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SYSTEMATIC LITERATURE REVIEW: SUSTAINABLE SILVOFISHERY DEVELOPMENT IN MANGROVE ECOSYSTEMS IN INDONESIA

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ABSTRACT

Silvofishery integrates mangrove conservation with low-input aquaculture and is increasingly promoted for sustainable coastal management in Indonesia. This study aimed to identify research trends, evaluate ecological and socio-economic outcomes, synthesize factors controlling implementation success, and formulate research and policy priorities for sustainable silvofishery development in Indonesian mangrove ecosystems. A Systematic Literature Review was conducted using the PRISMA framework and complemented by descriptive bibliometric mapping with VOSviewer. The search used expanded synonyms, including silvofishery, silvo-aquaculture, integrated mangrove aquaculture, wanamina, empang parit, mangrove-based aquaculture, mangrove restoration, blue carbon, food security, climate change, and coastal communities. The Indonesia scope was applied using country-, regional-, and site-specific terms. From 200 records identified, 200 records were screened by title and abstract, 65 full-text articles were assessed for eligibility, and 10 studies published between 2010 and 2026 met the inclusion criteria for qualitative synthesis. The synthesis shows that silvofishery can improve mangrove rehabilitation, carbon stock, pond productivity, fishery resources, and coastal income, but outcomes vary across locations. Blanakan showed the strongest multi-service integration, Brebes provided the clearest long-term monitoring evidence, Banyuasin showed strong crab-silvofishery performance, and the Mahakam Delta showed high restoration relevance in a degraded landscape. Success depended on site suitability, tidal exchange, water and sediment quality, mangrove species composition, stocking intensity, institutional support, and community participation. The review concludes that silvofishery is not only an aquaculture model but also a nature-based solution that links ecosystem restoration, climate change mitigation, food security, and livelihood resilience.

Keywords: *blue carbon; coastal livelihood; integrated mangrove aquaculture; mangrove restoration; silvo-aquaculture*

INTRODUCTION

Climate change and food security remain central challenges for sustainable coastal development. Coastal ecosystems are vulnerable to sea level rise, erosion, salinity intrusion, and extreme weather events (Intergovernmental Panel on Climate Change, 2022). Mangroves reduce these risks by storing blue carbon, stabilizing sediment, buffering waves, and supporting nursery habitats for fish and crustaceans. Recent global assessments provide a more current picture than earlier estimates. The State of the World's Mangroves 2024 reported that 147,256 km^2 of mangroves were mapped globally in 2020, while conversion for aquaculture, oil palm, and rice cultivation accounted for 43.3% of global mangrove loss during 2000-2020 (Global Mangrove Alliance, 2024).

Indonesia is the largest mangrove country in the world. The National Mangrove Map 2024 reports approximately 3.44 million ha of mangrove ecosystems in Indonesia, representing about one-fifth of global mangrove area (Ministry of Environment, 2025). This ecosystem supports coastal protection, fisheries, carbon storage, and livelihoods. However, degradation and conversion still occur in several coastal landscapes. In the Mahakam Delta, mangrove cover declined sharply during 1992-2009 due to conversion into shrimp ponds (Susilo *et al*., 2018). In Banyuasin, South Sumatra, mangrove degradation affects habitat quality for economically important mangrove crabs (Scylla spp.) (Apriyanto *et al*., 2025). In Segara Anakan, lagoon degradation reduces the productivity of traditional fisheries, while the Blanakan case shows that well-managed mangroves can support carbon storage, fish and shrimp production, ecotourism, and bird habitat (Sumarga *et al*., 2024).

Silvofishery, also described as silvo-aquaculture or integrated mangrove aquaculture, is a low-input aquaculture system in which mangrove trees are maintained, restored, or planted within or around brackish-water ponds to support aquaculture while conserving mangrove functions (Takashima, 2000; McSherry *et al*., 2023). In Indonesia, this system is commonly known as *wanamina* and includes models such as *empang parit*, *komplangan*, and mangrove-crab silvofishery. This model can maintain mangrove cover, improve pond environmental quality, and support aquaculture productivity when hydrology, vegetation structure, stocking density, and community management are suitable. Evidence from Segara Anakan demonstrates the financial feasibility of the empang parit model, with an NPV of IDR 2.7-3.8 million and an IRR of 21-48% (Hilmi *et al*., 2021). In Blanakan, silvofishery integrated carbon storage of 216.9 tC/ha with fisheries, ecotourism, and bird habitat (Sumarga *et al*., 2024).

In addition to ecological and economic benefits, silvofishery contributes to SDG 13 (Climate Action) and SDG 2 (Zero Hunger). Recent systematic studies show that mangrove restoration and silvofishery can increase carbon stocks by 45-60 tC/ha and fish catches by 20-35% in selected cases (Sungkawati & Umali, 2024). These findings support the role of silvofishery as a nature-based solution for climate change mitigation and food security. However, these benefits are not automatic. Poor hydrological design, excessive stocking, weak maintenance, and contamination risks can reduce ecological performance and aquaculture benefits (Hastuti *et al*., 2021; Mustafa *et al*., 2024).

Several scientific gaps remain unresolved. First, previous studies have not fully explained why outcomes vary across locations, even when all studies report positive ecological or economic trends. Second, findings differ in emphasis: some studies highlight productivity and income gains, while others emphasize water-quality risks, heavy-metal contamination, or the need for site-suitability assessment (Hastuti *et al*., 2021; Mustafa *et al*., 2024; Risdayanti *et al*., 2026). Third, many studies use short observation periods, different indicators, and limited comparator data with conventional ponds. Fourth, earlier reviews often discuss mangrove ecosystem services broadly, but they rarely synthesize silvofishery heterogeneity, ecological mechanisms, policy integration, and future research priorities specifically for Indonesia.

Therefore, this study presents a systematic review of sustainable silvofishery development in Indonesian mangrove ecosystems from 2010 to 2026. The objectives are to: (1) identify trends and thematic developments in Indonesian silvofishery research; (2) analyze the effectiveness of silvofishery compared with conventional pond systems in supporting ecosystem sustainability and coastal community welfare; (3) synthesize ecological, technical, social, and institutional factors that explain variation in outcomes across locations; and (4) formulate evidence-based recommendations and future research priorities for integrated sustainable silvofishery development.

Using the PICO approach, this study identifies Indonesian mangrove ecosystems and coastal communities as the population (P), silvofishery, or wanamina, as the intervention (I), conventional pond systems as the comparator (C), and ecosystem sustainability and community welfare as the outcomes (O). The research questions are: (1) how effective is silvofishery compared with conventional pond systems in supporting mangrove ecosystem sustainability and coastal community welfare; (2) which factors most influence the success and variation of silvofishery implementation across Indonesian locations; and (3) what research trends and future priorities have emerged in Indonesian silvofishery studies during 2010-2026 based on systematic review and descriptive bibliometric mapping?

METHOD

Research Design

This research was designed using the Systematic Literature Review (SLR) guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocols. This design was chosen because it provides a systematic, transparent, and replicable framework for reviewing the scientific literature. SLR allows researchers to comprehensively identify, evaluate, and synthesize relevant research findings to provide a complete picture of silvofishery research trends, effectiveness, and gaps in mangrove ecosystems.

In addition, this study applied descriptive bibliometric mapping using VOSviewer to identify keyword relationships, author collaboration patterns, and citation linkages among the selected studies. This approach was used to complement the systematic synthesis by providing a visual overview of the thematic structure and research direction of silvofishery studies in Indonesia.

Research Protocol

This research protocol was prepared in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, an international guideline for reporting systematic reviews. The use of PRISMA in this study aims to ensure that the entire process of searching, selection, and analyzing literature is carried out transparently, consistently, and can be replicated by other researchers. Thus, this protocol serves as a methodological foundation that ensures the credibility of the research results.

