

ETHNOBOTANICAL STUDY OF MANGROVES FROM COASTAL COMMUNITIES OF BUNAKEN NATIONAL PARK, INDONESIA

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ARTICLE HIGHLIGHTS

- Mangrove species like *Acanthus ilicifolius* and *Avicennia marina* aid food and health.
- Correlation and PCA reveal food, medicine, and firewood as key use dimensions.
- Location trends: Sondaken for firewood, Baboi for medicine, Mantehage for knowledge.
- This study supports mangrove ethnobotany and promotes community bioconservation.

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ABSTRACT

Mangrove ecosystems play a vital ecological and socio-economic role along coastal regions. However, their sustainable utilization faces significant challenges due to habitat degradation and modernization. This study aimed to characterize the ethnobotanical utilization of mangroves by coastal communities within Bunaken National Marine Park (BNMP) and its surrounding small islands, while exploring their potential for food and medicinal bioprospecting. Data were collected through questionnaire surveys, in-depth interviews with informants, and field observations within coastal communities in four locations such as Bahoi, Likupang Barat District, North Minahasa, Sondaken, Tatapaan District, South, Alung Banua, Bunaken Archipelago District, Manado, and Mantehage, Wori District, North Minahasa Regency. The data were subsequently analyzed descriptively, followed by Principal Component Analysis (PCA) and heatmap visualization. The findings revealed that specific species such as *Acanthus ilicifolius* and *Avicennia marina* occupy central roles as sources of food and traditional medicine, emphasizing the close integration between subsistence needs and community health. Correlation analysis and PCA indicated that the categories of food, medicine, and firewood represent the dominant dimensions of utilization, while cultural functions and species knowledge serve as secondary differentiators. Location-based variations underscored the heterogeneity of utilization practices, with Sondaken being more prominent in firewood use, Bahoi in ethnomedicine, and Mantehage in biodiversity knowledge. These findings highlight the necessity of mangrove management that extends beyond ecological conservation to include local wisdom as a foundation for bioprospecting, thereby supporting food security, health, and the well-being of coastal communities. Thus, this research significantly contributed to the literature on mangrove ethnobotany and provided a scientific framework for community-based bioconservation strategies in Indonesia.

Keywords: bioprospecting, Bunaken, ethnobotany, functional food, mangrove, traditional medicine

INTRODUCTION

Indonesia harbors approximately a quarter of the world's total mangrove area, making it the epicenter of global mangrove biodiversity. This ecosystem plays a critical role in climate change mitigation through its blue carbon storage capacity, natural protection against abrasion, storms, and tsunamis, and its ecological function as a nursery ground for economically valuable marine biota (Arceo-Carranza *et al.* 2021; Chen *et al.* 2024; Zeng *et al.* 2021). However, mangrove degradation continues due to anthropogenic pressures and a dominant management model that primarily focuses on ecological conservation without considering the socio-economic needs of coastal communities. Recent research, however, underscores that the resilience of coastal communities can only be achieved through mangrove management that integrates conservation with utilization based on local knowledge (Ayassamy 2025; Jennings *et al.* 2024).

In addition to its ecological value, mangroves also harbor significant ethnobotanical potential. For centuries, coastal communities in Asia and the Pacific have utilized specific mangrove species for food, traditional medicine, building materials, and cultural symbols (Mantiquilla *et al.* 2021). Studies in the Sundarbans, Bangladesh, and India have shown that *Rhizophora apiculata* and *Avicennia marina* are commonly used to treat wounds and gastrointestinal disorders, as well as being sources of firewood and honey (Beniwal *et al.* 2024; Zhou *et al.* 2025). Similarly, research along Brazil's coastline highlights the role of traditional knowledge in managing mangroves to enhance community resilience against flooding and erosion (Henud *et al.* 2024; Sarthi & Michael 2025). Despite Indonesia having the highest mangrove biodiversity in the world, systematic documentation of local ethnobotanical knowledge remains scarce and largely transmitted orally (Nugroho *et al.* 2022). This gap in the formal literature threatens the preservation of traditional ecological knowledge, as intergenerational understanding of mangrove species utilization is highly vulnerable to being lost if not systematically recorded. A study by Fajrin *et al.* (2021) in Tabanio Village, South Kalimantan, found that local knowledge of mangroves, particularly regarding *Avicennia* species, needs to be scientifically documented to ensure that future generations can learn from and benefit from it. Similarly, Melviani *et al.* (2024) in Lampung Province emphasized the need for practical documentation related to traditional mangrove management,

such as the use of *Rhizophora mucronata* as a potential food source, before such oral traditions disappear. Furthermore, other studies affirm that although the use of mangroves as food sources is widespread across Indonesia, systematic ethnobotanical documentation remains limited. This again emphasizes the need for preservation-oriented studies on local knowledge in various regions, including East Lampung (Wati *et al.* 2025). Ultimately, formal and systematic documentation of local knowledge on mangrove utilization not only serves to preserve intergenerational heritage but can also significantly enhance the economic income and climate resilience of coastal communities (Purba *et al.* 2022; Simanjuntak *et al.* 2025).

