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BIODIVERSITY INVENTORY OF INDUSTRIAL MANGROVE CONSERVATION AREA AS NATURE-BASED SOLUTION IN IMPROVING OIL AND GAS INDUSTRIAL PERFORMANCE IN INDONESIA

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ABSTRACT

This study explores the role of biodiversity inventories in industrial mangrove conservation areas as Nature-based Solution (NbS) to enhance the performance in the oil and gas sector. Mangrove ecosystems provide numerous ecological benefits, including carbon sequestration and habitats for diverse flora and fauna. By conserving these ecosystems, the oil and gas industry can improve its environmental performance and support sustainable development goals. Our research involved a comprehensive biodiversity inventory of the Karangtalun Mangrove Area (KMA) and the application of GIS mapping to assess carbon sequestration and sedimentation. Result showed an average mangrove rehabilitation success rate of 70% demonstrating effective restoration efforts. Carbon sequestration was significant, with 1.142 tons of carbon stored in rehabilitated areas. Sedimentation analysis revealed notable depth change in planting locations, ranging from 3.9 to 5.86 meters, indicating varied sediment stability influenced by proximity to natural mangrove areas. Biodiversity had increased with the addition of species such as *Excoecariaagallocha*, *Hibiscus tiliaceus*, *Paspalum conjugatum*, and *Sporobolus pyramidalis*. The biodiversity index also improved across multiple taxa, including water birds (2.87), fish (2.64), and crabs (2.84), reflecting enhanced ecosystem health.These findings highlight the effectiveness of mangrove conservation as an NbS in boosting biodiversity and contributing to the oil and gas industry's operational efficiency and sustainability. Additionally, PT Pertamina Patra Niaga FT Lomanis'NbS program in mangrove management supports several SDGs, including SDGs 1 (No Poverty), 2 (Zero Hunger), 8 (Decent Work and Economic Growth), 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land). This study emphasizes the need for broader adoption of NbS in industrial sectors to ensure long-term environmental and economic benefits.

Keywords: Biodiversity inventory; Mangrove conservation; Nature-based Solutions (NbS); Carbon sequestration; Ecosystem restoration; Sustainable Development Goals (SDGs).

INTRODUCTION

The oil and gas industry plays a crucial role in meeting global energy needs. However, its presence significantly impacts biodiversity. From exploration to distribution, every activity within this industry has the potential to alter natural ecosystems and affect various species (Harfootet al., 2018). The development of the oil and gas industry in Indonesia has seen a consumption trend increase from 75.6 million kiloliters in 2019 to an estimated 80 million kiloliters by 2024 (KESDM, 2020). As the industry grows, its role becomes vital in sustainable development, including managing natural resources and preserving biodiversity. Biodiversity is crucial for economic development, as many business sectors depend on it (Katic et al., 2023). Plants, animals, and microorganisms contribute significantly to humans through ecosystem interactions and interdependencies, providing natural resources and regulating processes like nutrient cycles and water cycles (Millennium Ecosystem Assessment, 2005).

One of the crucial biodiversity elements is the mangrove ecosystem. Indonesia boasts the highest mangrove ecosystem diversity (Rahman et al., 2024), spread across 34 provinces (Basyuniet al., 2022). Indonesia's mangrove forests are the largest globally, comprising about 20% of the world's total mangrove population (Giri et al., 2011). Mangrove ecosystems play significant roles such as carbon sequestration (Song et al., 2023), serving as habitats for diverse biodiversity, minimizing erosion, and contributing significantly to the welfare of coastal communities (Das et al., 2022). Despite this, mangrove forests face a damage potential 3-5 times greater than regular forests (Duke et al., 2015). Currently, mangrove conservation is undertaken by various entities, including the government, non-governmental organizations, and private sectors (Basyuniet al., 2022). According to the World Economic Forum (2015), accelerated ecosystem degradation and biodiversity loss are among the top ten global risks. Biodiversity loss, both locally and globally, is driven by human activities such as habitat destruction, overexploitation, and pollution (Harfootet al., 2018). The World Wildlife Fund (2018) indicates that species extinction rates are now 1,000 to 10,000 times higher than natural rates. This raises questions about how companies address these issues and achieve sustainable natural resource and biodiversity management (Hambali and Adhariani, 2022), including in the oil and gas sector.

In essence, environmental management in the industrial sector is part of sustainable development andresponsibility to the companies, guided by the Sustainable Development Goals (SDGs). Nature-based Solutions (NbS) are powerful instruments for achieving SDGs, providing sustainable approaches by combining natural principles with human innovation to address various problems. NbS aims to synergize technology and the environment, leveraging natural resilience effectively (Choi et al., 2023). Efforts to ensure environmental protection have been ongoing for a long time, but Nature-based Solutions (NbS) have recently gained attention due to a

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rapid increase in research findings demonstrating nature's remarkable recovery capabilities and numerous benefits (Seddon et al., 2021). Given the multifunctionality of nature, NbS in mangrove ecosystem, not only reduce greenhouse gas emissions but also provide a wide range of benefits (Choi et al., 2023).NbS is advantageous because a single action can lead to multiple positive outcomes, reflecting the complexity and diverse functions of mangrove ecosystems.

This study aims to systematically document the species richness and ecological health of the Industrial Mangrove Conservation Area of PT Pertamina Patra Niaga Fuel Terminal Lomanis (FT Lomanis), an oil and gas company located in Cilacap, Indonesia. As part of the company's commitment to managing natural resources and biodiversity, Nature-based Solutions (NbS) are employed. By identifying and cataloging various flora and fauna species in this ecosystem, we aim to provide a comprehensive biodiversity inventory. This paper analyzes findings from the company's NbS program, offering an overview of the current state of biodiversity within the industrial mangrove conservation area. It also highlights how the NbS program contributes to increasing species diversity and improving ecological health. Furthermore, this study explores how mangrove ecosystem conservation can enhance operational performance for the oil and gas industry. These findings are expected to inform policy, guide industrial practices, and support efforts to balance economic development with environmental stewardship.

METHODOLOGY

Study Area

This study focused on the Industrial Mangrove Conservation Area or specifically in theKarangtalun Mangrove Area (KMA), a conservation area where the company is a collaborative partner. Located in Karangtalun Village, North Cilacap, Central Java, Indonesia. KMA is part of the Segara Anakan Mangrove Ecosystem, a nationally protected area. Due to its high biodiversity and the company's commitment to mangrove rehabilitation, KMA was selected as the study site. Situated at coordinates 109°01'10" E and 7°40'22" S, observations were conducted specifically within mangrove planting areas as part of the ongoing ecosystem restoration efforts (Fig. 1).

Field Data Collection

Field data collection focused on inventorying biodiversity and assessing mangrove ecosystem health within the Industrial Mangrove Conservation Area or KMA. The study specifically targeted mangrove species and associated fauna. A sampling method utilizing 20x20 m² quadrat plots was employed, with adjustments made to accommodate varying mangrove densities. Tree and shrub measurements were conducted within these quadrats using direct observation. Transect walks and Visual Encounter Surveys (VES) were utilized to record arboreal and aquatic fauna, with point counts and direct observations employed to note fauna presence. Photographic documentation captured ecosystem conditions and species encountered.