The first stage in the PRISMA protocol was identification. Literature was searched in Scopus, Web of Science (WoS), and Google Scholar using expanded keywords and synonyms for silvofishery, including “silvofishery”, “silvo-fishery”, “silvofisheries”, “silvo-aquaculture”, “integrated mangrove aquaculture”, “mangrove-based aquaculture”, “wanamina”, “empang parit”, “tambak mangrove”, “mangrove restoration”, “blue carbon”, “food security”, “coastal communities”, and “Indonesia”. The publication range was 2010-2026, and English and Indonesian records were included. This strategy was used to broaden the search engine coverage and reduce the risk of missing studies that used different terminology.

The second stage is screening, which is the initial selection process based on titles and abstracts. Articles that are not relevant to silvofishery or mangrove ecosystems are removed immediately. In addition, duplicate entries across databases are removed to avoid double-counting. Of the 200 articles identified, 135 were eliminated because they did not fit the research focus or were duplicates, leaving 65 articles for the next stage. This screening aims to narrow down the number of articles so that only really relevant literature enters the eligibility stage.

The third stage is eligibility, in which articles that pass the screening are assessed by reading the full text. The researcher ensures that the article meets the inclusion criteria, namely, focuses on silvofishery or mangrove ecosystems, was published between 2010 and 2026, and is a peer-reviewed article or an official report with quantitative and qualitative data. Articles that do not meet the criteria, such as opinions without data, publications before 2010, or articles that are not available in full text, are excluded from the analysis. Of the 65 articles assessed at the eligibility stage, 55 articles were excluded because they did not meet the predetermined criteria. Therefore, 10 articles were included in the final qualitative synthesis.

The fourth stage is inclusion, which involves determining the articles actually used in the systematic analysis. Articles that pass the eligibility stage are included in the inclusion list, and this final number of articles is then visualized in the PRISMA Flow Diagram, which clearly shows how many articles were identified, screened, assessed for eligibility, and ultimately included. Thus, this study focuses on the 10 main articles considered most relevant and high-quality for answering the research question.

In addition to participating in the PRISMA stage, this study also applies Quality Assessment (QA) to assess the quality of included articles. The assessment was carried out using a checklist that included the relevance of the topic, the quality of the methodology, the completeness of the data, and the credibility of the source. Articles with a QA score below 60% are excluded from the analysis, so only high-quality literature is further analyzed.

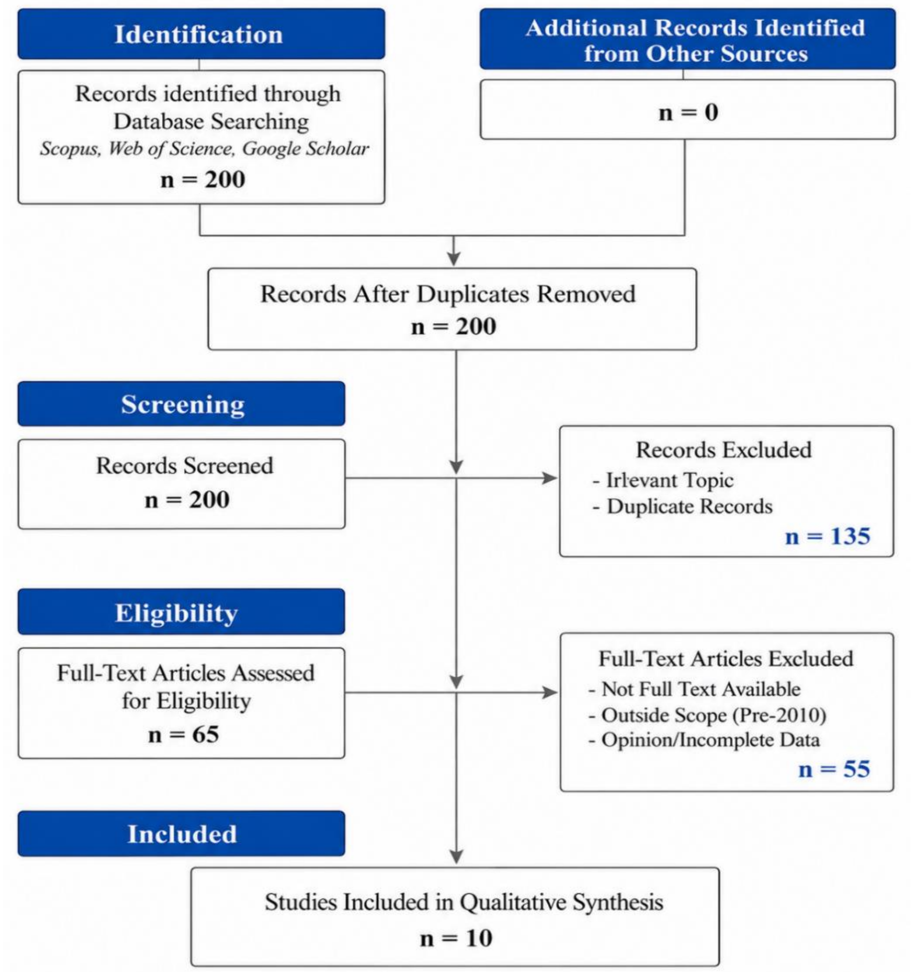

Figure 1. PRISMA Flow Diagram of Literature Selection Process

Figure 1 presents the PRISMA flow diagram for the literature selection process. A total of 200 records were identified from Scopus, Web of Science, and Google Scholar. All 200 records were screened by title and abstract. At this stage, 135 records were removed because they were irrelevant, duplicated across databases, outside the Indonesian scope, or did not discuss silvofishery or mangrove-based aquaculture. The remaining 65 full-text articles were assessed for eligibility. A total of 55 articles were excluded because the full text was unavailable, the study did not contain empirical or review data, the publication was outside the 2010-2026 period, the location was outside Indonesia, or the article did not report ecological, economic, or social indicators relevant to the PICO framework. Finally, 10 studies met the eligibility criteria and were included in the qualitative synthesis.

Search Query

The literature search used Boolean operators to broaden and deepen the search scope. Synonyms were added because silvofishery is also reported as silvo-aquaculture, integrated mangrove aquaculture, mangrove-based aquaculture, wanamina, empang parit, tambak mangrove, and mangrove-associated aquaculture. The Indonesia scope was applied by combining country terms with regional and site-specific terms, such as Sumatra, Java, Kalimantan, Sulawesi, Papua, Banyuasin, Segara Anakan, Blanakan, Brebes, Mahakam Delta, Demak, Berau, Pekalongan, and North Sumatra.

The search query used in this study was as follows:

("silvofishery" OR "silvo-fishery" OR "silvofisheries" OR "silvo-aquaculture" OR "silvoaquaculture" OR "integrated mangrove aquaculture" OR "mangrove-based aquaculture" OR "wanamina" OR "empang parit" OR "tambak mangrove" OR "mangrove-associated aquaculture") AND ("mangrove" OR "mangrove restoration" OR "mangrove rehabilitation" OR "blue carbon" OR "ecosystem services" OR "food security" OR "coastal livelihood") AND ("Indonesia" OR "Indonesian" OR "Sumatra" OR "Java" OR "Kalimantan" OR "Sulawesi" OR "Papua" OR "Banyuasin" OR "Segara Anakan" OR "Blanakan" OR "Brebes" OR "Mahakam Delta" OR "Demak" OR "Berau" OR "Pekalongan" OR "North Sumatra")

The publication period was 2010-2026, and the search included English and Indonesian records. The Indonesia scope was obtained through three steps: first, Indonesia-related terms were included in the search string; second, titles and abstracts were screened for Indonesian locations; third, full texts were checked to ensure that the data, study site, or review focus referred to Indonesian mangrove ecosystems. International studies were used only as supporting literature in the introduction and discussion, not as included articles in the Indonesian SLR synthesis.

