



# Integrating indigenous women's knowledge into mangrove management: the Tonotwiyat system in Papua, Indonesia

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## Research

### Abstract

**Background:** Effective mangrove management requires the integration of local ecological knowledge, customary institutions, and gender equity. This study examines Tonotwiyat-Women's Forest in Youtefa Bay, Papua, Indonesia, as a model of mangrove governance based on indigenous women's knowledge.

**Methods:** The methods used included a literature review, social-ecological systems (SES) surveys, in-depth interviews, observations, participatory mapping, and focus group discussions. A total of 62 purposively selected respondents participated in the study. The primary respondents were women whose activities were directly related to the mangrove. Additional participants included customary stakeholders, policymakers, village governments, and experts/NGOs. Data were analyzed using the SES framework and institutional analysis based on a common-pool resources (CPR) approach.

**Results:** The Tonotwiyat-Women's Forest System is a form of local knowledge and wisdom that is a form of gender-based biocultural governance of mangrove forests (mangrove ecosystems), where indigenous women's knowledge serves as an institutional foundation for conservation and collaborative management. This model can inform gender-responsive mangrove co-management policies in other coastal areas facing mangrove management challenges with adjustments to local contexts.

**Conclusions:** Tonotwiyat-Women's Forest shows that formally integrating indigenous women's knowledge, customary access rights, participatory mapping, and community monitoring can strengthen gender-responsive mangrove co-management and inform coastal policy beyond Youtefa Bay. This model can inform gender-responsive mangrove co-management policies in other coastal areas facing mangrove management challenges with adjustments to local contexts.

**Keywords:** Tonotwiyat; Women's Forest; local knowledge; local wisdom; mangrove; coastal ethnobotany; social-ecological system; Papua

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## Background

Mangrove ecosystems play a vital role in supporting coastal sustainability through their biophysical functions (Zhang *et al.* 2023; Lu *et al.* 2024), carbon sequestration capacity (Mahmud *et al.* 2025; Lee *et al.* 2025), function as natural pollution filters (Alongi *et al.* 2016). Mangroves also provide substantial socio-economic contributions by supporting livelihoods, household food security, nutrition, local economies, and community-based governance. In Indonesia, small-scale fisheries are closely linked to livelihood security, yet women's work and non-commercial exchanges are often under-recognized in livelihood assessments (Stacey *et al.* 2021). Evidence from West Africa further shows that women-led estuarine and mangrove shellfisheries can support food security, household economies, and rights-based co-management (Chuku *et al.* 2022). Economic valuation studies also demonstrate that mangrove ecosystem services generate significant provisioning, regulating, supporting, and cultural values that can inform conservation policy and environmental damage assessment (Arkham *et al.* 2024). From a gendered food-system perspective, mangroves provide diverse seasonal aquatic foods and income sources, while access to these resources is shaped by local knowledge, gender relations, and social norms (Middleton *et al.* 2024; Middleton *et al.* 2025). However, the relationship between ecosystem services and social well-being is not automatic, as benefits depend on equitable access, local awareness, and environmentally compatible economic development (Garmaeepour *et al.* 2025). Community-based management and mangrove-derived food products can therefore support household livelihoods and alternative income opportunities while strengthening conservation outcomes (Dulyakasem *et al.* 2025; Lukman *et al.* 2025). Conversely, mangrove loss can generate environmental, social, and economic impacts, including the weakening of coastal livelihoods and food systems (Arifanti *et al.* 2025). These studies provide a strong basis for understanding Tonotwiyat-Women's Forest not only as a conservation space, but also as a gendered livelihood, food-security, and socio-cultural governance system.

Current management trends increasingly emphasize the integration of local knowledge systems, customary practices, and indigenous governance structures into broader planning frameworks to ensure social legitimacy and contextual relevance of interventions (Marquez & Olavides 2024; Becker *et al.* 2025). Failures in mangrove ecosystem management are not only caused by technical factors, but also by socio-institutional challenges, such as limited recognition of local knowledge, weak community participation, neglect of customary rights, unequal distribution of benefits, and limited local authority to enforce regulations (Grimm *et al.* 2024; Sahana 2025; Macamo *et al.* 2024; Rodríguez-Rodríguez *et al.* 2024, 2025). Mangrove management policies often focus on biophysical and technocratic approaches (Khanum *et al.* 2026), ignoring the local political and economic context and the value of local wisdom, especially women's knowledge (Miller & Tonoto 2023; Grimm *et al.* 2024; Rodríguez-Rodríguez *et al.* 2024; Marquez & Olavides 2024; Sahana 2025). As a result, these policies often lack community acceptance (Kikpa Bio *et al.* 2025), and social legitimacy (Marquez & Olavides 2024; Rodríguez-Rodríguez *et al.* 2024). Successful mangrove management is increasingly understood to depend on social legitimacy, recognition of access rights, community participation, integration of indigenous and local knowledge (ILK), and gender equity in decision-making processes (Marquez & Olavides 2024; Rodríguez-Rodríguez *et al.* 2024; Harper *et al.* 2024; Sahana 2025).

In Enggros Village, Papua Province, Indonesia, the community continues to preserve the Tonotwiyat Women's Forest system despite ongoing pressure from mangrove destruction, pollution and land conversion (Tijjani *et al.* 2021; Salsabila & Soertikanti 2024; Flassy *et al.* 2024; Paulangan *et al.* 2025a; Paulangan *et al.* 2025b; Paulangan *et al.* 2025c). The Tonotwiyat-Women's Forest system is recognized not only for supporting mangrove ecosystem protection, but also as a coastal ethnobotanical landscape, a source of food security, and a gender-based customary institution (Rumahorbo *et al.* 2019; Rumahorbo *et al.* 2020; Flassy *et al.* 2022). However, development pressures, land conversion, pollution, and restricted access continue to threaten the remaining 173.47 ha of mangroves in Youtefa Bay (Paulangan *et al.* 2025a; Paulangan *et al.* 2025b; Paulangan *et al.* 2025c).

