior to the formal interviews.

3. Field observations: Direct observations were carried out at *Napnap Mor* sites in Kampung Inpendi using a structured observation grid (see Table 2) to document the sequence of activities, characteristics of natural materials, and environmental context. The process was documented through photographs and videos with customary consent.

Research instruments

The primary instrument in this study was the researchers themselves (human instrument), who facilitated in-depth inquiry while maintaining scientific objectivity. To minimize subjective bias, two structured instruments were employed to support data collection and analysis: Two structured tools were used to support data collection and reduce subjectivity: an interview grid (Table 1, see appendix), consisting of thematic open-ended and non-leading questions organized around local knowledge, macroscopic observations, and submicroscopic mental representations related to material preservation and medicinal aspects of *Napnap Mor* , and an observation grid (Table 2, see appendix), a detailed categorization sheet designed to systematically record what and how the *Sasisen* and *Napnap Mor* practices are carried out, while clearly distinguishing between the resource management aspects of *Sasisen* and the material preservation and medicinal aspects of *Napnap Mor*.

Data on trustworthiness and credibility

To ensure credibility and rigor, this study employed triangulation of data sources by cross-referencing interview transcripts with field observation notes and photographic documentation, thereby confirming that the interpretations accurately reflected the community's emic perspectives rather than the researcher's subjective assumptions.

Data analysis

This study employed thematic analysis following Braun and Clarke (2006). This method was selected over Miles et al.'s interactive analysis to enable a more nuanced reconstruction of participants' mental models. The analysis was conducted separately for *Sasisen* as a resource management tradition and *Napnap Mor* as a material preservation and medicinal tradition, and the findings were subsequently synthesized into an integrated ethnochemical framework.

RESULT AND DISCUSSION

The results of this study provide a comprehensive mapping of the ethnochemical mental models embedded in the *Sasisen* and *Napnap Mor* traditions of the Biak ethnic group. To ensure clarity and objectivity, the collected qualitative data were analyzed systematically.

Thematic coding and analytical process

Thematic coding was conducted through a systematic three-stage process to ensure analytical rigor. First, open coding was applied to interview transcripts and observation notes to identify initial semantic descriptors related to Biak traditions. Second, axial coding was used to organize these descriptors into five core themes: local community knowledge (*efrai*), key ethnochemical concepts, mental representations, sociocultural factors, and challenges.

Crucially, these themes were analyzed using a deductive–inductive approach through the lens of Johnstone's Triangle. For example, local descriptions of material "strength" or "potency" were coded at the macroscopic level, whereas the community's internal reasoning about material interactions was coded at the submicroscopic level. This process enabled the reconstruction of implicit mental models from explicit cultural narratives. Sub-codes were then developed for each theme based on specific indicators (see Table 3, see Appendix) to refine the classification and ensure that the resulting conceptual map was theoretically grounded in chemical education principles.

Thematic coding in this study functioned not simply as a process of categorization but as a reconstructive analytical strategy aimed at translating the community's internal logic into formal scientific frameworks. As presented in Table 3, raw data related to *Sasisen* and *Napnap Mor* were systematically coded into five central themes. This structured coding scheme enabled the researchers to clearly identify conceptual "bridges" between empirical traditional practices and formal chemical representations at the macroscopic, submicroscopic, and symbolic levels.

The Sasisen and Napnap Mor traditions of the Biak ethnic community provide a profound example of an ethnochemical framework that combines social, spiritual, and scientific principles and effectively functions as a model for natural resource conservation, as summarized in Table 3. The Sasisen tradition operates as a temporal closure system that allows biota and ecosystems to recover, reflecting concepts similar to taboo fishing practices in the South Pacific; at the submicroscopic level, this prohibition helps maintain the balance of nutrient cycles such as carbon, nitrogen, and phosphorus, which are essential for sustaining aquatic food webs. At the symbolic level, visual markers such as flags and designated forest boundaries reinforce communal adherence to these rules. The Napnap Mor tradition, which utilizes Elang leaves as a fish attractant, demonstrates practical yet implicit knowledge of plant secondary metabolites, including saponins and terpenoids, that influence fish behavior. In addition, traditional practices such as saguer fermentation and coconut oil production reveal an experiential mastery of chemical processes such as transformation and separation developed through generations of observation and practice. Together, these traditions illustrate how indigenous knowledge systems embody core principles of chemistry and environmental conservation, offering valuable insights for contemporary science education.

The Sasisen tradition represents a complex cosmological framework that illustrates the interdependence between humans and nature, serving as a foundation for sustainable environmental management and biodiversity protection (Malawat et al., 2024). Ethnochemistry

contributes to chemistry education by integrating cultural practices into instructional materials, thereby increasing relevance and student engagement, as demonstrated by the incorporation of the Baduy community's use of natural materials into teaching resources (Munandar et al., 2024). Similarly, the Sasisen tradition in Maluku, Indonesia demonstrates how indigenous approaches that integrate spiritual and cultural values can strengthen contemporary environmental accounting and resource management practices, consistent with the triple bottom line framework of sustainability (Malawat et al., 2024). Integrating indigenous cultural practices into the chemistry curriculum not only enhances students' conceptual understanding of chemical principles but also reinforces their cultural identity, fostering a more inclusive and contextually meaningful educational experience.

