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Development of a Local-Wisdom-Based Cage Aquaculture Management Model to Support Food Security among the Bajo Community in Wangkolabu Village, Towea District, Muna Regency

Ainun Jariyah[1*], Andi Sulia Sudirman[2]
[1-2] Universitas Halu Oleo, Indonesia
email: ainjryhhh@email.com[1]

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Abstract

This study examined local-wisdom-based cage aquaculture management, its contribution to household food security, and the development of an integrated conceptual management model among the Bajo community in Wangkolabu Village, Towea District, Muna Regency, Southeast Sulawesi. A qualitative descriptive-exploratory design was employed over a three-month research period. Nine informants representing cage farmers, community and customary actors, village leadership, and housewives with knowledge of household food utilization were selected purposively, with snowball sampling available when additional information was required. Data were collected through non-participant observation, semi-structured in-depth interviews, and documentation and were analysed through data collection, data condensation, data display, and conclusion drawing and verification. Credibility was maintained through source triangulation, technique triangulation, and member checking. The findings show that cage aquaculture is managed through planning, construction, stocking, maintenance, environmental monitoring, harvesting, and evaluation that are adapted to local coastal conditions. Bajo local wisdom operates through seasonal knowledge, collective labor, customary rules, the Popanga and Mallupa traditions, deliberative decision-making, and intergenerational ecological learning. Cage aquaculture contributes to household food security by strengthening food availability, access, utilization, and stability through direct consumption, income generation, fish processing, and the use of cultivated stocks as a household reserve. The study develops a conceptual model integrating coastal environmental conditions, local wisdom, cage-management processes, production utilization, and household food security. The model demonstrates that sustainable small-scale aquaculture is shaped by interactions among ecological knowledge, social institutions, cultivation practices, and household livelihood strategies.

Keywords: *Bajo community; cage aquaculture; food security; local ecological knowledge; local wisdom.*

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INTRODUCTION

Aquaculture has become increasingly important to contemporary food systems because capture fisheries alone cannot accommodate the combined pressures of population growth, nutritional demand, environmental degradation, and climate-related uncertainty. Current scholarship positions aquatic food production not merely as a sectoral economic activity but as an integral component of food availability, dietary quality, livelihood resilience, and environmental management, particularly in coastal and island communities that depend directly on aquatic resources (Cai & Leung, 2022; Cojocaru et al., 2022; Koehn et al., 2023). The expansion of aquaculture, however, has also intensified concerns regarding production efficiency, ecological carrying capacity, disease risks, feed dependence, environmental externalities, and the institutional capacity required to maintain production without exceeding ecosystem limits (Abisha et al., 2022; Noor & Harun, 2022). Floating cage culture illustrates this tension because it can generate relatively intensive production from existing water bodies while simultaneously creating pressures associated with feed inputs, waste accumulation, stocking density, water-quality change, and competition over aquatic space when management is weak or poorly adapted to local ecological conditions (Astuti et al., 2023; Junaidi et al., 2022; Kurniasih et al., 2024). Production sustainability is consequently shaped not only by

physical infrastructure and biological inputs, but also by the availability of affordable feed, resource efficiency, environmental adaptation, and governance arrangements capable of coordinating producers and institutions (Ahmad et al., 2022; Prabakusuma et al., 2023; Jolly et al., 2023). These concerns are particularly relevant in Indonesia, where aquaculture development occurs across socially and ecologically heterogeneous coastal settings and where management decisions must accommodate differences in local institutions, resource access, and environmental knowledge (Nagel et al., 2024; Riany et al., 2023). For Bajo communities whose social organization and livelihoods have historically been closely associated with marine space, aquaculture management also intersects with customary norms, inherited ecological knowledge, household livelihood strategies, and culturally embedded relationships with coastal ecosystems (Aswita et al., 2022; Upe et al., 2022; Wianti & McWilliam, 2023). The scientific problem is therefore not confined to increasing cage productivity, but concerns how cage aquaculture can be governed as a socially embedded production system that simultaneously maintains ecological viability, strengthens household food security, and retains locally adaptive knowledge within a rapidly changing coastal economy.

