



Ethnoscience of *Acropora formosa* as Raw Material for Betel Lime: Coastal Ecosystem Implications

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Abstract: Coral reefs are crucial coastal ecosystems because they provide various ecological functions and support the socio-cultural activities of coastal communities. On Mambor Island, Central Papua, *Acropora formosa* is traditionally used as a raw material for making betel lime, which is used in the tradition of chewing betel nut, a cultural practice still maintained by the local indigenous community. This study aims to analyze the use of *A. formosa* from an ethnoscientific perspective and evaluate its implications for the sustainability of coastal ecosystems. The study employed a mixed methods approach with a sequential explanatory design that integrates quantitative and qualitative data within the Driver-Pressure-State-Impact-Response (DPSIR) framework. Data were collected through questionnaire surveys, in-depth interviews, field observations, and coral reef condition assessments using the Line Intercept Transect (LIT) method. The results showed that all respondents (100%) were active users of betel lime, with the number of users on Mambor Island reaching 288 people aged 5 years and older. Coral harvesting was carried out routinely, averaging once per week, with each harvest yielding approximately 5 kg of *A. formosa*. The extraction rate is estimated at 74,880 kg per year (approximately 75 tons per year), indicating significant ecological pressure on reef-building coral resources. Coral reef assessments indicate that live coral cover is only 20%, while dead coral and coral debris cover reach 30% and 50%, respectively, indicating poor reef condition.

Keywords: *Acropora formosa*; Coastal ecosystem sustainability; Ethnoscience; Local knowledge; Whiting

Introduction

Coral reefs are one of the most important coastal ecosystems because they play a significant ecological role in maintaining the stability of tropical marine environments while supporting various social and economic activities of coastal communities. In Indonesia, coral reef ecosystems currently face various pressures stemming from global factors, such as climate change and rising sea temperatures, as well as local factors, including land-based pollution, coastal development, and unsustainable exploitation of marine resources (Hughes et al., 2017; Woodhead et al., 2019). The coastal waters of Papua are known for their relatively intact

coral reef ecosystems, with *Acropora formosa* as one of the dominant coral species commonly found in the intertidal zone and reef flats. This species has a relatively fast growth rate compared to many other coral species and is traditionally used by coastal communities as the main raw material for making betel lime for the areca nut chewing tradition. Due to its easy access and abundance in shallow reef habitats, especially at low tide, *A. formosa* is a species vulnerable to overexploitation (Fabricius, 2005; Sun et al., 2024). Among Papuans, the tradition of chewing areca nut (*Areca catechu*) combined with betel lime remains an important part of their cultural identity and social life. This practice serves not only as a consumption activity but also as a means of social

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interaction, a symbol of respect, a medium for cultural communication, and an important element in various traditional ceremonies. Therefore, the betel lime used in the betel nut chewing tradition holds high cultural value and is continuously maintained and passed down from generation to generation (Thilakarathne et al., 2025; Alaydrus et al., 2023).

Mambor Island, located in Nabire Regency, is one of the coastal areas where local communities still actively maintain the tradition of making and using betel lime derived from the coral *Acropora formosa*. The high demand for whiting lime drives the ongoing coral harvesting activity in intertidal areas (Enochs et al., 2018; Sánchez et al., 2025). This reflects the strong link between coastal resource utilization and the sustainability of local cultural practices. However, the use of *A. formosa* as a raw material for whiting lime has the potential to put pressure on the long-term sustainability of coral reef ecosystems. As a key reef-building species, the continued harvesting of *A. formosa* can reduce the ecosystem's ability to provide habitat for various marine organisms, reduce its coastal protection function, and weaken the ecosystem's resilience in supporting the lives of coastal communities facing environmental change (Ackerman et al., 2025; Angnuureng et al., 2025). From an ethnoscience perspective, the use of natural resources by local communities is seen as a manifestation of indigenous knowledge systems developed through empirical experience and passed down from generation to generation (Ijatuyi et al., 2025; Dei et al., 2025). In the context of Mambor Island, the community possesses specialized ecological knowledge regarding the extraction locations of *A. formosa*, the criteria for selecting coral that produces high-quality lime, the burning technique, and its use in the betel nut chewing tradition.