Key ethnochemical concepts

The results of coding the key ethnochemical concepts are presented in Table 4 (see appendix), which outlines the local terminology used by the Biak ethnic group and demonstrates its empirical alignment with modern chemical principles embedded within the *Sasisen* and *Napnap Mor* traditions.

The *Sasisen* and *Napnap Mor* traditions of the Biak ethnic group are grounded in ethnochemical concepts, reflected in their use and transformation of natural materials, which demonstrate a deep integration of cultural and chemical knowledge (Table 4). The *Napnap Mor* tradition involves the application of Elang leaves and the introduction of the fermented product saguer into the environment, while the *Sasisen* tradition includes the temporary restriction of coconut harvesting, followed by traditional processing into coconut oil through triglyceride hydrolysis, implicitly indicating an understanding of chemical transformation. However, coastal abrasion increasingly threatens the sustainability of this practice by reducing the availability of coconut trees, particularly in Yendidori Village. These traditions illustrate a sophisticated understanding of natural resources, and their ethnochemical analysis highlights the value of integrating indigenous knowledge with contemporary scientific principles to preserve cultural heritage and contextualize chemistry education. Additional cultural practices, such as the use of *Asystasia gangetica* and *Morinda citrifolia* as natural dyes in handicrafts, further demonstrate implicit knowledge of plant chemistry and interactions with mordants. Similarly, the Sasisen tradition in Maluku and Papua, including Biak, establishes regulated harvesting intervals to prevent overexploitation, thereby conserving biodiversity and reflecting an understanding of ecological balance, a central concept in environmental chemistry.

Mental representations

The results of coding the community's mental representations are presented in Table 5, illustrating how the internal perspectives and understandings of the Biak ethnic community regarding the *Sasisen* and *Napnap Mor* traditions are translated into visual concepts and shared beliefs that guide their ethnochemical practices.

Cultural factors

The *Sasisen* and *Napnap Mor* traditions of the Biak ethnic community are sustained by a cognitive framework comprising three interwoven forms of mental representation (Table 4): narrative (e.g., oral traditions, stories of eagles, and taboos), symbolic (e.g., coconut leaves, crosses on plants, and flags or poles [apyeper] marking sasi areas), and analogical (e.g., the philosophy of a "triangle of balance between humans, nature, and God"). These representations function as a cognitive structure that guides community practices across generations. This framework can be understood through the lenses of cultural codes, collective cognitive structures, and emergent cultural cognition. Cultural codes, such as symbols and oral narratives featuring figures like Manarmakeri and Marmar (Sriyono et al., 2015), act as narrative devices that preserve community values, beliefs, and social organization. Collective cognitive structures support the continuity and shared understanding of traditions such as *Sasisen* and *Napnap Mor* through rituals and social interaction (Romney & Moore, 1998). Finally, emergent cultural cognition emphasizes the dynamic nature of these traditions, enabling the Biak community to adapt and reinterpret practices in response to contemporary contexts while maintaining their core values, thereby ensuring continued relevance (Cicourel, 2015).

Table 6 (see appendix) presents the results of categorizing the cultural factors that shape the community's mental models. This section aims to identify the non-scientific influences that affect the interpretation and practice of ethnochemistry within the Biak ethnic group.

Challenges and opportunities

The continuity of the *Sasisen* and *Napnap Mor* traditions within the Biak ethnic community depends largely on customary and community leaders, who employ spiritual authority and traditional knowledge to ensure adherence (Table 6). These traditions are central to cultural identity and spiritual life, embodying indigenous knowledge while functioning as mechanisms for cultural education and social cohesion (Fatmi et al., 2024). However, these ethnochemical practices face *considerable* internal and external challenges. The growing influence of government institutions, religious organizations, and tourism has transformed *Napnap Mor* into a form of cultural "euphoria," potentially shifting its values and undermining authenticity. Broader pressures such as industrialization and globalization contribute to declining youth engagement (Lasaiba, 2024), while economic constraints encourage shifts toward less culturally grounded livelihoods. In addition, climate change and environmental degradation threaten the sustainability of these resource-based traditions (Ahmed, 2015). Preserving this cultural heritage requires a comprehensive strategy, including active involvement of elders and cultural leaders (Fajinmi & Oloyede, 2025), revitalization of youth engagement through educational initiatives that integrate traditional knowledge into formal curricula (Lasaiba, 2024), governmental and stakeholder support for legal and financial protection (Fajinmi & Oloyede, 2025), and adaptive approaches that ensure continued relevance in contemporary contexts.

Table 7 (see appendix) presents the results of coding the fifth aspect, focusing on the challenges and opportunities associated with preserving the community's ethnochemical

knowledge. This section identifies and analyzes key internal and external obstacles faced by the Biak ethnic group in sustaining the *Sasisen* and *Napnap Mor* traditions, including declining interest among younger generations and the limited documentation of traditional knowledge.