Recent literature on mangroves and local knowledge further reinforces the relevance of the Tonotwiyat-Women's Forest system. For example, in West Africa (Tcheton *et al.* 2025) and in West Kalimantan (Middleton *et al.* 2024), demonstrated that ILK practices in mangrove conservation reflect knowledge related to food systems, gender relations, and differentiated access between women and men. Similarly, Cruz Portorreal *et al.* (2024), in their study of mangrove governance as a socio-ecological system (SES) in Cuba, showed that community perceptions, livelihoods, and socio-ecological relationships shape patterns of resource utilization, ecosystem service valuation, and management policy design. Despite growing recognition of ILK in mangrove governance, no study has conceptualized gender-based customary institutions in Papua as a formal co-management model within the SES-CPR framework" would sharpen the contribution. This study aims to: (1) analyze the SES characteristics of the Tonotwiyat-Women's Forest; (2) examine its institutional components using the CPR framework; and (3) conceptualize Tonotwiyat as a gender-responsive co-management model.

## Materials and Methods

### Study area

This research was conducted over an eight-month period in Enggros Village, located in the Youtefa Bay area of Jayapura City, Papua Province, Indonesia, where the Tonotwiyat-Women's Forest system is practiced (Fig. 1). Enggros Village is a traditional floating settlement inhabited by indigenous Papuans within the Youtefa Bay Nature Tourism Park, located approximately at coordinates 2°34'32" to 2°38'25" South Latitude and 140°41'11" to 140°44'25" East Longitude.

The research area was selected because it reflects the direct interaction between mangrove ecosystems, small-scale fisheries, traditional institutions, and coastal women's knowledge (Tijjani *et al.* 2021; Flassy *et al.* 2024; Paulangan *et al.* 2025a).

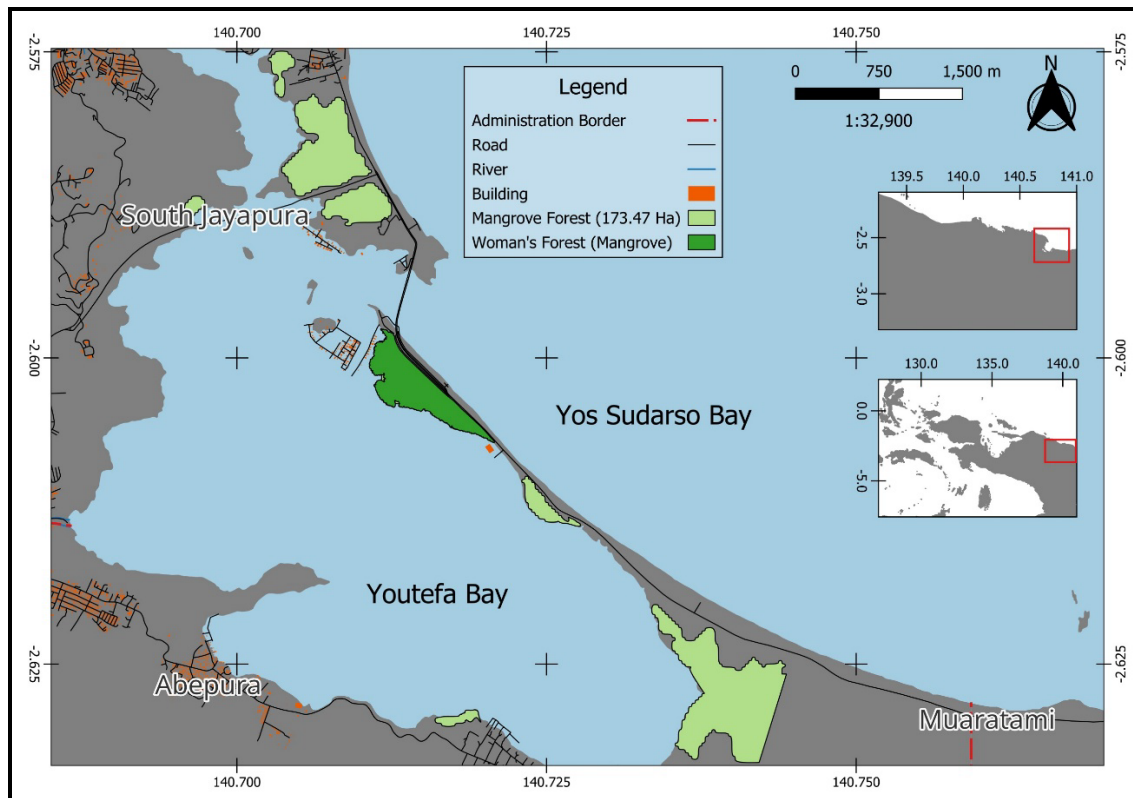


Figure 1. Map of Youtefa Bay, Jayapura City, showing the study area

### Research design

This research employed a qualitative-descriptive case study approach with a focus on coastal ethnobotany and socio-ecological systems (SES) in mangrove management. The Tonowiyat-Women's Forest in Enggros Village case was selected because it represents a highly contextual practice deeply embedded in customary law, local language, gender-based spatial divisions, access rights and the dynamics of external pressures such as development, land conversion, pollution and livelihood changes. The unit of analysis was the Tonotwiyat system, which encompasses not only individuals but also broader socio-ecological institutions. The collected data were used to understand the interaction among the mangrove ecosystem, women resource managers, traditional leaders, fishers, village government, local government institutions and external pressures, including development activities, pollution, changing access patterns and broader social transformation (livelihood).

