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CASE STUDY

# Quantification of ecosystem services from mangrove silvofishery

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Mangrove silvofishery, a unique system that combine aquaculture with mangrove forests, presents a promising sustainable solution for Indonesia's coastal communities. However, in order to achieve broad implementation, it is essential to bridge the existing knowledge gap concerning the economic and environmental benefits associated with it. The aim of this study was to assess the four primary services rendered by the Blanakan mangrove silvofishery area in Subang District, West Java: carbon sequestration, fisheries productivity, nature-based tourism, and bird sanctuary.

**METHODS:** Carbon storage was calculated by conducting vegetation surveys and utilizing allometric equations, which took into account both aboveground and belowground biomass. During the vegetation survey, data regarding the types of mangrove plants and the diameter of each tree at breast height was gathered. To quantify fisheries production, interviews were conducted with area managers and pond farmers who are engaged in silvofishery practices within the region. The point-count method was used to inventory the diversity of bird species. The analysis of natural tourism services encompassed an examination of visitor statistics, the state of the mangroves as a popular tourist destination, and the range of tourist activities available.

**FINDINGS:** The study revealed the high capacity of the mangrove stands at the study location for carbon storage, with an estimated 137.9 tonnes carbon per hectare aboveground and 79 tonnes carbon per hectare belowground. Local communities actively engage in silvofishery practices within the Blanakan mangroves, cultivating fish and shrimp, with an average annual income of around 1,513 United States dollar per hectare.

2. The natural beauty of the Blanakan mangrove area attracts tourists with its diverse ecosystem and opportunities to see crocodile breeding facilities. Visitor numbers vary, averaging around 128 people per month until mid-2023. The Blanakan mangroves are home to a total of 23 bird species, contributing to a species diversity index of 2.1. Two species with significant conservation value were found: the critically endangered Javan Blue-banded Kingfisher (*Alcedo euryzona*) and the vulnerable Black-capped Kingfisher (*Halcyon pileata*).

**CONCLUSION:** The results emphasize the importance of advancing and advocating for silvofishery as a primary alternative in Indonesia's mangrove conservation and rehabilitation initiatives, enhancing coastal environmental management. Community engagement is of utmost importance in the successful development of mangrove silvofishery, as it aims to tackle the issue of limited awareness and participation among the local community.