Recent research has developed three major and partially interconnected strands of knowledge relevant to sustainable cage aquaculture. The first strand concentrates on technical and ecological performance, demonstrating that the sustainability of floating cages depends on site suitability, carrying capacity, water conditions, production efficiency, and operational adjustment to environmental variability; Indonesian studies on Lake Maninjau, Pekalongan coastal waters, Lake Toba, Jatiluhur, and Gajah Mungkur collectively indicate that cage production cannot be separated from the ecological capacity of the aquatic environment in which cultivation is undertaken (Junaidi et al., 2022; Mardiana et al., 2023; Siringoringo et al., 2023; Suryana et al., 2023; Kurniasih et al., 2024). Economic feasibility research further shows that production decisions are affected by input requirements, capital allocation, productivity, and market returns, meaning that ecological sustainability and household economic viability are analytically connected rather than independent dimensions of aquaculture management (Lamo et al., 2023). A second strand has shifted attention from farm-level technique toward institutions and governance, showing that sustainable aquaculture is mediated by regulatory structures, producer resilience, voluntary standards, stakeholder interactions, and the mental models through which actors interpret management priorities (Engle & van Senten, 2022; Karim & Almira, 2023; Jolly et al., 2023; Nagel et al., 2024; Riany et al., 2023). A third strand demonstrates the continued analytical relevance of local ecological knowledge, customary institutions, and intergenerational knowledge transmission in fisheries and coastal management. Studies conducted across the Bay of Bengal, the Galapagos, Mexico, and West Africa indicate that locally accumulated observations of environmental change, species distribution, resource decline, and resource-use practices can complement formal scientific information and improve the contextual sensitivity of management systems (Pontón-Cevallos et al., 2022; Ullah et al., 2023; Fernández-Rivera Melo et al., 2024; Macedo et al., 2025). Research involving Bajo communities provides a more specific social foundation by identifying ecological knowledge, marine zoning practices, customary regulation, settlement adaptation, and livelihood resilience as persistent elements in the relationship between Bajo society and coastal resources (Aswita et al., 2022; Taufik et al., 2023; Upe et al., 2022; Wianti & McWilliam, 2023; Haris et al., 2019). Collectively, this state of the art indicates a movement away from narrowly production-oriented aquaculture toward socio-ecological governance, yet the technical, institutional, cultural, and food-security dimensions remain more frequently examined in parallel than integrated within a single locally grounded management model.

A critical reading of this literature reveals a research gap at the intersection of aquaculture management, local ecological knowledge, Bajo social institutions, and household food security. Studies of floating cage systems have generated considerable information on productivity, site suitability, environmental risk, carrying capacity, and business feasibility, but their principal units of analysis remain cultivation performance and resource conditions rather than the systematic incorporation of customary knowledge into the entire management process (Astuti et al., 2023; Mardiana et al., 2023; Lamo et al., 2023; Siringoringo et al., 2023; Suryana et al., 2023). Governance-oriented studies expand the analytical scope by demonstrating the importance of institutions, regulations, certification standards, actor perceptions, and community resilience, yet they do not adequately explain how culturally embedded ecological knowledge can be converted into operational principles for planning, implementation, monitoring, and evaluation at the level of small coastal

communities (Engle & van Senten, 2022; Karim & Almira, 2023; Jolly et al., 2023; Nagel et al., 2024). Local ecological knowledge research provides persuasive evidence that fishers possess detailed and temporally accumulated knowledge capable of supporting resource governance, but much of this literature addresses capture fisheries, mangrove management, environmental monitoring, or knowledge transmission rather than cage-aquaculture management linked directly to household food-security outcomes (Pontón-Cevallos et al., 2022; Ullah et al., 2023; Fernández-Rivera Melo et al., 2024; Macedo et al., 2025). The Bajo literature presents a comparable limitation: studies have documented customary marine practices, socio-spatial organization, livelihood adaptation, ecological values, and legal recognition of local wisdom, yet these dimensions have not been sufficiently synthesized into a management framework that explains how local knowledge influences cage cultivation and how cultivation, in turn, supports food availability, access, utilization, and stability (Aswita et al., 2022; Taufik et al., 2023; Upe et al., 2022; Wianti & McWilliam, 2023; Haris et al., 2019). Food-system scholarship further establishes the importance of aquatic foods for nutrition and food security, but generally operates at national, regional, or global scales and provides limited explanation of the household-level mechanisms through which community-based cage aquaculture stabilizes food access under seasonal and environmental uncertainty (Cai & Leung, 2022; Cojocaru et al., 2022; Ragasa et al., 2022; Koehn et al., 2023). The unresolved issue is therefore a contextual and conceptual gap: knowledge exists concerning sustainable aquaculture, community governance, local ecological knowledge, and aquatic-food security, but their interaction has not been adequately formulated as an integrated model for a Bajo cage-farming community such as Wangkolabu.

Leaving this gap unresolved has direct scientific and practical consequences. From a scientific standpoint, evaluating aquaculture primarily through technical productivity or environmental performance risks underestimating the social institutions through which production decisions are actually made, while analysing local wisdom only as cultural heritage risks separating indigenous knowledge from the material processes of food production, livelihood security, and ecological adaptation. Climate-related stress and abiotic variability already require aquaculture systems to become more adaptive, making locally accumulated knowledge of seasons, water conditions, resource availability, and risk particularly relevant to management design rather than merely descriptive ethnographic information (Abisha et al., 2022). Resource efficiency also remains central because feed availability and dependence on costly production inputs can affect both cultivation continuity and the capacity of households to retain economic benefits from aquaculture, a concern reinforced by research on alternative feed resources and circular production systems (Ahmad et al., 2022; Prabakusuma et al., 2023). Ecological limits create an additional constraint: findings on carrying capacity and environmentally responsible cage cultivation indicate that increased production without context-sensitive control can undermine the water conditions upon which cultivation itself depends (Astuti et al., 2023; Mardiana et al., 2023; Kurniasih et al., 2024). Governance research similarly implies that interventions based solely on external regulation or standardized production criteria may produce limited outcomes where actor perceptions, community institutions, and locally legitimate decision-making mechanisms are ignored (Engle & van Senten, 2022; Jolly et al., 2023; Karim & Almira, 2023; Nagel et al., 2024). For coastal households, weak integration between production management and livelihood strategies can also increase vulnerability because aquatic foods function simultaneously as food, income, and economic buffers against fluctuations in fishing opportunities and other shocks (Saksono et al., 2023; Taufik et al., 2023; Cai & Leung, 2022). A management model capable of linking ecological knowledge, social cooperation, cultivation practice, institutional support, and household food security would consequently provide a stronger analytical basis for designing interventions that are locally legitimate, environmentally adaptive, and economically relevant rather than transferring standardized aquaculture prescriptions into culturally distinct coastal settings.

