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# Prospects for mangrove reforestation using the silvofishery method in aquaculture areas in Bireuen Regency, Aceh

# Prospek reforestasi mangrove dengan metode wanamina pada kawasan pertambakan di Kabupaten Bireuen, Aceh

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## ABSTRACT

The conflict between shrimp productivity and mangrove conservation can be addressed through the “silvofishery” pond model, which integrates shrimp farming with mangrove intercropping especially relevant for traditional pond farmers who dominate aquaculture in Indonesia. However, silvofishery is not yet widely practiced. This research aims to assess the understanding and acceptance of pond farmers in Bireuen Regency toward mangroves and silvofishery, and to identify barriers to future implementation. The study was conducted in three sub-districts Kuala, Peusangan, and Jangka using in-depth interviews with ten respondents selected through a snowball method. Quantitative responses were analyzed descriptively, while qualitative data were interpreted using Miles and Huberman’s interactive model. Findings reveal that mangrove reforestation in Bireuen is still under threat from land conversion. Silvofishery remains challenging due to three core issues: (1) declining per capita landholding makes it difficult for farmers to allocate pond space for mangrove planting; (2) not all farmers accept silvofishery without first seeing proven models initiated by the government; and (3) concerns about increased pests, such as crabs and birds, which are attracted to mangrove habitats. These factors contribute to the currently low prospects for mangrove rehabilitation through silvofishery at the farmer level. A paradigm shift is needed, encouraging farmers to see mangroves not as a threat but as allies in solving persistent aquaculture problems, including disease and water pollution. Policy support, field schools, and demonstration ponds will be critical in building local trust and fostering long-term ecological and economic resilience.

Keywords: aquaculture, farmer perception, mangrove conservation, shrimp pond, silvofishery

## ABSTRAK

Konflik antara produktivitas budidaya udang dan konservasi mangrove dapat diatasi melalui model tambak “silvofishery” yang mengintegrasikan budidaya udang dengan penanaman mangrove terutama relevan bagi petambak tradisional yang mendominasi sektor akuakultur di Indonesia. Namun, praktik silvofishery belum banyak diterapkan. Penelitian ini bertujuan untuk menilai pemahaman dan penerimaan petambak di Kabupaten Bireuen terhadap mangrove dan sistem silvofishery, serta mengidentifikasi hambatan implementasi ke depan. Studi dilakukan di tiga kecamatan Kuala, Peusangan, dan Jangka melalui wawancara mendalam terhadap sepuluh responden yang dipilih dengan metode bola salju. Data kuantitatif dianalisis secara deskriptif, sementara data kualitatif dianalisis menggunakan model interaktif Miles dan Huberman. Hasil menunjukkan bahwa rehabilitasi mangrove di Bireuen masih terancam oleh alih fungsi lahan. Silvofishery menghadapi tantangan karena tiga hal utama: (1) penyusutan luas lahan per kapita menyulitkan petambak untuk menyediakan ruang tanam mangrove di dalam tambak; (2) tidak semua petambak menerima konsep silvofishery tanpa melihat model nyata yang diinisiasi pemerintah; dan (3) kekhawatiran akan meningkatnya hama seperti kepiting dan burung yang tertarik ke habitat mangrove. Faktor-faktor ini menyebabkan prospek rehabilitasi mangrove melalui silvofishery masih rendah di tingkat petambak. Diperlukan pergeseran paradigma, agar petambak mulai melihat mangrove bukan sebagai ancaman, melainkan sebagai sekutu dalam mengatasi persoalan budidaya seperti penyakit dan pencemaran air. Dukungan kebijakan, sekolah lapang, dan tambak percontohan akan sangat penting untuk membangun kepercayaan lokal dan mewujudkan ketahanan ekologi dan ekonomi jangka panjang.

Kata kunci: akuakultur, konservasi mangrove, persepsi petambak, tambak udang, wanamina

## INTRODUCTION

The demand for tiger prawns from importing countries has steadily increased since the 1980s, resulting in a continual rise in global market prices. To meet this demand, efforts to enhance tiger prawn production through aquaculture, both in terms of intensification and extensification, have become essential. However, the development efforts have caused negative impacts: (1) technology-driven intensification has reduced environmental carrying capacity; and (2) extensification, which converts mangrove ecosystems into shrimp ponds, has decreased mangrove forests in Indonesia (Richards & Friess, 2016). In Aceh, mangrove forests underwent major land-use conversion into brackish water ponds between 1982 and 2001 the golden era of tiger shrimp farming. During this period, nearly all cities and regencies along Aceh's eastern coast engaged in tiger shrimp aquaculture (Damora, 2017).

According to WIIP (2016), the total area of mangrove forests in Aceh prior to the 2004 tsunami was approximately 53,512 hectares, of which 27,592 hectares had already been converted into shrimp ponds. Of this total, only about 26,130 hectares have since been rehabilitated primarily through Rhizophora replanting efforts during the post-tsunami reconstruction phase. This leaves approximately 27,382 hectares that remain potentially restorable, including areas within abandoned ponds (WIIP, 2016). Tiger shrimp farming was introduced in Bireuen Regency in the mid-1980s, a time when pond yields were still high. Farmers experienced significant prosperity, exporting high-value tiger prawns to European markets. This newfound wealth was visibly reflected in local lifestyles, with residents purchasing motor vehicles and constructing concrete homes (Nurwalidiniati *et al.,* 2017).