Final thematic coding results

The ethnochemical knowledge of the Biak ethnic community, embodied in the Sasisen and Napnap Mor traditions, faces significant threats due to the fragility of oral transmission and ongoing shifts in cultural values (Table 7). Nevertheless, these challenges are balanced by strong internal community commitment and meaningful opportunities for ethical collaboration with external partners. The long-term sustainability of Biak's ethnochemical heritage depends on the community's capacity, supported by academics and government institutions, to transform the risks of cultural erosion into structured efforts for documentation and revitalization. All key stakeholders, including customary leaders, religious figures, community members, and government representatives, express consistent support for preserving these traditions and restoring their authentic cultural and spiritual meaning beyond their current reduction to "euphoric attractions,'' Such collaboration must be inclusive, consultative, and clearly goal-oriented, while respecting the autonomy and intellectual property rights of the indigenous community (Dwyer, 2010; Zega et al., 2025). Capacity-building initiatives and collaborative training are essential to ensure sustainable community benefits (Dwyer, 2010). Systematic documentation and archiving of indigenous knowledge, including medicinal and plant resource practices (Pangestu et al., 2025), are therefore crucial for long-term cultural preservation.

The content analysis of the interview transcripts identified five primary thematic aspects: (1) cultural traditions and practices; (2) key ethnochemical concepts; (3) mental representations; (4) cultural factors influencing mental models; and (5) challenges and opportunities in preserving ethnochemical knowledge. To provide a comprehensive and integrated overview of the findings, Table 8 presents a consolidated summary of all analytical results.

Mental model mapping

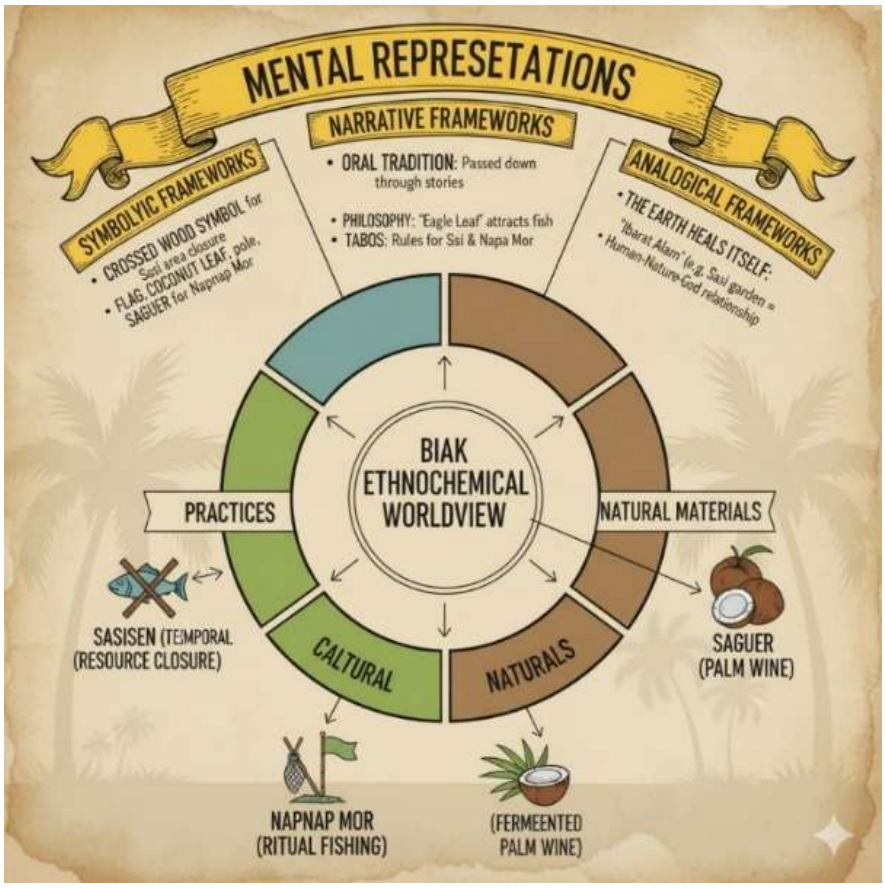
The *Sasisen* and *Napnap Mor* traditions of the Biak ethnic community represent an ethnochemical mental model—an integrated, conservation-oriented knowledge system grounded in natural material use and reinforced through symbolic markers such as crossed wood signs and flags. Customary leaders play a central role in sustaining these practices. However, this system now faces a severe crisis (Table 8) due to pressures from modernization and commercialization. A particularly striking paradox has emerged: *Napnap Mor*, originally intended as a conservation practice, is increasingly transformed into a large-scale "euphoric" cultural festival or fundraising event (Umar & Iskandar, 2023), attracting massive crowds for fishing activities that result in coral reef damage and threaten a fragile ecosystem that has endured for centuries. This environmental degradation reflects a shift from core conservation values toward short-term economic interests. The situation highlights the vulnerability of Biak's indigenous knowledge system, which offers deep ecological insight essential for sustainable

resource management and biodiversity protection (Umar & Iskandar, 2023). Sasisen practices demonstrate how principles of limitation, regulation, and collective decision-making contribute to environmental conservation. Yet, the gradual erosion of indigenous knowledge through Westernization and its limited integration into formal conservation frameworks further intensify the risks to both cultural and ecological sustainability (Masenya & Bhuda, 2025; Wandix-White, 2020).

The culmination of the thematic coding process resulted in the development of a comprehensive conceptual map outlining the Biak community's mental model. Visually presented in Figures 1 and 2, this map systematically depicts the interconnections among the core components that define the Biak ethnochemical worldview.