This local knowledge is a crucial part of cultural heritage that needs to be documented and scientifically understood as a basis for developing sustainable coastal resource management strategies (Zainal et al., 2024; Abdillah & Afriandi, 2023). Traditional ecological knowledge has been widely recognized as an adaptive management system that contributes to biodiversity conservation and sustainable use of natural resources (Sinthumule, 2023; Silva-Ávila et al., 2025). The success of coastal ecosystem conservation is determined not only by an ecological approach alone, but also by the ability to integrate social, cultural, and local knowledge dimensions into a natural resource management framework. Research specifically examining the use of *Acropora formosa* as a raw material for lime production from an ethnoscientific perspective and its implications for coastal ecosystem sustainability is still very limited, particularly in Papua. Consequently, the interrelationship between local cultural practices and

changes in coastal environmental conditions remains under-understood. This situation indicates a research gap: the lack of integrative studies that simultaneously examine the ethnoscientific dimension of *A. formosa* utilization and evaluate its ecological implications for coastal ecosystem sustainability. Such information is crucial to support the development of coastal resource management policies that accommodate cultural preservation while ensuring effective coral reef conservation (Vuong et al., 2024; Zhao et al., 2024).

Based on this background, this study aims to analyze the use of *Acropora formosa* as a raw material for lime production from an ethnoscientific perspective and evaluate its implications for coastal ecosystem sustainability on Mambor Island, Nabire Regency. The results of this study are expected to contribute to the development of coastal ethnoscience studies, support community-based coral reef conservation efforts, and serve as a basis for formulating sustainable coastal resource management strategies in Central Papua. Unlike previous studies, which generally examined coral reef degradation from an ecological perspective or documented the tradition of betel nut chewing as a socio-cultural practice, this study integrates ethnoscience knowledge, traditional coral use, and ecosystem sustainability assessments within the Driver-Pressure-State-Impact-Response (DPSIR) framework. This study offers a novel socio-ecological analysis of how indigenous cultural practices influence coral reef resource utilization and ecosystem condition in small island communities in Papua. Furthermore, this study provides empirical evidence linking the production of betel lime from *Acropora formosa* to coral reef sustainability, an aspect that has been rarely studied in the scientific literature.

Method

This research was conducted for one month, from April 20 to May 22, 2026, in the coastal waters of Mambor Island, Moora District, Nabire Regency, Central Papua Province, Indonesia. Mambor Island was purposively selected as the research location due to indications of a decline in the population of *Acropora formosa*, which is intensively utilized by the local community as the main raw material for making betel lime for the areca nut chewing tradition. The research area is a coastal socio-ecological system that shows a close relationship between coral reef resources and traditional cultural practices of the community. The continuous harvesting of *A. formosa* from the intertidal zone coral reef habitat raises concerns about the sustainability of the local coral reef ecosystem, especially considering the ecological role of this species as one of the main reef-building corals. Therefore, this research

location is considered suitable for examining the ethnoscientific dimension of coral utilization and its implications for the sustainability of coastal ecosystems.