The present study is positioned within this unresolved interface and proposes a distinct contribution by treating local wisdom not as an external cultural variable but as an operational component of cage-aquaculture management and food-security formation. Earlier studies of Indonesian cage cultivation have primarily examined ecological feasibility, productivity, environmental risk, or economic performance, whereas this research places the sequence of management activities—planning, implementation, maintenance, monitoring, harvesting, and collective evaluation—within the local knowledge system of a Bajo community (Junaidi et al., 2022;

Astuti et al., 2023; Lamo et al., 2023; Siringoringo et al., 2023; Suryana et al., 2023). The study also differs from governance research that concentrates on formal regulations, certification, institutional configurations, or stakeholder perceptions by investigating how community-based rules, cooperation, environmental reading, customary practices, and deliberative decision-making can operate within everyday cultivation management (Karim & Almira, 2023; Riany et al., 2023; Nagel et al., 2024). Its novelty is further distinguished from the established local ecological knowledge literature: rather than demonstrating only that local knowledge exists or can complement scientific information, the research seeks to organize that knowledge into a conceptual management architecture directly connected to aquaculture production and food-security outcomes (Pontón-Cevallos et al., 2022; Ullah et al., 2023; Fernández-Rivera Melo et al., 2024). The Bajo setting provides an additional dimension because previous studies emphasize marine spatial practices, cultural resilience, livelihood adaptation, settlement ecology, and customary legitimacy, while the relationship between these socio-cultural resources and the governance of cage aquaculture remains insufficiently specified (Aswita et al., 2022; Upe et al., 2022; Wianti & McWilliam, 2023; Haris et al., 2019). The proposed model also connects production with food security more explicitly than studies that treat aquatic foods mainly at aggregated food-system scales, by considering how cultivated fish may support household availability, purchasing capacity, utilization, and stability under changing production and fishing conditions (Cojocaru et al., 2022; Ragasa et al., 2022; Koehn et al., 2023). The novelty therefore lies in an empirically grounded integration of coastal environmental conditions, Bajo local wisdom, cage-management processes, institutional and social mechanisms, production utilization, and household food security within a single conceptual model developed for Wangkolabu Village rather than in the introduction of an isolated new variable.

This study aims to identify and analyse the management practices of cage aquaculture among the Bajo community in Wangkolabu Village, examine the forms and operational functions of local wisdom embedded in cultivation activities, assess the relationship between cage aquaculture and household food security, and synthesize these components into a conceptual model of local-wisdom-based cage aquaculture management. The analysis is designed to explain how environmental knowledge, social cooperation, customary norms, management practices, institutional conditions, and the utilization of aquaculture products interact within a coastal household production system. Its scientific contribution lies in integrating aquaculture management, community-based resource governance, local ecological knowledge, and food security into a coherent analytical framework that can extend current understanding of small-scale coastal aquaculture as a social-ecological system. Its methodological contribution is expected to emerge from the empirical synthesis of qualitative evidence obtained from actors directly involved in cultivation, customary institutions, and household food management rather than from imposing a predetermined production model. Its practical contribution is directed toward the formulation of locally grounded management principles that can inform community organizations, fisheries extension services, and local government when developing aquaculture programs that require both ecological adaptation and social legitimacy. The resulting model is expected to provide an analytical basis for strengthening sustainable cage cultivation while preserving the locally embedded capacities through which Bajo households manage marine resources and maintain food security.

RESEARCH METHODS

This study employed a qualitative descriptive-exploratory design to examine cage-aquaculture management practices, the forms and functions of local wisdom maintained by the Bajo community, and their relationship with household food security in Wangkolabu Village, Towea District, Muna Regency, Southeast Sulawesi. The research was conducted over a three-month period covering preparation, field data collection, data analysis, conceptual-model formulation, and report preparation. Wangkolabu Village was selected purposively because it is a coastal settlement in which the Bajo community depends substantially on capture fisheries and cage aquaculture while continuing to maintain locally inherited practices in the management of coastal resources. Informants were selected through purposive sampling based on their knowledge, experience, and direct involvement in cage aquaculture, customary practices, village administration, and household food management. The empirical records document nine informants representing cage farmers, community and customary actors, village leadership, and housewives with knowledge of household food utilization. When

additional information was required during fieldwork, informant recruitment could be extended through snowball sampling until additional interviews no longer generated substantively new information. Primary data were obtained through non-participant observation, semi-structured in-depth interviews, and documentation. Observation focused on cage-aquaculture activities, environmental conditions surrounding the cultivation sites, and the application of local practices, while interviews explored cultivation planning, implementation, maintenance, environmental monitoring, customary knowledge, production constraints, social cooperation, and the contribution of aquaculture to household food availability, access, utilization, and stability. Documentary materials included photographs, village profiles, fisheries production records, government reports, maps, institutional archives, and other records relevant to cage cultivation, coastal-resource management, and food-security conditions.