### Data collection

Collection of data was conducted through a literature review, SES surveys, participant observation, structured in-depth interviews, participatory mapping and focus group discussions (FGDs). This approach follows indigenous and local knowledge (ILK) documentation practices that emphasize contextual understanding, recognition of knowledge holders, community validation and careful disclosure of indigenous knowledge (Tcheton *et al.* 2025; Risley *et al.* 2025). The interviews involved 62 respondents, consisting of 50 female respondents directly involved in the utilization of mangrove ecosystem resources, 3 respondents representing indigenous communities/customary stakeholders, 7 respondents representing policymakers (including 2 respondents from the Papua Provincial Marine and Fisheries Office, 2 respondents from the Natural Resources

Conservation Agency, 2 respondents from the Environmental Office, and 1 respondent from the village government), and 2 experts (1 respondent from a university and 1 respondent from an NGO). Female respondents were determined to be more dominant considering that the Tonotwiyat system is a local wisdom system and local institution based on women and is considered representative of 116 fishing households in Enggros Village (Pemerintah Kampung Enggros 2025). Respondents were selected purposively based on their understanding of the Tonotwiyat system, ability to convey information, representation of occupational backgrounds, education level, age, and gender. Participatory mapping was used to identify socio-ecological boundaries, resource utilization areas, risk locations, and spatial narratives related to the Women's Forest. FGDs were conducted to explore the history, values, rules, sanction mechanisms, institutional dynamics, and resource mapping processes in a participatory manner. Participant observation was employed to understand practices of mollusk and crab harvesting, women's movement patterns within mangrove areas, and forms of social interaction occurring within the Women's Forest. Visual documentation and cultural narratives were also collected to strengthen the analysis, while respecting community agreements and restrictions regarding sensitive customary information.

### Data analysis

The analysis was conducted in three stages. First, socio-ecological data were mapped into the SES variables developed by Anderies *et al.* (2004), namely resource characteristics, resource users, public infrastructure providers, forms of public infrastructure, institutions, and the external environment. Second, the Tonotwiyat institutional analysis referred to the territorial system, rights system, rules system, monitoring system, and sanction system (Ruddle 2000; Paulangan *et al.* 2018; Castillo *et al.* 2024), followed by componential analysis (Saiful & Ruban 2021). Third, interview and FGD data were analyzed thematically through processes of data reduction, data presentation, and conclusion drawing. The collected data were then interpreted descriptively and triangulated to strengthen the validity of the findings (Alfansyur & Mariyani 2020; Kiger & Varpio 2020; Paulangan *et al.* 2021).

## Results

### Social-Ecological System Model of Tonotwiyat-Women's Forest

The characteristics of the six main components of the Tonotwiyat-Women's Forest SES are presented in Table 1. The interactions among these SES components (Fig. 2) demonstrate that the SES model of the Tonotwiyat-Women's Forest is characterized by reciprocal relationships among resource systems, resource units, actors, customary governance, utilization practices, and socio-ecological outcomes. External pressures such as pollution, land conversion, development activities, changes in access, weak policy recognition, and the erosion of intergenerational knowledge transmission have the potential to disrupt the stability and sustainability of the Tonotwiyat-Women's Forest system.

Table 1. Comparative SES characterization of the Tonotwiyat-Women's Forest system in Youtefa Bay, Papua, Indonesia.

SES Components	Baseline condition in the Youtefa Bay mangrove SES	Characteristics of the Tonotwiyat System
Characteristics of resources	Mangrove ecosystem is an intertidal coastal resource composed of mangrove vegetation, tidal waterways, mudflat areas, associated aquatic biota, and ecosystem services. In a general SES perspective, it functions as habitat, coastal protection, and a source of livelihood resources.	In the Tonotwiyat system, the mangrove is not merely an ecological resource but a gendered biocultural landscape. The Women's Forest represents a culturally defined mangrove space where ecological functions, women's food production, privacy, social interaction, and cultural identity are inseparable. Therefore, the resource value is evaluated not only through biophysical condition but also through its capacity to sustain indigenous women's access, knowledge transmission, and customary authority.
Resource users	Users of mangrove ecosystem resources generally include fishermen, local communities, tourism actors, service providers, and other coastal users who depend on mangrove forest resources and ecosystem services.	Tonotwiyat differentiates resource users through customary and gender-based access. Indigenous women are the primary legitimate users, knowledge holders, and daily observers of mangrove resources, especially fish, mollusks, crabs, and others food-related biota. Men and external users are not simply "other users" but actors whose access is socially regulated. This makes Tonotwiyat distinct from a general community-use system because resource use is organized around women's spatial autonomy and customary legitimacy.