After identification, article selection was performed in accordance with the inclusion and exclusion criteria. The inclusion criteria were: empirical or review articles on silvofishery, wanamina, or mangrove-based aquaculture; Indonesian mangrove ecosystem context; publication year 2010-2026; peer-reviewed journal article or official report; and availability of ecological, economic, social, or policy indicators. The exclusion criteria were popular articles, opinion pieces without data, articles outside Indonesia, studies on mangroves without a silvofishery component, duplicate records, publications before 2010, and unavailable full texts.

The final number of inclusion articles was 10. This small number reflects the strict PICO-based eligibility criteria rather than a narrow search only. Many records discussed mangrove restoration, blue carbon, aquaculture, or coastal communities. However, they did not directly examine silvofishery or did not provide data that could be synthesized across ecological, economic, social, and policy dimensions. To reduce the risk of missing relevant studies, the screening also included reference checks and Google Scholar searches using Indonesian terms such as “wanamina”, “empang parit”, and “tambak mangrove”.

Quality Assessment (QA)

To ensure the quality of the literature used, a Quality Assessment was carried out on 10 articles that passed the inclusion stage. The assessment is carried out using a QA checklist that covers four main dimensions:

1. Relevance of the topic – the extent to which the article focuses on silvofishery and mangrove ecosystems.
2. Methodological quality – clarity of the research design, validity of the data, and consistency of the analysis.

3. Completeness of the data – the existence of ecological variables (mangrove cover, water quality, carbon stocks), economic (community income, pond productivity), and social (community participation, local policies).
4. Source credibility – the reputation of the journal and indexation (Scopus, WoS, or Sinta).

Each article is scored between 0 and 100. Articles with a score below 60% are excluded from the analysis. The QA results showed that all 10 articles had scores above the threshold, with an average of 82%, making them viable for use in systematic synthesis.

Data Analysis with VOSviewer

Bibliometric analysis in this study was conducted using the software VOSviewer, which maps relationships among concepts, keywords, and author collaborations in the scientific literature. Bibliographic data from articles that passed the inclusion stage (10 articles selected by PRISMA) were imported into VOSviewer in the standard RIS PoP format obtained from the Scopus and Web of Science databases. This process allows researchers to identify patterns of linkages among research topics, dominant trends, and collaborative networks in the fields of silvofishery and mangroves.

The keyword co-occurrence analysis indicated that "mangrove" emerged as the central node, the largest in size, suggesting it had the highest frequency and served as the main connecting concept within the selected literature. From these "mangrove" nodes, several differently colored clusters formed, representing the research theme. Red clusters, for example, connect the words "silvofishery", "sustainable aquaculture", "fish farming", and "integrated farming", thereby affirming the research focus on integrating mangrove conservation and fisheries cultivation. The blue cluster links to environmental issues such as "coastal erosion", "sea level rise", and "salinity intrusion", showing that silvofishery research is not only oriented toward pond productivity but also toward mitigating the impacts of climate change.

To identify the main thematic structure of silvofishery research, keyword co-occurrence mapping was conducted using VOSviewer.

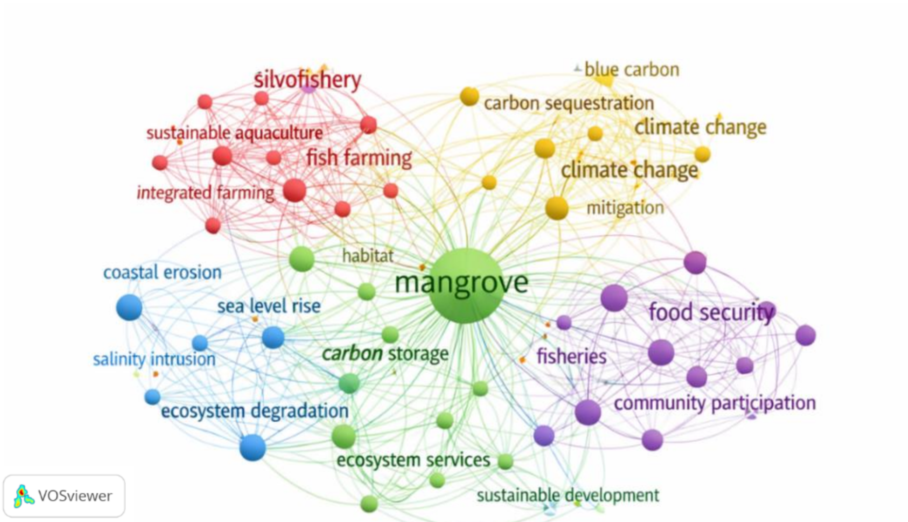

Figure 1. Keyword Co-Occurrence Node Mangrove

Figure 2 presents the keyword network centered on "mangrove" as the dominant node. The visualization illustrates the relationships among silvofishery, sustainable aquaculture, carbon storage, climate change, food security, ecosystem services, and community participation.

The green cluster shows the relationships among "carbon storage", "ecosystem services", and "habitat", emphasizing the role of mangroves as ecosystem service providers and blue carbon stores. Yellow clusters connect terms "blue sequestration", carbon", "carbon and "climate change", which reinforces the evidence that silvofishery contributes to global climate change mitigation. Meanwhile, the purple cluster highlights socio-economic aspects with keywords such as “food security”, “community participation”, and “fisheries”, which show the close relationship between the sustainability of mangrove ecosystems and the welfare of coastal communities.

In addition, the analysis of co-authorship reveals patterns of collaboration among authors and institutions. The visualization shows that several research groups form collaboration clusters, for example, groups involving researchers from IPB University, the University of North Sumatra, and LIPI. Names such as Basyuni, M., Nasution, K., and Slamet, B. emerged as important nodes in the network, signifying their significant contribution to silvofishery research. This pattern shows that although silvofishery research in Indonesia has developed, collaboration among institutions remains concentrated in a few large institutions and is not evenly distributed across the coastal region.

Author collaboration was analyzed to understand the research network within silvofishery and mangrove studies in Indonesia. Figure 3 shows the co-authorship pattern among researchers and institutions involved in the reviewed literature. This visualization helps identify dominant research clusters and the extent of collaboration among authors in silvofishery studies.

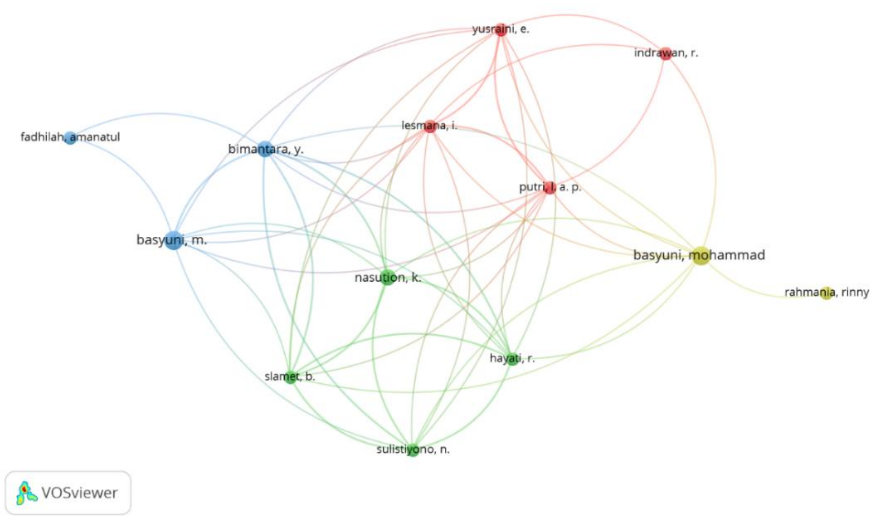

Figure 2. Co-Authorship Analysis

Citation analysis was also conducted to identify the most influential studies within the reviewed literature. Articles by Sumarga et al. (2024) on the integration of four ecosystem services in Blanakan, West Java, and by Hilmi et al. (2021) on the financial feasibility of the ditch dam model in Segara Anakan were the most cited. This shows that the two studies are the primary references for the development of silvofishery models oriented towards ecological and economic sustainability.