However, by the late 1990s and early 2000s, tiger shrimp farming abruptly declined due to outbreaks of viral and bacterial diseases. A 1998 report from Jangka Sub-district documented at least three viruses that severely affected local shrimp: Monodon Baculo Virus (MBV), White Spot Syndrome Virus (WSSV), and Taura Syndrome Virus (TSV) all of which caused mass die-offs within three to four days (Nurwalidiniati *et al.,* 2017). WSSV was first reported in Indonesia in 1994 in shrimp farming areas of Tangerang, Serang, and Karawang, and was also identified in South Aceh in the same year (Latritiani *et al.,* 2017; Ferasyi *et al.,* 2015). These disease outbreaks have persisted, even after tiger shrimp were largely replaced with *vannamei*, a species officially endorsed by the Indonesian government through Ministry of Fisheries and Aquaculture Decree No. 41/2001 for its higher disease resistance and salinity tolerance (Tambunan *et al.,* 2022). Nevertheless, new viral threats soon emerged, including TSV in East Java (2003) and Infectious Myonecrosis Virus (IMNV) in Situbondo (2006). Currently, the most significant threats to shrimp farming in Indonesia remain viral diseases such as WSSV, TSV, YHV, IMNV, and IHHNV (Amelia *et al.,* 2021).

Experts explain the recurring disease outbreaks through the "disease triangle" theory, which highlights imbalances in the interaction between host, pathogen, and environment. Declining environmental quality caused by organic matter buildup and intensive pond activity leads to shrimp stress and increased susceptibility to pathogens including viruses, bacteria, and protozoa (Xiong *et al.,* 2016). Furthermore, the success of shrimp aquaculture is closely linked to pond environmental quality (e.g., water, soil, and surrounding ecosystems) (Dahlia *et al.,* 2020), with general agreement that pond conditions should mirror those of natural shrimp habitats in terms of physical, chemical, and biological parameters (Marda *et al.,* 2023). As an alternative solution, the Indonesian government introduced the silvofishery system as early as 1978. This low-input aquaculture model integrates mangrove conservation with shrimp pond cultivation (Susilo *et al.,* 2018). According to Perwitasari *et al.* (2020), the silvofishery system has the potential to enhance the tiger shrimp productivity in a more sustainable manner.

However, adoption of silvofishery has remained limited. One major obstacle is a common misconception among local communities that mangroves hinder shrimp development. Additionally, shrimp farmers often worry that allocating pond space for mangrove planting will reduce their cultivation area and, consequently, income (Baumgartner *et al.,* 2016). Changing this perception takes time and sustained engagement. For instance, in Mahakam, East Kalimantan, a mangrove rehabilitation program was introduced in 2000, followed by the silvofishery program in 2007. Yet, actual planting activities only began in earnest in 2015 through the establishment of demonstration plots, which also introduced flexibility in mangrove planting percentages within brackish ponds to reduce farmer resistance (Salminah *et al.*, 2020).

Based on these key issues, the study formulated the following research questions: (1) What factors do farmers identify as causes of shrimp farming failures? (2) What role do mangroves play, and how significant are they to shrimp farming success? (3) What is the level of knowledge and acceptance among shrimp farmers regarding integrated shrimp mangrove systems? And (4) What are their motivations and reservations concerning the silvofishery approach?. Consequently, this study aims to map farmers' perceptions of shrimp farming challenges, identify perceived benefits of mangroves in aquaculture, assess understanding and interest in silvofishery, and explore anticipated barriers to its implementation.

## MATERIAL AND METHODS

This research utilizes a combination of quantitative and qualitative methods. The quantitative approach is employed to establish generalizable insights regarding levels of understanding, information sources, and acceptance. Meanwhile, the qualitative approach is used to gain in-depth understanding of farmers' knowledge and attitudes toward shrimp farming, mangrove conservation, and the silvofishery system.

### Location and time

The study was conducted in shrimp farming areas spanning from Kuala Sub-district to Jangka Sub-district, located between coordinates 5°12'46"–5°16'40" North Latitude and 96°41'10"–96°51'38" East Longitude (Figure 1). These areas cover three sub-districts and 31 villages, with a total pond area of 2,349.60 hectares and 2,364 registered shrimp farmers (BPS, 2022). Although only three of the 12 shrimp-farming sub-districts in Bireuen Regency were selected, the research location remains representative due to its extensive area and large number of shrimp farmers accounting for nearly half of the total in the district. The research was conducted over a seven-month period, from November 15, 2023, to June 15, 2024.

### Types and sources of data

The study aimed to collect comprehensive data that reflects the full range of issues occurring in the field and to represent the situation as it is. The data covered the historical and current condition of mangrove forest conversion into brackishwater ponds; farmers' perceptions of shrimp farming failures (causes and mitigation efforts); knowledge regarding the benefits of mangroves for aquaculture; familiarity with the silvofishery concept; and the prospects for future implementation. Additionally, the research

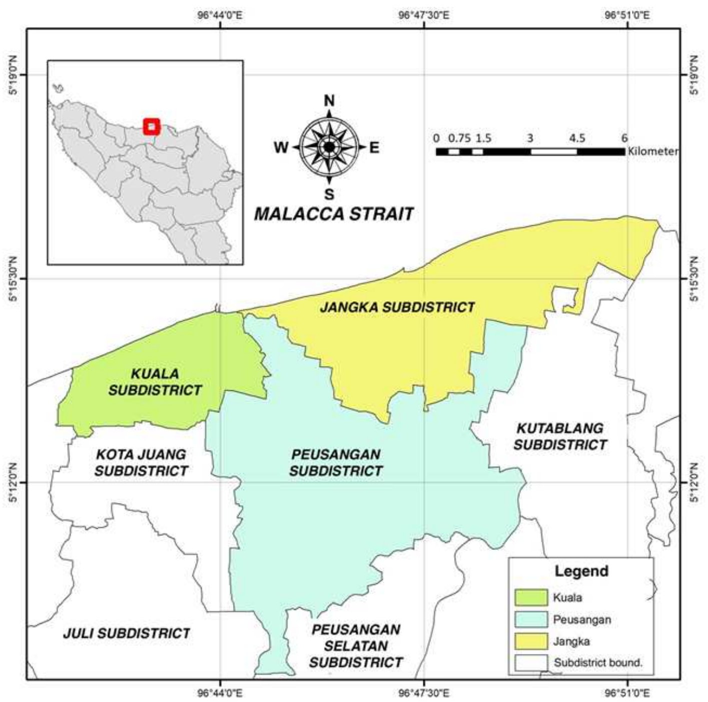


Figure 1. The research location was in the mangrove and pond areas in the sub-districts of Kuala, Peusangan, and Jangka, Bireuen Regency.