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## INTRODUCTION

Indonesia's ongoing endeavors to tackle environmental issues have placed mangrove restoration at the forefront, recognizing its significance in countering the extensive degradation and transformation of mangrove ecosystems. With this objective in mind, the government set up the Peat and Mangrove Restoration Agency (BRGM) in 2021, with the aim of rejuvenating a notable 600 thousand hectares (ha) of mangroves by 2024. (BRGM, 2021). This ambitious restoration effort encompasses both conservation areas and protected forests that have suffered degradation, as well as mangrove areas previously converted into fish farms. The advancement of silvofishery is becoming increasingly important in Indonesia's initiatives to restore mangrove ecosystems (Basyuni *et al.,* 2018; Harefa *et al*., 2022; Wulandari *et al*., 2022). This method merges the cultivation of brackish water fish with forestry, providing a sustainable and holistic strategy. Silvofishery development focuses on regions where local communities heavily depend on fish farming as their main source of income. In these areas, there is usually a significant need for land to cultivate fish, which unfortunately often results in the conversion of mangroves to establish new ponds (Arifanti, 2020; Eddy *et al*., 2021). Silvofishery presents numerous unique benefits when compared to traditional coastal fish farming practices without mangroves. Numerous studies have documented these benefits, encompassing aspects such as enhanced natural food availability (Sahidin *et al.,* 2019), improved water quality (Musa *et al*., 2020), and increased carbon absorption and storage (Ahmed *et al*., 2018; Sumarga *et al*., 2022). Mangrove trees serve as a critical source of organic matter (Muro-Torres *et al*., 2020), contributing to a richer natural food supply for cultivated fish. The decomposition of organic matter and the subsequent formation of intricate food chains are responsible for this phenomenon. Mangrove roots play a crucial role in providing a safe haven for juvenile fish, protecting them from predators and enhancing their chances of survival (Srikanth *et al*., 2016; Nanjo, 2022). The presence of mangrove trees plays a key role in carbon sequestration (Inoue, 2019; Song *et al*., 2023), aligning with global efforts to mitigate climate change. By incorporating trees into agricultural landscapes, silvofishery represents a unique agroforestry system that not only enhances food production but also contributes to carbon sequestration (Kamyab *et al*., 2024). The main obstacle impeding the progress of silvofishery development in Indonesia arises from a limited comprehension among coastal fish farming communities regarding the crucial significance of mangrove presence in facilitating prosperous fish farming methods (Susilo *et al.,* 2018). A widespread misconception persists within these communities, equating larger pond areas devoid of mangroves with greater fish production potential. In Indonesia, the prevailing method of coastal fish farming involves the use of non-mangrove open ponds, while the availability of mangrove stands is frequently inadequate (Aslan *et al*., 2021; Prakoso *et al*., 2023). It is evident that more scientific research is required to highlight the economic and ecological advantages of silvofishery, especially in regions where mangroves are abundant. This study focuses on overcoming these obstacles by selecting the Blanakan mangrove area in West Java, Indonesia as the research site. The area is characterized by the implementation of silvofishery practices, where there is a substantial presence of mangroves, accounting for 80 percent (%) of the area, while the remaining 20% is allocated for ponds. The study encompasses a 15 ha region. This area is also being developed as a natural tourist destination, with the mangrove ecosystem serving as the central attraction. As the silvofishery model implemented in Blanakan remains relatively rare in Indonesia, revealing its ecological and economic benefits will provide valuable information for furthering silvofishery development efforts in diverse locations. This study utilizes an ecosystem services framework to highlight the environmental and financial advantages of silvofishery. This strategy has been extensively employed to assist in the preservation of mangrove ecosystems, encompassing the protection of mangroves against the perils of degradation and deforestation (Dasgupta *et al.*, 2022; Gnansounou *et al*., 2022; Sumarga *et al.*, 2023). With the ecosystem approach, this study seeks to provide scientific evidence for the crucial importance of protecting mangrove ecosystems and encourage the adoption of the silvofishery model for mangrove rehabilitation in various degraded areas. The advancement of silvofishery as a method for rehabilitating mangroves enhances the array of restoration approaches available. This array spans

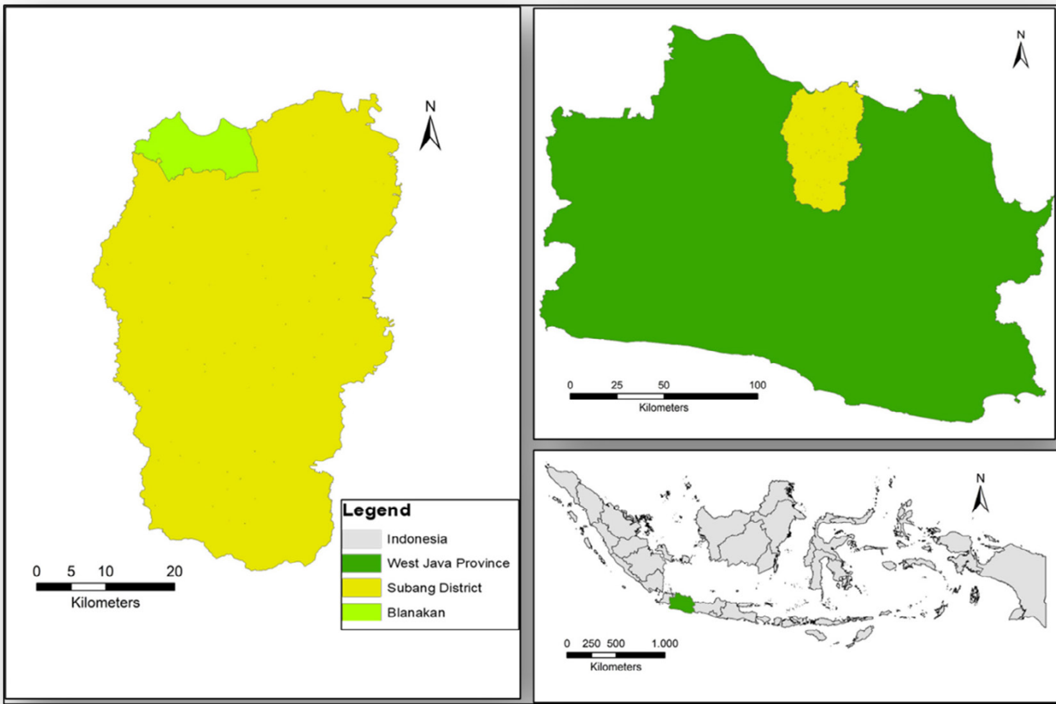


Fig 1. Geographic location of study area in Subang District, West Java Province, Indonesia