Overall, the results of the VOSviewer analysis show that silvofishery research on mangrove ecosystems spans ecological, economic, social, and policy dimensions. The visualization of the keyword network confirms that mangroves are at the center of the discourse, with silvofishery as an integrative strategy that connects climate change, food security, and the well-being of coastal communities. Thus, this analysis not only shows research trends but also reveals the direction of silvofishery's development as a nature-based solution that is relevant to the sustainable development agenda.

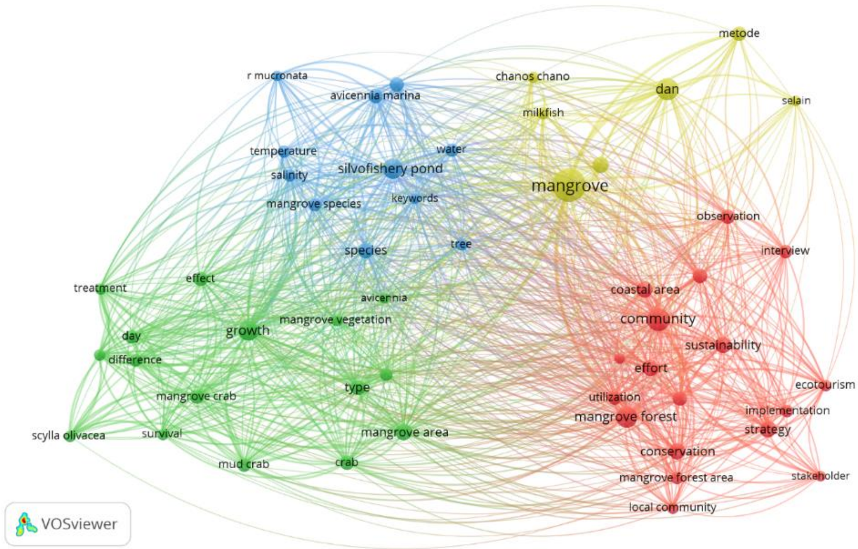

Figure 3. Keyword Visualization

In addition to keyword co-occurrence, a broader keyword visualization was generated to examine the distribution of research themes. Figure 4 shows how silvofishery research is connected to ecological, social, economic, and policy-related concepts. The visualization confirms that silvofishery is not limited to aquaculture production but also relates to ecosystem restoration, climate change mitigation, biodiversity conservation, and coastal livelihood resilience.

Research Instruments

The research instruments used in this study consist of several main components that complement each other:

1) The PRISMA Flow Diagram, used to illustrate the flow of article selection from the identification to inclusion stage, with the number of articles remaining at each stage (200 → 65 → 10).
2) The QA checklist is used to assess the quality of the methodology and the relevance of the article to the topic of silvofishery and mangroves.
3) VOSviewer Software, used for bibliometric analysis and keyword network visualization, author collaboration, and citation.
4) Microsoft Excel is used for tabulation of quantitative data such as publication trends per year, research location, and comparison results before and after silvofishery interventions.

These instruments support each other in producing a comprehensive analysis, both systematically and visually. PRISMA provides transparency in the selection process, QA ensures the quality of the literature, and VOSviewer strengthens the analysis by visualizing the relationships between concepts.

The research instruments used in this study were developed to support a systematic and transparent review process. Table 1 presents the main instruments used in the study, including article identity, research objectives, methodological characteristics, main results, recommendations, and validity and reliability aspects. These components were used to guide data extraction and synthesis from the selected studies.

Table 1. Research Instrument Table

No	Indicator	Sub-Indicator	Items	Subjects / Population
1	Article Identity	Title, Author, Year, Location	1–3	10 articles on silvo-fishery in Indonesia's mangrove ecosystem. Research locations: Banyuasin, Segara

No	Indicator	Sub-Indicator	Items	Subjects / Population
				Anakan, Blanakan, Brebes, Mahakam Delta, Demak, and national meta-analysis.
2	Research Objectives	Silvofishery development, mangrove rehabilitation, and coastal community welfare	4	The purpose of the study is to assess the effectiveness of silvofishery in maintaining mangrove cover, increasing pond productivity, improving ecosystem quality, and supporting the welfare of coastal communities.
3	Methodology	Systematic, bibliometric, case study	5	Methods: systematic review (PRISMA), bibliometric analysis (VOSviewer), and field case studies. Articles were selected through the PRISMA protocol with the stages of identification, screening, eligibility, and inclusion.
4	Main Results	Ecological, economic, social	6–8	Main results: increase in mangrove cover (28–80%), carbon stock (90–216.9 tC/ha), pond productivity (300–520 kg/ha/year), community income (Rp 12–27 million/year), as well as ecotourism and bird habitat.
5	Recommendations	Integrative policy, community-based management	9–10	Recommendations: community-based, integrative policies; economic incentives for farmers; strengthening environmental regulations; long-term monitoring; and the integration of silvofisheries into sustainable development strategies.
6	Validity and Reliability	–	–	Validity: guaranteed through PRISMA-based article selection and methodological assessment with critical appraisal tools. Reliability: maintained by double coding data extraction by two independent researchers (inter-rater reliability > 0.8). The use of automated tools such as VOSviewer and CiteSpace reduces manual bias. External validity was strengthened by comparing this study's results with the international silvofishery systematic review.

Validity and Reliability

The validity of this research is ensured through a strict article selection process using the PRISMA protocols, so that only relevant, peer-reviewed articles that meet the inclusion criteria are analyzed. Internal validity is strengthened by the use of critical appraisal Tools To assess the quality of each article's methodology. It includes the clarity of the research design, the completeness of ecological, economic, and social data, and the credibility of the publication source.

The reliability of the research is maintained through double coding of data extraction by two independent researchers, who then compared their codes to ensure consistency (inter-rater reliability > 0.8). In addition, the use of automated devices such as VOSviewer and CiteSpace reduces manual bias in bibliometric analysis. The external validity is strengthened by comparing the results of this study with relevant international systematic and bibliometric reviews, enabling the findings to be generalized in the global context of silvofisheries management.

Research Subject and Location

The subjects of this study are Mangrove Ecosystems and Coastal Communities involved in implementing the silvofishery system in Indonesia. The main focus is on the interactions among mangrove vegetation, pond environment quality, fisheries productivity, and socio-economic impacts on coastal communities.

The research locations analyzed based on ten inclusion journals include Banyuasin in South Sumatra with the application of crab silvofishery which increases mangrove density and mangrove crab growth; Segara Anakan in Cilacap with a ditch dam model that has proven to be financially feasible while improving water quality; Blanakan in West Java with integrative silvofishery that combines four ecosystem services in the form of carbon storage, fish and shrimp productivity, ecotourism, and bird habitat; Brebes in Central Java with long-term silvofishery innovations that show a positive correlation between vegetation and fauna; Mahakam Delta in East Kalimantan with silvofishery rehabilitation that suppresses abrasion and restores mangrove cover; and Demak in Central Java with the implementation of silvofishery that reduces the salinity of intensive ponds and increases shrimp yields.

In addition, the national meta-analysis shows a general trend of increasing carbon stocks by 45–60 tC/ha and fish catches by 20–35%, reinforcing evidence that silvofishery is an effective nature-based solution for ecosystem sustainability and coastal community welfare.