Data analysis followed an interactive qualitative procedure comprising data collection, data condensation, data display, and conclusion drawing and verification. Interview, observation, and documentary evidence were organized and compared to identify recurring patterns related to cage-management stages, environmental knowledge, local norms, collective practices, production constraints, and household food-security functions. The analytical process then synthesized relationships among coastal environmental conditions, Bajo local wisdom, cultivation-management processes, supporting and constraining factors, the utilization of aquaculture products, and the dimensions of household food security. This synthesis was used to construct a conceptual model of local-wisdom-based cage aquaculture management rather than a mathematical or statistically estimated model. The model formulation therefore depended on qualitative integration of empirical categories derived from field evidence and was directed toward explaining how ecological, social, cultural, institutional, and economic components interact within the local aquaculture system. Credibility was maintained through source triangulation by comparing information across different informant groups, technique triangulation by cross-checking interview data against observation and documentary evidence, and member checking by confirming the researchers' interpretations with informants. These procedures enabled the study to connect its objectives directly with the evidence used to describe existing cage-management practices, identify the operational role of local wisdom, assess the contribution of aquaculture to household food security, and formulate an empirically grounded conceptual management model.

RESULTS AND DISCUSSION

Local-Wisdom-Based Cage Aquaculture Management as a Social-Ecological Adaptation

Field findings indicate that cage aquaculture in Wangkolabu Village operates through an interconnected sequence of planning, cage construction, stocking, maintenance, environmental monitoring, harvesting, and evaluation. Cultivation decisions are not determined solely by expected economic returns because farmers also assess seasonal conditions, water depth, tidal movement, currents, and perceived water quality before initiating production. This pattern indicates an adaptive production system in which environmental observation is embedded in routine managerial decisions rather than treated as a separate conservation activity (Abisha et al., 2022). Comparable evidence from Indonesian floating-cage systems confirms that the viability of aquaculture is strongly affected by the compatibility between cultivation practices and the ecological characteristics of the water body (Junaidi et al., 2022; Mardiana et al., 2023).

Planning represents a critical point at which ecological knowledge and economic calculation intersect. Farmers consider commodity value, seed availability, ease of maintenance, expected production prospects, and the suitability of local waters before determining what will be cultivated and where cages will be positioned. Observations of temperature, depth, currents, and tidal behavior provide practical indicators for reducing exposure to unsuitable cultivation conditions, consistent with studies showing that site characteristics and environmental carrying capacity influence floating-cage performance (Siringoringo et al., 2023; Suryana et al., 2023). The planning process observed in Wangkolabu differs from strictly technical site-selection procedures because the interpretation of environmental indicators is largely derived from accumulated experience and intergenerational knowledge.



Figure 1. Cage Aquaculture Location
Source: Personal Documentation, 2026.

Figure 1 visually situates cage cultivation within the coastal waters used by the Wangkolabu community and supports the interview evidence concerning direct dependence on surrounding marine conditions. The location of cages in an open aquatic environment means that farmers cannot fully control currents, tides, weather changes, or variations in water quality, making environmental interpretation a continuous component of cultivation management. This exposure explains why experiential knowledge of local waters remains important even when cage aquaculture adopts increasingly structured production practices. Research on environmentally responsible cage aquaculture similarly identifies the relationship between cage placement, surrounding water conditions, and ecological carrying capacity as central to sustainable production (Astuti et al., 2023; Kurniasih et al., 2024).

Cage construction further demonstrates that aquaculture management is supported by locally available material and social resources. Field evidence shows that cages are constructed using materials such as timber, bamboo, and aquaculture nets, while family members and neighboring residents commonly participate in construction and maintenance activities. Collective labor reduces the immediate labor burden and production costs borne by individual farmers while simultaneously maintaining reciprocal relationships among community members. Such cooperation supports the proposition that the resilience of small-scale aquaculture depends partly on social organization and institutional relationships rather than exclusively on physical infrastructure and financial capital (Engle & van Senten, 2022; Jolly et al., 2023).



Figure 2. Cage Construction or Maintenance Process
Source: Personal Documentation, 2026.

Figure 2 documents the material and labor dimensions of cage construction or maintenance and provides visual support for the finding that cultivation is embedded in routine community practices. Construction and maintenance require direct interaction with cage structures and the surrounding waters, making operational knowledge inseparable from repeated practical experience. The observed

process also illustrates why cooperation functions as more than a cultural value, since collective labor has direct implications for workload distribution, maintenance continuity, and the capacity of farmers to sustain production with limited resources. Studies of community resilience in aquaculture similarly show that social relationships can influence the capacity of producers to respond to economic and environmental pressures (Engle & van Senten, 2022).