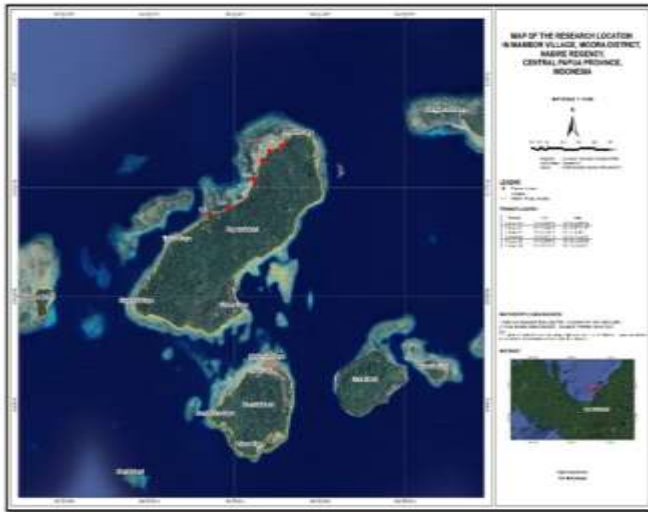


Figure 1. Research location

Research Design

This study employed a mixed method approach with a sequential explanatory design that integrates quantitative and qualitative data to gain a comprehensive understanding of the relationship between the cultural practice of using *Acropora formosa* as a raw material for making betel lime and the sustainability of coastal ecosystems. The quantitative approach was used to assess the level of coral utilization and the condition of the coral reef ecosystem, while the qualitative approach explored local ecological knowledge, cultural values, and community perceptions regarding coral use in the betel nut chewing tradition. This study adopted the Driver-Pressure-State-Impact-Response (DPSIR) framework developed by the European Environment Agency. This framework is used to explain the causal relationships between socio-cultural drivers, resource utilization activities, environmental conditions, ecological and social impacts, and management responses that support the sustainability of coastal ecosystems.

Population and Sampling Technique

The study population consisted of all betel lime users aged 5 years and older residing on Mambo Island, totaling 288 individuals. The sample size was determined using the Slovin formula with a margin of error of 5%, resulting in 90 respondents. Respondents were selected using a purposive sampling technique with the following criteria: Regular use of betel lime; Knowledge of the betel lime production process; Willingness to participate in the research. In addition, key informants were identified using a snowball

sampling technique involving traditional leaders, betel lime producers, village heads, and community members directly involved in *Acropora formosa* harvesting activities.

Data Collection Techniques

Research data were collected through field observations, questionnaire surveys, in-depth interviews, documentation, and coral reef condition assessments. Field observations were conducted to identify coral harvesting activities, harvesting locations, and the general condition of the coastal ecosystem in the study area. A questionnaire survey was used to obtain information on the frequency of betel lime use, the number of corals harvested, and community perceptions of coral reef conditions. In-depth interviews were conducted with key informants to obtain information on local ecological knowledge related to the use of *Acropora formosa*, the process of making betel lime, the cultural significance of the betel nut chewing tradition, and community perspectives on the sustainability of coral reef resources. Documentation was conducted through photography, field notes, and the collection of various information related to community activities in coral utilization.

Coral Reef Condition Assessment

Coral reef condition assessments were conducted in the intertidal area, the primary location for *Acropora formosa* collection, using the 50-meter Line Intercept Transect (LIT) method. This method was used to identify benthic composition and measure the percentage of coral cover at the study site. The observed ecological parameters included: Live coral cover; Dead coral cover; Coral rubble; Bottom substrate condition. The percentage of coral cover was calculated using the formula of Gimez and Yap (1988):

$$C = (\Sigma Li / L) \times 100\% \quad (1)$$

Where:

C = Percentage of coral cover (%);

ΣLi = Total length of benthic categories intersecting the transect line (m);

L = Total length of transect (m).

Coral reef condition was classified according to Gimez and Yap (1988), as follows: Excellent: 75–100%; Good: 50–74.90%; Fair: 25–49.90%; Poor: < 25%.