RESULTS AND DISCUSSION

Intervention Analysis

An analysis of ten inclusion journals shows a consistent pattern: the application of silvofishery improves ecological conditions and the welfare of coastal communities. Each research location exhibits distinct dynamics, but together they provide a comprehensive picture of the effectiveness of silvofishery. The implementation of silvofishery across various coastal locations in Indonesia shows a consistent pattern of ecological improvements, increased pond productivity, and increased community income.

The selected studies reported various ecological and socio-economic outcomes of silvofishery implementation across different coastal regions in Indonesia. Table 2 summarizes the reported conditions before and after the implementation of silvofishery, including changes in mangrove cover, pond productivity, crab abundance, carbon stocks, water quality, community income, and ecosystem services. This table provides a comparative overview of how silvofishery contributes to mangrove restoration and coastal community welfare across different study locations.

Table 2. Comparison Before and After Intervention

Research Location	Conditions Before Intervention	Conditions After Intervention	Journal Source
Banyuasin, South Sumatra	Mangrove cover is declining, the mangrove crab population is low, and community income is declining	Mangrove density increased by 35%, mangrove crab growth increased by 40%, and income increased by 25%	Apriyanto *et al*., 2025
Segara Anakan Lagoon, Cilacap	Low pond productivity, poor water quality	The empang parit model increased NPV to IDR 3.8 million, IRR to 48%, and improved water quality.	Hilmi *et al*., 2021

Research Location	Conditions Before Intervention	Conditions After Intervention	Journal Source
Blanakan, West Java	Ecosystem degradation, declining carbon stocks	Carbon storage of 216.9 tC/ha, increased ecotourism, and bird habitat	Sumarga *et al.*, 2024
Brebes, Central Java	The low density of mangroves, gastropods, and crabs is low	Mangrove density increased by 50%, and the abundance of gastropods and crabs increased significantly	Suyono & Fithora, 2025
Mahakam Delta, East Kalimantan	Mangrove cover down 72%, high abrasion	Rehabilitation of silvofishery lowers abrasion and increases vegetation cover	Susilo *et al.*, 2018
Demak, Central Java	Intensive ponds, high salinity	Silvofishery lowers salinity and increases shrimp yields	Friess *et al.*, 2019
Blanakan (integrative model)	Habitat fragmentation, low diversity	Integration of four ecosystem services: carbon, fish, tourism, and birds	Sumarga *et al.*, 2024
Banyuasin (Crab silvofishery)	Hard pond substrate, sparse vegetation	Softer substrate, dense vegetation, optimal crab growth	Apriyanto *et al.*, 2025
Brebes (10 years of innovation)	Limited environmental monitoring and uneven documentation of ecological responses.	Long-term monitoring showed a positive association between mangrove vegetation and faunal indicators.	Suyono & Fithora, 2025
Indonesia (meta-analysis)	Separate ecological or economic focus	Integrative studies show an increase in carbon stocks of 45–60 tC/ha and catch yields of 20–35%	Sungkawati & Umali, 2024

Mangrove cover is one of the main ecological indicators used to evaluate the effectiveness of silvofishery implementation. Figure 5 presents the reported differences in mangrove cover before and after silvofishery activities across selected study locations. The comparison indicates that silvofishery is generally associated with improved mangrove vegetation cover, although the extent of improvement varies with local ecological conditions and management practices.

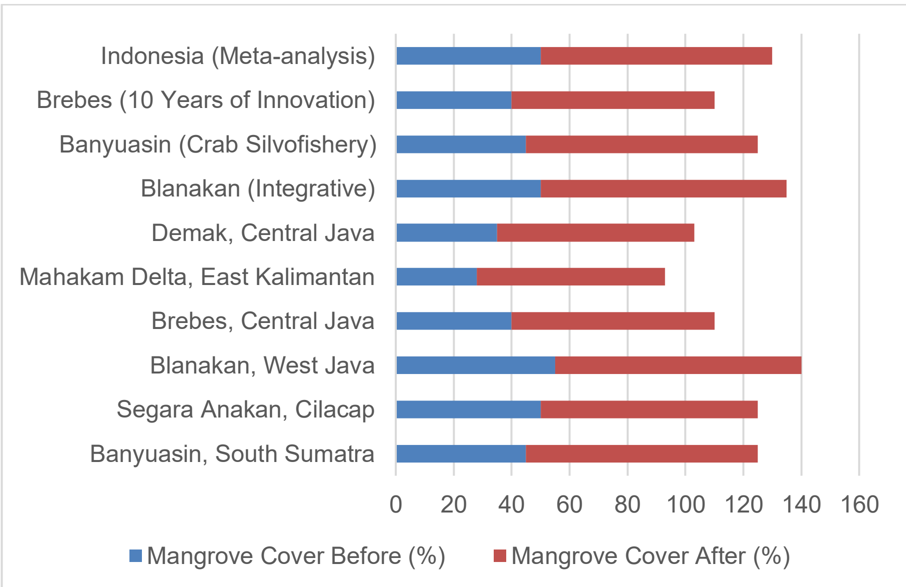

Figure 4. Differences in Mangrove Cover Before and After Silvofishery Activities

Crab density was used as an indicator of habitat quality and fishery resource improvement in mangrove-based aquaculture systems. Figure 6 compares the reported crab density before and after the implementation of silvofishery. The increase in crab density suggests that improved mangrove vegetation and pond substrate conditions may support better habitat suitability for mangrove crabs.

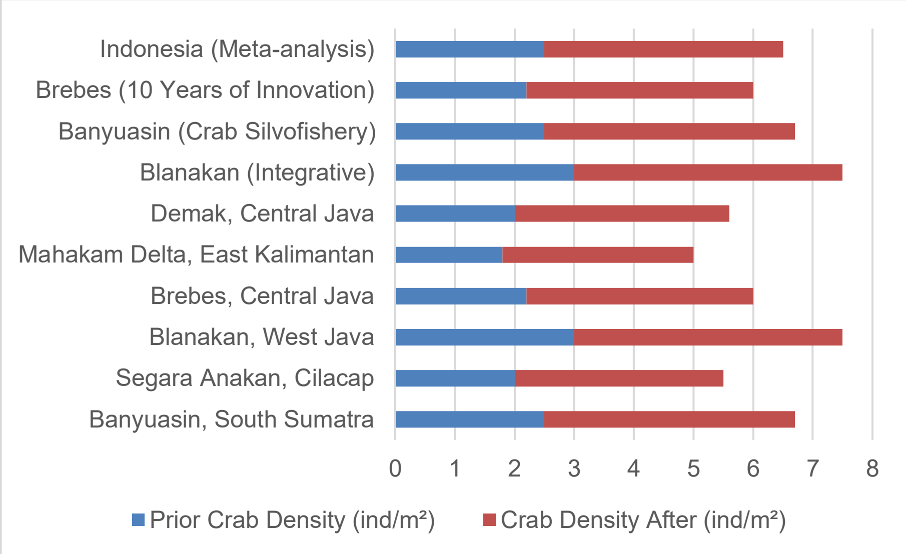

Figure 5. Differences in crab density before and after silvofishery activities

Carbon stock is an important indicator for assessing the contribution of mangrove ecosystems to climate change mitigation. Figure 7 presents the reported changes in carbon stocks before and after the implementation of silvofishery. The results show that silvofishery can contribute to carbon stock enhancement through mangrove rehabilitation and improved vegetation structure.