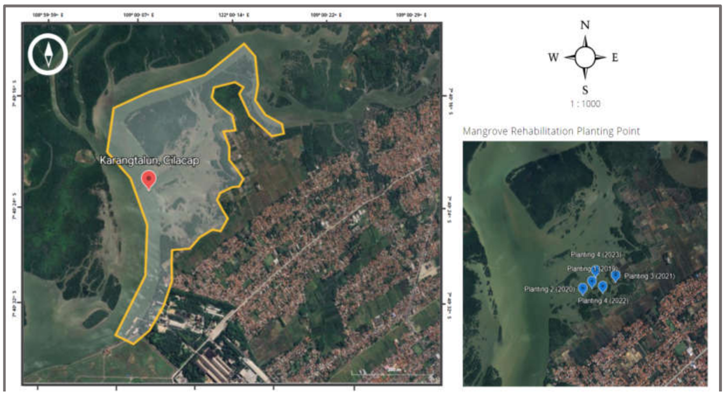

Fig. 1.Spatialrepresentation of the study area, with the Karangtalun Mangrove Area (KMA) prominently featured. The KMA, located in North Cilacap, is the epicenter of the company's mangrove restoration project initiated in 2019 under the NbS framework.

Data Analysis

Mangrove Density and Distribution Analysis

Mangrove density was calculated by comparing the number of surviving mangroves post-planting with the total observation plot area, then converting these results to density per hectare:

$$MangroveDensity(Ki) = \frac{\text{Number of Surviving Mangroves (ni)}}{\text{Plot Area (A)}} \quad (1)$$

Biodiversity Assessment and Conservation Status

Biodiversity for both mangroves and fauna in the KMA was assessed using the Shannon-Wiener diversity index, which quantifies species richness and evenness within a community. This index was calculated using the formula (Krebs, 1989):

$$H' = -\sum_{i}^{s}(PixlnPi) \quad (2)$$

where H' is the diversity index, Pi is the relative abundance of each species, ln is the natural logarithm, and S is species richness. Species were subsequently analyzed for conservation status based on the IUCN Red List.

Carbon Stock Estimation and Analysis

Carbon content was estimated using allometric equations based on Diameter at Breast Height (DBH) for various mangrove species, focusing on Above-Ground Biomass (AGB).

Table 1. Mangrove species and allometric formula for biomass content calculation

Species	Allometric formula	Reference
Avicennia marina	W_{top} = 0,308DBH$^{2.11}$ r^2=0,97 n=22 D_{max}=35 cm	Comley and McGuinness (2005)
Rhizophora apiculata	W_{top} = 0,235DBH$^{2.42}$ r^2=0,98 n=57 D_{max}=28 cm W_{silt} = 0,0209DBH$^{2.55}$	Ong et al. (2004)
	W_{agb} = 0,38363DBH$^{2.2348}$ r^2=0,976	Van Vinh et al. (2019)
	W_{top} = 0,268DBH$^{2.345}$ r^2=0,93 n=8	Kangkuso et al. (2018)
Rhizophora	W_{top} = 0,251ρDBH$^{2.46}$	Komiyama et al.

mucronata		(2005)
	W_{top} = 0,1709DBH$^{2.516}$	Putz and Chan (1986)
	W_{top} = 0,143DBH$^{2.52}$ r^2=0,97 n=8	Kangkuso et al. (2018)
Bruguieragymnorrhiza	W_{top} = 0,186DBH$^{2.31}$ r^2=0,99 n=17 D_{max}=25 cm	Clough and Scott (1989)

Following the calculation of AGB, carbon stocks in the planted mangrove were determined using equation (3),

$$Carbonstock = AGBxCarbonFraction \quad (3)$$

with species-specific carbon fractions (e.g., 47% for *Avicennia marina*and *Bruguieragymnorrhiza*, 39% for *Rhizophora* sp.)were used to calculate carbon stocks for each mangrove species. Finally, CO_2 equivalents were determined using the equation from Penman et al., (2006) in equation(4).

$$CO_{2-equivalent} = \left(\frac{44}{12}\right) xcarbonstock \quad (4)$$

Spatial Analysis and GIS Mapping

This study leverages GIS for the comprehensive management and analysis of geographic data, including bathymetry and elevation data. Bathymetry data, which measures water depths, and elevation data derived from Digital Elevation Models (DEMs) were utilized as secondary data sources. DEMs provide a digital representation of the Earth's surface topography, capturing elevation variations across different landforms.

Data Resampling and Interpolation

Toensure spatial resolution uniformity, the cubic convolution resampling method was applied, following the rules of equation (5). This technique calculates the intensity of new pixels by averaging the weighted values of neighboring pixels from the original image, using the cubic convolution function as weights.

$$l(x) = \sum_{n=\infty}^{\infty}\big(f(n).h(x-n)\big)(5)$$

This technique calculates the intensity of new pixels *I(x)* by averaging the weighted values of neighboring pixels from the original image *f(n)*, with weights determined by the cubic convolution function *h(x−n)*. This process enhances image resolution and clarity, enabling more precise spatial analyses within GIS.

Terrain Modeling

A 3D terrain slope model was generated using hill shading, a visualization technique that simulates sunlight based on azimuth and altitude. The azimuth was calculated using the equation (6) and (7):

$$A = 180 + \arctan\left[\frac{\tan(G)}{\sin(L)}\right] \quad (6)$$

$$Fg = G\frac{mM}{(R+h)^2}(7)$$

where A is the azimuth, G is the satellite longitude difference, m is the satellite mass, and h is the satellite altitude. The model provided valuable insights into spatial variations within the mangrove areas, aiding in the assessment of mangrove land suitability in relation to coastal geomorphological changes.

RESULT AND DISCUSSION

Nature-based Solutionon Karangtalun Mangrove Area

The mangrove conservation efforts at theKMA, managed by FT Lomanis, have yielded significant results. The biodiversity inventory serves as a baseline assessment to monitor the long-term sustainability of NbS program implemented over the past five years. The program encompassed mangrove planting, nursery establishment, habitat management, and long-term monitoring of flora and fauna. The integrated approach aligns with the company's commitment to sustainable development.

Table 2.FT Lomanis' planting program with various types of mangroves

Program	Year of Planting	Total	Types of Mangroves Planted
P1	2019	1.000	*Rhizophora mucronate* and*Bruguiera sp.*
P2	2020	5.000	*Rhizophora sp.*
P3	2021	8.000	*Rhizophora sp.*
P4	2022	8.000	*Rhizophora sp.*
P5	2023	10.000	*Rhizophora sp.* and *Avicennia sp.*

FT Lomanis' annual mangrove planting program in the KMA focuses on native species that are well-suited to local conditions, ensuring long-term sustainability (Table 2). Species selection prioritizes seedling availability, adaptability, and resilience to local environmental factors. By utilizing locally available seedlings, FT Lomanis reduces costs and efforts associated with seedling collection (Shaw et al., 2020) while minimizing the risk of introducing non-native species, which can have detrimental ecological consequences (Akram et al., 2023; Carlson et al., 2021).