Data Analysis

This study used a mixed method approach with a sequential explanatory design that integrated quantitative and qualitative data to analyze the relationship between the cultural practice of utilizing *Acropora formosa* as a raw material for making betel lime and the sustainability of the coastal ecosystem on

Mambor Island, Nabire Regency. Data analysis was conducted using the DPSIR (Driver-Pressure-State-Impact-Response) framework developed by the European Environment Agency. This framework is used to systematically explain the cause-and-effect relationships between human activities and environmental change. In this study, the Driver component was analyzed by identifying sociocultural factors that encourage communities to utilize *A. formosa* as a raw material for whiting lime. The Pressure component was used to evaluate the pressures caused by coral harvesting activities. The State component was used to assess the current condition of the coral reef ecosystem in the intertidal zone. Next, the Impact component is used to identify ecological and social impacts arising from changes in ecosystem conditions.

Meanwhile, the Response component is used to formulate management alternatives based on ethnoscience knowledge and conservation principles. The operationalization of the DPSIR framework used in this study is presented in Table 1.

Table 1. Operationalization of the DPSIR framework in research

DPSIR components	Variables	Indicators
Drivers	Betel nut chewing tradition	Number of betel lime users, cultural value, local knowledge
Pressure	<i>A. formosa</i> harvesting	Frequency of extraction, amount of coral harvested
State	Coral reef conditions	Live coral cover, dead coral cover, coral debris
Impact	Ecological and social impacts	Habitat change, raw material availability
Response	Management strategies	Conservation, rehabilitation, customary rules

Result and Discussion

The Indigenous People of Mambor Island

The indigenous people of Mambor Island largely rely on the capture fisheries sector for their livelihoods, utilizing marine resources within the Mambor tribe's customary maritime territory. Fishing activities not only serve to meet household food needs but also serve as a primary source of income through marketing the catch to Nabire City. The community's dependence on coastal resources reflects the close interconnectedness of economic, social, cultural, and environmental dimensions in daily life. This dependence is a common characteristic of indigenous coastal communities in Papua, where marine resources are the primary basis of livelihood and part of a local knowledge system passed down through generations (Molan et al., 2023; Middleton et al., 2024). In addition to fishing activities,

the tradition of chewing betel nut remains an important part of the cultural identity of the Mambor Island community. Consuming betel nut has become a deeply rooted habit in local life, both as a snack and as a cultural symbol used by various age groups, from children to adults (Lutfianasari et al., 2025; Aggarwal et al., 2025). Betel leaves and betel nuts also symbolize harmony and family ties, while also serving social, cultural, economic, and health functions (Hobbis & Hobbis, 2023).

In Papuan society, chewing betel nut is not simply a consumption activity but also carries high social and cultural values as a symbol of brotherhood, respect, hospitality (Fakdawer et al., 2023). The continuity of this tradition demonstrates its role as a cultural heritage that strengthens local identity and social solidarity within indigenous communities (Fitriana & Wirdanengsih, 2024). To meet the demand for betel lime, communities routinely harvest *Acropora formosa* from intertidal coral reefs and process it into lime. This practice has been passed down through generations and is part of local ecological knowledge regarding coastal resource utilization. This knowledge encompasses extraction locations, criteria for selecting coral colonies that produce high-quality lime, and processing techniques for lime. Utilization of natural resources based on empirical experience and the transmission of knowledge between generations are key characteristics of indigenous communities' ecological knowledge systems (Malapane et al., 2024; Carroll et al., 2025).

The high consumption of betel nut in Nabire City has also increased demand for lime. Consequently, the people of Mambor Island produce lime not only for their own consumption but also for marketing in Nabire City as a source of additional income. Therefore, the use of *Acropora formosa* has both economic and cultural value for the local community. However, increased demand without adequate management has the potential to increase pressure on coral reef ecosystems. Therefore, integrating local knowledge and principles of sustainable coastal resource management is crucial to maintain a balance between socio-cultural needs and coastal ecosystem conservation (Djosetro & Behagel, 2024; Rizal et al., 2022).