from full mangrove reforestation in protected zones to the incorporation of mangroves into fish ponds in aquaculture zones. This study aims to quantify four key ecosystem services provided by mangrove silvofishery, encompassing three service categories: provisioning services (fisheries production), regulating services (carbon storage), and cultural services (bird habitat and nature tourism). Quantifying the ecological, social, and economic benefits of mangrove silvofishery is essential in order to showcase the value of this sustainable system and encourage its widespread adoption. This study was conducted in the Blanakan mangrove area, Subang, Indonesia in 2023.

## MATERIALS AND METHODS

Fig. 1 presents the geographical information of Blanakan region, Subang District, West Java Province, Indonesia. The Blanakan mangrove area is located in the northern coastal area of Subang District (107°31’ - 107°54’ longitude and -6°11’ - -6°49’ latitude). The annual precipitation in this region averages 3,160 millimeters (mm), with an average of 184 rainy days per year (y) and an average temperature of 27.5 degrees Celsius (°C). (WJSB, 2024). This 15 ha site is managed by the state-owned forestry company, i.e. Perum Perhutani. A silvofishery model is implemented here, integrated with the development of natural recreation activities. Local communities are actively involved in the advancement of silvofishery, taking on the roles of fish and shrimp farmers. The distinctive mangrove ecosystem is utilized for recreational activities, including initiatives for crocodile breeding, with the support of the community.

*Data collection and analysis*

This study examined four distinct ecosystem services: carbon storage, fish production, nature recreation, and bird habitat.

*Carbon storage*

This study evaluated the carbon storage found in mangrove biomass, taking into account both the aboveground and belowground elements. Data

Table 1: Allometric equations for aboveground biomass estimation

| No. | Mangrove species | Allometric equation | Sources |
|---|---|---|---|
| 1 | *Avicennia marina* | $B = 0{,}1848D^{2{,}3524}$ | Dharmawan dan Siregar, 2008 |
| 2 | *Rhizophora apiculata* | $B = 0.235 \; x \; D^{2{,}42}$ | Ong *et al.,* 2004 |

B = Biomass (kilogram), D = DBH (centimeter/cm)

Table 2: Allometric equations for belowground biomass estimation

| No. | Mangrove species | Allometric equation | Sources |
|---|---|---|---|
| 1 | *Avicennia marina* | $B = 0{,}199\rho^{0{,}899}D^{2{,}22}$ | Komiyama *et al.,* 2005 |
| 2 | *Rhizophora apiculata* | $B = 0{,}199\rho^{0{,}899}D^{2{,}22}$ | Komiyama *et al.,* 2005 |

collection in the field included setting up ten 10m x 10m sample plots strategically placed in areas that reflect the range of the study area. Within each plot, data was collected on the species of mangrove vegetation and the diameter at breast height (DBH) of every mangrove tree. The vegetation survey data was utilized to calculate carbon storage levels (both above and below ground) by applying well-established allometric biomass models derived from earlier research results (Komiyama *et al.,* 2005, Ong *et al.,* 2004, Dharmawan dan Siregar, 2008). The allometric models convert DBH into biomass. Only two mangrove species were present at the study location: *Avicennia marina and Rhizophora apiculata*. The allometric equations for estimating the biomass above and below the ground for these two species are provided in Tables 1 and 2, respectively.

The conversion of biomass into carbon was carried out using a conversion factor of 0.47 (Aalde *et al.,* 2006).

*Fish production*

In order to assess the quantity of fish production, interviews were carried out with area managers and community members who are actively engaged in fish/shrimp cultivation within the silvofishery area. The interviews delved into a range of topics, encompassing pond management techniques, the cultivation of different fish and shrimp species, the expenses involved in production, the quantity of harvests, and the income of pond farmers. Field observations were conducted to gather data on pond conditions and direct sales of harvested products at the study location.