The first planting (P1) in 2019 utilized *Rhizophora mucronata* and *Bruguiera* sp. seedlings, selected for their readiness and adaptability. Monitoring results indicated that *Rhizophor*a sp. had higher survival rates compared to *Bruguiera* sp., which struggled after planting due to environmental factors such as extreme tidal fluctuations and water deficiency (Usman et al., 2022). *Rhizophora* sp. proved to be more resilient and suitable for high tidal ranges, which supported its continued selection for subsequent plantings. From 2020 to 2022 (P2-P4), *Rhizophora* sp. remained the primary species used, owing to its success and resilience. In 2023, *Avicennia* sp. was introduced in planting phase 5 (P5) to enhance species diversity; its pneumatophore roots are well-suited for waterlogged conditions (Hao *et al.,* 2021; Inoue *et al.,* 2024).The conservation area is predominantly populated by *Rhizophora apiculata* and *Rhizophora mucronata*, which are well-adapted to coastal environments and contribute to ecosystem stability in the face of salinity and tidal changes (Rahman et al*.,* 2024). The pneumatophores of these species facilitate gas exchange in muddy soils, aiding in their growth and stability (Dasgupta et al., 2022). Integrating diverse species like *Bruguiera* sp. and *Avicennia* sp. helps enhance ecosystem resilience against environmental variations, which is crucial for sustaining mangrove biodiversity in the KMA (Surbaktiet al., 2023).

Mangrove density is an important indicator of the health and sustainability of mangrove ecosystems. Its annual measurement shows a consistent upward trend. In the first year, mangrove density was relatively low, but over time, mangrove density increased significantly. Post-rehabilitation mangrove density has increased, with planting success up to 50% each year (Table 3). This increase in mangrove density indicates that the rehabilitation program can create conditions that support healthy and sustainable mangrove growth. This indicates the success of the FT Lomanis' NbS program.

High mangrove density supports the provision of more habitat for various species. Complex root structures can serve to increase the survival of various species (Ainindya et al*.,* 2024). In addition, high mangrove density increases the production of leaf litter, which is a source of nutrients for organisms living in this area (Das et al., 2022), and serves to support a complex food web due to increased mangrove's organic matter (Soria-Barreto et al., 2023; Lee et al., 2023; Harefa et al., 2023; Harmonis et al., 2024; Henri et al., 2023).

Table 3. Annual mangrove density assessment

Program	Year	Species	Total Seedlings Planted	Planting Success (%)	Mangrove Density (ind/ha)
P1	2019	*Rhizophora mucronata* *Bruguiera*sp.	1000	60%	267
P2	2020	*Rhizophora* sp.	5250	60%	788
P3	2021	*Rhizophora* sp.	8000	70%	1400
P4	2022	*Rhizophora* sp.	8000	75%	1500
P5	2023	*Rhizophora* sp. *Avicennia* sp..	10000	80%	2000

Planting programs have significant potential to increase overall mangrove presence, with results evident in the diversity and presence of mangroves in the same area over different time periods. An inventory of mangrove presence was conducted annually over the past five years. These inventories show that the number and variety of mangrove species in the Karangtalun ecosystem has increased significantly and showing a positive development in species composition (Table 4).

Mangrove diversity in the KMA has significantly improved through ongoing rehabilitation efforts. In 2019, the area was dominated by planted species like *Rhizophora* spp., with low species diversity. However, by 2023, new species such as *Excoecariaagallocha*, *Hibiscus tiliaceus*, *Paspalum conjugatum*, and *Sporobolus pyramidalis*were introduced, reflecting ecological improvements and a more favorable environment for diverse flora.The NbS program has created stable,conducive conditions that have allowed naturally occurring mangrove species to return and thrive (Damastutiet al*.,* 2022). Enhanced habitat structure, soil stabilization, and improved microclimates have facilitated the reintroduction of these species, enriching KMA's biodiversity. The NbS program's significant positive impacts include expanding mangrove coverage and increasing species diversity, thereby supporting the ecosystem's long-term sustainability. This initiative not only strengthens the existing mangrove ecosystem but also contributes to biodiversity, providing tangible environmental and community benefits.

Tabel 4. Diversity, presence, and IUCN status ofmangrove species in the KMA

Species	Local Name	Presence Per-Year					IUCN Status
		2019	2020	2021	2022	2023	
Acanthus ebracteatus	Jeruju Putih		+	+	+	+	LC*
Acanthus ilicifolius	Jeruju Hitam		+	+	+	+	LC
Avicennia alba	Api-api Hitam	+	+	+	+	+	LC
Avicennia marina	Api-api Putih	+	+	+	+	+	LC
Avicennia officinalis	Api-apiKacang	+	+		+		LC
Bruguieragym norhiza	Tanjang Merah	+	+	+	+	+	LC
Ceriops tagal	Mentigi	+	+	+	+	+	LC
Excoecariaag allocha	Kayu Buta-buta		+	+		+	LC
Hibiscus tiliaceus	Waru Laut					+	LC
Nypafruticans	Nipah	+	+	+	+	+	LC
Paspalum conjugatum	Papaitan					+	LC
Rhizophora apiculata	Bakau Minyak	+	+	+	+	+	LC
Rhizophora mucronata	Bakau Kurap	+	+	+	+	+	LC
Sonneratia alba	Pidada Putih	+	+	+	+	+	LC
Sonneratiacas eolaris	Pidada Merah	+	+	+	+		LC
Sporobolus pyramidalis	Rumputekortikus raksasa					+	-

*LC, Least Concern (the species is not considered at risk of extinction due to its widespread and abundantpopulation, and it faces no significant threats that could endanger its survival in the near future)

NbS Impacts on Business Biodiversity Enhancement

Business biodiversity performance is crucial for long-term operational sustainability, encompassing environmental management and protection strategies. FT Lomanis demonstrates this through its NbS program in the Karangtalun Mangrove Area (KMA), a key indicator in assessing the company's biodiversity efforts. Over five years, this initiative has significantly increased biodiversity, particularly among mangrove species, and successfully restored degraded ecosystems (Arifantiet al*.,* 2022). The program not only enhances flora diversity but also plays a critical role in maintaining ecosystem balance and supporting complex food webs, crucial for the overall health and functionality of coastal ecosystems (Muro-Torres et al*.,* 2020). The resilience of the Karangtalun mangroves highlights the importance of such restoration efforts in sustaining biodiversity and promoting long-term conservation.