The limited documentation poses a risk of losing traditional knowledge due to modernization, which weakens the potential for developing mangrove bioprospecting as a source of functional food and medicinal products. Recent pharmacological studies indicate that genera such as *Acanthus*, *Avicennia*, and *Sonneratia* contain bioactive compounds with potent antioxidant, antidiabetic, and anti-inflammatory activities (Liu *et al.* 2023; Zhou *et al.* 2025). However, this potential has yet to be fully explored at the community level in Indonesia, particularly within the context of Bunaken National Marine Park (BNMP), a region located at the heart of the world's marine biodiversity hotspot. BNMP is strategically important not only as a marine conservation center but also as a socio-ecological landscape where coastal communities depend on mangroves for food security, traditional health practices, and livelihoods. Unfortunately, ethnobotanical studies in this region are still limited to basic ecological inventory and species identification (Djamaluddin & Djabar 2022). Ethnobotanical research that have been conducted were limited to certain locations, such as Bantik Village coastal area, Sulawesi Utara, regarding the utilization of mangrove (pahapa) bark for soaking fishing nets for about a week to strengthen them (Kepel *et al.* 2024). Meanwhile, research regarding pharmacological processing methods, usage dosages, therapeutic effectiveness, or the relationships between utilization categories of mangrove have not been conducted.

This presents a research gap: the need for a comprehensive approach that combines ethnobotanical surveys, in-depth interviews, and field observations with quantitative analysis (descriptive statistics, PCA, and heatmap visualizations) to map the relationships between

utilization functions and explore the potential for bioprospecting. Therefore, this study aimed to characterize the ethnobotanical utilization of mangroves by coastal communities in BNMP and its surrounding small islands, linking it to bioprospecting strategies for food and medicine to support conservation efforts.

While the ecological and ethnobotanical potential of mangroves in Indonesia is immense, studies integrating socio-ecological dimensions, traditional utilization practices, and scientific validation are still rare, especially in the BNMP region. Most previous studies have focused solely on species inventories and general functions, without exploring the interconnections between categories of utilization, such as food, medicine, firewood, and traditions, nor the socio-cultural factors influencing usage variations among communities. This condition raises fundamental questions regarding how coastal communities utilize mangroves in a multidimensional manner, how the relationships between utilization categories can be mapped quantitatively, and how this traditional knowledge can serve as the foundation for bioprospecting to support conservation and enhance community resilience.

By applying descriptive analysis to depict the diversity of usage, as well as PCA and heatmap analyses to map the interconnections between utilization categories and highlight the most influential dimensions, the research is expected to comprehensively document the at-risk traditional

knowledge, strengthen the scientific foundation for developing functional food and medicinal products based on mangroves, and make a meaningful contribution to community-based bioconservation strategies for improving coastal community welfare and mitigating global climate change.

MATERIALS AND METHODS

Study Area

This study was conducted in coastal communities within mangrove areas in the villages of Bahoi, Likupang Barat District, North Minahasa (1°43'16.2" N, 125°1'14.2" E), Sondaken, Tatapaan District, South Minahasa (1°21'45.3" N, 124°32'34.4" E), Alung Banua, Bunaken Archipelago District, Manado City (1°37'5.4" N, 124°44'37.0" E), and Mantehage, Wori District, North Minahasa Regency (1°41'58.2" N, 124°45'9.6" E) (Fig 1).

The different locations were chosen to represent variations in resource access and coastal ecological typologies especially distribution of mangroves area (Fig. 2). The location selection was purposive to capture the spectrum of utilization practices (food, medicine, firewood, materials, fodder, and cultural functions), as recommended in mangrove ethnobiology studies, which emphasize the mapping of actual harvesting practices and local socio-economic contexts as the basis for socio-ecological analysis.

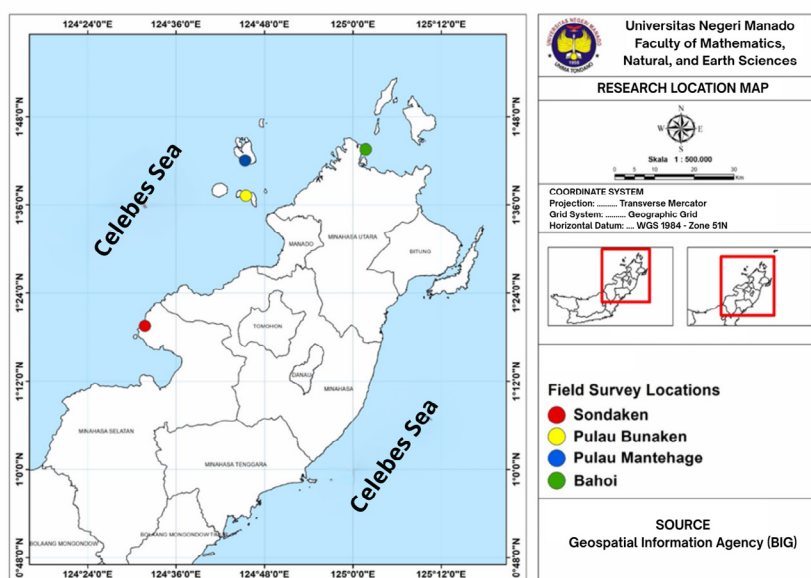


Figure 1 Map of research area in North Sulawesi, Indonesia, indicating the four field survey locations

Notes: Sites are distributed along the mainland coast and offshore islands within the Celebes Sea: Sondaken (red marker); Bunaken Island (yellow marker); Mantehage Island (blue marker), and Bahoi (green marker). Inset maps illustrate the location of study areas relative to the greater Sulawesi region. Source: Geospatial Information Agency (BIG).