*Nature recreation*

Natural recreation service was quantified through a combination of visitor data (Hein *et al.,* 2020), surveys of tourist attractions, and interviews with visitors and area managers. A total of 40 respondents participated in the survey, which covered various aspects such as their origin, primary purpose of visit, and their perceptions of the area's beauty, comfort, cleanliness, facilities, and accessibility.

*Bird habitat*

Bird habitat services are quantified through an assessment of species diversity and bird population abundance. Data was collected using the point count method, involving observations at four points each morning and evening for two hours. The recorded data includes both bird species and individual counts. Observations were conducted visually with the aid of binoculars and through bird sounds. Identification relied on bird species identifiers and the field guide "Birds in Sumatra, Java, Bali and Kalimantan" (Mackinnon, 1993). The data collected was subsequently examined to ascertain the richness of bird species, the diversity index of bird species, the relative abundance of each bird species within the population, and the classification of bird species according to their protection status.

## RESULTS AND DISCUSSION

*Carbon storage*

Two mangrove species are present at the study location: *Avicennia marina* and *Rhizophora apiculata*. Planted in 1972, these trees are now mature, with large diameters and exceeding 10 meters (m) in

Table 3: Estimated biomass carbon in the study area

| Mangrove tree species | Aboveground carbon (ton carbon/ha) | Belowground carbon (ton carbon/ha) | Total biomass carbon (ton carbon/ha) |
|---|---|---|---|
| *Avicennia marina* | 135.4 | 77.6 | 213 |
| *Rhizophora apiculata* | 2.5 | 1.4 | 3.9 |
| Total | 137.9 | 79 | 216.9 |

Fig. 2: Silvofishery model in the Blanakan mangrove area

height. The healthy growth of these mangroves suggests a high capacity for carbon absorption and storage.

The study site's vegetation analysis across the 10 plots indicated that *Avicennia* marina holds the position of the most prevalent species. In total, 55 mature *Avicennia marina* trees (diameter > 20 cm) and 25 pole-stage *Avicennia marina* trees (diameter 10-20 cm) were documented. Notably, *Rhizophora apiculata* was only found in the pole stage, with 16 individuals recorded. Table 3 displays the calculated carbon stocks above and below the ground for each of the mangrove species.

*Fish production*

The silvofishery model implemented in the Blanakan mangrove area adopts a ditch-pond pattern, with 80% of the area dedicated to mangrove conservation and the remaining 20% utilized for fishponds. These fishponds were constructed on the periphery, encircling the core mangrove forest (Fig. 2).

Local communities collaborate with Perum Perhutani, the area manager, to carry out fish cultivation activities. Pond farmers lease land at a rate of 12.8 United States dollar (USD)/ha/y. On average, each pond farmer manages 2 ha of ponds. Widely grown fish types comprise milkfish, tilapia, and vannamei shrimp. In-depth interviews with three pond farmers revealed that fish farming activities are conducted on average three times a y. The primary cost components include seed purchase (averaging 641 USD/ha/y), labour (averaging 76.9 USD/ha/y), and land rental (12.8 USD/ha/y). Pond farmers do not have to bear any expenses for feed, since the decomposition of organic matter from mangrove litter offers ample sustenance for the fish and shrimp, making natural resources easily accessible. Pond farmers can achieve an average income of 2,308 USD per hectare by harvesting three times a year. The average annual net income for pond farmers, after considering cultivation costs, is roughly 1,513 USD per hectare.

Table 4: Number of visitors and income from Blanakan mangrove tourism

| Year | Number of visitors | Number of vehicles | Income (USD) |
|---|---|---|---|
| 2018 | 13,066 | 2,909 | 12,563 |
| 2019 | 10,236 | 2,604 | 9,842 |
| 2020 | 671 | 219 | 645 |
| 2021 | 2,694 | 595 | 2,590 |
| 2022 | 1,504 | 466 | 1,446 |
| 2023 (until July) | 893 | 293 | 859 |

Fig. 3: Crocodile breeding in Blanakan mangrove area

*Nature recreation*

As of 2023, the Blanakan mangrove area receives an average of 128 visitors per month. Visitor numbers have fluctuated significantly in previous years (Table 4), primarily due to the impact of the COVID-19 pandemic between 2020 and 2022. Notably, visitor numbers typically peak during community sea festivals held in September and October. Visitors can partake in a multitude of natural tourism activities within the Blanakan mangrove area. These activities encompass trekking, observing crocodiles, capturing photographs, enjoying picnics, and indulging in educational and culinary experiences. The integration of estuarine crocodile breeding into the area's tourism development (Fig. 3) further enhances the visitor experience.