explored potential barriers and challenges to implementation through hypothetical questions posed during interviews. These data were collected through desk reviews, field observations, and in-depth interviews.

**Respondent selection**

Respondents were initially selected based on their long-standing experience and deep knowledge of local aquaculture practices, focusing on elderly farmers. Subsequent respondents were identified using a snowball sampling technique, based on recommendations from earlier participants. Using this method, the researchers successfully conducted in-depth interviews with ten farmer respondents (Table 1).

**Data analysis**

Quantitative data obtained during interviews were analyzed using basic statistical techniques available in Microsoft Excel. Qualitative data were analyzed using the interactive model by Miles *et al.* (2018), a widely used approach in qualitative research (Sugiyono, 2016). Synthesis was employed for the literature review section, requiring an extensive analysis of key findings from various primary documents from government agencies and other stakeholders especially on the temporal dynamics of mangrove forest cover. Themes were identified, and hypotheses were developed to guide the creation of the in-depth interview questionnaire. Concept mapping was also used to visualize key findings from the qualitative data.

## RESULT AND DISCUSSION

### Result

*History of ecology and mangrove deforestation in Bireuen regency*

The research area, located on the eastern coast of Bireuen Regency and directly facing the Strait of Malacca, is a lowland region with elevations below sea level and is heavily influenced by tidal movements. These tidal influences manifest as the movement of seawater flowing in and out of the land through several naturally formed estuaries, which then branch out into a network of distributary channels resembling an inverted delta. Locally, these estuaries are known as *Kuala Raja, Kuala Jangka, Kuala Pawôn,* and *Kuala Ceurapè* (Figure 2). According to Verstappen (1964), the lowlands of Bireuen were formed from sediment deposits carried by the Krueng (River) Peusangan, which originates from Lake Lut Tawar in Central Aceh Regency. Initially, the Krueng Peusangan flowed into the Krueng Juli, passing through what is now Kota Juang Sub-district and forming a delta to the north of Bireuen (the old delta). However, this delta was later eroded following a natural course shift of the Peusangan River near the village of Teupin Mane, redirecting it eastward and forming a new delta in the eastern region.

The remnants of the ancient Peusangan channels now appear as short rivers connected to the four estuaries in the research area. The sediment-laden flow of the Krueng Peusangan has shaped the coastal landscape through the formation of beach ridges a process driven by the interaction between sediment and wave action. These beach ridges, stretching along the shoreline, restrict the direct outflow of freshwater to the sea, channeling it instead through estuaries. This condition has led to the development of coastal wetlands known locally as *beurawang*. As freshwater flow from the Krueng Peusangan diminished, the water characteristics in these rivers and wetlands gradually became more brackish, with tidal seawater becoming increasingly dominant over surface runoff. This brackish condition also altered the nutrient composition of the surrounding soils.

Over time, the estuaries and short rivers evolved into suitable habitats for mangrove ecosystems. This process explains the spatial distribution of mangrove forests in Bireuen, which are consistently located inland from the shoreline and are thus classified as protected or basin-type mangrove forests. Over the course of centuries, the decomposition of mangrove biomass has contributed significantly to the region's soil fertility. The strategic placement of these mangrove forests around estuaries and rivers enabled a consistent supply of seawater and the formation of stable brackish environments. Eventually, local communities began to transform the ecological services provided by mangrove ecosystems into productive aquaculture spaces. This transition laid the foundation for Bireuen to become one of Indonesia's most prominent centers of tiger shrimp (*Penaeus monodon*) production.

*The deforestation of mangrove forests to the point of disappearance*

The conversion of mangrove forests into ponds in Bireuen Regency is believed to have first occurred in the Kuala Raja estuary area, dating back to the late 1920s or early 1930s. This assumption is based on a comparison of topographic maps of Bireuen produced by the Dutch colonial Topographic Service in 1915 and 1937. The 1915 map depicts Kuala Raja as a wetland plain (Topographische Inrichting, 1915), while the 1937 map shows the presence of several constructed fishponds (Topografische Dienst, 1941). Although no specific records detail the mangrove species present at the time, the presence of clay soils suggests that *Rhizophora* species were likely dominant a conclusion supported by the surviving remnants of mangroves still found in the area today. From the initial developments in Kuala Raja, the expansion of fishpond construction spread to other sub-districts.

This expansion escalated sharply with the issuance of the Minister of Agriculture Decree No. 05/SK/Mentan/Bimas/IV/1984 concerning the intensification of shrimp and milkfish aquaculture widely known as *INTAM* which promoted the adoption of the "Pancausaha Tambak" cultivation technology (Yasin *et al.,* 2022). Further destruction of mangrove forests occurred during the armed conflict period in Aceh. Government forces perceived these forests as potential hiding places for separatist groups. In one notable case in 1999, the mangrove forest behind the present-day fish port in Kuala Raja was cleared by local residents under military orders to establish a reconnaissance post. Post-2004 tsunami and following the 2005 peace agreement, the Aceh Rehabilitation and Reconstruction Phase (2005–2009) saw multiple replanting efforts spearheaded by international donors and NGOs. However, these efforts were repeatedly undermined by local communities who, eager to return to shrimp farming, cleared newly planted mangroves.