The empirical structure of cage management can be condensed into several interrelated components that connect ecological observation, production practice, and social coordination. Interview, observation, and documentary evidence consistently indicate that planning and implementation are followed by continuous monitoring, while production constraints require farmers to adjust management decisions according to changing conditions. Table 1 summarizes these patterns and clarifies their functional significance within the local aquaculture system (Nagel et al., 2024).

Table 1. Empirical Structure of Cage Aquaculture Management in Wangkolabu Village

Management component	Empirical findings	Analytical significance
Planning	Commodity selection considers season, water conditions, seed availability, ease of maintenance, and economic value	Integrates ecological observation with household economic calculation
Cage construction	Cages use locally accessible materials and are commonly constructed through collective labor	Reduces operational burden and reinforces community cooperation
Cultivation	Stocking, feeding, net cleaning, growth monitoring, and harvesting are conducted according to production and environmental conditions	Demonstrates adaptive rather than rigid production management
Environmental monitoring	Farmers observe seasonal changes, currents, salinity, tides, and water conditions	Provides locally embedded ecological risk assessment
Social regulation	Cage ownership is respected and problems are addressed through mutual assistance and deliberation	Supports informal institutional order
Production constraints	Feed, capital, seed availability, weather, and water conditions remain major constraints	Expose the limits of household-level adaptive capacity

Table 1 demonstrates that technical management and local ecological knowledge do not operate as independent systems. Farmers perform recognizable aquaculture activities such as stocking, feeding, cage cleaning, monitoring, and harvesting, but the timing and adjustment of these practices remain influenced by interpretations of marine conditions and locally accumulated experience. Production efficiency in this setting therefore cannot be evaluated only through conventional input-output measures because access to local knowledge and cooperative labor also shapes operational performance. This finding extends economically oriented cage studies that predominantly emphasize productivity, cost structures, and business feasibility by identifying social and ecological knowledge as additional production resources (Lamo et al., 2023).

Environmental monitoring is particularly important because cages remain directly exposed to fluctuations in the surrounding ecosystem. Farmers observe changes in seasons, salinity, currents, and water conditions and may adjust feeding or harvesting when environmental changes are considered likely to affect cultivation. Such practices resemble locally embedded risk assessment, even though they are not based exclusively on formal measurement instruments. Studies of local ecological knowledge show that sustained interaction with marine ecosystems can generate detailed observations capable of supporting locally responsive resource-management decisions (Pontón-Cevallos et al., 2022; Ullah et al., 2023).

Informal social regulation complements ecological adaptation by organizing relationships among cage farmers. Respect for cage ownership, mutual assistance, shared vigilance, and deliberative settlement of problems reduce the likelihood that cultivation becomes governed solely

through individual competition over marine space. Aquaculture governance research demonstrates that institutional performance depends not only on written regulations but also on how actors understand responsibilities, legitimate rules, and relationships with other resource users (Riany et al., 2023; Nagel et al., 2024). The Wangkolabu findings indicate that community norms provide a locally legitimate regulatory layer that supports the day-to-day functioning of cage cultivation.

Adaptive capacity nevertheless operates within clear material constraints. Farmers continue to encounter feed costs, limited production capital, seed availability, weather variability, and changing water conditions, indicating that accumulated ecological knowledge cannot eliminate every source of production risk. Feed-related pressures are especially relevant because expenditure on production inputs directly affects economic viability, while current aquaculture research emphasizes the need for more resource-efficient and locally accessible feed systems (Ahmad et al., 2022; Prabakusuma et al., 2023). These constraints distinguish adaptive management from complete resilience: local knowledge allows farmers to respond to certain environmental and operational changes, but structural input and financial limitations still require broader institutional and technical support.

The empirical evidence positions cage aquaculture management in Wangkolabu as a social-ecological adaptation system formed by interactions among environmental observation, technical cultivation, collective labor, informal regulation, and responses to production risk. The two field photographs reinforce this interpretation by locating cultivation within the marine environment and documenting the material practices through which cage infrastructure is established and maintained. Contemporary aquaculture governance scholarship similarly argues that sustainable production depends on the interaction of ecological conditions, institutions, producer behavior, and management capacity rather than technological improvement alone (Jolly et al., 2023; Fernández-Rivera Melo et al., 2024). The principal implication is that strengthening cage aquaculture in Wangkolabu requires technical development to remain compatible with local environmental knowledge and community-based mechanisms that currently support adaptation, labor organization, and social regulation.

Local Wisdom as Social and Ecological Capital in Cage Aquaculture Management

The empirical evidence shows that local wisdom among the Bajo community functions as an operational resource within cage aquaculture rather than as a cultural attribute detached from production. Informants described five recurrent forms of local wisdom: seasonal knowledge, collective labor, customary rules, the Popanga and Mallupa traditions, and deliberative decision-making. These practices influence how farmers interpret environmental conditions, allocate labor, regulate social conduct, and resolve production-related problems, demonstrating that local knowledge is embedded in both ecological and institutional dimensions of cultivation. Comparable studies of Bajo communities have documented that marine knowledge, customary spatial arrangements, and culturally embedded practices remain central to the governance of coastal resources (Aswita et al., 2022; Upe et al., 2022).