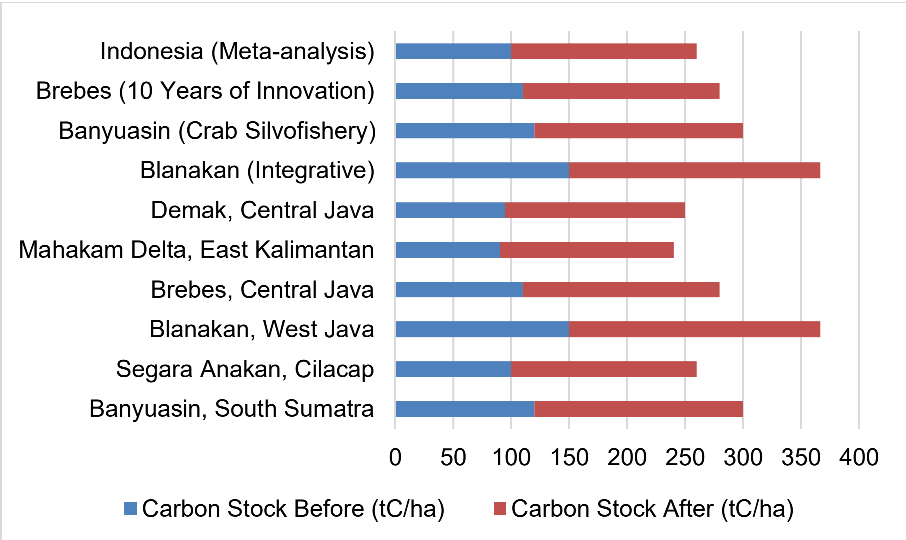

Figure 6. Differences in Carbon Stocks Before and After Silvofishery Activities

Socio-economic benefits are central to evaluating the sustainability of silvofishery as a community-based coastal management strategy. Figure 8 illustrates the reported changes in community income before and after the implementation of silvofishery. The trend indicates that silvofishery may improve coastal household income by combining fisheries production with mangrove ecosystem management.

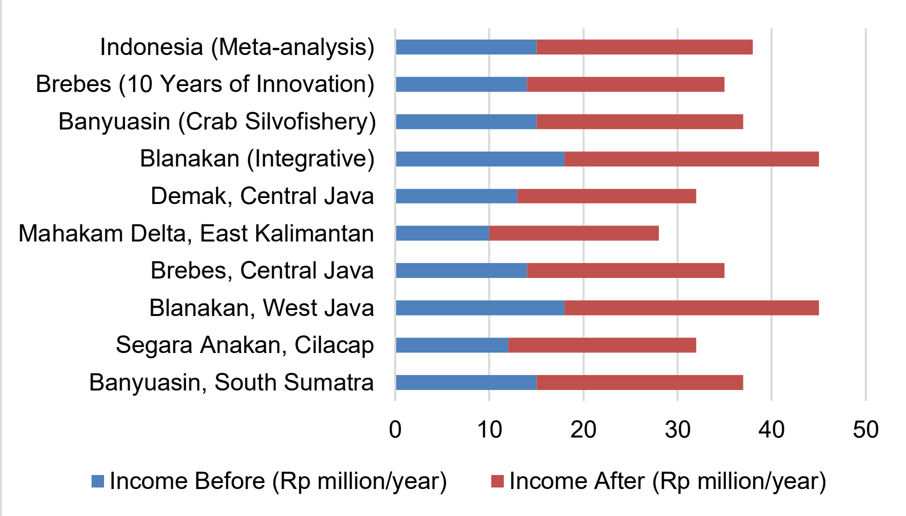

Figure 7. Community Income Trends Before and After Silvofishery Activities

Pond productivity is a key economic indicator for measuring the performance of silvofishery compared with conventional pond systems. Figure 9 presents the reported differences in pond productivity before and after silvofishery activities. The increase in productivity suggests that better water quality, mangrove vegetation, and pond management may enhance aquaculture performance in silvofishery systems.

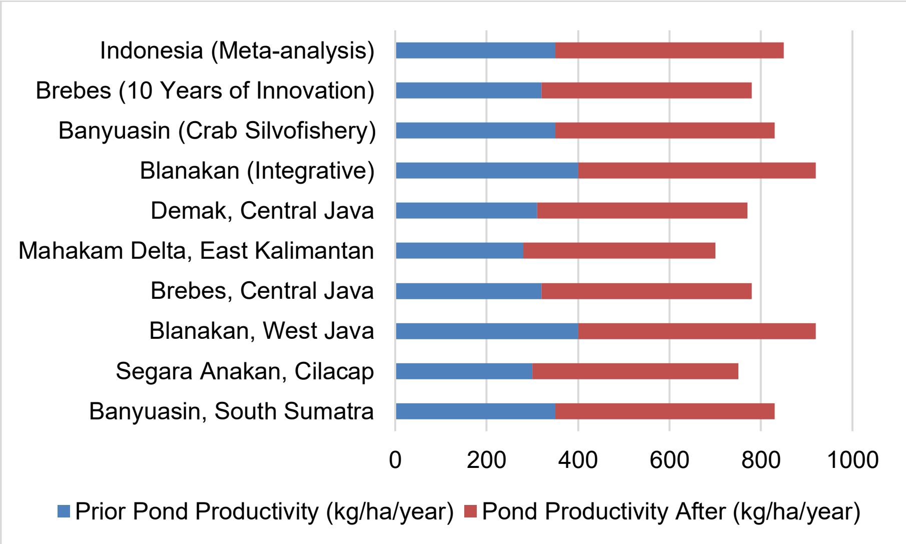

Figure 8. Differences in Pond Productivity Before and After Silvofishery Activities

The quality of mangrove ecosystems and habitats reflects the broader ecological function of silvofishery beyond aquaculture productivity. Figure 10 shows the reported differences in ecosystem and habitat conditions before and after the implementation of silvofishery. The improvement in habitat scores indicates that silvofishery can support biodiversity conservation, ecotourism potential, and the recovery of ecosystem services.

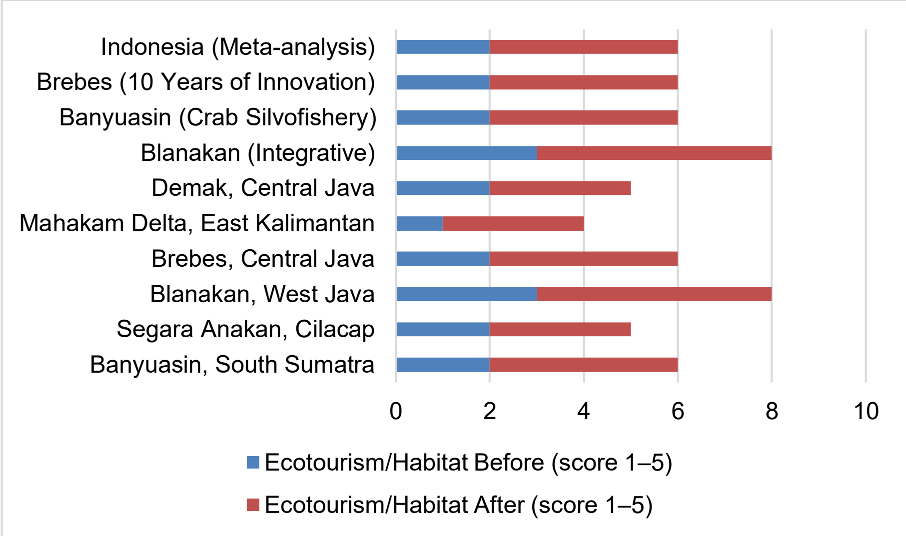

Figure 9. Differences in Mangrove Ecosystems/Habitats Before and After Silvofishery Activities

Research in Banyuasin, South Sumatra (Apriyanto et al., 2025) shows that crab silvofishery can improve mangrove cover, mangrove crab density, carbon stock, community income, and pond productivity. These findings are supported by studies showing that mangrove vegetation improves pond habitat quality through root structure, litter input, substrate stabilization, and nursery functions for benthic organisms and crustaceans (Hastuti et al., 2018; McSherry et al., 2023; Mustafa et al., 2024). The result suggests that crab-oriented silvofishery is most effective when substrate quality, mangrove density, and pond water exchange align with the habitat requirements of Scylla spp.