The rehabilitation efforts in the study area greatly enhanced mangrove diversity and density, effectively reversing degradation caused by logging and illegal harvesting. The resilient mangroves in Karangtalunare crucial for maintaining ecosystem balance and biodiversity, supporting sustainable conservation (Sudharakaet al*.,* 2023).The interaction of organic and mineral elements in mangrove soils, along with essential nutrients, is vital for vegetation growth and sustaining resources across trophic levels (Jimenez et al., 2021). Leaf litter production enriches sediments and supports complex food webs, benefiting microorganisms and higher trophic levels, which are essential for maintaining carbon stocks in mangroves (Mamidalaet al., 2023; Cahyaningsihet al., 2022). Overall, these rehabilitation efforts are key to the long-term health of coastal ecosystems.Mangrove ecosystems are critical for supporting biodiversity, providing shelter, nesting sites, and food for various species, including birds, fish, and crabs. The complex root structures and dense vegetation create rich environments for small fish, crustaceans, and invertebrates, which are primary food sources for birds. Waterbirds, as key indicators of mangrove health, benefit from improved conditions, such as increased food availability and suitable roosting sites, enhancing their populations and diversity (Oracion et al., 2022; Kurucz et al., 2021).

Our study identified a rise in bird populations within the KMA, particularly species reliant on mangroves for nesting and foraging, such as *Ardea alba*, *Centropusnigrorofus*, and *Charadrius javanicus* (Fig. 3), reflecting greater diversity and density (Fig. 4). Rehabilitated mangroves have become crucial spawning and nursery grounds, supporting fish populations by providing protection and stable conditions for larvae development (Wambrauw and Ilham, 2023). These efforts have enhanced aquatic habitats, boosting fish populations, species diversity, and adjacent water productivity by fostering phytoplankton growth, a key element in the aquatic food chain (Febrianti et al., 2023; Carlson et al., 2021). Mangrove ecosystems are closely tied to crustaceans, especially crabs, which are vital for nutrient cycling and soil aeration. Crabs play a key role in maintaining ecosystem health through their habitat use and bioturbation, which enhances soil aeration, nutrient cycling, and supports mangrove growth (Egawa et al., 2021). Their burrowing and feeding behaviors influence nutrient dynamics, particularly carbon and nitrogen cycles, contributing to organic matter decomposition and nutrient recycling. These processes are crucial for the resilience and health of mangrove ecosystems, ensuring nutrient availability and regulating greenhouse gases in coastal areas (Tongununui et al., 2021).The mangrove planting program in KMA highlights the positive impact of such initiatives on biodiversity, demonstrated by significant increases in waterbirds, fish, and crabs (Fig. 3), which reflect improved habitat quality and more balanced population distributions. FT Lomanis' NbS program enhances habitat quality, fostering the growth and diversity of fauna. This approach offers a valuable model for managing mangrove ecosystems, both in Indonesia and globally. Data from the NbS program show its beneficial effects on flora and fauna, enriching biodiversity and creating habitats for various arboreal and aquatic species (Fig. 4). The program also restores degraded ecosystems, supports local biodiversity, and boosts environmental resilience to climate change and human activities.

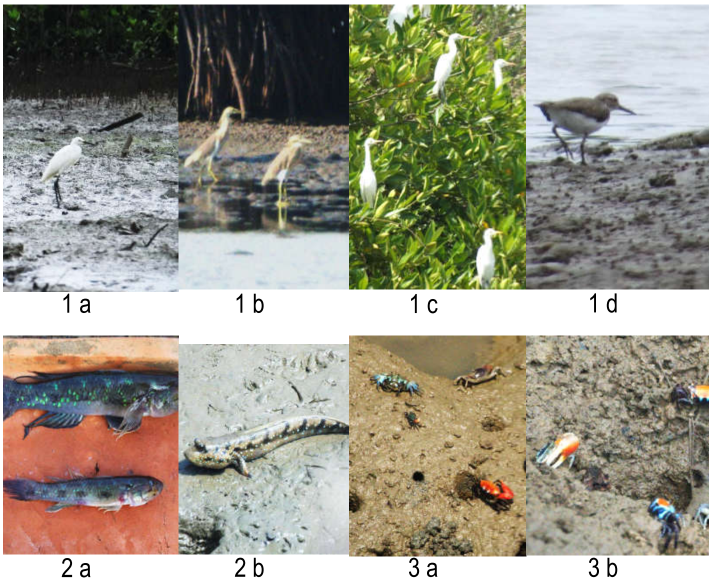

Fig. 2.Representativespecies of KMA's diverse fauna: (1a) *Egrettagarzetta*(1b) *Ardeola speciosa* (1c) *Lonchuramaja* (1d) *Bulbulcus ibis* (2a)*Periophtalmusbarbarus* (2b) *Acentrogobiuscyanomos* (3a) *Uca* sp. and (3b) *Episesarmalafondi*

Mangrove ecosystems are exceptionally productive and biodiverse, surpassing other coastal ecosystems in providing habitats for a variety of species, including reptiles, birds, fish, mammals, insects, and crustaceans, forming a complex ecological network (Zainal et al., 2021). Mangrove biota can be classified into arboreal fauna, which reside on vegetation, and aquatic fauna, which occupy water areas (Sari et al., 2022). The mangrove restoration program in Karangtalun has significantly improved habitats for local species like crabs, clams, shrimp, and fish, while also offering safer environments for endangered species such as small-clawed otters and long-tailed monkeys. Conservation efforts by FT Lomanis, through regular plantings and support for conservation groups, have successfully increased biodiversity, demonstrating an effective of NbS. This program has enhanced the biodiversity index, strengthened species diversity and populations, and created essential habitats for coastal fauna and flora.

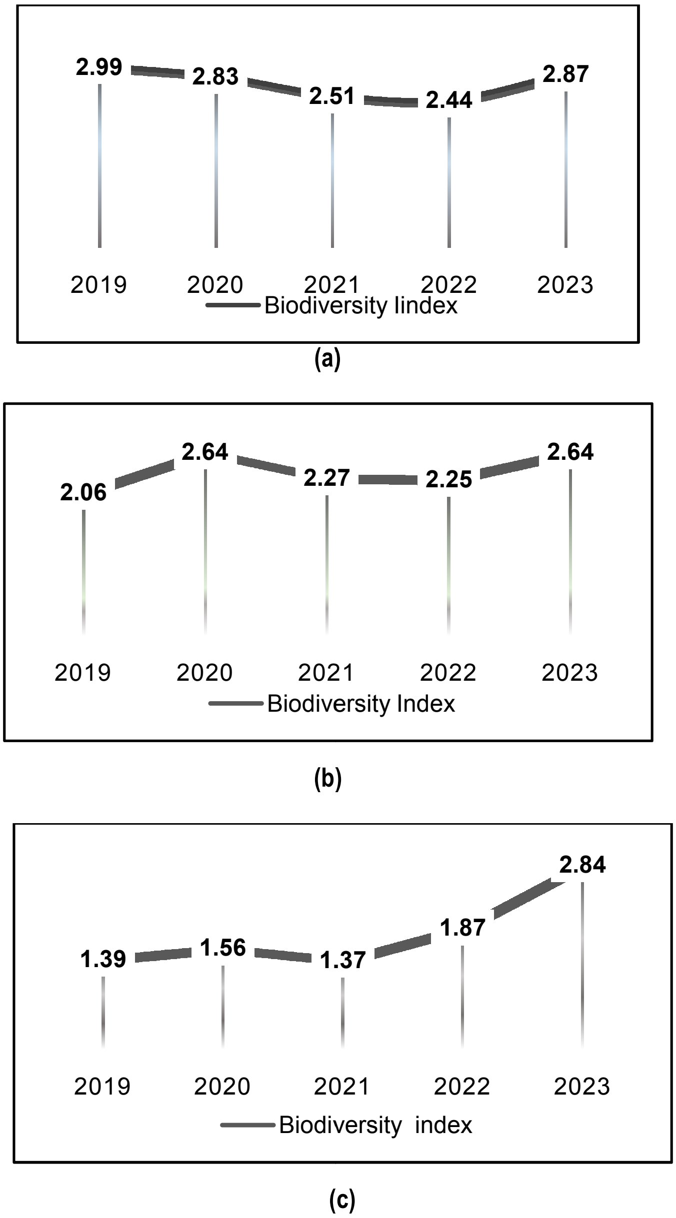

Fig. 3.Biodiversity index (Shannon-Wiener Index) of each category: (a) water birds, (b) fish, and (c) crabs