Figure 2 Map showing the spatial distribution of mangrove areas in Bunaken National Marine Park and surrounding areas

Notes: The green areas on the map indicate the distribution of mangrove ecosystems along the coastline. Four field survey locations are marked with colored arrows that are directly linked to photos of the actual conditions in the field: Sondaken (red arrow), Bunaken Island (yellow arrow), Mantehage Island (blue arrow), and Bahoi (green arrow). The inset map shows the geographical location of the study area.

Data Collection Methods

Data for this study were gathered through semi-structured questionnaires designed to capture both quantitative and qualitative insights into the knowledge, perceptions, and practices of local residents regarding mangrove species. The focus was on understanding (i) species identification, (ii) utilization patterns, particularly for food and medicinal purposes, and (iii) attitudes toward conservation and sustainable management.

Species identification was carried out by presenting respondents with images of mangrove species previously recorded in the coastal areas of Sulawesi, focusing particularly on leaf and propagule characteristics. Respondents were asked to recognize/identify the morphological features of the mangroves in the images to determine the local names of the species. They were also invited to directly point out mangrove plants in the field to the researchers. The comparison of images, local names, and direct field observations was then used to determine the scientific names of the mangrove species recognized by the community. Mangrove species for which scientific names had been confirmed were subsequently documented.

Sampling in this study included all villagers who were willing to be interviewed and complete the survey. Respondents who were unable to read or write, as well as those who were not present in the village during the data collection period, were excluded. As a result, the final sample consisted of 42 respondents. These 42 participants represented a diverse cross-section of the community, including house caretakers, farmers, employees, fishermen, students, laborers, and teachers. This

diversity ensured that perspectives from different socio-economic and occupational backgrounds were incorporated.

The questionnaire consisted of five main sections: Respondent identity (demographic details such as age, gender, occupation, and length of residence), knowledge of mangrove species (ability to identify species by local and scientific names), categories of utilization (including food, medicine, energy/firewood, building materials/catching tools, animal feed, and arts/traditional uses), plant parts used (specific parts, e.g., leaves, bark, roots, fruits), and frequency and intensity of use (to assess reliance and cultural significance). Prior to full deployment, the instrument underwent pilot testing to evaluate clarity, item relevance, and consistency in categorization. Feedback from the pilot phase informed refinements to ensure reliability and validity of responses.

The structured survey approach aligns with quantitative practices in coastal ethnobotany research, which integrate species identification with inventories of ecosystem goods and services. This method is widely adopted in studies examining human–mangrove interactions (Arbiastutie *et al.* 2021; Christopher 2024; Safitri *et al.* 2024), enabling systematic documentation of traditional ecological knowledge and resource use patterns.

Data Analysis

Ethnobotanical data were analyzed using a quantitative descriptive mixed approach. Survey data were tabulated by species and utilization categories to generate summary metrics (household user proportion, frequency, plant part variety, and

ecological role/threats). Cross-site descriptive analysis was employed to compare utilization patterns and species knowledge between villages, consistent with the social-ecological comparative approach in mangrove literature.

Principal Component Analysis (PCA) was applied to a standardized matrix of utilization/knowledge variables (e.g., scale 0 – 1 or z-score) to reduce dimensions and identify major variation axes that distinguish utilitarian practices (food, medicine, firewood) from cultural dimensions or species knowledge. The selection of PCA aligns with quantitative practices in ethnobotany to map utilization gradients and function clustering, and has been used in coastal studies to interpret respondents' perceptions/knowledge structure of mangrove services. Biplot visualizations display variable loadings and respondent/site scores (Mafaziya Nijamdeen *et al.* 2023). Heatmaps were used to visualize the intensity of utilization across species-categories/locations (scale: frequency or user proportion), with optional hierarchical clustering to highlight utilization “hotspots” and species co-utilization. This technique is common in ethnobotany/ethnomedicine studies to display usage distribution patterns and category overlaps.

Triangulation was performed by cross-referencing survey, interview, and observational data. Informed consent was obtained from all respondents; local names/cultural identities were recorded with sensitivity, ensuring no disclosure

of community-confidential information. These procedures align with ethnobotanical study guidelines and best practices in coastal community research.

RESULTS AND DISCUSSION

Limitation of Sample Size

The sample size in this study was limited to 42 respondents distributed across four villages. Nevertheless, for exploratory ethnobotanical research, this number was considered sufficient. Ethnobotany prioritizes the depth and specificity of local knowledge rather than statistical representativeness of the general population (Tongco 2007). Several previous studies have demonstrated that a sample range of approximately 40 to 45 informants is adequate to achieve data saturation and produce a valid and comprehensive ethnobotanical inventory (Henri *et al.* 2020; Zhang *et al.* 2026). Therefore, the 42 respondents included in this study were considered sufficient to map local ecological knowledge, particularly in the Bunaken National Marine Park area.

Demography

Among the 42 respondents interviewed in this study, 28 (67%) were women and 14 (33%) were men. The mean age of the respondents was 46.31 ± 12.10 years old, with the majority (64%) being over 40 years old (Table 1).