Seasonal knowledge represents the strongest ecological component identified in the field data. Farmers use accumulated observations of wind direction, currents, tides, water depth, and seasonal transitions to determine appropriate periods for stocking, cage maintenance, and harvesting, indicating that environmental decision-making is based on repeated interaction with local waters. Research on local ecological knowledge has similarly shown that coastal communities can develop detailed site-specific information about environmental change and resource dynamics through long-term experiential learning (Pontón-Cevallos et al., 2022; Ullah et al., 2023). The analytical significance of this finding lies in the capacity of locally generated knowledge to function as an early interpretive system for reducing cultivation risk where formal monitoring remains limited.

The transmission of environmental knowledge across generations further strengthens its role in cage management. Informants indicated that knowledge of marine conditions is largely acquired from parents, older fishers, and repeated practical exposure rather than from written manuals or standardized technical training. Intergenerational transmission is important because ecological knowledge remains useful only when it is continually interpreted and adapted to changing environmental conditions rather than reproduced as static tradition. Fernández-Rivera Melo et al. (2024) similarly emphasize that the continuity of traditional, scientific, and ecological knowledge depends on social processes that enable younger generations to acquire, reinterpret, and apply accumulated experience.

Collective labor constitutes the principal social mechanism supporting the material operation of cage aquaculture. Cage construction, installation, maintenance, and harvesting frequently involve family members and neighboring residents, reducing labor costs while distributing work across trusted social relations. This pattern indicates that production capacity is partly generated through social capital because access to labor and mutual assistance affects the ability of households to maintain cultivation activities under limited financial resources. Evidence from small-scale coastal livelihoods also shows that social networks and collective strategies can strengthen household resilience where economic opportunities and production conditions are unstable (Saksono et al., 2023; Taufik et al., 2023).

The forms and managerial functions of local wisdom identified from the field data are synthesized in Table 2. The table illustrates that each practice performs a distinct role within the cultivation system, ranging from ecological risk reduction to social coordination and normative control. Such differentiation is analytically important because local wisdom should not be treated as a single cultural variable when its individual components influence separate stages of resource management (Haris et al., 2019).

Table 2. Forms and Management Functions of Bajo Local Wisdom in Cage Aquaculture

Form of local wisdom	Field practice	Management function
Seasonal knowledge	Reading wind, currents, tides, weather, and changes in water conditions	Supports timing decisions and reduces environmental risk
Collective labor	Joint construction, maintenance, and harvesting of cages	Reduces labor burden and strengthens reciprocal cooperation
Customary rules	Respect for cage ownership and accepted use of marine space	Regulates behavior and limits interpersonal conflict
Popanga and Mallupa	Cultural practices expressing respect and gratitude toward the sea	Reinforces ethical relationships with marine resources
Deliberation	Collective discussion of cultivation problems and disputes	Supports locally legitimate decision-making
Intergenerational learning	Transmission of marine knowledge through family and community experience	Maintains continuity of locally adapted ecological knowledge

Customary rules provide a complementary form of regulation by establishing expectations regarding ownership, use of marine space, and acceptable behavior toward other farmers' cages. Informants described norms against damaging or interfering with other people's cages and emphasized the use of community deliberation when disputes occur, suggesting that informal rules function as practical governance mechanisms. Legal and socio-cultural research on Bajo communities has similarly shown that customary norms can structure relationships with marine resources even where formal legal recognition is incomplete or uneven (Haris et al., 2019). These findings indicate that aquaculture governance in Wangkolabu operates through a hybrid institutional environment in which formal administrative structures coexist with locally legitimate social regulation.

Popanga and Mallupa introduce a cultural and symbolic dimension that is not captured by technical aquaculture models. The traditions are maintained as expressions of gratitude and respect toward the sea, linking production activity to a moral understanding of the marine environment as a source of livelihood that should not be treated solely as an economic asset. Ethnographic research among Bajo communities has repeatedly shown that social identity, spatial practices, and ecological relationships are closely intertwined, making cultural meaning relevant to resource-management behavior (Aswita et al., 2022; Upe et al., 2022). Their managerial relevance lies less in direct production control than in reinforcing norms of restraint, respect, and collective responsibility toward coastal resources.

Deliberation functions as a local decision-making mechanism that connects ecological knowledge, social relations, and practical production problems. Community discussions are used to evaluate cultivation activities, address disagreements, and determine responses to operational

difficulties, indicating that decision-making is not always centralized at the individual household level. Governance research has demonstrated that participation and locally legitimate decision processes can improve the responsiveness of resource management because users possess information that may not be available to external institutions (Jolly et al., 2023; Riany et al., 2023). In Wangkolabu, deliberation therefore contributes to institutional resilience by transforming individual experiences into shared management responses.