The Blanakan mangrove area has a thriving mangrove ecosystem, a natural draw for tourists. The two dominant mangrove species are *Avicennia marina* and *Rhizophora apiculata*, which contribute to a high canopy cover exceeding 75%. The Blanakan mangroves offer a lush canopy that provides a cool and shaded atmosphere, perfect for a range of nature-based tourism activities. Alongside the estuarine crocodiles that are nurtured in this area, the presence of a wide variety of bird species adds to the educational and natural tourism appeal of these mangroves. Notably, egrets, swallows, blekok birds, and Javanese bondols are frequently observed engaging in their natural behaviours. The Blanakan mangrove area has moderate accessibility. Two entrances provide access, one sufficiently wide to accommodate buses used for student educational visits. Although visitors can typically reach the location using different motor vehicles, some areas may have road damage causing slight hindrances along the way. Survey responses and interviews with visitors revealed that the majority (73%) originated

Table 5: Bird species and its number of individuals found in the Blanakan mangrove area

| No. | Local name | Scientific name | Number of individuals |
|---|---|---|---|
| 1 | Kuntul | *Egretta alba* | 326 |
| 2 | Blekok | *Ardeola speciosa* | 241 |
| 3 | Burung Gereja | *Passer domesticus* | 75 |
| 4 | Bondol Jawa | *Lonchura leucogastroides* | 112 |
| 5 | Cekakak Suci | *Todirhampus sanctus* | 27 |
| 6 | Cekakak Cina | *Halcyon pileata* | 10 |
| 7 | Cekakak Sungai | *Todirhampus chloris* | 12 |
| 8 | Raja Udang | *Alcedo euryzona* | 4 |
| 9 | Kareo Padi | *Amaurornis phoenicurus* | 15 |
| 10 | Bambangan Cokelat | *Ixobrychus eurhythmus* | 18 |
| 11 | Bambangan Kuning | *Ixobrychus sinensis* | 33 |
| 12 | Burung Layang | *Hirundo rustica* | 17 |
| 13 | Tekukur | *Streptopelia chinensis* | 11 |
| 14 | Pecuk padi Hitam | *Phalacrocorax sulcirostris* | 2 |
| 15 | Caladi Tilik | *Dendrocopos moluccensis* | 19 |
| 16 | Kekep babi | *Artamus leucorynchus* | 3 |
| 17 | Mandar Batu | *Gallinula chloropus* | 2 |
| 18 | Tikusan Merah | *Porzana fusca* | 2 |
| 19 | Elang Raja Bondol | *Haliastur indus* | 1 |
| 20 | Kuntul Karang | *Egretta sacra* | 2 |
| 21 | Mandar Padi Sintar | *Gallirallus striatus* | 4 |
| 22 | Cici Padi | *Cisticola juncidis* | 19 |
| 23 | Walet | *Collocalia vestita* | 287 |

from Subang Regency, while the remaining visitors came from other regions like Karawang, Bekasi, Indramayu, and Bandung. Visitors' primary objectives were diverse, with the majority seeking to observe crocodiles. Mangrove exploration and culinary experiences were also popular destinations. The average scores (1-5 scale) of visitors' impressions of the area's facilities, comfort, cleanliness, beauty, and accessibility are 3.18, 3.25, 3.28, 3.49, and 2.75 respectively. Visitor feedback plays a vital role in enhancing the management of the mangrove ecosystem, which serves as the main attraction in the study area. Additionally, it helps in the development of suitable facilities to ensure a better natural recreation experience.

*Bird habitat*

Bird inventory activities in the Blanakan mangrove area identified 23 unique bird species (Table 5). Egrets (*Egretta alba*), blekok (*Ardeola speciosa*), Javanese bondols (*Lonchura leucogastroides*), and swallows (*Collocalia vestita*) were observed in particularly high numbers. The study area yielded a species diversity index of 2.1 based on the analysis of bird species diversity using both the number of species and individual count.