Table 1 Demographic characteristic of the respondents

Parameter	Male	Female	Male + Female	P value ^a
Age (years old, mean + SD)	48.71+10.51	45.11+12.83	46.31 + 12.10	0.369
Duration of stay (year, mean + SD)	40.64+15.33	42.53+14.89	41.90+14.88	0.703
Occupation (n)				
House caretaker	4	24	28	0.003*
Farmer	6	2	8	
Employer	2	0	2	
Fisherman	1	0	1	
Student	0	1	1	
Labor	1	0	1	
each	0	1	1	

Note: ^a = P values were calculated using Chi-square or t-test for categorical or numerical data, respectively; * = P < 0.05.

The mean length of residence was 41.90 ± 14.88 years, with no significant difference observed between male and female respondents. Occupational patterns exhibited clear gender disparities, with most women working as house caretakers (24 out of 28), while men were more commonly employed in farming and other types of work. This demographic profile provided important implications for the intergenerational transmission of ethnobotanical knowledge. Previous studies demonstrated that older generations, particularly women, serve as the primary custodians and transmitters of Traditional Ecological Knowledge (TEK) within families (da Costa *et al.* 2021; Mota *et al.* 2023). Women generally possess deeper experiential knowledge related to the management and everyday use of plants, and they preserve these traditions through oral transmission embedded within kinship networks. However, the concentration of knowledge among individuals over the age of 40 also highlights a critical vulnerability: an expanding intergenerational gap. As younger generations shift toward more modern lifestyles, the vertical transmission of specialized ecological knowledge

has experienced a drastic decline (Arjona Gracia *et al.* 2021; Zhang *et al.* 2026). Therefore, the demographic pattern observed in this study not only underscored the vital role of older women in safeguarding local mangrove ethnobotanical knowledge, but also gave signal about the urgent need for intergenerational preservation efforts and systematic documentation before this cultural heritage is lost.

Mangroves Utilization

The mangrove species were utilized by the coastal communities of Bunaken, with a focus on traditional medicine and food (Table 2). Several species, such as *A. ilicifolius* and *A. marina*, serve dual purposes as both food and traditional medicine sources, while other species are more predominantly utilized for a specific function. Information regarding the plant parts used, the products derived, and the ecological roles and threats faced by these species is also included, making this table not only a reflection of ethnobotanical practices but also relevant to conservation strategies and the sustainable management of mangroves.

Table 2 Description of mangrove utilization by coastal communities of Bunaken National Marine Park

Scientific name	Local name	Medicine		Food		Conservation Unnamed: 8	
		Part used	Treated diseases	Part used	Food product	Ecological importance	Identified threats
<i>Acanthus ilicifolius</i> L.	<i>Jeruju</i>	Leaf	Aphthous stomatitis, feverish, and antihypertension	Leaf	Indonesian crispy peanut crackers, tea, fried jeruju		
<i>Acanthus ilicifolius</i> L.	<i>kabisasu</i>	Leaf	Rheumatoid arthritis				
<i>Avicennia marina</i> (Forssk.) Vierh.	<i>Api-api Putih</i>	Young leaf, fruit	Cancer sores, feverish, and antihypertension	Young fruit, fruit	Fresh vegetable side dishes, <i>tempe</i>		
<i>Avicennia</i> sp.	<i>Api-api, Kayu Ting, Tandu</i>	Leaf	Wound	Fruit	Cookies	Mangroves serve as fish spawning grounds and natural wave barriers	Climate change and over-exploitation
<i>Bruguiera cylindrica</i> (L.) Bl	<i>Burus, tanjang, lengadai, lindur</i>	Leaf	Cancer				
<i>Bruguiera gymnorhiza</i> (L.) Lamk	Guwoi	Fruit	Oral candidiasis, pruritus				

Scientific name	Local name	Medicine		Food		Conservation Unnamed: 8	
		Part used	Treated diseases	Part used	Food product	Ecological importance	Identified threats
<i>Bruguiera gymnorrhiza</i> (L.) Lamk	<i>Sarau, tancang, tumu</i>	Flower	Treating ear infection				
<i>Bruguiera parviflora</i> (Roxb.) W.& A. ex Griff	<i>Paproti, bius, lenggadai</i>	Fruit	Treating herpes				
<i>Calophyllum inophyllum</i> L.	<i>Mares</i>	Leaf sap	Eye pain				
<i>Ceriops decandra</i> (Griff) Ding Hou	<i>Parum, tingi, tinci</i>	Bark	Body slimming effect				
<i>Nypa fruticans</i> Wurmb	<i>Bobo</i>	Juvenile petiole	Wound				
<i>Pongamia pinnata</i> (L.) Pierre	<i>W'rar</i>	Bark	Liver disease				
<i>Rhizophora mucronata</i> Lmk		Propagules without roots	Anti-gastritis, improves blood circulation, and prevents anemia	Propagules without roots	Propagules coffee		
<i>Rhizophora apiculata</i> BI	<i>Los</i>	Bark, juvenile root, leaf	Oral candidiasis, wound, toothache, lusiang, liver disease, pruritus				
<i>Rhizophora apiculata</i> BI	<i>Bakau minyak</i>	Leaves	Wound medicine and neutralize poison				
<i>Rhizophora mucronata</i> Lmk	<i>Bakau</i>	Fruit	Diabetes, inflammation	Fruit without roots	Flour, syrup, coffee		
<i>Rhizophora mucronata</i> Lmk	<i>Blukap, bangko, lului, tanjang lanang</i>	Bark	Treating hematuria				
<i>Rhizophora</i> sp.	<i>Tongke, Kayu lolaro</i>	Bark	Wound	Fruit	Juice	Mangroves serve as fish spawning grounds and natural wave barriers	Climate change and over-exploitation
<i>Rhizophora stylosa</i> Griff	<i>Bako-kurap, slindur,</i>	Fruit	Treating hematuria				
<i>Scaevola taccada</i> (Gaertn.) Roxb.	<i>Anas</i>	Leaf	Contusion, myalgia, strain				
<i>Scyphiphora hydrophyllacea</i> C.F.Gaertn.	<i>Parem</i>	Leaf bud	Contraception				
<i>Sonneratia alba</i> Sm.	<i>Gieg</i>	Young fruit, bark, root	<i>Lusiang</i> (postpartum care), muscle pain (lumbago), bone pain, rheumatic), malaria				