The persistence of local wisdom does not imply that Bajo aquaculture operates independently from broader economic and institutional pressures. Market demand, input costs, seed availability, environmental degradation, and changing cultivation technologies can alter the conditions under which inherited practices remain effective, creating the need for selective adaptation rather than unconditional preservation. Research on aquaculture governance indicates that local institutions are most effective when they can interact with scientific knowledge, public regulation, and technical support without losing their social legitimacy (Nagel et al., 2024; Karim & Almira, 2023). This point is particularly relevant for Wangkolabu because customary knowledge can guide environmental interpretation and collective behavior but cannot independently resolve structural constraints related to finance, infrastructure, or input supply.

The analytical pattern emerging from the field evidence positions Bajo local wisdom as a combination of ecological knowledge, social capital, normative regulation, and cultural meaning that directly influences cage-aquaculture management. Its contribution is strongest where environmental uncertainty and limited formal support require producers to rely on accumulated experience, reciprocal labor, and locally accepted rules to sustain production. Similar observations have been reported in studies showing that local knowledge can strengthen the adaptive capacity of fishing communities and improve the contextual relevance of resource governance when integrated with wider management systems (Macedo et al., 2025; Wianti & McWilliam, 2023). For Wangkolabu, the principal implication is that efforts to modernize cage aquaculture should treat local wisdom as a functional management resource that can be strengthened through institutional recognition and technical integration rather than reduced to a symbolic cultural component.

Cage Aquaculture, Household Food Security, and the Integrated Management Model

Field evidence indicates that cage aquaculture contributes to household food security in Wangkolabu through two interconnected channels: direct provision of fish for consumption and income generation from the sale of cultivated products. Informants described harvested fish as a household resource that can be consumed, sold, or retained until economic needs arise, giving cultivation a function that extends beyond commercial production. This dual role corresponds with research positioning aquatic foods as important sources of nutrition and livelihood security, particularly for communities whose food systems remain closely connected to fisheries and aquaculture (Cai & Leung, 2022; Cojocaru et al., 2022). The Wangkolabu case adds household-level evidence by showing how cage production links food availability with purchasing capacity within a single livelihood activity.

Food availability is strengthened because cage cultivation provides a relatively controllable source of aquatic protein alongside capture fishing. Informants reported that part of the harvest is retained for household consumption before the remaining production is marketed, indicating that cage output is not treated exclusively as a commodity. This arrangement can reduce dependence on daily fishing catches, which are more sensitive to weather, seasonal conditions, and access to fishing grounds. The nutritional relevance of such production is consistent with wider evidence that aquatic foods can support dietary quality while increasing the diversity of food sources available to vulnerable households (Koehn et al., 2023).

The contribution to food access is expressed primarily through household income generated from the sale of cultivated fish and lobster. Revenue from cage production enables families to purchase staple foods and other items that cannot be produced directly within the household, making aquaculture a mechanism for converting marine production into broader food access. Studies of aquatic food systems emphasize that food security depends not only on the physical presence of food but also on the economic capacity of households to obtain it consistently (Cojocaru et al., 2022; Ragasa et al., 2022). This relationship is particularly relevant for small-scale coastal households because livelihood diversification can reduce exposure to fluctuations in a single income source.

Food utilization is supported by household practices for processing and preserving fish after harvest. Informants identified consumption of fresh fish as well as preparation into products such as salted fish and fish floss, extending storage life and allowing aquatic foods to remain available beyond the immediate harvest period. Such practices show that food-security outcomes are influenced not only by production volume but also by household knowledge concerning preservation, preparation, and allocation of food resources. Sustainable aquaculture research similarly recognizes that production benefits are maximized when cultivation systems are connected to efficient resource use and broader food-system functions rather than evaluated solely through output indicators (Noor & Harun, 2022).

The four dimensions of household food security identified through interviews and observation are summarized in Table 3. The evidence shows that cage aquaculture contributes differently to availability, access, utilization, and stability, while each dimension remains exposed to environmental and economic constraints. This multidimensional structure is consistent with contemporary aquatic-food research, which treats food security as the interaction of production, economic access, consumption practices, and resilience rather than as a simple measure of food supply (Cai & Leung, 2022; Koehn et al., 2023).

Table 3. Contribution of Cage Aquaculture to Household Food Security in Wangkolabu Village

Food-security dimension	Empirical evidence	Analytical interpretation
Availability	Fish produced from cages are consumed by households and provide an additional source of animal protein	Reduces exclusive dependence on capture fisheries
Access	Part of the harvest is sold and income is used to purchase other household food needs	Strengthens economic capacity to obtain food
Utilization	Fish are consumed fresh or processed into products such as salted fish and fish floss	Extends use value and storage potential of aquaculture output
Stability	Cage stocks can be harvested when fishing activity declines or households require food or cash	Provides a buffer against seasonal and livelihood fluctuations
Main vulnerabilities	Feed costs, weather variability, water-quality change, seed constraints, and production capital	Limit the consistency of aquaculture-based food-security benefits

Food stability constitutes the most analytically distinctive contribution of cage aquaculture because cultivated stocks can function as a reserve during periods when marine capture activities become less reliable. Informants characterized cage stocks as a form of living reserve that can be harvested when weather restricts fishing or when households require food and cash, suggesting that aquaculture increases temporal flexibility in resource use. Coastal livelihood research has similarly shown that diversified livelihood strategies can strengthen resilience by reducing dependence on one activity during periods of environmental or economic stress (Saksono et al., 2023; Taufik et al., 2023). Cage cultivation therefore acts as both a production system and a household buffering mechanism against seasonal uncertainty.