Driver: The Betel Nut Chewing Tradition as a Driver for Coral Utilization

Descriptive analysis showed that all respondents (n = 90; 100%) were active users of betel nut, consuming it more than ten times per day. These results indicate that betel nut remains an integral component of the betel nut chewing tradition on Mambor Island. The estimated number of active users, 288 people aged 5 years and older, further demonstrates that this cultural practice is deeply embedded in the community's socio-cultural system and continues to be passed down from

generation to generation. Within the DPSIR framework, cultural traditions serve as the primary driver influencing natural resource utilization. The high demand for betel nut directly increases the demand for coral-derived raw materials. Previous research has shown that the betel nut chewing tradition in Papua functions not only as a consumption practice but also as a cultural institution that strengthens social identity, solidarity, social relations, and customary interactions within the community (Jennissen et al., 2023; Nardi, 2024). The findings of this study indicate that the cultural values inherent in the betel nut chewing tradition contribute significantly to the sustainability of coral resource extraction activities. Therefore, understanding the socio-cultural drivers is crucial in developing sustainable coastal resource management strategies.

Pressure: Acropora formosa Harvesting as a Source of Ecological Pressure

The results indicate that *Acropora formosa* harvesting is carried out routinely, with an average frequency of once per week. Each harvesting activity produces approximately 5 kg of coral material, equivalent to approximately 25 coral colonies per individual. With a significant number of active users, the cumulative pressure on intertidal coral populations is significant. Based on an average harvest of 5 kg per week by 288 active users, the potential extraction of *Acropora formosa* is estimated to reach approximately 74.880 kg per year (± 74.88 tons per year). This figure indicates a high level of ecological pressure on reef-building coral resources. Within the DPSIR framework, coral harvesting activities constitute a direct form of pressure on coral reef ecosystems. The removal of reef-building corals can reduce coral abundance and hinder natural recruitment and recovery. The predominance of coral rubble found during field surveys further strengthens the indication of long-term exploitation pressure on intertidal coral reef habitats (Malkamäki et al., 2025; Keshavmurthy et al., 2019).

State: Current Condition of the Coral Reef Ecosystem

Assessment of coral reef condition using six 50-meter Line Intercept Transects (LIT) showed that live coral cover ranged from 18–22%, with an average of 19.67%. Dead coral cover ranged from 28–32%, with an average of 29.50%. Coral debris was the most dominant benthic component, ranging from 50–52%, with an average of 50.83%. Based on the classification of Roth et al. (2018) and Najeib et al. (2025), the average live coral cover indicates that the coral reef condition on Mambor Island is in the poor category ($< 25\%$). The dominance of coral debris indicates significant physical degradation of the reef structure and a decrease in habitat complexity. The complexity of reef structure is crucial for

maintaining biodiversity and supporting various ecological functions such as shelter, foraging, and nursery areas for various marine organisms. Within the DPSIR framework, these findings represent a state component indicating that coral reef ecosystems have experienced significant degradation.

Impact: Ecological and Social Impacts of Coral Reef Degradation

The decline in live coral cover can have various ecological consequences, including reduced biodiversity, loss of habitat for reef-associated organisms, and reduced coastal protection. Coral reefs play a crucial role in attenuating wave energy and protecting coastlines from abrasion and storm surges. Coral reef degradation can reduce various ecosystem services that support fisheries, coastal community livelihoods, biodiversity conservation, and environmental stability (Prato et al., 2025; Banda et al., 2024). From a socio-cultural perspective, the reduced availability of *Acropora formosa* has the potential to threaten the sustainability of whiting production, which has long been part of community traditions. Therefore, ecological degradation impacts not only the environment but also the continuity of cultural practices that have been passed down through generations (Theocharis, 2025; Nyakuwanika, 2025).

Response: Ethnoscience-Based Management Strategy

The interview results indicate an opportunity to develop a management strategy that integrates local ecological knowledge with modern conservation approaches. Proposed strategies include: Limiting coral harvesting; Rehabilitating coral reefs through coral transplantation; Developing alternative raw materials to replace coral for the production of whiting lime; Strengthening customary rules regarding the use of coastal resources. Community participation is a crucial factor in the successful management of coastal resources. Integrating indigenous knowledge systems into conservation programs can increase management effectiveness while maintaining cultural identity and local responsibility for the environment.