Public infrastructure providers	Public infrastructure providers around the mangrove area include central and local governments, village government, religious institutions, customary organizations, private actors, and tourism or transportation service providers.	In Tonotwiyat, the most relevant “providers” are not only formal agencies but also customary institutions and women knowledge holders who provide social legitimacy, access regulation, and community compliance. Formal government and private-sector actors may support the system when their programs recognize customary boundaries, but they may also create pressure when infrastructure, tourism, or development projects weaken women’s access. The effectiveness of public infrastructure therefore depends on its alignment with Tonotwiyat’s customary rules and women’s authority.
Forms of public infrastructure	Public infrastructure generally consists of physical facilities such as settlements, roads, bridges, cafes, restaurants, transportation facilities, and other supporting infrastructure, as well as social institutions such as village government, churches, and customary institutions.	In the Tonotwiyat system, the most critical infrastructure is socio-institutional rather than physical. This includes customary boundaries, information boards, women’s ecological knowledge, access rules, prohibitions, social monitoring, customary deliberation, and sanction mechanisms. Physical infrastructure should therefore be evaluated by whether it protects or disrupts women’s access, privacy, harvesting routes, and mangrove ecological functions. In this sense, women’s knowledge operates as a form of non-physical conservation infrastructure.
Institutional (relationship between human interaction and mangrove resources)	Mangrove management in Youtefa Bay is shaped by the coexistence of formal regulations and customary or communal rights. In general, institutions regulate access, resource use, compliance, and management authority.	Tonotwiyat institutionalizes a gender-responsive common-pool resource system through spatial boundaries, women’s access rights, prohibitions on men entering certain areas, ethical harvesting norms, social monitoring, customary sanctions, and collective deliberation. Its strength lies in social legitimacy and daily compliance mechanisms rooted in women’s ecological practice. However, its vulnerability lies in limited formal recognition and documentation, which may weaken legal protection against development pressure and external intervention.
External factors	The wider mangrove SES is affected by climate, politics, economic change, development, pollution, land conversion, and policy decisions that influence both ecosystem condition and community livelihoods.	For Tonotwiyat, external pressures are critical because they threaten both the mangrove ecosystem and the cultural-institutional basis of women’s authority. Pollution, land conversion, infrastructure development, restricted access, weak policy recognition, changing livelihoods, and erosion of intergenerational knowledge may reduce the system’s resilience. Thus, revitalization should not focus only on mangrove rehabilitation, but also on legal recognition, participatory mapping, protection of women’s access rights, and restoration of indigenous knowledge transmission.

The graph in Figure 2 illustrates that the Youtefa Bay mangrove ecosystem, as a resource system, provides resource units in the form of mangrove vegetation, fish, mollusks, crabs, associated biota, and various ecosystem services. Indigenous women, as the primary resource users, interact directly with these resources through food-related, economic, social, and cultural practices. These interactions generate ecological knowledge held by women, which is institutionalized through spatial boundaries, access rights, customary rules, social monitoring, sanctions, and collective community decision-making.

The Tonotwiyat-Women’s Forest institution plays an important role in maintaining compliance, regulating resource use pressures, and producing socio-ecological outcomes such as habitat conservation, food security, preservation of cultural identity, women’s spatial autonomy, and the strengthening of co-management practices. However, external pressures, including pollution, land conversion, development activities, changing access patterns, weak policy recognition, and the erosion of intergenerational knowledge transmission, have the potential to disrupt system stability.

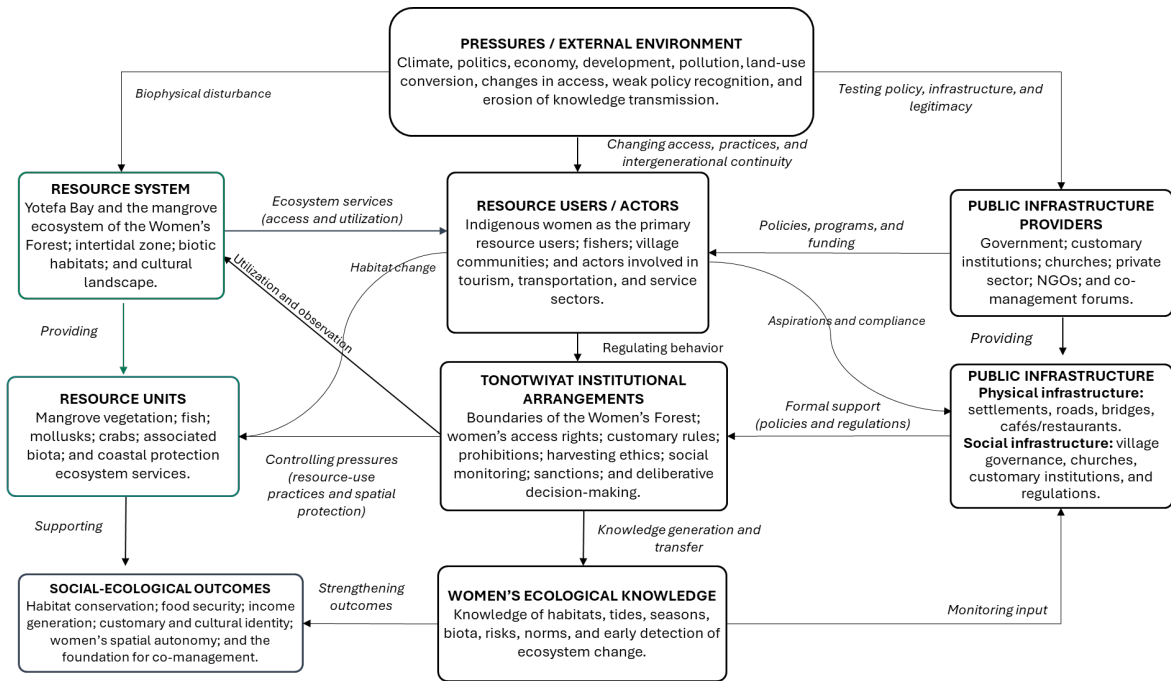


Figure 2. Connectivity system of the Tonotwiyat-Women’s Forest Social-Ecological System (SES) in Youtefa Bay

**Tonotwiyat-Women's Forest Institutional System**

The research results show that the Tonotwiyat-Women’s Forest system operates through customary institutional mechanisms, namely territory system, right system, rules system, monitoring system and sanction system (Table 2). A territorial boundary system designates certain mangrove areas as Women’s Forests. A rights system positions women as key actors in resource access and utilization. A regulatory system governs prohibitions, utilization ethics, and patterns of resource use. A regulatory system defines prohibitions, ethical use, and methods for resource use. A monitoring system functions through social oversight carried out by women, customary leaders, and the broader community. Sanctions are enforced through customary fines and social reprimands, in accordance with the principle of compliance in CPR management (Ruddle 2000; Castillo *et al.* 2024).