Figure 1.

Concept map of mental representation of chemistry of Biak ethnic society

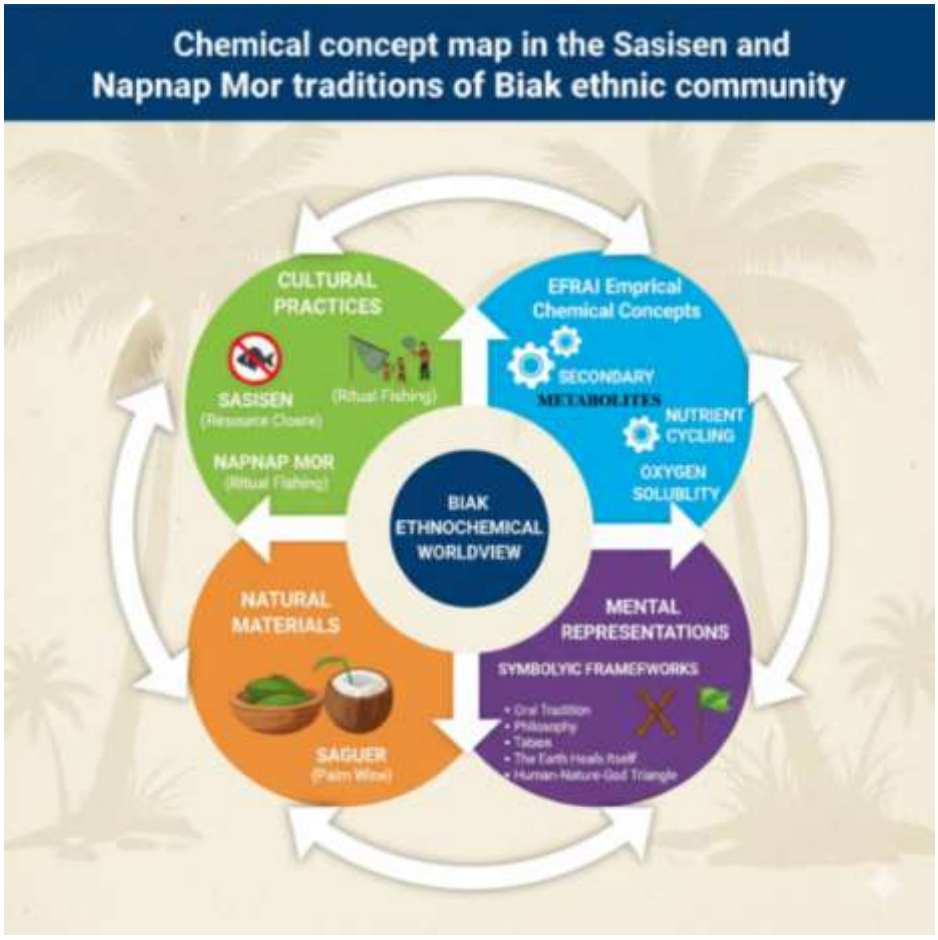


(Source: Developed by authors based on field data and Johnstone's (1991) framework. Visual layout assisted by Gemini AI).

Figure 1 presents a concept map that systematically illustrates the close interconnections within the ethno-chemical worldview of the Biak ethnic community. At the center of this worldview are four primary interacting components: cultural practices, particularly *Sasisen* (temporal resource closure) and *Napnap Mor* (ritual fishing), which are directly connected to the natural materials employed in these traditions, including eagle leaves (used to attract fish), saguer (fermented palm wine), and coconut.

Figure 2.

Chemical concept map in the Sasisen and Napnap Mor traditions of the Biak ethnic community.



(Source: Developed by the authors based on field data regarding the Sasisen and Napnap Mor traditions, structured using Johnstone's (1991) chemical representation framework. The visual layout was generated with the assistance of Gemini AI).

Frequency data for the *Sasisen* and *Napnap Mor* traditions

Tables 9 and 10 present the frequency data related to the *Sasisen* and *Napnap Mor* traditions. This section provides a quantitative analysis that measures how often specific themes and concepts appear in the Biak community's discourse, thereby indicating their relative emphasis and significance within the ethnochemical mental model.

Table 9.

Frequency data of keywords for Sasisen and Napnap Mor traditions

Keyword	Frequency
Sasisen	28
Napnap Mor	25
Elang leaves	10
Prohibition	15
Coral reefs	7
Wor	5
Coconut	12
Tides	9

The information presented in Table 9 shows that "*Sasisen*" (28 occurrences) and "*Napnap Mor*" (25 occurrences) are the most frequently mentioned keywords, confirming that both function as central cognitive nodes within the Biak community's local knowledge structure. Their high frequency suggests that these traditions are not peripheral cultural activities but instead serve as the primary normative and functional framework for natural resource management. The repeated appearance of "prohibition" (15) and "taboo" (8) indicates that informants conceptualize these traditions as socio-ecological regulatory systems, where taboos act as behavioral control mechanisms that implicitly embody precautionary principles by regulating the timing and methods of resource use in alignment with modern sustainability concepts. The relatively high frequency of "conservation" (14) reflects a shared ecological awareness within the community and may represent a contemporary articulation of traditional values. This ecological orientation is reinforced by references to observable natural elements such as "coconut" (12), "Elang leaf" (10), "tides" (9), and "coral reef" (7), suggesting that these traditions are grounded in empirical knowledge of local biological materials and environmental processes. From an ethnochemical perspective, the specific mention of materials such as the Elang leaf indicates practical understanding of plant properties and their functional roles. In contrast, the lower frequency of "Wor" (5) suggests that ceremonial or artistic aspects are less emphasized compared to ecological and functional dimensions. Overall, the keyword distribution demonstrates that *Sasisen* and *Napnap Mor* integrate ecological regulation, social norms, and material knowledge into a coherent mental model that supports sustainable coastal resource management.