Scientific name	Local name	Medicine		Food		Conservation	
		Part used	Treated diseases	Part used	Food product	Ecological importance	Identified threats
<i>Sonneratia caseolaris</i> (L.) Engl	<i>Pidada</i>	Fruit	Cancer sores, feverish, and antihypertension	Fruit	Syrup, <i>dodol</i> , jam		
<i>Sonneratia caseolaris</i> (L.) Engl	<i>Pedada, perepat</i>	Leaves	Medicine for smallpox, diarrhea, and bruises on the skin				
<i>Sonneratia</i> sp.	<i>Posi-posi, Pabepa, Kira-kira</i>	Root, Bark	Asthma, GERD	Fruit, seed	Juice, flour	Mangroves serve as fish spawning grounds and natural wave barriers	Climate change and over-exploitation
<i>Sonneratia</i> sp.	<i>swai</i>	Bark	Toothache				
<i>Xylocarpus granatum</i> J.Koenig	<i>Lelim</i>	Bark, fruit	Stomachache, disease				

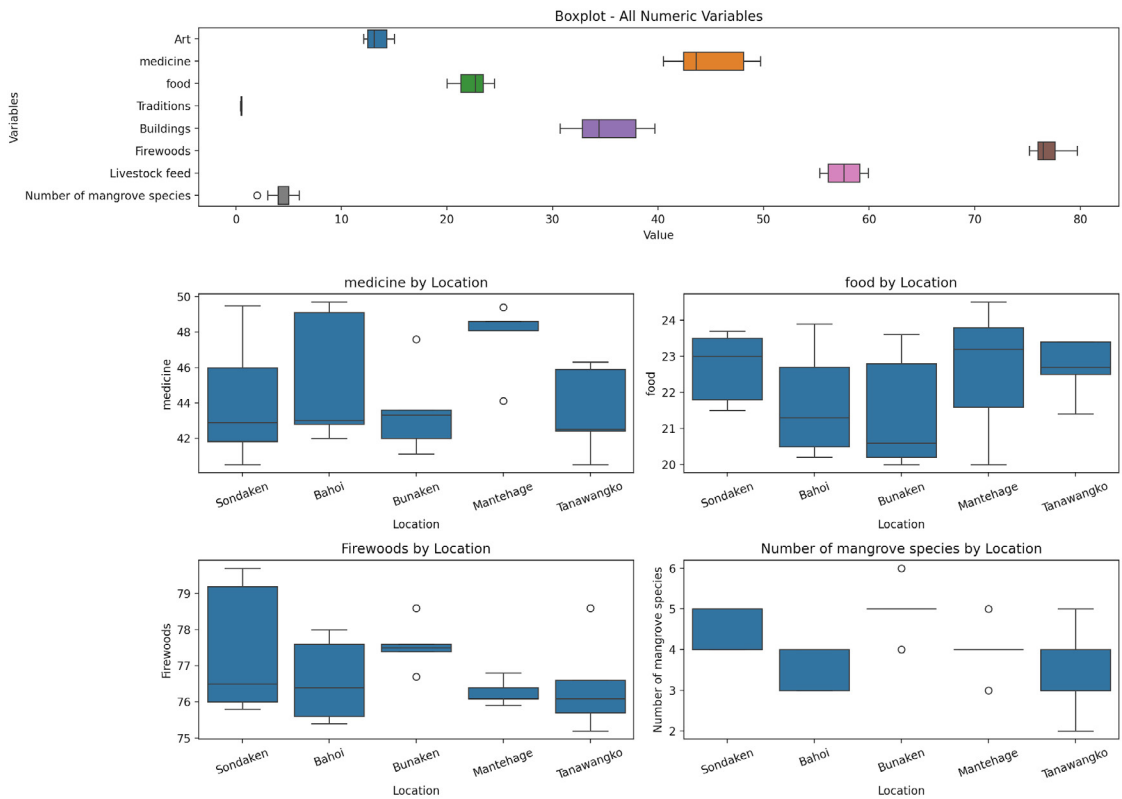


Figure 3 Boxplot analysis detailing the characteristics of mangrove utilization by coastal communities

Notes: The top plot illustrates the aggregate distribution of various utilization types, showing that the highest utilization values are associated with firewoods, livestock feed, and medicine, while traditional and artistic uses remain low. The four subplots below demonstrate the significant spatial variability in specific uses across five villages: Sondaken, Bahoi, Bunaken, and Mantehage. Variations in medians and interquartile ranges across locations indicate distinct community dependencies on specific mangrove resources.