DPSIR Integration: Empirical Validation of the Conceptual Framework

The integration of quantitative and qualitative findings within the DPSIR framework confirms the conceptual framework proposed in the introduction. The results indicate that the tradition of betel nut chewing and local ecological knowledge are the main driving factors influencing coral resource utilization. The high demand for betel lime drives the routine harvesting of *Acropora formosa*, resulting in significant ecological pressure on coral reef habitats. This pressure

is reflected in the ecosystem's low live coral cover and high dominance of coral debris. Furthermore, the degraded ecosystem has the potential to reduce ecosystem services and threaten the sustainability of coral resources used in traditional cultural practices. The research findings also demonstrate that communities have the adaptive capacity to support conservation efforts through strengthening customary rules, coral reef rehabilitation, and ethnoscience-based management. Overall, the research results support the developed conceptual framework and demonstrate that the use of *Acropora formosa* for betel lime production is a complex socio-ecological interaction, in which cultural traditions, resource exploitation, ecosystem conditions, and management responses are closely interconnected (Liu et al., 2025).

Implications for Sustainable Development Goals (SDGs)

The estimated annual extraction of *Acropora formosa* at approximately 74,880 kg indicates that the use of coral for the production of whiting has important implications for sustainable development in coastal areas. The findings of this study are particularly relevant to:

SDG 14 (Life Below Water)

Continuous coral extraction has the potential to cause degradation of coral reef ecosystems, as reflected in low live coral cover and high levels of coral debris. Therefore, reducing unsustainable extraction practices and strengthening community-based conservation are crucial steps to support the achievement of SDG 14.

SDG 11 (Sustainable Cities and Communities)

The betel nut chewing tradition is an important part of the cultural identity of the indigenous people of Mambor Island. However, the sustainability of this tradition is highly dependent on the availability of coral resources as raw material for whiting. Ethnoscience-based management that integrates cultural preservation and environmental conservation can support community resilience and the sustainability of local cultural heritage.

SDG 13 (Climate Action)

Coral reefs function as natural barriers that can absorb wave energy, reduce coastal erosion, and increase the resilience of coastal communities to the impacts of climate change. Degradation of coral reefs due to overexploitation can reduce this protective function. Therefore, coral reef conservation and rehabilitation are also essential components of climate change adaptation strategies. Overall, sustainable management of *Acropora formosa* is essential to support marine ecosystem conservation, the cultural

sustainability of indigenous communities, and increased climate resilience in coastal areas.

Conclusion

The use of *Acropora formosa* as a raw material for lime production on Mambor Island is heavily influenced by the tradition of chewing betel nut and the ecological knowledge of indigenous communities that has been passed down through generations. Within the DPSIR framework, these cultural practices serve as a major driving force, resulting in ongoing pressure on coral reef resources. The estimated extraction rate of approximately 74,880 kg per year (approximately 75 tons per year) and the low live coral cover (20%) indicate that current utilization practices have the potential to contribute to coral reef degradation and threaten the sustainability of coastal ecosystems. The research findings confirm the developed conceptual framework, which demonstrates a strong link between cultural traditions, coral resource utilization, ecosystem conditions, and management responses. Therefore, the implementation of ethnoscience-based management that integrates local knowledge, customary rules, coral reef conservation, ecosystem rehabilitation, and the use of alternative raw materials is essential to balance cultural preservation with the long-term sustainability of coastal ecosystems.

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Author Contributions

Conceptualization, methodology, formal analysis, investigation, resources, writing—preparation of original draft, writing—reviewing and editing, visualization, supervision, project administration, obtaining funding, Y.M. and L.T. All authors have read and approved the published version of the manuscript

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Conflicts of Interest

The author declares no conflict of interest.

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