Table 10.

Frequency of keywords for mental representation of society

Type of Representation	Keyword	Frequency
Symbolic	Coconut leaves	1
	Sign of the cross	1
	Saguer	4
	Flag	1
	Pole	1
Narrative	Story	2
	Philosophy	2
	Eagle bird	3
	Taboo	4
Analogical	Like	4
	As if	4

The Biak ethnochemical mental model is highly effective for intergenerational knowledge transfer because it relies primarily on oral mechanisms, particularly narrative and analogical frameworks, rather than on visual symbols, as supported by the quantitative data in Table 10. Although certain visual elements such as "saguer" (4 mentions) appear in the discourse,

symbolic representations overall are less consistent and less dominant than oral forms. The narrative framework is strongly grounded in rule-based language, with “taboo” (4 mentions) emerging as one of the most recurrent terms, indicating that prohibitive storytelling plays a central regulatory role. Most notably, the analogical framework carries the greatest cognitive weight, as comparative expressions such as “like” and “as if” (4 mentions each) show the highest consistency, suggesting that community members internalize complex ecological and chemical processes through comparison with familiar social experiences. While visual markers may serve to designate or signal practices, the oral tradition, including storytelling, the articulation of taboos, and the use of analogy, functions as the primary mechanism for explaining, legitimizing, and transmitting ethnochemical knowledge. In interpreting Tables 9 and 10, keyword frequency can be understood as a proxy for cognitive saliency within the collective mental model. The prominence of terms such as “*Sasisen*” and “prohibition” indicates that ethnochemical knowledge is structured as a normative-functional system rooted in regulation and ecological balance. Furthermore, the reliance on analogical representations demonstrates how abstract chemical and environmental interactions are cognitively framed through culturally meaningful comparisons. This integration of empirical observation and symbolic meaning reinforces the view that *Sasisen* and *Napnap Mor* are not merely ritual practices but constitute a sophisticated indigenous scientific system relevant to sustainable resource management. The narrative-analogical strategy enhances retention and memorization, aligning with broader theories of cultural transmission that emphasize storytelling and metaphor as effective vehicles for preserving complex knowledge across generations (Jones & Hilde-Jones, 2023). Examples such as metaphorical expressions in Biak folksongs (Fatubun & Rumansara, 2022) illustrate how new or abstract ideas are connected to familiar contexts (Brand et al., 2020), facilitate the communication of tacit knowledge (Miton & Dedeo, 2022), and contribute to the long-term stability and resilience of Biak cultural knowledge systems (Miton & DeDeo, 2022).

Analysis of three levels of chemical representation (Johnstone’s Triangle)

The analysis of chemical concepts embedded in the Biak traditions is structured according to Johnstone’s Triangle, encompassing the macroscopic, submicroscopic, and symbolic levels of representation, as summarized in Table 9. At the macroscopic level, *Sasisen* is understood as a temporary closure of resource exploitation, a clearly observable practice aimed at allowing ecosystems to recover, while *Napnap Mor* involves the practical use of natural materials such as Elang leaves, saguer, and coconut in fishing, preservation, and processing activities. At the submicroscopic level, these practices implicitly relate to chemical and ecological processes, including nutrient cycling, material transformations, and the role of secondary metabolites in influencing biological systems. For example, the temporary prohibition in *Sasisen* contributes to the stabilization of C, N, and P cycles in marine environments, while the use of plant materials in *Napnap Mor* reflects an empirical understanding of bioactive compounds and fermentation processes. At the symbolic level, these practices are preserved and reinforced through customary terms, taboos, ritual narratives, and visual markers such as flags and crossed wood

signs, which encode and transmit complex ecological and chemical meanings within the community. By systematically mapping these ethnochemical practices across the three representational levels, this analysis demonstrates a strong conceptual bridge between the local wisdom of the Biak ethnic group and the structured framework of formal chemistry, confirming that indigenous practices embody coherent and scientifically relevant knowledge systems.