Table 2. Institutional Components, Expressions, Forms and Functions of SES of Tonotwiyat-Women’s Forest in Enggros Village, Jayapura City, Papua, Indonesia

Institutional Components	Expression in Tonotwiyat-Women's Forest	Institutional functions in the context of SES
Territory system	There are social and spatial boundaries for the Women's Forest within the Youtefa Bay mangrove area, but they have not been documented in formal regulations. Information boards have been installed.	Define management space and reduce access conflicts, as well as demonstrate existence.
Right system	The primary rights of access and utilization rest with indigenous women. Although men can utilize these resources, there are restrictions on access.	Protecting women's workspace, food, and freedom of expression and providing a sense of justice.
Rules system	Prohibitions on men entering certain areas and norms governing resource use. Sanctions apply for violations.	Controlling the pressure of utilization and maintaining the sacred value of space and providing privacy for women.
Monitoring system	Social supervision by women, traditional leaders, and the community.	Increasing compliance through social proximity and customary legitimacy.
Sanction system	Customary fines, warnings, and social consequences for violations.	Prevent violations and strengthen collective norms.

## Discussion

### Tonotwiyat-Women's Forest as a Coastal Ethnobotanical Landscape

Etymologically, the term *Tonotwiyat* derives from the words *Tonot*, meaning “mangrove forest,” and *Wiyat*, meaning “invitation.” Thus, *Tonotwiyat* can be understood as “an invitation to enter or explore the mangrove forest” (Sekar 2022). This system also reflects the relationship between indigenous women and mangroves as spaces that support food security, economic activities, social interaction, cultural practices, and conservation. In their daily lives, women in Enggros Village utilize mangrove areas to collect fish, mollusks, and crabs to meet household food needs, generate income, and strengthen social networks among women. While men spend time in traditional pavilions or engage in fishing activities at sea, women enter the mangrove areas to gather fish, crabs, mollusks, and other resources (Tebay 2023; Flassy *et al.* 2024).

In Papua, “para-para adat” (traditional pavilions) are generally places and spaces for men (Sulastri *et al.* 2020). However, in Enggros village, women are given a separate socio-spatial domain within the mangrove forest, commonly known as the Women's Forest (Pekpekai *et al.* 2024). The restriction of men to Women's Forest areas suggests that *Tonotwiyat* functions not only as a system for regulating resource utilization, but also as a mechanism that supports the spatial autonomy of coastal indigenous women (Paulangan *et al.* 2025b). Therefore, *Tonotwiyat* represents not merely an invitation to the mangrove forest, but also a space for food production, work, storytelling, solidarity, and recognition of indigenous women's roles (Tebay 2023; Flassy *et al.* 2024).

Various studies have shown that Papuan women play a crucial role in food production, land and forest management, the transmission of local knowledge, and the maintenance of socio-ecological values within their communities (Sulastri *et al.* 2020; Tebay 2023; Tijjani *et al.* 2021; Salsabila & Soertikanti 2024; Paulangan *et al.* 2025b). However, these substantive roles are often not accompanied by formal recognition within customary decision-making structures, particularly in matters related to customary rights, land tenure, forest governance, and natural resource management (Ilham *et al.* 2023). In the context of the Tonotwiyat-Women's Forest system in Youtefa Bay, women's roles can be understood as forms of socio-ecological authority institutionalized through customary spaces, access rights, gender-based restrictions, mangrove utilization practices, and ecological knowledge transmitted across generations. Accordingly, Tonotwiyat-Women's Forest represents a distinctive form of indigenous Papuan women's authority in the biocultural governance of mangroves, while also serving as a critique of customary systems and formal policies that have not yet fully recognized indigenous women as subjects of decision-making.

### Women's Knowledge as Conservation Infrastructure

Women's knowledge can function as a form of non-physical conservation infrastructure because it helps maintain balanced relationships among people, customary spaces, and mangrove ecosystems. In the context of the Tonotwiyat-Women's Forest system, women are not only resource users but also custodians of knowledge regarding the location of biota, seasonal patterns, tidal conditions, permitted harvesting areas, and signs of environmental change. Women in Enggros village possess a unique knowledge system involving customary values, social norms, and the role of the forest as a living space for women (Flassy *et al.* 2024). This shows that women's knowledge plays a crucial role in mangrove management (conservation) in Enggros Village, as they interact directly and regularly with ecosystem through activities such as harvesting shellfish, fish, crabs, and the other biota, especially those of economic value. This interaction also enables women to detect environmental changes, including if it happens declining catches, habitat degradation, increased debris accumulation, or disturbances within the mangrove forest area. A study by Senis *et al.* (2026), conducted in Enggros and Tobati, Youtefa Bay, confirmed that indigenous women play a crucial role in mangrove forest utilization, traditional management, and adaptation strategies to ecosystem change. Thus, women's knowledge and participation in mangrove management deserve greater recognition, as their knowledge is not only ecological but also social, cultural, and institutional. Women understand spatial boundaries, ethical resource use, prohibitions, and intergenerational knowledge transmission. This aligns with research by Tcheton *et al.* (2025) on local knowledge in mangrove conservation management, which shows how local practices, taboos, customary norms, and community knowledge contribute significantly to the sustainability of mangrove ecosystems and the protection of biodiversity.

### Women's Participation and Knowledge Authority

The Tonotwiyat-Women's Forest knowledge and local wisdom system in Enggros Village, Papua, enriches the global discourse on women, livelihood, food, mangroves, and coastal management. Several studies have confirmed that women often have less participation in mangrove management, despite the fact that their active involvement is strongly associated with broader socio-ecological benefits (Chambon *et al.* 2024; Harper *et al.* 2024; Ruano-Chamorro *et al.* 2024; Anariba *et al.* 2025). The Tonotwiyat-Women's Forest system demonstrates a more substantive model in which women possess recognized

access spaces, access rights, ecological knowledge, and social control mechanisms. Therefore, a relevant policy framework should move beyond simple gender inclusion toward formal recognition of Indigenous women's authority (Lionata *et al.* 2025).