In a particularly troubling development, some mangrove destruction was later justified with dubious claims farmers accused seabirds of spreading shrimp diseases such as viruses and bacteria from one pond to another, and thus cleared mangroves to eliminate the birds' habitat. The continued and unrelenting deforestation of mangrove areas in Bireuen ultimately led to what can be described as the near-total disappearance

Table 1. List of research respondents.

| No. | Name | Sex | Age | Sub-district | Village | Description |
|---|---|---|---|---|---|---|
| 1. | Asnidar | F | 50 y.o. | Jangka | Kuala Ceurape | Active |
| 2. | Syafruddin | M | 60 y.o. | Jangka | Kuala Ceurape | Active |
| 3. | Marwandi | M | 45 y.o. | Jangka | Kuala Ceurape | Active |
| 4. | Sayed Ishar | M | 56 y.o. | Kuala | Kuala Raja | Active |
| 5. | Nurdin | M | 50 y.o. | Kuala | Kuala Raja | Active |
| 6. | Mahyudi Musri | M | 42 y.o. | Kuala | Kareung | Active |
| 7. | Hussein | M | 39 y.o. | Kuala | Kareung | Active |
| 8. | Husaini | M | 50 y.o. | Jangka | Alue kuta | Active |
| 9. | Azhar | M | 43 y.o. | Jangka | Alue Bayeu Utang | Active |
| 10. | Mustafa Abdullah | M | 53 y.o. | Jangka | Alue Paya Pasie | Active |

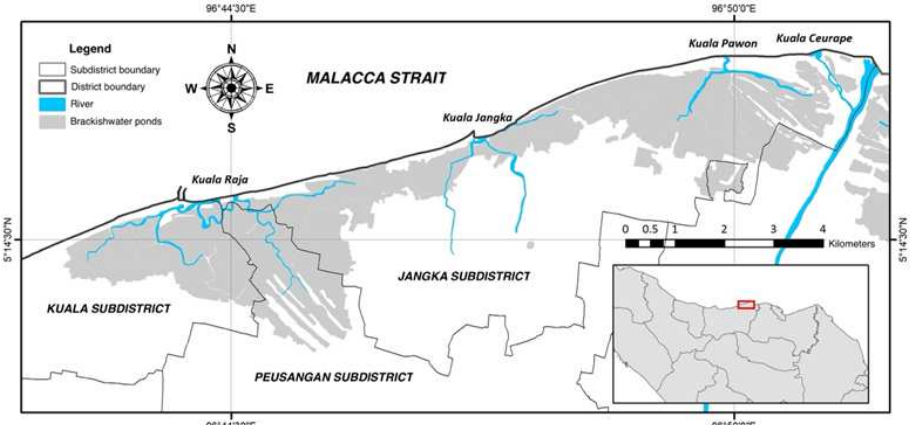


Figure 2. The estuaries' presence dramatically influences pond area formation at the research location.

of mangroves in the region. Today, only scattered patches remain, usually along pond channels and in isolated clusters. Their presence is so minimal that the National Mangrove Map (PMN) 2021, published by the Ministry of Environment and Forestry, did not record any existing mangrove cover in Bireuen Regency (KTA, 2021).

*Farmers' perceptions of shrimp cultivation failure*

The majority of respondent pond farmers perceive their shrimp cultivation efforts as unsatisfactory. As shown in Figure 3, most respondents rated their shrimp cultivation success between scores 4 and 6, with score 4 being the most frequent (reported by four farmers). This suggests a prevailing perception of poor to moderate outcomes. Two farmers gave a score of 5, one rated a 6, and two rated an 8 indicating a small minority experiencing relatively better yields. Notably, one respondent assigned the lowest possible score (1), reinforcing the sentiment that farming outcomes are increasingly unpredictable and susceptible to environmental and systemic pressures. The absence of any scores above 8 or between 9 and 10 underscores the widespread dissatisfaction and challenges faced in sustaining productive aquaculture under current conditions.

This distribution reflects the magnitude of challenges faced by shrimp farmers in the region. In particular, traditional farmers often continue cultivating shrimp out of necessity, rather than strategic planning, due to a lack of alternative skills or livelihoods. One respondent likened the current state of pond farming to a race against time a race between harvesting and the inevitable outbreak of disease. Farmers identified several key factors contributing to the frequent failures in shrimp cultivation. Foremost among these is the poor quality of shrimp fry (post-larvae), which many believe to be already infected during the hatchery stage, resulting in rapid mortality once introduced to the ponds. Compounding this issue is soil contamination years of continuous cultivation have left pond soils degraded by the accumulation of uneaten feed, shrimp waste, and residual pesticides, consistent with findings by Evania *et al.* (2018) and Supono (2018).

Water pollution further exacerbates the problem, as waste and garbage from upstream communities enter the ponds through interconnected drainage, irrigation, and aquaculture channels before discharging into the sea. In locations distant from estuaries, access to seawater is increasingly difficult due to sedimentation, illegal expansion of ponds that obstruct channels, and reduced tidal inflow all of which impair the essential saline balance required for shrimp health. Furthermore, farmers admit to having limited understanding of shrimp diseases both in terms of identifying specific illnesses and implementing effective treatments. Almost all respondents view birds such as herons and seagulls as disease vectors, believing they spread infections from one pond to another.