Data triangulation results

The findings presented in Table 9 confirm that *Sasisen* and *Napnap Mor* are not merely cultural rituals but represent knowledge systems with a strong scientific foundation. These traditions can be coherently interpreted through the three levels of scientific representation proposed by Johnstone: macroscopic, submicroscopic, and symbolic. At the macroscopic level, the community observes tangible phenomena such as ecosystem recovery during *Sasisen* or the practical effects of natural materials used in *Napnap Mor*. At the submicroscopic level, these practices implicitly relate to underlying chemical, biological, and physical mechanisms, including nutrient cycling, fermentation processes, and the action of plant secondary metabolites. At the symbolic level, customary terms, taboos, and ritual markers function as encoded representations that preserve and transmit this knowledge across generations. Biak ethnochemical knowledge thus offers a clear example of how traditional practices can be translated into the conceptual language of contemporary chemistry, strengthening the relevance of chemistry education. Similar approaches in other cultural contexts, such as the analysis of Acehnese natural materials for food and medicine, have demonstrated improved conceptual understanding and scientific competence when chemistry is contextualized within local traditions (Junaidi et al., 2025; Munandar et al., 2024). Furthermore, integrating cultural insights with scientific literature enables the identification of plausible chemical constituents, such as saponins in Elang leaves, providing explanatory bridges between observed traditional practices and modern chemical principles (Carvalho & Dantas Filho, 2023).

The interview data clarified the cultural meanings, rules, and values underlying *Sasisen* and *Napnap Mor*, as well as the impact of external sociocultural shifts. Field observations validated the technical aspects of the practices, confirming that the rituals were conducted during wampasi, characterized by calm seas and extreme low tide at Inpendi beach, and documenting the use of specific materials such as Elang leaves and symbolic markers including flags and poles. Document analysis, including records from customary institutions, NGOs, and photographic evidence, further confirmed a significant transformation: *Sasisen* and *Napnap Mor* have increasingly shifted from conservation-based systems toward tourist-oriented events. Across all data sources, the technical procedures of the traditions remained consistent. However, a critical difference emerged in how their purpose was interpreted. Indigenous leaders consistently emphasized conservation and spiritual responsibility, whereas external influences increasingly framed the practices in economic and promotional terms. The scarcity of formal written documentation in government archives highlights a serious risk of knowledge erosion, underscoring the urgency of systematic scientific documentation. The spiritual

principles embedded in *Sasi*-based activities prioritize moral and ecological responsibility over short-term economic gain, reinforcing ecological integrity (Ikerd, 2016). In contrast, the commercialization of traditional rituals may weaken their environmental effectiveness, potentially leading to overexploitation of resources and social disruption (Aptasari et al., 2024).

CONCLUSION

This study successfully reconstructed the implicit ethnochemical knowledge embedded in the *Sasisen* and *Napnap Mor* traditions of the Biak ethnic group. By mapping the community's mental models through Johnstone's Triangle multi-level framework, the findings demonstrate that local emic cognitive models are empirically aligned with contemporary chemical concepts at the etic level. This alignment is reflected in practical aspects such as the understanding of natural material utilization, including the role of secondary metabolites and ecological resource management principles. The results confirm that *Sasisen* and *Napnap Mor* are not merely cultural rituals but rich, contextual vehicles for chemistry learning. Integrating Biak local wisdom into the formal curriculum can enhance the relevance of science education, increase student motivation, and strengthen scientific literacy, while simultaneously contributing to cultural preservation and the decolonization of science education. Furthermore, this integration offers a pedagogical foundation that supports sustainable development. Nevertheless, this study has limitations, particularly due to its qualitative and context-specific focus on Biak mental models. Future research should move toward quantitative intervention studies to rigorously evaluate the effectiveness of tradition-based chemistry curricula in improving students' conceptual understanding and pro-environmental attitudes. In addition, cross-cultural comparative studies are needed to explore how ethnochemical mental models are transmitted and transformed amid ongoing social change and commercialization pressures.

Conflict of interest

The authors declare that they have no conflict of interest.

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APPENDIXES

Table 1.

Semi-structured interview grid for eliciting ethnochemical mental models based on Johnstone's Triangle.

Aspect	Indicators	Sources
Local knowledge of chemical concepts is embedded in cultural traditions and practices.	- Types of traditions or cultural practices performed by the community. - Traditions or cultural practices closely related to the use of natural materials from plants, animals, or other substances. - The methods of acquiring knowledge and how it is passed down through generations are also important. - The use of these natural materials has changed traditions or cultural practices over time.	- Customary leaders - Religious leaders - Community leaders - Cultural experts. - Youth leaders. -Non-governmental organization.
Community cultural practices incorporate key ethnochemical concepts.	- The utilization of natural ingredients and materials is a common practice. - Selection process of natural materials. - Processing methods of natural materials.	

There are mental representations (symbolic, narrative, and analogical) associated with ethnochemical practices.	- Narrative representations. - Symbolic representations. - Analogical representations.
Cultural factors play a significant role in the selection of natural materials.	- Cultural factors play a significant role in the selection of natural materials. - Community leaders or customary elders play a specific role. - The selection of natural materials is subject to external influences from beyond the community. - The local community's worldview or perspective plays a significant role.
There are both challenges and opportunities in the preservation of community ethnochemical knowledge.	- The preservation of indigenous ethnochemical knowledge presents significant challenges. - There are opportunities for the preservation of indigenous ethnochemical knowledge.

Table 2.

Structured observation grid for documenting the physical and procedural aspects of Sasisen and Napnap Mor traditions.

Aspect of observation	Indicators
The indicator refers to the general observation of ethnochemical cultural practices.	- Community activities related to the use of natural materials in daily cultural practices. - The selection process of natural materials in customary rituals or traditional medicine. - The process involves selecting natural materials for use in customary rituals or traditional medicine.