From an ethnobotanical perspective, women's knowledge of mangroves is relational in nature. Mangrove vegetation is understood not only as a biological resource, but also through its functions as habitat for food-related biota, a natural barrier against waves, a spatial boundary marker, a symbol of Indigenous identity, and a protected space for women's social interactions. Conservation and management approaches that ignore women's knowledge risk overlooking ecological information that is often not captured through short-term biophysical surveys and may also violate the principle of recognizing knowledge holders (Vandebroek *et al.* 2025; Teixidor-Toneu *et al.* 2026).

A study by Middleton *et al.* (2024) demonstrated that mangroves function as a gendered food system characterized by different access barriers for women and men. Tonotwiyat adds a new dimension to this understanding because women's relationships with mangroves are not only associated with food systems, but also with women's customary rights to space, privacy, and autonomy outside male-dominated customary structures such as the *para-para*. These findings enrich gendered food systems theory by demonstrating that food production spaces can function simultaneously as political and cultural spaces for women.

In some places, local taboo systems, customary norms, and ritual practices can also serve as conservation tools (Gnansounou *et al.* 2024). However, the Tonotwiyat system demonstrates that the primary holders and practitioners of this knowledge are women who engage daily with mangrove ecosystems. Similarly, Tcheton *et al.* (2025) found that mangrove management is sustained not only through formal regulations, but also through customary institutional mechanisms. Therefore, recognition of women's customary rights, involvement of indigenous women, knowledge transfer, and community-based mangrove restoration initiatives can mutually reinforce the health of mangrove ecosystems and women's well-being (McGinnis & Ostrom 2014; Delevaux *et al.* 2025).

#### **Tonotwiyat-Women Forest as Gendered Biocultural Mangrove Management**

The concept of gender-based biocultural mangrove ecosystem management explains mangrove management through four interrelated pillars: women's ecological knowledge, customary spatial rights, sacred cultural norms, and ecosystem functions (Rasquinha 2024; Dookie 2025; Chávez-Páez *et al.* 2025). Integrating formal legal frameworks and local customary rules can strengthen the resilience of mangrove ecosystems (Gnansounou *et al.* 2026). In the Tonotwiyat-Women's Forest system, women manage resources through ecological experience, customary territorial boundaries, gender-based restrictions, customary sanctions, and knowledge transfer. These pillars foster community compliance because these rules have social legitimacy and cultural significance. This framework connects plants (mangrove vegetation), people, customary institutions, and practical conservation measures, thereby positioning mangroves as the foundation of biocultural relationships.

Recognition of the Tonotwiyat-Women's Forest needs to be integrated into management planning documents so that mangrove revitalization does not weaken the authority of indigenous women. Thus, the Tonotwiyat Women's Forest system is not only understood as a mangrove forest utilization practice, but also as an SES that connects mangrove forest health, coastal food, indigenous women's authority, and intergenerational knowledge transfer. This perspective aligns with Delevaux *et al.* (2025), who argue that ecosystem conservation cannot be separated from local knowledge, food systems, cultural values, and the rights of indigenous peoples. On the other hand, indigenous women, as holders of ecological knowledge and guardians of the Tonotwiyat-Women's Forest institution, require formal recognition of their authority, not just documentation of local practices (Teixidor-Toneu *et al.* 2026).

#### **Pressure, Vulnerability, and the Risk of Knowledge Loss**

The challenges and pressures on the mangrove at Youtefa Bay, especially the Tonotwiyat Women's Forest system are ecological, social, and institutional. These challenges and pressures include: 1). Ecological challenges include mangrove degradation, mangrove land conversion such as ponds and settlements, pollution, habitat degradation, and the decline of food-related biota, especially fish, mollusks, and mangrove crabs; 2). Social challenges involve changes in livelihoods, modernization, and the declining interest of the younger generation in maintaining traditional practices; 3). Institutional challenges arise when development decisions fail to position indigenous women as key actors in consultation and decision-making processes. Regarding socio-institutional challenges, ecosystem restoration is often technocratic, ignoring access rights and the politics of local knowledge (Arifanti *et al.* 2025; Sahana 2025). ILK studies show that loss of generations of knowledge holders, migration, changing values, and modernization can accelerate the extinction of indigenous practices

(Tcheton *et al.* 2025). This is particularly important in the Tonotwiyat case, as women's knowledge is not yet documented in formal management plans. This is in line with the findings of Mondal *et al.* (2025) that indigenous women are the holders, guardians, and transmitters of local knowledge, but this knowledge is often unrecognized and inadequately documented.

Therefore, the policy of revitalizing the Tonotwiyat-Women's Forest system in mangrove planning and management needs to combine biophysical restoration and knowledge restoration (Khanum *et al.* 2026). Biophysical restoration includes mangrove rehabilitation, pollution control, water quality monitoring, and habitat protection. Meanwhile, knowledge restoration includes participatory documentation, indigenous education and outreach, strengthening women's organizations, protecting local languages, and recognizing knowledge holders (Vandebroek *et al.*, 2025; Teixidor-Toneu *et al.*, 2026). The revitalization of the Tonotwiyat-Women's Forest system needs to be supported by strengthening regional regulations or formalizing it (Kadir *et al.* 2021; Ilham *et al.* 2023). The agenda for formalizing the Tonotwiyat-Women's Forest must also be supported by scientific studies.