The mangrove restoration program has also impacted sediment characteristics, with bathymetry analysis showing changes in sediment depth and stability within the ecosystem. Evaluating sedimentation patterns is crucial for assessing the NbS program's success and sustainability. The KMA, managed by FT Lomanis, is located in a dynamic estuarine environment influenced by tides, high currents, and variable conditions leading to abrasion risks

(Largier, 2023). The area is prone to flooding during high tides, exacerbated by rising sea levels due to climate change (Ahmad et al., 2022). Sustainable management, including mangrove rehabilitation and conservation, offers ecosystem services like shoreline stabilization. Mangroves' intricate root systems reduce coastal erosion by trapping sediments and slowing water flow, addressing abrasion and flooding issues in the KMA. Changes in coastal geomorphology, driven by sedimentation processes, significantly impact mangrove planting efforts in Karangtalun. Understanding sedimentation is crucial for identifying spatial changes. Bathymetry analysis revealed stable sediments at the rehabilitation site (Fig. 5). Sedimentation characteristics affect soil texture, composition, and stability, which are essential for mangrove growth. Sediment accumulation shows patterns related to hydrodynamics, controlling organic and inorganic sediment supplies (Cinco-Castro et al., 2022). High sedimentation areas form new soil faster, impacting mangrove zonation and potentially causing planting failures. Selecting appropriate rehabilitation sites is essential for ecosystem sustainability and increased biodiversity.

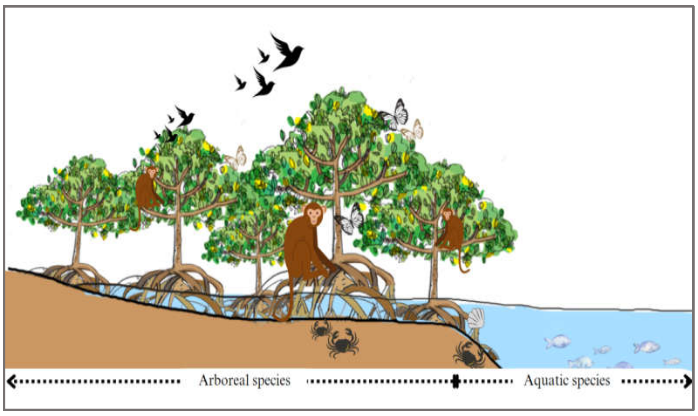

Fig. 4.Illustration of biodiversity pattern of Karangtalun Mangrove Area (KMA). Illustrate the intricate root system of mangrove trees supports a rich biodiversity, creating a unique ecosystem that transitions from land to sea.

Our findings on underwater surface characteristics (Fig. 5) reveal significant spatial changes, contributing to a better understanding of mangrove land suitability amid changing coastal geomorphology. This model helps assess the potential impacts of geomorphological changes on previous mangrove plantings. Evaluating geomorphology, especially sedimentation data, is crucial since mangroves closely interact with sedimentation processes, trapping sediments and promoting siltation in tidal coastal and estuarine environments. The depth change model in the mangrove planting area of FT Lomanis (Fig. 6), shows significant sedimentation over the past five years. Detailed comparisons of depth changes at five planting locations reveal substantial sedimentation. Planting location for P1 experienced a depth change of 5.86 m, and location for P2 had a similar change of 5.4 m in 2020. Planting location for P3 showed a smaller depth change of 3.9 m, likely due to its proximity to a natural mangrove area stabilizing sediment condition. Planting locations for P4 and P5 experienced depth changes of 5.54 m and 5.14 m, respectively.

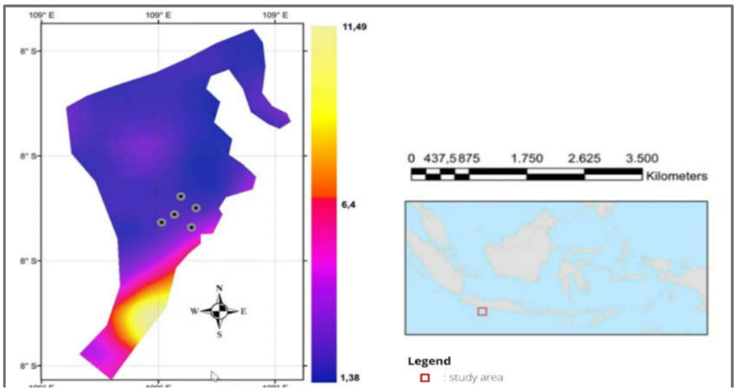

Fig. 5.Underwater surface map of KMA. Illustrates the underwater surface characteristics of the KMA, based on a detailed evaluation.

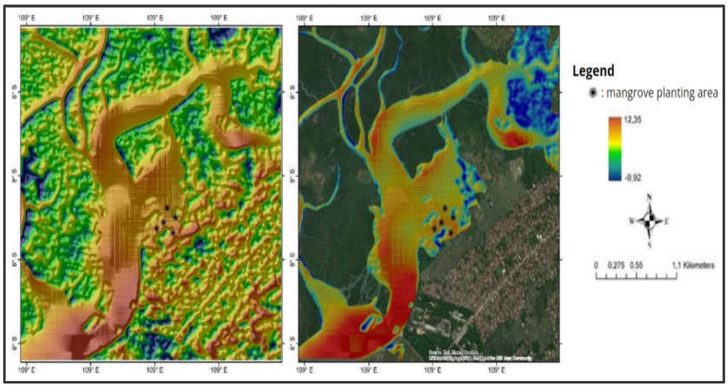

Fig. 6.Temporal changes in mangrove planting area depth. Depicts the changes in the depth of mangrove planting area over a specified time period.

The positive depth changes observed across all areas indicate significant sedimentation, sourced from the river estuary southwest of the planting site (Fig. 6). This sedimentation likely contributes to mangrove zoning changes, affecting rehabilitation outcomes. Planting location 3, closest to a natural mangrove forest, proves optimal due to lower sedimentation levels compared to other sites, benefiting from mangroves' role as natural flood mitigators (Menéndez et al., 2020). Conversely, sites with depth changes exceeding 5 meters facilitate zoning shifts that alter community structure, biodiversity, and mangrove geomorphology (Pratiwi et al., 2023). Mangroves' robust roots capture sediment and organic matter, stabilizing coastal soil and mitigating erosion by slowing water flow and promoting sediment buildup. This process, known as soil accretion, fortifies coastal areas like Karangtalun against flooding (Menéndez et al., 2020). Consequently, mangrove planting programs enhance sedimentation rates, supporting aquatic ecosystem balance, shoreline protection, and local biodiversity (Menéndez et al., 2020).