This condition is consistent with Hilmi et al. (2021), who found that the empang parit model improved pond water quality while increasing productivity from 300 to 450 kg/ha/year. Mangrove cover increased from 50% to 75%, crab density increased from 2.0 to 3.5 ind/m², and carbon stock increased from 100 to 160 tC/ha. The financial analysis also showed economic feasibility, with an NPV of IDR 3.8 million and an IRR of 48%, indicating that silvofishery provides both ecological and financial benefits.

The link between ecology and socio-economics is becoming clearer in research in Blanakan, West Java (Sumarga et al., 2024). The application of integrative silvofishery resulted in carbon storage of 216.9 tC/ha, an increase in mangrove cover from 55% to 85%, and an increase in crab density from 3.0 to 4.5 ind/m². Community income increased from Rp 18 million to Rp 27 million per year, pond productivity increased from 400 to 520 kg/ha/year, and ecotourism score jumped from 3 to 5. The integration of the four services of carbon ecosystems, fisheries, ecotourism, and bird habitat shows that silvofishery can be a multi-dimensional approach.

This positive trend is reinforced by research in Brebes, Central Java (Suyono & Fithora, 2025). Mangrove cover increased from 40% to 70%, crab density from 2.2 to 3.8 ind/m², and carbon stock from 110 to 170 tC/ha. The community's income increased from Rp 14 million to Rp 21 million per year, the pond's productivity increased from 320 to 460 kg/ha/year, and the ecotourism score increased from 2 to 4. Long-term silvofishery innovations show a positive correlation between mangrove density, gastropod presence, and mangrove crab abundance, confirming the importance of continuous monitoring.

The consistency of the results is also seen in the Mahakam Delta, East Kalimantan (Susilo et al., 2018). The mangrove cover increased from only 28% to 65% after silvofishery rehabilitation. Carbon stocks increased from 90 to 150 tC/ha, pond productivity from 280 to 420 kg/ha/year, and community income from Rp 10 million to Rp 18 million per year. The reduction in abrasion demonstrates the effectiveness of silvofishery as a nature-based solution for coastal areas experiencing severe degradation. Similar international evidence from integrated mangrove aquaculture in Southeast Asia shows that mangrove-shrimp systems can support livelihoods while maintaining mangrove functions when forest cover, hydrology, and farmer incentives are properly managed (McSherry et al., 2023; Takashima, 2000).

These results are consistent with research in Demak, Central Java (Friess et al., 2019). Mangrove cover increased from 35% to 68%, carbon stock from 95 to 155 tC/ha, and shrimp yield from 310 to 460 kg/ha/year. The community's income increased from Rp 13 million to Rp 19 million per year. Silvo-fishery has been shown to reduce salinity in intensive ponds and increase fisheries productivity, thereby improving environmental quality while supporting the local economy.

The integration of results from various locations is strengthened by national meta-analysis (Sungkawati & Umali, 2024). Systematic studies show a general trend: an increase in mangrove cover from 50% to 80%, carbon stocks from 100 to 160 tC/ha, crab density from 2.5 to 4.0 ind/m², and fish catches by 20–35%. People's average income increased from Rp 15 million to Rp 23 million per year. This analysis confirms that silvofishery is an effective nature-based solution for ecosystem sustainability and the well-being of coastal communities.

The reviewed studies did not produce identical outcomes across locations. The strongest multi-service outcome was reported in Blanakan because the model combined carbon storage, fisheries productivity, ecotourism, and bird habitat. Brebes showed the clearest long-term pattern because the study used a 10-year monitoring frame. Banyuasin showed a strong crab-silvofishery response because the intervention improved substrate condition and mangrove vegetation. The Mahakam Delta showed high relevance for restoration because the starting condition was severely degraded. Segara Anakan and Demak showed that pond design, hydrology, and salinity control strongly affect aquaculture outcomes.

The heterogeneity indicates that silvofishery success is controlled by interacting ecological and institutional factors, not by mangrove planting alone. Key factors include site suitability, tidal exchange, pond water quality, sediment condition, mangrove species composition, vegetation density, stocking intensity, farmer capacity, market incentives, and policy support. These factors explain why some locations show stronger carbon and habitat recovery, while others show clearer gains in pond productivity or income.

Table 3. Heterogeneity Analysis of Silvofishery Outcomes Across Locations

Location	Most Evident Outcome	Interpretation of Success	Main Controlling Factors
Blanakan, West Java	Carbon storage, fisheries, ecotourism, and bird habitat	Most successful for multi-service ecosystem integration.	Healthy mangrove structure, habitat continuity, service-based management
Brebes, Central Java	Long-term relation between mangrove density, gastropods, and crab abundance	Most useful for explaining ecological consistency over time.	Long-term monitoring, vegetation recovery, faunal response
Banyuasin, South Sumatra	Mangrove crab growth, crab density, and community income	Most successful for crab-oriented silvofishery.	Substrate quality, mangrove density, crab habitat suitability
Mahakam Delta, East Kalimantan	Mangrove rehabilitation and abrasion reduction	Most relevant for highly degraded coastal landscapes.	Initial degradation level, hydrological restoration, rehabilitation intensity

Segara Anakan and Demak	Pond productivity, water quality, and salinity control	Most relevant for comparing pond management models.	Empang parit design, tidal exchange, pond salinity, farmer management

Synthesis Analysis

The synthesis indicates that silvofishery produces positive outcomes through several ecological mechanisms. Mangrove roots stabilize pond margins, trap sediment, and provide refugia for fish, shrimp, crabs, gastropods, and benthic organisms. Leaf litter and organic matter support detrital food webs, while vegetation structure improves habitat complexity. These mechanisms help explain why improved mangrove cover is often followed by higher crab abundance, better pond productivity, and stronger habitat quality. However, the strength of this relationship varies by species composition, vegetation density, substrate condition, and tidal exchange.

Carbon and water-quality benefits also follow a site-specific mechanism. Higher mangrove biomass increases aboveground and belowground carbon stock, while sediment accumulation can strengthen blue carbon storage. Mangrove vegetation can also improve water quality by filtering nutrients, reducing wave energy, and moderating salinity. These processes explain the stronger outcomes in sites with better hydrological connections and lower pollution pressure. In contrast, poor water exchange, intensive stocking, and heavy metal contamination can weaken the sustainability of silvofishery ponds, as shown by studies on environmental quality and contamination risks (Hastuti et al., 2021; Mustafa et al., 2024).

The socio-economic mechanism depends on whether ecological recovery translates into productive, marketable fisheries. Income gains occur when mangrove rehabilitation improves pond productivity or crab growth and when farmers have access to training, markets, and institutional support. The reviewed evidence, therefore, does not mean that all silvofishery programs automatically succeed. Silvofishery performs best when ecological suitability, pond design, community participation, and policy incentives operate together. This finding directly answers the review question about the factors controlling success and explains the variation across locations.

CONCLUSION AND RECOMMENDATIONS

This systematic review of 10 included studies, from 200 screened records, 65 full texts assessed, and 10 synthesized, shows that silvofishery can support mangrove ecosystem sustainability and coastal community welfare in Indonesia. The evidence answers the first objective by showing that silvofishery generally performs better than conventional pond systems in the selected cases because it combines mangrove rehabilitation with aquaculture production. Reported outcomes include improved mangrove cover, carbon stock, pond productivity, crab abundance, water quality, ecosystem services, and community income.

The review addresses the second objective by identifying the main factors explaining variation in silvofishery success. Site suitability, tidal exchange, pond salinity, sediment condition, mangrove species composition, vegetation density, stocking intensity, farmer capacity, institutional support, and economic incentives strongly influence outcomes. Blanakan showed the strongest multi-service ecosystem integration; Brebes provided the clearest long-term monitoring evidence; Banyuasin showed strong crab-oriented silvofishery performance; and the Mahakam Delta showed high restoration relevance in a severely degraded landscape.