This perception contributes to the justification for mangrove clearance, as birds are seen as pests. Weather patterns are also believed to influence disease outbreaks. Most farmers avoid cultivating during the rainy season due to perceived higher disease risks. Economically, farmers complain that profits have shrunk dramatically: feed prices have doubled over the past decade, while shrimp selling prices have remained stagnant.

*The role of mangroves in shrimp farming*

Respondent farmers generally assess mangroves through a lens of service versus disservice in relation to shrimp cultivation.

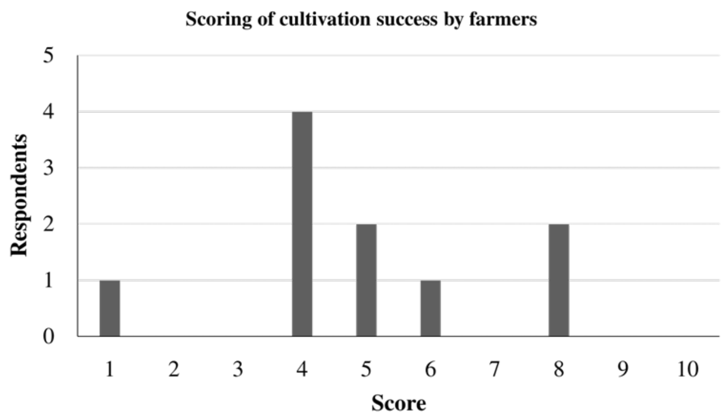


Figure 3. Graph of farmers' scoring of the success of pond cultivation.

While they recognize certain ecological benefits, they also cite numerous perceived drawbacks. This cost–benefit perception appears to serve as a primary determinant in their decision not to replant mangroves independently. In fact, all of the farmers interviewed (100%) stated that they have not actively reintroduced mangroves into their pond systems, aside from a few leftover saplings from past NGO-driven initiatives.

On the benefit side, farmers note that mangroves can serve as natural shade providers; their canopy helps reduce direct sunlight and cool pond temperatures during the hot season. The intricate root systems offer shelter for shrimp and other cultured species, which use them for refuge and feeding grounds. Farmers also acknowledge that mangrove roots can stabilize pond embankments, reducing erosion caused by tidal and rainwater. Additionally, mangrove stands may function as a natural breeding ground for native shrimp species such as *udeung reuti/ reukieh* and *udeung jambô* although these species are less economically valuable than *Litopenaeus vannamei* and tiger prawns.

Some farmers also associate mangrove presence with improved shrimp growth rates. However, the disservices cited often outweigh these perceived benefits in farmers' eyes. Many believe that *Rhizophora* species release reddish sap that discolors pond water and harms shrimp quality and marketability. The accumulation of leaf litter is seen as a nuisance that clutters and dirties the pond environment. Farmers fear that mangrove roots complicate harvesting operations, especially during partial harvests, by snagging or tearing the nets.

Moreover, they claim that mature mangroves raise the pond bed, reducing the desired depth needed for optimal shrimp cultivation. Lastly, dense mangrove growth is thought to attract organisms considered harmful, such as crabs and birds, which are blamed for spreading diseases between ponds. These perceptions seem to stem from limited access to reliable information, if not outright misinformation. This is underscored by the sources farmers cite for their knowledge: 60% attribute their understanding of mangroves solely to informal word-of-mouth. Only 30% report having participated in any form of training, while the remaining 10% received information through brief interactions with visiting government agency staff.

*Knowledge and acceptance of shrimp-mangrove integration among pond farmers*

Awareness of silvofishery the integrated system of shrimp farming with mangrove planting is notably limited among the surveyed pond farmers. Only 30% of respondents reported having heard of the concept, though even this knowledge was vague and dated, primarily recalled from training sessions held between 2004 and 2006. Upon closer examination, it became evident that their understanding was superficial, mostly associating silvofishery with traditional planting of mangroves along pond embankments for erosion control, rather than as a structured ecological-aquacultural system. The remaining 70% of respondents had never heard of silvofishery or the broader idea of shrimp–mangrove intercropping. Thus, the concept remains largely unfamiliar and underexplored within the community.

When asked about their willingness to implement silvofishery (Figure 4), 70% of farmers expressed disagreement. Their primary concern was the potential loss of pond area, as silvofishery typically requires dedicating up to 50% of the land for mangrove cover. In contrast, 30% of respondents were open to the idea, citing the ecological benefits of mangroves and a desire to revive traditional practices observed in earlier generations of shrimp farmers. Nevertheless, this openness was often qualified by practical concerns; one respondent commented, "If possible, don't put too many mangroves in the ponds," underscoring a hesitant and conditional form of acceptance. Interestingly, when the same farmers were asked how they would respond if the local government mandated silvofishery (Figure 5), attitudes shifted modestly.

The percentage of those willing to comply rose to 40%, with an additional 10% remaining neutral, while those opposed decreased to 50%. Farmers who disagreed feared negative impacts such as increased pond maintenance due to mangrove litter and sediment accumulation, which they believed would necessitate more frequent dredging. However, the slight increase in agreement indicates that government policy can influence local acceptance. Furthermore, several farmers noted that their stance could change if they observed a broader trend of adoption among their peers, suggesting that social proof or crowd psychology could play a key role in shifting attitudes.

*Obstacles and Challenges Faced by Farmers Towards Silvofishery*

Despite varying levels of knowledge and acceptance, pond farmers in the study area face several structural and perceptual challenges that could significantly impede the implementation of silvofishery-based mangrove rehabilitation. These challenges reflect a combination of land-related constraints, policy expectations, economic concerns, and ecological apprehensions.