NbS Impacts on Business' Performance

The environment's role in business sustainability is a key focus for companies across various sectors. FT Lomanis has implemented a mangrove rehabilitation program as a NbS to enhance business sustainability. This program supports global nature goals and ecosystem services, improving biodiversity and environmental performance while strengthening business integrity. The mangrove rehabilitation program offers dual benefits for the environment and business sustainability.This study evaluates FT Lomanis' role in nature restoration by analyzing carbon sequestration from its NbS program. Mangroves, as highly efficient carbon sinks, absorb CO2 through photosynthesis and store it in biomass (Dinilhuda et al., 2020). Globally, mangrove ecosystems store approximately 1.023

tons of CO2e per hectare. In Indonesia, which holds 22.4% of the world's mangroves, the blue carbon stock absorption rate is 891.7 tons C/ha, with a total national blue carbon stock of 2.89 Tt C (Wahyudi et al., 2018; Haryati et al., 2024). This storage capability makes mangroves crucial for mitigating climate change by significantly reducing greenhouse gases. Mangroves store 3-5 times more carbon than terrestrial forests, securing carbon for centuries.

2019 to 2023, the mangrove rehabilitation success rate averaged 70% (Table 2), resulting in 1.142 tons of carbon sequestration, with the highest sequestration recorded in 2021 (Fig. 7). This demonstrates the effectiveness of mangroves in reducing atmospheric carbon and mitigating the greenhouse effect. Although the local impact may seem modest compared to global potential, these efforts highlight that local mangrove rehabilitation significantly contributes to climate change mitigation, consistent with studies showing high carbon storage in global mangrove ecosystems (Chatting et al., 2022). Heatmap and violin plot analyses reveal carbon stock distribution and fluctuation during the rehabilitation period. Using native mangrove species enhances carbon sequestration due to their better survival and adaptation to local conditions, leading to higher density and larger carbon stocks (Fig. 8). These findings underscore the critical role of mangrove rehabilitation in the NbS strategy for climate change mitigation and nature restoration. By increasing mangrove coverage and expanding rehabilitation areas, carbon sequestration is optimized. The significant potential of mangroves for carbon sequestration emphasizes their importance in global climate change mitigation efforts, making FT Lomanis' NbS program a key contributor to both coastal protection and global climate targets.

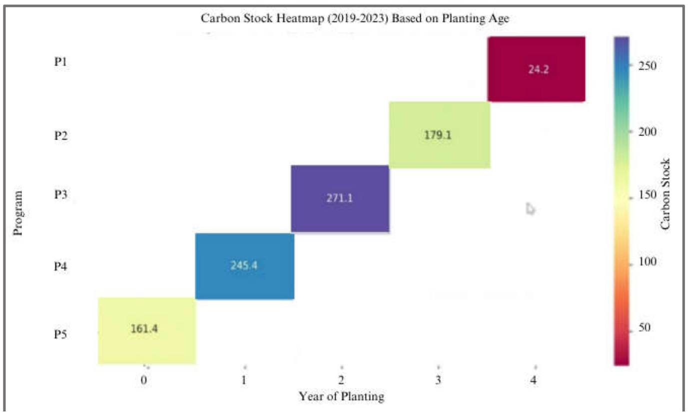

Fig. 7. Heatmap of carbon stock distribution in mangrove conservation areas from 2019 to 2023

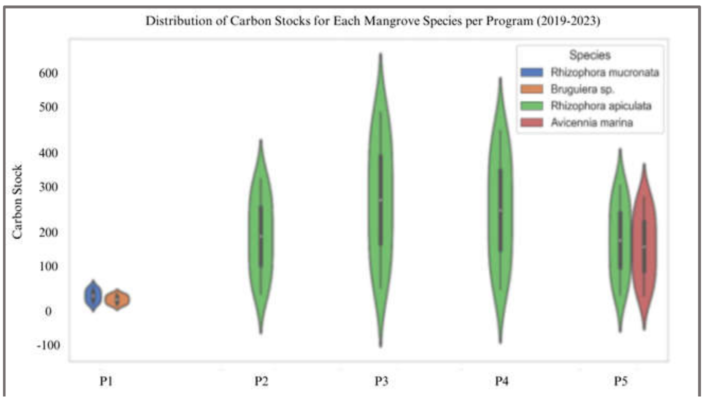

Fig. 8. Violin plot to show carbon stock variation over the study period

Future Biodiversity Strategies in Improving Business' Performance

The NbS program at KMA has significantly improved mangrove ecosystem health and biodiversity over the past five years, achieving a 70% rehabilitation success rate, stabilizing coastal land, and reducing erosion. Inventory data shows an increase in flora and fauna species, indicating significant ecosystem recovery. Healthy mangroves now support a diverse range of fauna, including water birds, fish, and crabs. For the oil and gas industry, the mangrove conservation area enhances environmental compliance and demonstrate a commitment to sustainability,contributing to both environmental and operational performance. The success of FT Lomanis' NbS program stabilizes mangrove environments, reduces infrastructure risk, and improves corporate reputation among environmentally conscious stakeholders. It also lowers mitigation costs and improves operational efficiency through ecosystem stabilization.

PT Pertamina Patra Niaga FT Lomanis' NbS program in mangrove management supports several SDGs, including SDGs 1 (No Poverty), 2 (Zero Hunger), 8 (Decent Work and Economic Growth), 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land) (Fig. 9). Activities such as rehabilitation, nursery provision, habitat management, and monitoring directly contribute to these goals (Fig. 10), positively impacting local communities by creating jobs and supporting the local economy.

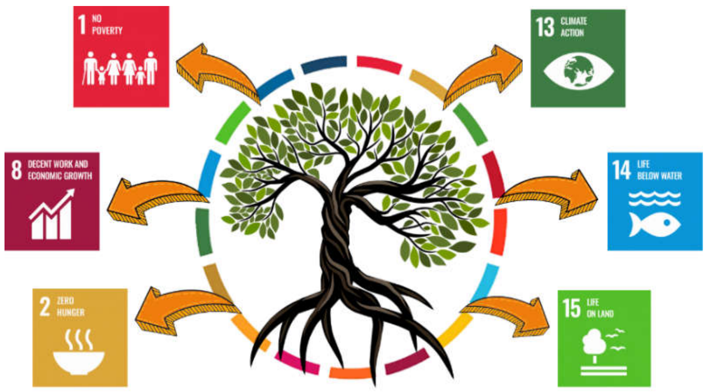

Fig. 9. PT Pertamina Patra Niaga FT LomanisNbS program contribution points towards Sustainable Development Goals (SDGs)

CONCLUSION

This study highlights the importance of Nature-based Solutions (NbS), particularly mangrove conservation, as a strategic asset in industrial operations. Integrating biodiversity conservation into oil and gas practices enhances operational efficiency and economic performance while supporting environmental preservation and community well-being. Mangrove conservation offers benefits like coastline stabilization, carbon sequestration, and environmental compliance, making it a valuable NbS. The findings underscore the need for broader NbS adoption in the industrial sector to balance economic growth with ecosystem sustainability and support SDGs. The study calls for further research to explore the practical implementation of these approaches across various industries and regions, assessing their long-term impact on both industry and the environment.