The results of the boxplot analysis presented in Figure 3 indicated significant differences in mangrove utilization across the five coastal villages surrounding Bunaken National Park. Utilization for firewood exhibited the highest median values, from 77 to 79. Sondaken was the most dominant village, with a median close to 79 and a range of 75 to 80, while other villages such as Bahoi and Bunaken had relatively lower values (76 to 77). This suggests varying levels of dependency on mangroves as an energy source. Utilization for medicine displayed a more variable distribution, with Bahoi recording the highest median at nearly 49, surpassing all other locations. Sondaken had a slightly lower median 45, but with a broader range (41 to 49), while Bunaken remained relatively stable between 42 and 44. This data emphasizes the strong presence of ethnomedical practices in Bahoi compared to the other villages (Fig. 3).

Regarding food, the median values ranged between 22 and 23 across all locations, with Bahoi and Tanawangko reaching 23 to 24, while Bunaken was slightly lower at around 21 to 22. This consistency indicates that mangrove utilization for food is a common practice across the villages. Meanwhile, knowledge of the number of mangrove species showed significant variation. Sondaken and

Mantehage recorded the highest medians (5 to 6 species), while Tanawangko recognized only 1 to 2 species. Outliers in Bahoi and Bunaken indicated that some respondents identified more species than the majority. Overall, these data underscored that Bahoi excels in ethnomedical utilization (~49), Sondaken in energy use (~79), and Mantehage in biodiversity knowledge (~6 species). In contrast, Tanawangko demonstrated the lowest values for knowledge of mangrove species. The numerical differences reinforce the argument that mangrove conservation strategies must be tailored to the specific socio-ecological needs and characteristics of each village.

Principal Component Analysis (PCA) used in the ethnobotanical study of mangrove utilization by coastal communities in Bunaken National Park showed that Principal Component 1 (PC1) accounted for approximately 20 – 21% of the total variance, PC2 about 17%, and components up to PC5 cumulatively explained around 77 – 78% of the variance. From the PC1 vs PC2 biplot, variables such as medicine, food, and firewood exhibited high positive loadings on PC1, while variables like the number of mangrove species, livestock feed, and traditions tended to have negative loadings or weaker loadings on both PC1 and PC2 (Fig. 4).

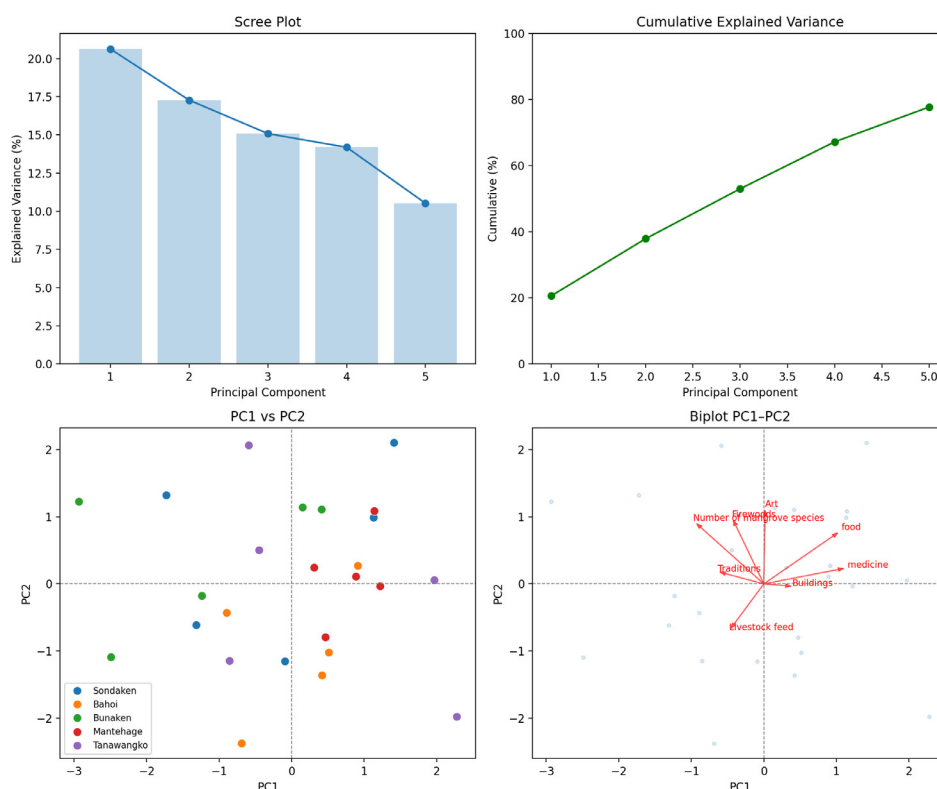


Figure 4 Principal Component Analysis (PCA) of mangrove ethnobotany characteristics across five coastal communities in Bunaken National Park

Notes: The top panels display the Scree Plot (left), showing the percentage of explained variance for the first five principal components, and the Cumulative Explained Variance (right). The bottom panels illustrate the spatial distribution of respondents based on their village location in the PC1 and PC2 dimensions (left), and a biplot (right) mapping the direction and magnitude of the utilization variables driving these components.