*Limited land availability*

The most frequently cited constraint is land size. The majority of respondents operate small-scale ponds, typically less than one hectare. Requiring up to 50% of pond area for mangrove planting under the silvofishery model, as suggested by Tran *et al.* (2021), is considered highly impractical. This concern is supported by statistical data from the Bireuen Regency's Central Statistics Agency (BPS, 2023), which reports a total of 4,945.60 hectares of shrimp pond area managed by 4,861 farmers. This equates to an average of 1.017 hectares per farmer without factoring in disparities in land ownership. For smallholders, the perceived loss of productive area is seen as a direct threat to income stability.

*The Need for Government-Led Demonstration*

Several respondents expressed skepticism about the ecological and economic benefits of integrating mangroves with shrimp aquaculture. Their reluctance is rooted in a lack of firsthand experience and visible success stories. Many farmers emphasized that they would be more open to adopting silvofishery if the local government led by example initiating pilot projects or demonstration ponds that visibly prove the system's viability and benefits.

*Avoiding Farmer Burden*

While some farmers might be willing to comply with silvofishery mandates, there is a clear expectation that such programs should not impose undue financial or logistical burdens. Farmers voiced concerns about being required to procure mangrove seedlings or conduct planting at their own expense. Given increasing economic

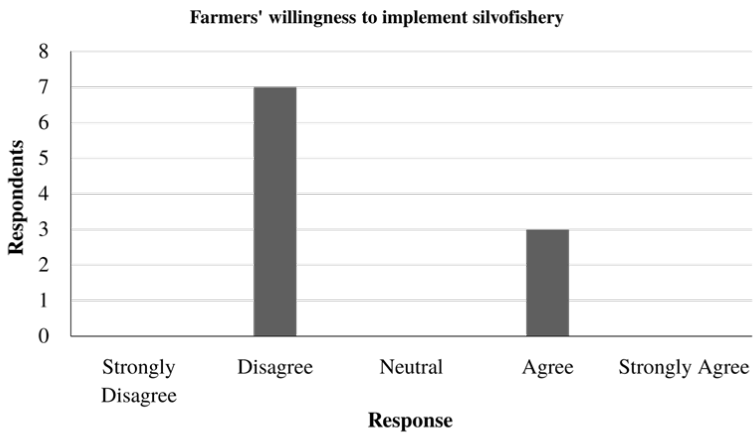


Figure 4. Graph of farmers' willingness to implement silvofishery.

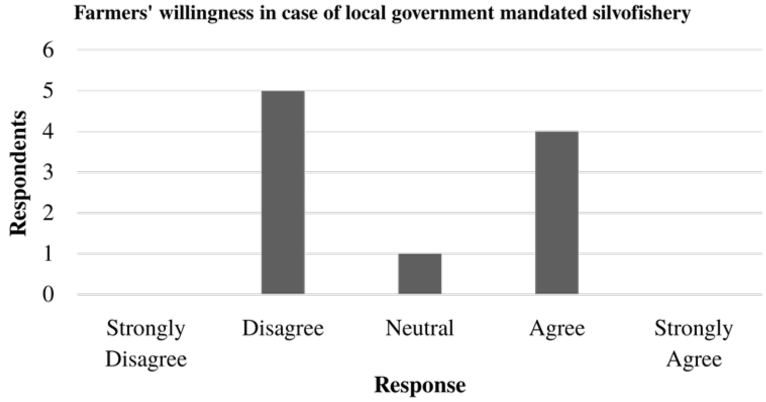


Figure 5. Graph of farmers' willingness against the local government-mandated silvofishery.

pressures, they called for public support, including seedling distribution and possibly compensation or incentives for participating in mangrove restoration activities.

*The Fear of Pest Infestation*

Ecological concerns also shape farmers' resistance. Some respondents believe that planting mangroves within or near ponds could attract pests, particularly crabs and predatory seabirds such as herons and seagulls. These species are feared not only for preying on shrimp but also for potentially spreading disease between ponds. This perception contributes to a general wariness about introducing significant vegetative cover into aquaculture environments.

**Discussion**

*Mangrove Rights to Exist Within Brackishwater Ponds: A Critical Reframing*

One of the most intractable obstacles to mangrove rehabilitation in Bireuen Regency is the near-total transformation of its coastal zones into brackishwater ponds many under private ownership or customary communal claims. In this context, restoring mangrove ecosystems is not a simple act of reforestation; it implies reclaiming lands that have long been converted into aquaculture estates. This effort calls not only for ecological restoration but also for a social and historical reckoning: a recognition that these ponds were once mangrove forests, cleared either by communities or commercial interests over the past century. To advance this agenda, we must first establish a compelling historical claim for mangroves' "right to return." This requires substantiating the extent of historical mangrove coverage and the gradual deforestation over time. Given the absence of a comprehensive deforestation archive, this paper proposes a heuristic estimation model, or a proxy estimation model based on the inverse relationship between the expansion of pond areas and the reduction of mangrove forests (Table 2).

The foundational assumption of this model is that all existing brackishwater ponds in Bireuen were established through the direct conversion of fertile mangrove forests cleared by local communities or entrepreneurs to make way for aquaculture infrastructure. Based on this premise, we can estimate the minimum extent of the original mangrove cover by referring to the current pond area, which spans approximately 5,000 hectares. Conversely, the maximum extent can be inferred from the landscape prior to the introduction of pond-based aquaculture by Dutch colonial authorities in the early 1920s, when mangrove forests likely dominated the coastal zone. This historical range forms the reference point for the spatial-temporal modeling framework proposed in this study.

This logic is reinforced by several key records. According to BPS (2004), first documented the pond area in Bireuen Regency as distinct from its parent district, North Aceh, in publication Aceh in Figures 2003, estimating it at 4,338 hectares. Two years later, the inaugural edition of Bireuen in Figures 2005 published by BPS (2006) recorded an increase to 5,070 hectares. A similar trend is corroborated by a report from the Aceh-Nias Rehabilitation and Reconstruction Agency (BRR, 2006), which noted that between 2000 and 2003, the pond area had expanded by 551 hectares, from 4,549.5 hectares previously.