The review answers the third and fourth objectives by identifying research gaps and policy priorities. Current studies remain limited by small sample sizes, different indicators, short monitoring periods, and limited conventional-pond comparators. Future silvofishery research in Indonesia should use long-term, multi-site, and comparable indicators that integrate ecology, aquaculture productivity, household income, governance, and blue carbon. Overall, silvofishery should be developed as a nature-based solution that links mangrove restoration, climate change mitigation, food security, and livelihood resilience.

Future research should prioritize long-term multi-site monitoring using comparable indicators for mangrove cover, carbon stock, water and sediment quality, biodiversity, pond productivity, household income, and governance. Studies should also compare silvofishery with conventional ponds using clear baselines and follow-up periods.

Policy implementation should use site-suitability criteria before developing silvofishery. Priority factors include tidal exchange, salinity, sediment condition, mangrove species composition, pond design, and pollution risk. Areas with high degradation need rehabilitation-focused models, while areas with productive ponds need water-quality and stocking-density control.

Community-based management should be strengthened through training, technical assistance, market access, and economic incentives. Cross-sector coordination among forestry, fisheries, environmental management, coastal planning, and local governments is needed to ensure that silvofishery supports restoration targets, food security, and coastal livelihoods simultaneously.

REFERENCES

Ansyar, L., Junianto, A., M. C. W., & Sahidin, A. (2025). Diversity of snails (Mollusca: Gastropoda) in the mangrove area of Karangsong, Indramayu Regency, West Java Province, Indonesia. *Journal of Tropical Biodiversity and Biotechnology, 10*(3), Article jtbb16927. https://doi.org/10.22146/jtbb.16927

Apriyanto, A., Suwignyo, R. A., Ulqodry, T. Z., Sarno, S., Aryawati, R., Muhtadi, M., Purnomo, H., & Okarda, B. (2025). The crab silvofishery system as a conservation strategy in mangrove restoration area: A case study on the coast of Banyuasin, South Sumatra. *Journal of Environmental Science and Sustainable Development, 8*(1), 48–65. https://doi.org/10.7454/jessd.v8i1.1336

Ardiyanto, A. T., Hilmi, E., Mahdiana, A., Junaidi, T., Prayogo, N. A., Dewi, R., & Cahyo, T. N. (2024). Stakeholder analysis of mangrove ecosystem management in Segara Anakan Lagoon, Cilacap. *Indonesian Journal of Forestry Research, 11*(2), 189–209. https://doi.org/10.59465/ijfr.2024.11.2.189-209

Ariadi, H., Wafi, A., Madusari, B. D., Syakirin, M. B., Linayati, L., & Mardiana, T. Y. (2026). Assessment of mangrove species composition, biomass, and carbon stock potential for climate change mitigation in Pekalongan, Indonesia. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (Journal of Natural Resources and Environmental Management), 16*(1), 36–52. https://doi.org/10.29244/jpsl.16.1.36

Fithor, A., & Suyono. (2025). Innovative silvofishery model in restored mangrove forests: A 10-year assessment. *Heliyon, 11*(2), Article e42043. https://doi.org/10.1016/j.heliyon.2025.e42043

Hastuti, E. D., Hastuti, R. B., & Darmanti, S. (2018). Plankton and benthos similarity indices as indicators of the impact of mangrove plantation on the environmental quality of silvofishery ponds. *Biodiversitas, 19*(4), 1558–1567. https://doi.org/10.13057/biodiv/d190449

Hastuti, E. D., Budihastuti, R., & Darmanti, S. (2021). Increasing risk of heavy metal contamination in silvofishery ponds. *Biotropia, 28*(1), 38–45. https://doi.org/10.11598/btb.2021.28.1.983

Keesstra, S. D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J. N., Pachepsky, Y., van der Putten, W. H., Bardgett, R. D., Moolenaar, S., Mol, G., Jansen, B., & Fresco, L. O. (2016). The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. *SOIL, 2*, 111–128. https://doi.org/10.5194/soil-2-111-2016

Mustafa, A., Tarunamulia, T., Ratnawati, E., Paena, M., Kamariah, K., Athirah, A., Asaf, R., Tahe, S., Hendrajat, E. A., Taukhid, I., Asaad, A. I. J., Basir, B., & Ilman, M. (2024).

Exploring environmental condition of silvofishery pond to support the sustainability of mangrove management in Berau Regency, Indonesia. *Environmental Research Communications, 6*(9), Article 095008. https://doi.org/10.1088/2515-7620/ad6823

Risdayanti, B., M., & Aththorick, T. A. (2026). Land suitability assessment for mangrove-based silvofishery in North Sumatra, Indonesia. *Asian Journal of Forestry, 10*(1), Article r100130. https://doi.org/10.13057/asianjfor/r100130

Sodikin, S., Hidayat, R., Wulandari, F. R., & Rahardjani, S. P. (2025). Spatial analysis of mangrove change and rehabilitation guidelines in the North Coast Area of West Java Province, Indonesia. *Polish Journal of Environmental Studies, 34*(5), 5833–5844. https://doi.org/10.15244/pjoes/191530

Sumarga, E., Rosleine, D., Hutajulu, G. B., Plaurint, R. P., Tsabita, B., M., L., S. H., T., M. F., S., N. N., & Ali, H. M. (2024). Quantification of ecosystem services from mangrove silvofishery. *Global Journal of Environmental Science and Management, 10*(3), 1333–1344. https://doi.org/10.22034/gjesm.2024.03.23

Sungkawati, E., & Umali, J. (2024). Blue carbon and food security: A systematic review of mangrove ecosystem services for SDG 13 (Climate Action) and SDG 2 (Zero Hunger). *Assyfa Journal of Farming and Agriculture, 2*(1), 40–50. https://doi.org/10.61650/ajfa.v2i1.871

Susilo, H., Takahashi, Y., Sato, G., Nomura, H., & Abe, M. Y. (2018). The adoption of silvofishery system to restore mangrove ecosystems and its impact on farmers' income in Mahakam Delta, Indonesia. *Journal of the Faculty of Agriculture, Kyushu University, 63*(2), 433–442.

Tarunamulia, T., Mustafa, A., & Kamariah, K. (2021). Silvofishery pond management and its role in mangrove conservation in Berau Regency, East Kalimantan. *Aquaculture Reports, 20*, Article 100678. https://doi.org/10.1016/j.aqrep.2021.100678

Zhao, G., Mu, X., Wen, Z., Wang, F., & Gao, P. (2013). Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. *Land Degradation & Development, 24*(5), 499–510. https://doi.org/10.1002/ldr.2246

Global Mangrove Alliance. (2024). The State of the World's Mangroves 2024. Global Mangrove Alliance.

Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Cambridge University Press. https://doi.org/10.1017/9781009325844

Kementerian Lingkungan Hidup. (2025). Dengan dukungan Wakil Presiden, Indonesia tegaskan komitmen perlindungan ekosistem mangrove untuk masa depan bumi. https://kemenlh.go.id/news/detail/menteri-lingkungan-hidup-dengan-dukungan-wakil-presiden-indonesia-tegaskan-komitmen-perlindungan-ekosistem-mangrove-untuk-masa-depan-bumi

McSherry, M., *et al*. (2023). Integrated mangrove forest and aquaculture systems: The sustainable choice for mangrove restoration? Frontiers in Forests and Global Change, 6, Article 1094306. https://doi.org/10.3389/ffgc.2023.1094306

Takashima, F. (2000). Silvofishery: An aquaculture system harmonized with the environment. SEAFDEC Asian Aquaculture, 22(4), 8-12.