	- Community activities aimed at conserving the natural materials used. - Involvement of the younger generation in ethnochemical knowledge-based activities (as practitioners, learners, or observers).
Observation of community mental representations (symbolic, narrative, and analogical).	- Symbols used by the community related to natural chemical substances (symbols in ceremonies, special signs, etc.). - Stories or narratives (through oral delivery, songs, dances, or folklore) circulating in the community regarding the benefits or taboos of certain natural materials. - Use of analogies/metaphors related to the properties of natural materials. - Expressions or attitudes of the community when explaining symbols/narratives related to ethnochemistry.
Observation of cultural factors in the formation of mental models.	- The role of customary leaders or community leaders in ethnochemical practices. - Customary norms or rules governing the utilization of natural chemical substances. - Interactions between community members in the transmission of ethnochemical knowledge. - External influences (modernization, formal education, or technology) on the use of natural materials in cultural practices. - Changes or conflicts in cultural values as a result of modernization or formal education.

Table 3.

Analytical coding grid: Bridging Biak indigenous knowledge with Johnstone's three levels of chemical representation.

Main theme	Sub-themes (Sub-codes)	Local knowledge indicator (emic)	Johnstone's level alignment (Etic)	Chemical reconstruction (the bridge)
Local community	Traditional taxonomy	Identification of plants/materials	Macroscopic	Classification of natural sources

knowledge (*Efrai*)		used in *Sasisen* and *Napnap Mor*.		based on observable physical properties.
Key ethnochemical concepts	Material transformation	Descriptions of changes in color, texture, and odor during processing.	macroscopic	Identification of empirical chemical reaction indicators (e.g., pH changes, oxidation).
Mental representations	Internal logic & mechanisms	Beliefs regarding the "unseen" force or spirit that preserves the materials.	Submicroscopic	Mapping community logic to molecular interactions (e.g., antimicrobial properties of secondary metabolites).
Cultural factors	Normative regulations	Taboos and customary laws (*Sasi*) govern the extraction of materials.	Symbolic/ contextual	Understanding the socio-chemical symbols and the ethics of resource management is crucial.
Challenges & opportunities	Knowledge transmission	Barriers exist in the transmission of knowledge to the younger generation.	Cross-level integration	Assessing the stability of mental model transmission in a modern context.

Table 4.

Results of coding key concepts of ethnochemistry

Indicator	Representative quotation
Use of natural ingredients	"Elang leaves are used in *Napnap Mor* so that fish appear on the surface." "*Saguer* (palm wine) is poured into the sea as part of the customary ritual."

Process of selecting natural ingredients	"The prohibition on harvesting natural resources is determined based on the weather, east wind." "Customary elders perform calculations using natural signs to determine which plants or fish must be protected." "Leaf selection is based on the philosophy of the eagle dropping a leaf into the sea."
Process of processing natural ingredients	"The nets used for fishing are smoked with burnt wood to create a smudge on the nets or fishing gear." The making of coconut oil is traditionally done with the abundant coconuts in the village. "The making of s*aguer* involves a natural fermentation process."
Use of special names	"The term '*Sasisen*' is used to refer to the temporary prohibition on harvesting natural resources."
Specific customary rules in the use of natural ingredients	"The taboo for *Napnap Mor* is that the wife of the person performing *Napnap Mor* must not be pregnant." "People on the boat during *Napnap Mor* are not allowed to eat or turn on a flashlight." "If the *sasi* prohibition is violated, one will face punishment, such as vomiting blood or passing bloody stools."

Table 5.

Results of coding mental representations of society (symbolic, narrative, analogous)

Indicator	Representative quotation
Narrative representation	"The story of the eagle spreading leaves into the sea so that fish could surface." "The *Napnap Mor* taboo is that the wife of the person performing *Napnap Mor* must not be pregnant, as it affects the catch." "Stories of the ancestors' experiences regarding taboo violations that caused the fish catch to decrease."
Symbolic representation	"The symbols of coconut leaves and saguer are used in customary rituals as a form of communication with nature." "Plants that will undergo *sasisen* are marked with a cross using wood." "A flag is used to mark the area designated for *sasisen*.
Analogical representation	"The human-nature-God relationship is depicted like a triangle of balance." "An

	unattended garden is likened to the garden healing itself." "The timing of harvest and *Sasi* is explained by comparing the behavior of nature to human life.”

Table 6.
Results of coding cultural factors influencing community mental models

Indicator	Representative quotation
Factors influencing the selection of natural materials	"Customary elders perform calculations using natural signs to determine which plants or fish must be protected." "Leaf selection is based on the philosophy of the eagle dropping a leaf into the sea." "The prohibition on harvesting natural resources is determined based on the weather, the east wind, or the movement of stars or constellations (*romangkuandi*)."
The special roles of community figures	"The person leading *sasisen* is the customary elder, who is also a priest, ensuring community compliance." "The traditional chief (*mananwir*) from a specific clan distributes the harvest to orphans and widows." "A special shaman (*mon in* or *morin*) casts the net during *Napnap Mor*, and only they know the specific type of leaf used."
External influences on the community	"The current generation sees a shift in *Sasisen* due to the influence of the government and the church." "Now *Napnap Mor* has become a tourist destination, leaning more toward “euphoria." "NGOs mostly hold written documents about *Sasisen* and *Napnap Mor*. The government lacks written documents."
The local community's perspective	"The human-nature-God relationship must be balanced; otherwise, it will bring problems."