*Implication for silvofishery management*

The research showcases the impressive capacity of silvofishery systems that have extensive mangrove coverage to offer a wide range of ecosystem services. Among these services, carbon storage is highlighted as a significant benefit. With an average value aboveground carbon of 137.9 tons carbon/hectare (tC/ha), the study area's mangroves exhibit a higher carbon storage capacity than other silvofishery areas, such as the one in Malang (Sugiatmo *et al*., 2023) and in Deli Serdang (Harefa *et al*., 2022). This finding emphasizes the noteworthy role of mangrove silvofishery in alleviating the impacts of climate change. In the Indonesian context, developing silvofishery possesses the potential to support the country's commitment to achieving a 31.89% reduction in carbon emissions by 2030 (without international aid). Indonesia has set a specific goal to achieve a net carbon sink by 2030, particularly within the forestry sector (MEF, 2022). The study findings indicate the necessity of incorporating silvofishery development into carbon projects, which could potentially attract financial assistance for the purpose of sustainable management. This study further emphasizes the vital importance of silvofishery-managed mangrove ecosystems in facilitating the production of fish and shrimp. The study area's economic output from fish and shrimp farming is slightly lower than that of the Ciasem silvofishery with a mangrove proportion of 50% (Sumarga *et al*., 2022) and surpasses the output of other mangrove-fish pond in the region with lower mangrove proportions (31%, and 19%) (Sumarga *et al*., 2022). This finding validates the effectiveness of silvofishery models that have a substantial mangrove cover (50-75%) in yielding abundant fish and shrimp production, while also guaranteeing adequate income for the local communities. A key factor contributing to this success is the absence of maintenance costs, particularly for fish feed, as sustenance is readily available through natural resources. The average net income of 1,513 USD/ha/year (equivalent to 252 USD/month, assuming a farmer manage 2 ha of silvofishery areas, is categorized as significantly high, exceeding the minimum wage standard of Subang District in 2023, which stands at 210 USD/month (WJPP, 2023). The natural tourism services provided by the study area's mangrove ecosystem are classified as moderate. This is reflected in the limited number of visitors and their moderate feedback to potential attractions, facilities, and accessibility. Nonetheless, the integration of eco-tourism and silvofishery practices in this region showcases a unique and pioneering approach that is seldom seen in other parts of Indonesia. Mangrove-based tourism in Indonesia is mostly developed in intact mangrove forests, including in protected areas (Azzahra *et al.,* 2023; Ewaldo *et al*., 2023). Identifying the ideal integration model is an ongoing challenge, and assessing the existing practices in silvofishery regions, like the study site, can play a crucial role in this pursuit. The presence of mangrove trees within the study area's silvofishery has attracted approximately 23 bird species, including two with significant rehabilitation value: the critically endangered Javan blue-banded Kingfisher (*Alcedo euryzona*) and the vulnerable Black-capped Kingfisher (*Halcyon pileata*) as classified by the IUCN Red List (BirdLife International, 2018; BirdLife International, 2022). The mangrove ecosystem in the study area exemplifies its remarkable ability to provide crucial habitat resources for a wide range of bird species, particularly in terms of food sources. While not identified as a primary driver of visitor motivation based on questionnaire results, the diverse presence of these birds has the potential to enhance the attractiveness of engaging in natural recreation within the area. Several initiatives can be implemented to leverage the presence of these birds, including the development of environmental interpretation programs (Walker and Moscardo, 2014; Xie *et al*., 2023) to provide appropriate information and educate visitors about the importance of bird diversity. These programs have the potential to offer valuable insights into the diverse range of bird species, their ecological contributions, and the pressing need for their conservation efforts. This study's exploration of four key ecosystem services reinforces the need to expand silvofishery development as a critical component of coastal conservation efforts. In coastal regions where the economy relies on fish farming, it is essential to focus on mangrove rehabilitation, giving priority to the silvofishery model, especially with a significant mangrove cover of 70-80%. The findings of this research showcase the possibility of attaining a harmonious ecosystem, where the ecological advantages of mangroves are maximized while ensuring sufficient economic benefits for the nearby communities. It is recommended that the Indonesian government agency, BRGM, focuses on promoting silvofishery as a primary approach for mangrove restoration. Additionally, close collaboration between BRGM and the local communities is essential for the success of this strategy. Research suggests that public participation in Indonesian mangrove rehabilitation efforts remains low (Listiana and Arianto, 2024). To ensure the successful implementation of large-scale mangrove silvofishery, it is crucial to actively engage with communities.