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REFERENCES

1. Ainindya DG, Khansa AR, Khotrotun NF, Muhammad FW, Chee KY, Ahmad DS. Characteristics of mangroves and carbon stocks estimation in Sampang and Pamekasan District, Madura Island, Indonesia. International Journal Bonorowo Wetlands. 2024; 14:19-25. DOI:10.13057/bonorowo/w140103.
2. Akram H, Hussain S, Mazumdar P, Chua KO, Butt TE, Harikrishna JA. Mangrove health: a review of functions, threats, and challenges associated with mangrove management practices. Forests. 2023; 14(9):1698. DOI: 10.3390/f14091698.
3. Ahmad A, Luqman M, Din M, Hassan A, Rasib A. A short review on causes of sea level rise for climate monitoring. Earth and Environmental Science. 2022; 1051(012003): (IOP Conference). DOI: 10.1088/1755-1315/1051/1/012003.
4. Arifanti.VB, Sidik F, Mulyanto B, Susilowati A., Wahyuni TSY, Yuniarti N, et al. Challenges and strategies for sustainable mangrove management in Indonesia: a review. Forests. 2022; 13(695). DOI: 10.3390/ f13050695.
5. Basyuni M, Sasmito S, Analuddin K, Ulqodry TZ, Saragi-Sasmito MF, Eddy S, et al. Mangrove biodiversity, conservation, and roles for livelihoods in Indonesia. Springer Nature. 2022; 397-445. DOI: 10.1007/978-981-19-0519-3_16.
6. Cahyaningsih AP, Deanova AK, Pristiawati CM, Ulumuddin YI, Kusumaningrum L, Setyawan AD. Review: causes and impacts of anthropogenic activities on mangrove deforestation and degradation in Indonesia. International Journal of Bonorowo Wetlands. 2022; 12(1): 12-22. DOI: 10.13057/bonorowo/w120102.
7. Carlson RR, Evans LJ, Foo SA, Grady BW, Li J, Seeley M, Xu Y, Asnes GP. Synergistic benefits of conserving land-sea ecosystems. Global Ecology and Conservation. 2021; 28 (1684). DOI: 10.1016/j.gecco.2021.e01684.
8. Chatting M, Al-Maslamani I, Walton M, Skov MW, Kennedy H, Husrevoglu YS, et al. Future mangrove carbon storage under climate change and deforestation. Frontiers in Marine Science. 2022; 9 (781876). DOI: 10.3389/fmars.2022.781876.
9. Choi E, Raehyun K, Jeongyeon C, A-Ram Y, Eunjo J, Ki Yong L. Analysis of nature-based solutions research trends and integrated means of implementation in climate change. Atmosphere. 2023; 14: 1-17. DOI: 10.3390/atmos14121775.
10. Cinco-Castro S, Jorge HS, Francisco C. Sedimentation as a support ecosystem service in different ecological types of mangroves. Frontiers in Forest and Global Change. 2022; 5: 1-14. DOI: 10.3389/ffgc.2022.733820.
11. Clough BF, Scott K. Allometric relationship for estimating above-ground biomass in 6 mangroves species. Forest Ecology and Management. 1989; 27(1): 117-127. DOI: 10.1016/0378-1127(89)90034-0.
12. Comley BWT, McGuinness KA. Above- and below-ground biomass, and allometry, of four common Northen Australian mangroves. Australian Journal of Botany. 2005; 53(5): 431-436. DOI: 10.1071/BT04162.
13. Damastuti E, de Groot R, Debrot AO, Silvius MJ. Effectiveness of community-based mangrove management for biodiversity conservation: A case study from Central Java, Indonesia. Trees, Forests and People. 2022; 7:100202. DOI: 10.1016/j.tfp.2022.100202.
14. Das SC, Pullaiah T, Ashton E. Mangroves: a unique ecosystem and its significance in mangrove: biodiversity, livelihoods and conservation. Biodiversity, Livelihoods and Conservation. 2022; 3-11. DOI: 10.1007/978-981-19-0519-3-1.
15. Dasgupta R, Hashimoto S, Saito O. Envisioning the future of mangroves through mapping and modeling of mangrove ecosystem services. Assessing, Mapping and Modelling of Mangrove Ecosystem Services in the Asia-Pacific Region. Science for Sustainable Societies. Springer. 2022. DOI: 10.1007/978-981-19-2738-6-1.
16. Dinilhuda A, Akbar AA, Jumiati, Herawati H. Potentials of mangrove ecosystem as storage of carbon for global warming mitigation. Biodiversitas. 2020; 21(11). DOI: 10.13057/biodiv/d211141.
17. Duke N, Nagelkerken I, Agardy T, Wells S, van Lavieren H. The importance of mangrove to people: a call to action. Report. Cambridge: United Nations Environment Programme World Conservation Monitoring (UNEP-WCMC); 2014.
18. Egawa R, Sharma S, Nadaoka K, MacKenzie RA. Burrow dynamics of crabs in subtropical estuarine mangrove forest. Estuarine, Coastal and Shelf Science. 2021; 252. DOI: 10.1016/j.ecss.2021.107244.
19. Febrianti AAP, Fauziyah, Agustriani F, Ningsih EN, Manik HM, Wijopriono, et al. The effect of phytoplankton abundance on zooplankton behavior during the day and night in the waters of the northern Peninsula of the Banyuasin Coast, South Sumatra. Earth and Environmental Science. 2023; 1137(012006); (IOP Conference). DOI: 10.1088/1755-1315/1137/1/012006.
20. Giri C, Ochieng E, Tieszen LL, Zhu A, Singh A, Loveland T, et al. Status and distribution of mangrove forest of the world using earth observation satellite data. Global Ecology and Biogeography. 2011; 20(1): 154-159. DOI: 10.1111/j/1466-8238.2010.00584.
21. Hambali A, Adhariani D. Biodiversity disclosure of Indonesian companies and the role of the board of commissioners. JurnalAkuntansi dan Keuangan Indonesia. 2022; 19(1): 1-23. DOI: 10.21002/jaki.2022.01.
22. Hao S, Su W, Li QQ. Adaptive roots of mangrove Avicennia marina: Structure and gene expressions analyses of pneumatophores. Science of The Total Environment. 2021; 757(143994). DOI: 10.1016/j.scitotenv.2020.143994.
23. Harefa MS, Rohim N, Pramuja I, Harahap PR, Agustin S, Siregar K, et al. Bio-ecological study on Aceh coast to determine mangrove ecosystem restoration areas suitability. Depik. 2023; 12(3): 361-372. DOI: 10.13170/depik.12.3.32211.
24. Harfoot MBJ, Tittensor DP, Knight S, Arnell AP, Blyth S, Brooks S, et al. Present and future biodiversity risks from fossil fuel exploitation. Conservation Letters. 2018; 11(4): 1-13. DOI 10.1111/conl.12448.