This indicates that the primary variation in mangrove utilization by the community is primarily driven by the role of mangroves as a source of traditional medicine, food, and fuel. In contrast, cultural/traditional functions and species diversity contributed to lower variance, but remained relevant in differentiating locations or community groups. Comparison with other mangrove ethnomedical studies further supports this interpretation.

A study in West Kalimantan, Indonesia, found that communities recognize hundreds of plant species (including mangroves) and utilize various species for medicinal purposes, highlighting that medicinal use often emerges as a primary dimension in mangrove studies and is correlated with high levels of local knowledge (Middleton 2024). Additionally, research in Benin on household socio-economic profiles and mangrove use found that dependency on mangroves for resources (including firewood and building materials) became one of the dominant factors identified through PCA/species-related component analysis.

The Pearson correlation matrix displayed reveals diverse patterns of relationships between the various categories of mangrove utilization by coastal communities. A moderate positive correlation between the use of mangroves as a source of food and traditional medicine ($r \approx 0.34$) suggests that communities knowledgeable about

utilizing mangroves as food sources generally also possess knowledge regarding their use in traditional medicine (Fig. 5).

Several mangrove species used as food also possess medicinal properties, including *Acanthus ilicifolius* (Jeruju), *Avicennia marina* (Api api), *Rhizophora mucronata* (Bakau), and *Sonneratia caseolaris* (Pedada). According to documented local practices, in addition to their use as herbal remedies, communities creatively process these plants into everyday food products such as tea, tempeh, flour, and syrup to treat various ailments including hypertension, inflammation, and digestive disorders. These traditional practices are supported by ethnopharmacological studies (Purba *et al.* 2022; Wati *et al.* 2024; Simanjuntak *et al.* 2025; Melviana *et al.* 2025), which confirm that appropriate preparation techniques such as boiling, filtering, and fermentation, effectively and safely neutralize natural toxins such as tannins while preserving beneficial bioactive compounds including flavonoids and antioxidants. As a result, this dual use demonstrated that the traditional diets of coastal communities' function as a natural preventive healthcare system, intelligently integrating food security with readily accessible medicinal resources. Furthermore, this finding aligns with Sarkar *et al.* (2024), who highlight the dual potential of certain mangrove plant parts as both food sources and reservoirs of pharmacologically valuable bioactive compounds.

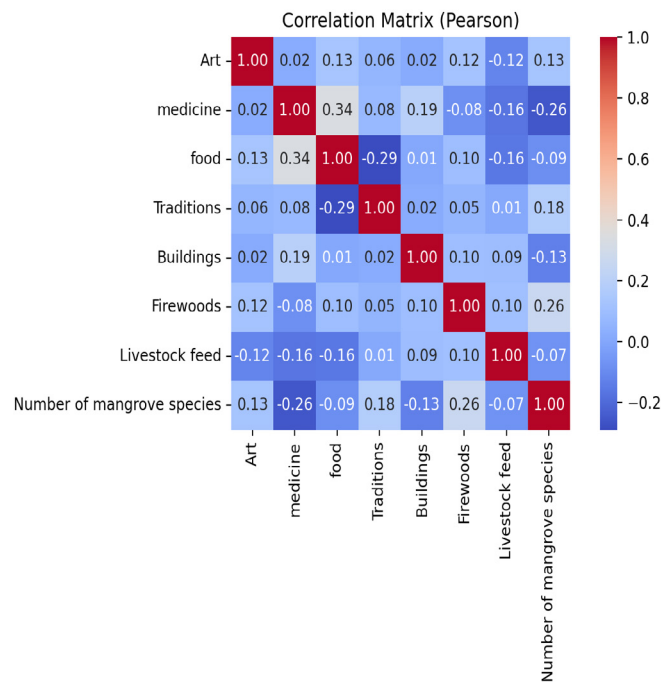


Figure 5 Pearson correlation matrix (heatmap) illustrating the relationships between different categories of mangrove utilization among coastal communities in Bunaken National Park
Notes: Positive correlations are indicated by shades of red, while negative correlations are indicated by shades of blue. The numerical values and color intensity correspond to the strength of the correlation coefficient (r).

Conversely, the negative correlation between utilization for tradition and food ($r \approx -0.29$) indicated a differentiation of functions, where traditional use emphasized symbolic and cultural aspects rather than consumptive ones. Several specific mangrove species, such as *Sonneratia alba* (Gieg), *Scyphiphora hydrophyllacea* (Parem), *Rhizophora apiculata* (Los/Bakau minyak), and *Xylocarpus granatum* (Lelim) held substantial traditional and medicinal importance in this study, yet they were restricted in use and were not consumed as food. For example, *Sonneratia alba* (locally known as Gieg) played a crucial role in maternal healthcare, particularly for postpartum recovery (lusiang), and was also used to treat muscle pain and malaria. Also, the young leaves of *Scyphiphora hydrophyllacea* (Parem) served as a form of traditional contraception, while *Rhizophora apiculata* (Bakau minyak) was used to neutralize toxins and treat oral infections. Despite their significant cultural and medicinal value, none of these species were utilized as everyday food sources by local communities. This pattern is consistent with observations by Treviño (2022), who reported that certain mangrove species are embedded within ritual and symbolic social contexts rather than incorporated into daily diets. Restrictions on the consumption of these plants are largely attributed to their toxicity levels and organoleptic properties, particularly bitterness, which strongly dictate their use by humans (Medeiros *et al.* 2021).