#### **Social-Ecological System Characteristics of the Tonotwiyat Women's Forest**

The Tonotwiyat Women's Forest can be understood as a social-ecological system (SES) that links mangrove ecosystems, Indigenous women, customary rules, local knowledge, development pressures, and socio-ecological outcomes (Paulangan *et al.* 2025b; Paulangan *et al.* 2025c). In the Tonotwiyat context, mangroves are not merely coastal vegetation zones, but constitute a gendered biocultural landscape with ecological, economic, social, cultural, and institutional functions (Flassy *et al.* 2024; Salsabila & Soertikanti 2024; Middleton *et al.* 2024).

Accordingly, the principal characteristic of the Tonotwiyat-Women's Forest SES is the reciprocal relationship between mangroves as a common-pool resource, Indigenous women as central actors, women's knowledge as conservation infrastructure, and customary rules as mechanisms for regulating resource use. The expected outcomes of this system include habitat conservation, food security, protection of cultural identity, women's spatial autonomy, social compliance, and the strengthening of co-management. However, external pressures such as pollution, land conversion, infrastructure development, changes in access, and weak formal recognition may disrupt system stability, particularly when development processes and formal policies fail to recognize customary boundaries and women's access rights (Marquez & Olavides 2024; Harper *et al.* 2024; Rodríguez-Rodríguez *et al.* 2024; Paulangan *et al.* 2025a).

#### **Institutional Components of the Tonotwiyat-Women's Forest within the CPR Framework**

Within the Common-Pool Resources (CPR) framework, the Tonotwiyat-Women's Forest is a shared resource whose use must be governed to prevent access conflicts, overexploitation, and the loss of socio-ecological functions. CPR analysis emphasizes the importance of clearly defined resource boundaries, recognized access rights, locally appropriate rules, monitoring, sanctions, and the fit between rules and local social-ecological conditions (Ostrom 2009; McGinnis & Ostrom 2014; Castillo *et al.* 2024). In Tonotwiyat, the institutional system operates through five main components: the territory system, rights system, rules system, monitoring system, and sanction system.

Based on CPR principles, Tonotwiyat-Women's Forest already contains several essential elements: socially recognized resource boundaries, Indigenous women's access rights, local rules, community-based monitoring, and social or customary sanctions. Nevertheless, its weaknesses lie in limited formal recognition, incomplete documentation of boundaries and rules, and the risk that women's rights may be weakened when formal development is not aligned with customary systems (Ilham *et al.* 2023; Salsabila & Soertikanti 2024). Therefore, the Tonotwiyat-Women's Forest CPR system needs to be strengthened through participatory mapping, recognition in village or regional regulations, conflict-resolution mechanisms, and co-management forums that integrate customary legitimacy with formal policy support (Macamo *et al.* 2024; Risley *et al.* 2025).

#### **Conceptualizing Tonotwiyat-Women's Forest as a Gender-Responsive Co-Management Model**

Tonotwiyat can be conceptualized as a gender-responsive, biocultural co-management model because it does not only regulate mangrove conservation, but also recognizes Indigenous women as rights holders, knowledge holders, social monitors, and decision-makers. Recent literature indicates that gender-responsive coastal and mangrove governance must move beyond symbolic inclusion of women toward the recognition of women's authority, access, benefits, and roles in decision-making (Chuku *et al.* 2022; Harper *et al.* 2024; Begum *et al.* 2025).

Conceptually, the Tonotwiyat-Women's Forest system consists of mangrove ecosystems, women's knowledge, customary spatial rights, customary rules and sanctions, formal recognition, and co-management forums. This framework is consistent with a biocultural approach that positions the relationship between nature, food, culture, and local institutions as the

foundation for conservation sustainability (Marquez & Olavides 2024; Delevaux *et al.* 2025). Operationally, a gender-responsive co-management model can be developed through four main stages:

1. Participatory mapping of the Women's Forest: This stage identifies socio-ecological boundaries, women's access routes, biota harvesting sites, areas exposed to pressures, and spaces with cultural value. Participatory mapping is important because it integrates local knowledge with place-based decision-making needs (Risley *et al.* 2025; Rodríguez-Rodríguez *et al.* 2024).
2. Recognition of Indigenous women's access rights: Women's rights to space, food, knowledge, and mangrove use need to be recognized in village regulations, area management documents, spatial planning instruments, or regional regulations. Such recognition is important so that women are positioned not merely as beneficiaries, but as legal and institutional subjects in mangrove governance (Ilham *et al.* 2023; Begum *et al.* 2025).
3. Establishment of a co-management forum: This forum should involve Indigenous women as decision-makers rather than merely as participants. Customary institutions, village governments, local governments, conservation-area managers, academics, NGOs, and relevant sectors can serve as supporting actors. Experiences from co-management across various mangrove ecosystems show that effective collaborative governance requires clear role sharing, local legitimacy, and cross-actor institutional support (Chuku *et al.* 2022; Macamo *et al.* 2024; Begum *et al.* 2025).
4. Integration of ecological monitoring and local knowledge monitoring: Monitoring should not only record mangrove condition, water quality, and biota, but also changes in women's access, the continuity of intergenerational knowledge, compliance with customary rules, and development pressures. Integrating formal and informal monitoring can strengthen compliance and position local knowledge as part of the management evaluation system (Castillo *et al.* 2024; Marquez & Olavides 2024; Risley *et al.* 2025).

Thus, the core value of Tonotwiyat is not simply the prohibition on men entering certain areas, but the recognition that Indigenous women possess ecological and institutional authority in mangrove governance. This model may provide an example for other coastal areas, although any replication should be undertaken carefully and adapted to local cultural contexts. The central issue is not to reproduce the form of prohibition, but to adopt its underlying principles: clear boundaries, recognized access rights, locally legitimate rules, community monitoring, social sanctions, and women as central actors in decision-making (Flassy *et al.* 2024; Salsabila & Soertikanti 2024; Middleton *et al.* 2024; Harper *et al.* 2024).