The food-security contribution remains conditional rather than automatic because several production constraints can reduce the reliability of cage-based livelihoods. High feed expenditure, seed limitations, fluctuations in water conditions, and weather disturbances may reduce harvest performance or delay production, weakening both direct food supply and income effects. Aquaculture management scholarship has repeatedly emphasized that sustainability requires simultaneous attention to biological productivity, environmental limits, economic viability, and governance capacity (Noor & Harun, 2022; Jolly et al., 2023). The field evidence indicates that local knowledge improves adaptive capacity, but structural constraints related to inputs and environmental change can still exceed the coping capacity of individual households.

The conceptual model emerging from the empirical synthesis links five interacting components: coastal environmental conditions, Bajo local wisdom, cage-management processes, production

outcomes, and household food security. Environmental observations inform decisions about cultivation timing and location, while local knowledge, collective labor, customary norms, and deliberation shape the social organization of production; management practices then influence harvest outcomes that are allocated between household consumption and market exchange. This structure is compatible with governance research showing that aquaculture performance is produced through interactions among ecological conditions, producer behavior, institutions, and market arrangements rather than through isolated technical variables (Nagel et al., 2024; Riany et al., 2023). The model differs from production-centered frameworks by explicitly positioning household food security as an outcome generated through both biological production and socially embedded resource management.

The relationship between local wisdom and food security is mediated by adaptive capacity rather than by cultural continuity alone. Seasonal knowledge can reduce exposure to environmental risk, collective labor can lower operational burdens, customary rules can stabilize resource-use relationships, and household processing practices can extend the utility of harvested products, creating several pathways through which local institutions influence food-security outcomes. Research on Bajo resilience and local ecological knowledge supports the interpretation that culturally embedded practices remain most relevant when they retain practical functions in livelihood adaptation and resource governance (Wianti & McWilliam, 2023; Ullah et al., 2023). The Wangkolabu evidence therefore suggests that local wisdom becomes materially significant when it shapes decisions that affect production continuity, household access to aquatic foods, and the capacity to respond to seasonal disruption.

The integrated management model developed from these findings positions sustainable cage aquaculture as a socio-ecological food-security system rather than a narrowly defined fisheries enterprise. Its analytical value lies in showing that environmental knowledge, collective institutions, cultivation practices, and household food-use strategies operate as interdependent components whose effectiveness depends on their ability to respond to ecological and economic change. Broader scholarship on sustainable aquaculture and aquatic food systems similarly argues that food production, livelihood resilience, environmental stewardship, and governance need to be considered jointly if aquaculture is expected to contribute meaningfully to food security (Ragasa et al., 2022; Engle & van Senten, 2022). For Wangkolabu, the model indicates that strengthening food security requires preservation of locally adaptive practices alongside improved technical support, input access, environmental management, and institutional coordination.

CONCLUSION

The study demonstrates that cage aquaculture management in Wangkolabu Village is organized through an adaptive process that combines cultivation planning, cage construction, stocking, maintenance, environmental monitoring, harvesting, and evaluation with locally accumulated ecological knowledge. Bajo farmers use observations of seasonal change, currents, tides, water depth, water conditions, and other environmental indicators to guide production decisions, while collective labor, customary rules, deliberation, and the Popanga and Mallupa traditions provide social and cultural mechanisms that support the continuity of cultivation. Local wisdom therefore functions not merely as inherited cultural knowledge but as practical ecological and social capital that influences risk management, labor organization, conflict regulation, and adaptation to changing coastal conditions. Cage aquaculture also contributes to household food security through the availability of fish for direct consumption, income that strengthens household access to other foods, local practices of processing and preserving fish, and the capacity of cultivated stocks to serve as a reserve when capture-fishing opportunities decline. These contributions remain constrained by feed costs, limited access to seed and capital, weather variability, and changing water conditions, indicating that local adaptive capacity does not eliminate structural and environmental vulnerabilities.

The conceptual model developed from the empirical findings integrates coastal environmental conditions, Bajo local wisdom, cage-aquaculture management processes, production utilization, and household food security within a single social-ecological management framework. Its principal scientific contribution lies in demonstrating that sustainable small-scale aquaculture cannot be adequately explained through production performance alone because environmental knowledge, community institutions, cultural practices, household livelihood strategies, and food-security

functions interact throughout the cultivation system. The model also provides a practical basis for strengthening aquaculture development in Wangkolabu by positioning local knowledge and community-based institutions as functional components that should be maintained alongside improvements in technical assistance, access to production inputs, environmental management, and institutional support. Its application should remain sensitive to the ecological and socio-cultural characteristics of the local community rather than assuming that the model can be transferred unchanged to other coastal areas. Future development of the model may focus on empirical testing across comparable coastal communities and on assessing how different forms of institutional and technical support influence its effectiveness in strengthening sustainable aquaculture and household food security.

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