This sharp increase in pond development correlates with findings from a post-tsunami survey conducted by PT. Geotrav Bhuana, which identified only 782.95 hectares of remaining primary mangrove forest in Bireuen a stark contrast to earlier ecological baselines (Sari *et al.,* 2006). The presence of these remnants was further confirmed by the Indonesian National Institute of Aeronautics and Space (LAPAN), which conducted a satellite image analysis in 2005. According to LAPAN, the 2004 tsunami had damaged approximately 623.1 hectares of mangrove forest in the region (Sari *et al.,* 2006). In the aftermath of the 2004 tsunami, large-scale mangrove reforestation initiatives were launched as part of the national rehabilitation and reconstruction program. In Bireuen, the *Gerakan Rehabilitasi Hutan dan Lahan* (GERHAN) under BPDAS, along with the District Office of Plantation and Forestry (*Disbunhut Bireuen*), is committed to restoring mangrove ecosystems.

These agencies planned to plant approximately 1.8 million mangrove seedlings across 1,850 hectares, targeting both degraded mangrove zones and areas along pond embankments and channels (Sari *et al.,* 2006). Later, a spatial analysis conducted by WWF Aceh in 2013 estimated that Bireuen had 25.57 hectares of remaining mangrove cover. Yet, just four years later, this figure declined to 20.48 hectares (Hanafiah, 2019). BPS Aceh's Aceh in Figures 2012 stated that Bireuen had no mangrove forest at all. This was later revised in the BPS Aceh's Aceh in Figures 2014, which recorded a modest mangrove cover of 2.3 hectares (BPS, 2015). Critically, while full-scale restoration of mangroves to their pre-aquaculture extent may appear ideal from an ecological standpoint, it remains politically and socially untenable.

Such an initiative would likely be perceived by shrimp farmers as a direct threat to their livelihoods tantamount to state-sanctioned expropriation. In this context, the silvofishery model offers a pragmatic and reconciliatory alternative. Rather than demanding the relinquishment of land, silvofishery enables mangroves to be reintegrated into existing pond systems offering ecological rehabilitation without triggering social displacement. Beyond its conciliatory function, silvofishery delivers tangible co-benefits for farmers themselves: phytoremediation of toxins in pond soils, improved biofiltration of water, microclimate regulation via canopy shading, erosion control through mangrove root structures, and increased availability of natural feed like algae. These are not abstract ecological goods; they align directly with the productivity, resilience, and sustainability of brackishwater aquaculture systems.

To unlock this transformative potential, local governments must go beyond technical prescriptions. What is needed is a robust strategy of political persuasion anchored in historical evidence, spatial mapping, and community memory. While demonstration ponds serve as important entry points, they are not sufficient on their own. Equally crucial is a narrative shift: a collective reimagining of aquaculture landscapes not merely as sites of economic production, but as palimpsests of once-thriving mangrove ecosystems. This recognition may open new pathways where mangroves are no longer seen as encroachments, but as rightful co-inhabitants and essential partners in ensuring the long-term viability of coastal livelihoods.

*A Necessity for Paradigm Shift: Integrating Mangrove Planting Within Ponds*

Based on farmers' perceptions gathered during the research, many of the challenges currently affecting their aquaculture systems ranging from water quality degradation to disease outbreaks could, in fact, be addressed through the conservation or reintroduction of mangroves, even within pond environments, as promoted by the silvofishery model. However, the key to realizing this potential lies in transforming farmers' mindsets. Awareness and understanding of the ecological benefits of mangroves remain limited or distorted among many pond owners and aquaculture practitioners. Field findings revealed several persistent misconceptions regarding mangrove presence in aquaculture areas. For instance, the reddish tint in pond water is often misattributed solely to mangrove degradation, when in fact it can result from various organic materials, including decomposing plant litter rich in tannins.

While tannins remain a debated compound in aquaculture, recent research (Nisa, 2023) highlights their beneficial effects: inhibiting parasitic worms, providing antibacterial and antifungal functions, improving nutrient absorption, and serving as potent antioxidants. These properties have led to their inclusion in feed formulations for shrimp and fish. Another widespread concern is the belief that mangrove roots damage harvest nets. However, this is not universally true. In Bireuen, for example, Rhizophora species, which dominate pondside soils, have prop roots that do

Table 2. Estimation of mangrove forests area in Bireuen regency from time to time.

| **Years** | Area estimation | **Remarks** |
|---|---|---|
| The early 1920s | ± 5,000 hectares | Before the introduction of fishing ponds by the Dutch colonial. |
| 2000–2005 | Between 500–800 hectares | Survey of PT. Geotrav Bhuana Survey, 2006. |
| End of 2004, Tsunami struck | <175–0 hectares | Deduct from satellite image analysis by LAPAN 2005. |
| 2005–2009 | Commitment to replanting for 1.850 hectares. No information on success rate. | In the rehabilitation-reconstruction phase, NGOs and government agencies deliver replanting to former mangrove forests and ponds. |
| 2013–2017 | Between 20–25 hectares | Spatial Analysis by WWF Indonesia. |
| 2015–2016 | 2,3 hectares | BPS Provinsi Aceh. |
| 2022–Now | Officially recognized as none. | PMN 2021, Ministry of Environment and Forestry. |

not interfere with or tear netting infrastructure. Similarly, the presence of crabs, birds, and other wildlife in mangrove–aquaculture landscapes are often viewed as a pest problem, when in reality, these organisms are part of the broader ecosystem.