Additionally, the number of mangrove species showed a positive correlation with use as firewood ($r \approx 0.26$), but a negative correlation with medicinal use ($r \approx -0.26$). This phenomenon can be explained by the limited local knowledge, which typically recognizes only specific species as medicinal plants, while almost all species are utilized for household energy needs as firewood. These findings are consistent with ethnobotanical research in East Lampung, which reported that despite the high species diversity, only a small subset is used for medicinal purposes (Duryat *et al.* 2023). The weak correlation patterns for other variables, such as arts and livestock feed, reflected more sporadic and contextual utilization, not consistently tied to other functions. Thus, these correlation results emphasized the importance of understanding that biological diversity does not necessarily reflect the diversity of uses, but is influenced by cultural factors, local wisdom, and the transmission of knowledge across generations.

The results of this study demonstrated that several mangrove species have dual uses as both food sources and traditional medicine, reinforcing the idea that coastal communities not only utilize mangroves for subsistence needs but also as part of an established local medicinal system. This is consistent with previous research results which found that of around 84 mangrove species, 27 were reported to be used in traditional practices, particularly for pharmacological activities such as antioxidant, antimicrobial, and antidiabetic effects (Akram *et al.* 2023; Sarkar *et al.* 2024).

The moderate positive correlation between food and medicinal utilization in our data also reflected findings from several field studies, where the use of mangroves as food is often accompanied or followed by their use for traditional medicine. For example, Red Mangrove (*Rhizophora stylosa*) is discussed in traditional contexts as a medicine, insecticide, and source of firewood/charcoal (Middleton 2024).

In contrast, our findings showed that the cultural/traditional use category has a negative or weak correlation with food utilization, which suggested a differentiation of roles, with traditional use emphasizing symbolic or non-consumptive aspects. This pattern is relevant to research reported by Gnansounou *et al.* (2021) which indicate that the use of mangroves for food and medicine is rarely reported, and non-medical or traditional functions are more dominant in certain locations (Gnansounou *et al.* 2021). The cross-site analysis in this study revealed that local factors such as access to mangrove species, levels of traditional knowledge, and the role of older generations as knowledge keepers play a significant role in the variation of utilization intensity. The results of the study were consistent with research findings that suggest that although certain species are used traditionally, not all have been explored pharmacologically, and that traditional knowledge relies heavily on cultural preservation and intergenerational transmission of knowledge (Khatun *et al.* 2023; Sarma *et al.* 2025).

From a conservation and policy perspective, this study showed that increased use of firewood and other utility needs can create ecological pressures if not balanced with species conservation and maintenance of mangrove habitats. However, it is important to emphasize that in several villages included in this study, the use of mangrove plants as firewood is highly restricted, and primarily

limited to collecting dried branches or twigs. This practice contrasts with extractive communities in the Amazon, where species such as *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa* are widely utilized, and where Traditional Ecological Knowledge (TEK) regarding wood use is passed down to older generations (Galvão *et al.* 2024a; Galvão *et al.* 2024b). Ecological studies also validate that selective harvesting of hard wooded mangrove species particularly *Rhizophora* spp. for timber and charcoal directly reduces forest structural complexity, hinders natural regeneration processes, and diminishes the capacity of the ecosystem to function as a coastal buffer (Friess *et al.* 2019; Nugroho *et al.* 2022).

Finally, the study also warned that environmental degradation and exploitation pressures can reduce the availability of key species. Therefore, since ethnobotanical knowledge and resource dependence vary substantially across the villages studied, management strategies should not rely on a uniform, one size fits all policy. Conservation efforts must adopt decentralized, community-based approaches that are tailored to local socio ecological dynamics (Rahman *et al.* 2024). For example, in villages where communities heavily depend on mangroves for firewood and construction material, management strategies should prioritize the establishment of strict zoning systems (distinguishing between protected core zones and sustainable use zones) alongside the introduction of fast-growing agroforestry species as alternative firewood sources. Conversely, in villages where mangroves are primarily used for medicinal purposes and functional foods, local policies should prioritize the sustainable harvesting of non-timber forest products and empower communities to cultivate frequently harvested medicinal species (Mashur *et al.* 2025). By aligning conservation policies with the specific utilization profiles of each village, local governments can ensure long term ecological sustainability while simultaneously safeguarding traditional livelihoods.

CONCLUSION

Mangrove utilization by coastal communities reveals a close integration between subsistence needs, traditional knowledge, and cultural values, with specific species like *A. ilicifolius* and *A. marina* playing central roles as both food and traditional medicine sources. Correlation and PCA analysis showed that utilitarian dimensions' food, medicine, and firewood are the main drivers of variation

in practices, while cultural functions and species knowledge serve as differentiating elements. These results align with global ethnobotanical literature that emphasizes the dual functions of mangroves and the importance of the social context in determining utilization patterns, highlighting the urgent need to preserve local knowledge as a foundation for conservation and sustainable management. Thus, the sustainability of mangrove ecosystems can only be achieved through a holistic approach that integrates ecological, household economic, and cultural dimensions of coastal communities.

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