## CONCLUSIONS

This study analyzed ecosystem services provided by a mangrove restoration area utilizing the silvofishery model in Blanakan, Subang District, Indonesia. These services include carbon storage, fish production, nature tourism, and bird habitat. The mangrove stands in this area consist of two dominant species: *Avicennia marina* and *Rhizophora apiculata*. With optimal growth conditions, these stands are able to store significant amounts of carbon. The estimated carbon deposits above and below the surface are 137.9 tons/ha and 79 tons/ha, respectively. The silvofishery model offers local communities the opportunity to cultivate fish and shrimp within the mangrove ecosystem, generating an average annual income of approximately 1,513 USD per ha.

The Blanakan mangrove area serves as a natural recreation area, offering attractions such as the mangrove ecosystem itself and a crocodile breeding facility. Visitor numbers fluctuate, with an average of 128 individuals per month recorded in mid-2023. Notably, the area provides habitat for 23 bird species, with high abundances observed for egrets (*Egretta alba*), blekok (*Ardeola speciosa*), Javanese bondols (*Lonchura leucogastroides*), and swallows (*Collocalia vestita*). The results of this study provide important perspectives on mangrove conservation and restoration by promoting silvofishery development, which is crucial for combating mangrove degradation in Indonesia. To tackle the key challenge of silvofishery development in Indonesia – the limited understanding among coastal fish farming communities about the vital role of mangrove trees in successful aquaculture – prioritizing community engagement is crucial. Training programs should be offered to local communities to enhance their skills and capacity in implementing sustainable silvofishery practices. It is crucial to acknowledge and integrate the traditional ecological knowledge of local communities into the planning and operation of the silvofishery system. Along with enhancing productivity, training programs should cover effective business management and marketing techniques. This includes building relationships with nearby markets and regional markets is essential for selling fish products directly. Creating community-based groups can also strengthen these communities by allowing them to promote and sell their fish together, leading to improved negotiation power and increased prices. Enhancing the income-generating potential of the silvofishery system will contribute to improved livelihoods and the overall well-being of local communities. It is essential to conduct regular monitoring of a silvofishery-based mangrove rehabilitation program, with a specific focus on the well-being of both the mangrove and fishpond ecosystems. Any necessary adjustments to management practices should be made in order to maximize the effectiveness of the program.

## AUTHOR CONTRIBUTIONS

E. Sumarga wrote research proposal, supervised the research steps from designing sampling technique, collecting field data to analyzing the data, wrote the manuscript draft, reviewed and edited manuscript text. D. Rosleine co-supervised the research steps from designing sampling technique, collecting field data to analyzing the data. G.B. Hutajulu designed sampling technique, collected field data, analyzed and interpreted the data related to carbon storage. R.P. Plaurint designed sampling technique, collected field data, analyzed and interpreted the data related to bird diversity. Tsabita designed sampling technique, collected field data, analyzed and interpreted the data related nature recreation. M. Basyuni led the research proposal writing, reviewed the manuscript draft. S. Halimah wrote research proposal, reviewed the manuscript draft. M.F. Taqiyudin designed sampling technique, collected field data, analyzed and interpreted the data related to fish production. N.N. Shohihah interviewed visitors and pond farmers, analyzed and interpreted the social data. H.M. Ali reviewed the manuscript text.

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## CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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| ABBREVIATIONS | DEFINITION |
|---|---|
| *%* | Percent |
| *°C* | Degree Celsius |
| *BRGM* | Peat and Mangrove Restoration Agency |
| *cm* | Centimetre |
| *DBH* | Diameter at breast height |
| *ha* | Hectare |
| *m* | Meter |
| *mm* | Millimeter |
| *MEF* | Ministry of Environment and Forestry |
| *tC/ha* | tons carbon/hectare |
| *USD* | United States dollar |
| *WJPP* | West Java Province Portal |
| *y* | Year |

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