As in other farming systems, pests are unavoidable but with wise management (e.g., non-chemical deterrents), their impact can be minimized without resorting to harmful pesticides that degrade water and soil quality. More critically, the study found significant gaps in farmers' knowledge regarding the ecosystem services that mangroves provide. Mangroves act as natural phytoremediators, absorbing and neutralizing pollutants through biological processes. Their root systems function as biofilters, capturing excess nutrients like nitrogen and phosphorus from agricultural runoff and household waste, thus preventing eutrophication. Mangroves also absorb heavy metals and improve water clarity. Furthermore, the leaf litter from mangroves becomes a natural food source, enriching the pond ecosystem. These leaves are rich in compounds such as tannins, flavonoids, terpenoids, saponins, and alkaloids each with known antibacterial and antiviral effects (Samuria *et al.,* 2018).

To shift this entrenched paradigm marked by limited understanding and misconceptions a deliberate, community-centered learning process is essential. One promising pathway is the establishment of adult education initiatives, particularly field schools, where learning takes place directly within the aquaculture landscape. These programs must go beyond technical training to include ecological literacy and reflective learning. Ideally, such efforts should be integrated into and synergized with existing government extension services (*penyuluhan perikanan*), ensuring continuity, institutional support, and relevance to local realities.

*Transitioning from Intensive to Environmental-Friendly Pond Systems*

To illustrate the complexity of ecological degradation and productivity issues in shrimp farming, the researchers developed a cause-and-effect diagram (Figure 6). This concept map highlights not only the linear flow of problems but also several causal loops vicious cycles that continue to trap coastal communities in unsustainable practices. At the heart of the system lies the intensive shrimp farming model, which has been promoted by central policies focused on maximizing foreign exchange. While this model initially boosted short-term profits, it ultimately led to land-use changes, mangrove deforestation, and ecological degradation within pond environments. As shown in the diagram, this transformation has triggered a cascading set of environmental and economic consequences: from biofilter loss and water pollution to sedimentation, disease outbreaks, and ultimately, productivity collapse. The diagram also shows how external factors, such as waste disposal from upstream communities and irrigation runoff, exacerbate these internal problems creating an intertwined system of degradation.

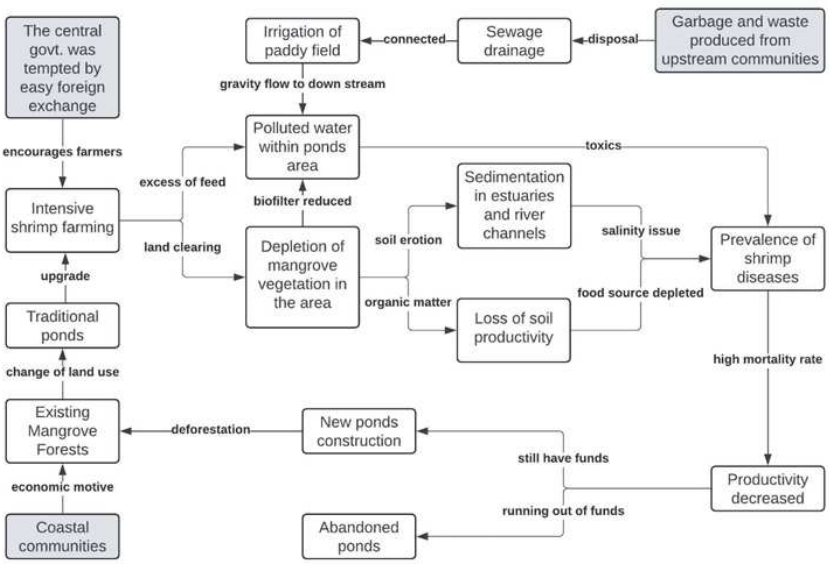


Figure 6. Problem concept map using a cause-and-effect diagram approach.

Given this landscape, replacing the intensive pond system is not just preferable it is imperative. One viable alternative is the silvofishery system, which reintroduces mangrove vegetation into pond areas to restore natural filtration, improve water quality, and rebuild ecological resilience. Instead of pursuing maximum yield through mass production, farmers and policymakers must pivot toward a high-quality, high-value production model. This shift acknowledges the trade-off between the short-term economic gains of intensive shrimp farming and the long-term sustainability of silvofishery systems (Shell *et al.,* 2024). Reducing the emphasis on tons of shrimp harvested would ease the pressure on pond ecosystems by lowering feed input, minimizing pesticide and antibiotic use, and reducing waste accumulation. In doing so, the ecological carrying capacity of the pond and of the mangroves themselves can begin to recover.

## CONCLUSION

The research findings reveal that the prospect of mangrove conservation through silvofishery in Bireuen Regency remains limited. This stems not from a lack of environmental need, but from the disconnect between farmers' perceptions and ecological realities. Shrimp farmers key actors who would directly implement and maintain mangrove integration continue to undervalue the benefits of mangroves. Many do not yet recognize mangroves as a viable response to the water quality issues, disease prevalence, and declining productivity in their ponds. Given this gap, a paradigm shifts at the farmer level is imperative.

This shift must move beyond awareness campaigns; it requires deep engagement, participatory learning, and the reframing of mangroves not as constraints, but as strategic assets for long-term sustainability. Without this transformation, any policy requiring silvofishery risks being met with resistance. This study contributes both empirically and methodologically to silvofishery discourse. Empirically, it documents farmers' resistance rooted in land scarcity, knowledge gaps, and ecological misperceptions. Methodologically, it introduces a reverse modelling approach for estimating historical mangrove loss where time-series data are absent. These findings offer a grounded framework for designing participatory and historically conscious coastal restoration strategies in highly degraded aquaculture landscapes.

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