#### Implications for Co-management and Policy

The Tonotwiyat-Women's Forest system can be developed as an adaptive co-management approach. Therefore, it needs to be translated into a formal mechanism. This is in line with Ilham *et al.* (2023), as an effort to save and protect the local wisdom of the coastal communities of Youtefa Bay, it needs to be strengthened with a regional regulation. The development of this adaptive co-management model consists of at least four stages, namely: 1) participatory mapping of the Women's Forest and its socio-ecological boundaries (James 2025); 2) recognition of indigenous women's access rights in village regulations, area management plans, or regional instruments (James *et al.* 2021; Lionata *et al.* 2025; Ilham *et al.* 2023); 3) establishment of a joint management forum with an institutional design that places indigenous women as decision-makers (Anariba *et al.* 2025; Bitzer *et al.*, 2024; Begum *et al.*, 2025); and 4) integration of ecological monitoring and local knowledge monitoring into evaluation systems. Recent evidence suggests that effective co-management requires political commitment, appropriate local institutions, regulatory compliance, and incentives for community actors (Begum *et al.* 2025; Castillo *et al.* 2024; Kuran *et al.* 2025).

Mangrove management in Youtefa Bay is inseparable from a hierarchical and cross-sectoral approach. At the local level, for example, strengthening customary rules, educating the younger generation, managing pollution and waste, and planting mangroves are priorities. At the city/provincial government level, the priorities are harmonizing policies for the Youtefa Bay Nature Tourism Park, spatial planning, protecting customary areas, and infrastructure. At the national/international level, Tonotwiyat can be positioned as a community-based Other Effective Area-Based Conservation Measure (OECM), biocultural conservation, and protecting indigenous women's knowledge within the biodiversity, blue carbon, and climate agendas (Delevaux *et al.* 2025; Lee *et al.* 2025).

Although the Tonotwiyat-Women's Forest values and systems can be replicated in other areas, they must be done with caution. The primary value of Tonotwiyat-Women's Forest is not simply the replication of gender prohibitions, but rather the principle that clear socio-ecological boundaries, recognized access rights, rules based on customary legitimacy, supervision, social sanctions, and local knowledge should be designed as the basis for decision-making. In this way, these values and systems can inspire community-based mangrove management without diminishing the uniqueness of local culture (Marquez & Olavides 2024; Macamo *et al.* 2024).

## Conclusion

Based on this research, the Tonotwiyat-Women's Forest system in Youtefa Bay is a mangrove management system based on indigenous women's knowledge that combines ecological, economic, social, cultural, and institutional functions. This system regulates spatial boundaries, women's access rights, prohibitions, social, cultural and institutional functions as a social-ecological institution that contributes to sustainable mangrove management of coastal livelihoods in Enggros Village, Youtefa Bay. The conceptualization of Tonotwiyat-Women's Forest as gendered biocultural mangrove management positions indigenous women as holders of knowledge and institutional authority, not merely vulnerable groups or beneficiaries of management or conservation programs. The Tonotwiyat-Women's Forest System through the SES-CPR framework shows that effective mangrove management (conservation) requires recognizing the relationship between mangrove vegetation, associated biota, customary authority, gender, and local knowledge practices. To be relevant for policy, formalization of the Tonotwiyat-Women's Forest must be carried out through equitable co-management, participatory mapping, protection of women's access rights, strengthening intergenerational education and managing ecological pressures. In addition, the strengthening of Tonotwiyat-Women's Forest is not only a mangrove conservation agenda, but also an agenda of epistemic justice, cultural protection, and the sustainability of Papua's coastal indigenous communities.

## Declarations

**List of abbreviations:** SES - social-ecological systems; CPR - common-pool resources; ILK - indigenous and local knowledge; FGD - Focus Group Discussion; NGO - non Government Organization

**Ethics approval and consent to participate:** This research was conducted in accordance with the principles of informed consent, informant confidentiality, respect for customary norms, and due care in documenting local knowledge. All informants involved in in-depth interviews, participant observation, participatory mapping, and focus group discussions were provided with clear information regarding the purpose of the research, the nature of their involvement, and the intended use of the data, after which they gave their consent to participate. Information considered culturally sensitive was not disclosed in detail without the approval of the community. This research received ethical clearance from the Ethical Committee on Social Studies and Humanities, National Research and Innovation Agency, under approval number: 984/KE.01/SK/12/2025.

**Consent for publication:** This manuscript does not directly reveal the personal identities of the informants. The data presented is aggregated, descriptive, and compiled with consideration for the protection of indigenous knowledge and the rights of communities as knowledge holders.

**Availability of data and materials:** Research data is not publicly available because it contains socio-cultural information, traditional narratives, and local knowledge that are potentially sensitive to the community. Selected data may be reasonably requested from the corresponding author, while still considering community consent, research ethics, and the protection of knowledge holders.

**Competing interests:** The authors declare that they have no conflict of interest.

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**Authors' contributions:** Y.P.P. contributed to the research conceptualization, methodological design, data collection, data analysis, drafting of the manuscript, and correspondence. T. contributed to strengthening the conceptual framework, validation of the methodology, and SES analysis, as well as reviewing the manuscript. M.A.A. contributed to institutional analysis, development of the CPR framework, data interpretation, and substantial editing of the manuscript. E.I. contributed to data collection, ecological analysis, and reviewing the manuscript. K.A.A.M. contributed to data collection and reviewing the manuscript. E.F.R. contributed to data collection. F.Y.R. contributed to data collection, research administration, and field technical support. M.H. contributed to the visualization of the research map and the Women's Forest Location map. All authors read and approved the final version of the manuscript.

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