Table 7.
Coding results of challenges and opportunities for preserving community ethnochemical knowledge.

Indicator	Representative quotation
Documentation of community knowledge about natural materials in cultural practices	"Written documentation is very scarce; the culture or tradition is mostly inherited orally." "Documents related to *Sasisen and Napnap Mor* are mainly held by NGOs. The

	government has very few written documents." "The *Sasisen* and *Napnap Mor* traditions are generally recounted from generation to generation, not poured into written documents like books."
Community interest in writing or documenting their traditional knowledge	"The hope is that this tradition is maintained, and nature is preserved. I strongly support the preservation of this tradition." "I support the government in preserving this tradition." "Starting next year, the regional government will limit the attractions and restore the true function of *Napnap Mor*."
Obstacles to maintaining the sustainability of local knowledge	"Now *Napnap Mor* has become a tourist destination, it's more about euphoria." "Technological advancement poses a threat to the young generation's efforts to preserve their culture." "Value shifts have occurred due to economic interests and development politics."
Steps for the younger generation to care for and preserve their local knowledge	"There is a need for activities to mentor or train young people about the *Sasisen and Napnap Mor* traditions by inviting customary elders." "The village government's annual program to preserve existing traditions." "Revitalization of the *Napnap Mor* ritual process, not just for fun."
Willingness to cooperate with academics	"I support the government and academics in preserving this tradition." "The regional government will, in the future, focus more on the customary ritual process and the essence of *Napnap Mor*."

Table 8.
Final thematic coding results aspect

Aspect	Indicator	Key Finding	Representative quotation
Local knowledge	Type of tradition	*Sasisen, Napnap Mor*	"*Sasisen* means closure or prohibition..."
Key ethnochemical concepts	Use of natural materials	Elang leaves, *saguer*, coconut, coconut oil	"Elang leaves are used in *Napnap Mor* so that fish surface..."
Mental representation	Symbolic	Coconut leaves, *saguer*, crossed	"Plants that will undergo *sasi* are

		wood mark (X), flag (*barbar*)	marked with a cross (*apyeper*)"
Cultural factors	Role of traditional figures	Customary elders, shamans (mon in/morin), traditional chiefs (*mananwir*)	"The person who leads *sasisen* is the customary elder who is also a priest..."
Challenges and opportunities	Preservation obstacles	Modernization, commercialization, decreasing interest of the younger generation	"Technological advancement poses a threat to the young generation..."
Threats		Damage to coral reefs due to *Napnap Mor* being used as a cultural festival (euphoric nature).	"I do not want to participate in the *Napnap Mor* tradition during the *munara wampasi* festival because it damages coral reefs due to the huge number of people in the napnap mor festival hunting fish. A value shift has occurred. Coral reefs take thousands of years to form but are destroyed in minutes."

Table 9.
Analysis of chemical concept based on Johnstone's Triangle

Concept	Macroscopic	Sub-microscopic	Symbolic
conservation & ecosystem balance	The community restricts the harvesting of marine or land resources for a certain period, allowing the population of fish, coconuts, and other plants to recover. An example is the *sasi* on marine resources for 6 months for	The nutrient cycles: carbon, nitrogen, and phosphorus (C, N, P) proceed normally without excessive harvesting. The activity of microorganisms in the soil and water restores the physico-chemical condition of the environment.	Diagrams of the C, N, P cycles. Equation for the organic decomposition process: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ energy

	ecosystem rehabilitation.		
Saguer fermentation and coconut oil production	*Saguer* fermentation produces an alcoholic beverage. Coconut oil is made by heating coconut milk until the oil and water separate.	Fermentation by yeast (*Saccharomyces cerevisiae*) converts glucose into ethanol and CO_2. Heating breaks the triglyceride bonds (hydrolysis) into glycerol and fatty acids.	Fermentation reaction equation: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ $C_3H_5(OOCR)_3 + 3H_2O \rightarrow C_3H_5(OH)_3 + 3RCOOH$
Use of "Elang leaves" in the *Napnap Mor* tradition	Certain leaves are scattered into the sea to attract fish closer.	Secondary metabolite compounds such as saponins and terpenoids found in certain plants (leaves) dissolve in water, making fish easier to catch.	Molecular structures of saponin and terpenoid.
Determining the time for *Napnap Mor* (tides)	Fishing is done during long low tide (*meti wampasi*) so that fish are trapped in shallow areas.	The concentration of dissolved oxygen is affected by temperature, partial pressure of O_2, and salinity, which influences fish distribution.	Henry's Law: C=kH. P C = Concentration of dissolved gas in liquid (mol/L) kH = Henry's constant P = Partial pressure of the gas above the liquid (atm)
Symbolic, narrative, and analogical representation	Symbols of coconut leaves, *saguer*, and wooden cross signs are used in customary rituals.	Natural materials contain long-lasting aromatic and volatile compounds, imparting sacred and aesthetic value.	Use of symbols (wooden cross, flag) as markers of prohibition.