25. Harmonis, Haqiqi MT, Fahroni MFA, Jefry, Gunawan S, Sekedang MA, et al. Identification of the pest outbreak in the coastal mangrove ecosystem of Mahakam Delta, East Kalimantan, Indonesia. Biodiversitas.2024; 25: 829-835. DOI: 10.13057/biodiv/d250243.
26. Haryati A., Fikriyya N, Prihatiningsih I. Estimation of organic carbon stocks in the mangrove ecosystem in Mojo Village, Ulujami District, Pemalang. JurnalIlmu dan TeknologiKelautanTropis. 2024; 16(1): 75-88. DOI: 10.29244/jitkt.v16i1.51920.
27. Henri, Farhaby AM, Supratman O, Adi W, Febrianto S. Assessment of species diversity, biomass and carbon stock of mangrove forests on Belitung Island, Indonesia. Biodiversitas2023; 24. DOI: 10.13057/biodiv/d250103.
28. Inoue T, Kohzu A, Akaji Y, Miura S, Baba S. Diazotrophic nitrogen fixation through aerial roots occurs in Avicennia marina: implications for adaptation of mangrove plant growth to low-nitrogen tidal flats. New Phytologist. 2024; 241(4): 1464-1475. DOI: 10.1111/nph.19442.
29. Jimenez LCZ, Queiroz HM, Otero XL, Nóbrega GN, Ferreira TO. Soil organic matter responses to mangrove restoration: a replanting experience in Northeast Brazil. International Journal of Environmental Research and Public Helath. 2021; 18(17): 8981. DOI:10.3390/ijerph18178981.
30. Kangkuso A, Sharma S, Jamili J, Septiana A, Sahidin I, Rianse U, etal. Trends in allometric models and aboveground biomass of family Rhizophoraceae mangroves in the Coral Triangle ecoregion, Southeast Sulawesi, Indonesia. Journal of Sustainable Forestry. 2018; 37 (7): 691-711. DOI: 10.1080/10549811.2018.1453843.
31. Katic PG, Carretelli S, Haggar J, Santika T, Walsh C. Mainstreaming biodiversity in business decisions: taking stock of tools and gaps. Biological Conservation. 2023; 277: 1-20. DOI: 10.1016/j.biocon.2022.109831.
32. Kementerian Energi dan Sumber Daya Mineral. Pembangunan RDMP dan GRR terwujud, 2026 Indonesia takperluimpor BBM; 2020.Available:https://www.esdm.go.id/id/berita-unit/direktorat-jenderal-minyak-dan-gas-bumi/pembangunan-rdmp-dan-grr-terwujud-2026-indonesia-tak-perlu-impor-bbm.
33. Krebs CJ. Ecological Methodolgy. New York: Harper Collins Publishers; 1989
34. Kurucz K, Purger JJ, Batary P. Urbanization shapes bird communities and nest survival, but not their food quantity. Global Ecology and Conservation. 2021; 26: 1-13. DOI: 10.1016/j.gecco.2021.e01475.
35. Largier JL. Recognizing low-inflow estuaries as a common estuary paradigm. Estuaries and Coasts. 2023; 46: 1949–1970. DOI: 10.1007/s12237-023-01271-1.
36. Lee IO, Noh J, Kim B, Kwon I, Kim H, Kwon BO, et al. Food web dynamics in the mangrove ecosystem of the Pearl River Estuary surrounded by megacities. Marine pollution Bulletion. 2023; 189 (114747). DOI: 10.1016/j.marpolbul.2023.114747.
37. Mamidala HP, Ganguly D, Purvaja R, Singh G, Das S, Rao MN, et al. Interspecific variations in leaf litter decomposition and nutrient release from tropical mangroves. Journal of Environmental Management.2022; 382. DOI: 10.1016/j.jenvman.2022.116902.
38. Menéndez P, Losada IJ, Torres-Ortega S, Nayaran S, Beck MB. The global flood protection benefits of mangroves. Scientific Reports. 2020; 10: 1-11. DOI: 10.1038/s41598-020-61136-6.
39. Millenium Ecosystem Assessment. Ecosystem and human well-being: synthesis. washington, DC: Island Press; 2005.
40. Ong JE, Gong WK, Wong CH. Allometry and partitioning of the mangrove, Rhizophora apiculata. Forest Ecology and Management. 2024; 188(1): 395-408. DOI: 10.1016/j.foreco.2003.08.002.
41. Oracion JHM, Paalan R, Canja JDD, Sumondong KL. Community structure of resident and migratory bird species in Talabong Mangrove Forest, Bais City, Negros Oriental, Philippines. Philippine Journal of Science. 2022; 151(2). DOI: 10.56899/151.02.15.
42. Pratiwi D, Oktavia D, Sumiarsa D, Sunardi S. Influences of zonation on water fertility and structure communities of phytoplankton and benthos in Batukaras Mangrove Forest, Pangandaran District, Indonesia. Biodiversitas. 2023; 24: 4978-4988. DOI: 10.13057/biodiv/d240941.
43. Penman J, Gytarsky M, Hiraishi T, Irving W, Krug T. IPCC guidelines for national greenhouse gas inventories; 2006. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/0_Overview/V0_1_Overview.pdf.
44. Putz FE, Chan HT. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. Forest ecology and Management. 1986; 17(2-3): 211-230. DOI: 10.1016/0378-1127(86)90113-1.
45. Rahman, Lokollo FF, Manuputty GD, Hukubun RD, Krisye, Maryono, et al. A review on the biodiversity and conservation of mangrove ecosystems in Indonesia. Biodiversity and Conservation. 2024; 33: 875–903. DOI: 10.1007/s10531-023-02767-9.
46. Sari A, Tuwo A, Saru A, Rani C. Diversity of fauna species in the mangrove ecosystem of Youtefa Bay Tourism Park, Papua, Indonesia. Biodiversitas. 2022; 23. DOI: 10.13057/biodiv/d230915.
47. Seddon N, Smith A, Smith P, Key I, Chausson A, Girardin C, et al. Getting the message right on nature-based solutions to climate change. Global Change Biology. 2021; 27(8): 1518-1546. DOI: 10.1111/gcb.15513.
48. Shaw N, Barak RS, Campbell RE, Kirmer A, Pedrini S, Dixon K, Frischie S. Seed use in the field: Delivering seeds for restoration success. Restoration Ecology. 2020; 28(3): 276-285. DOI: 10.1111/rec.13210.
49. Song S, Ding Y, Li W, Meng Y, Zhou J, Gou R, et al. Mangrove reforestation provides greater blue carbon benefit than afforestation for mitigating global climate change. Nature Communications. 2023; 14(1): 756. DOI: 10.1038/s4-1467-023-36477-1.
50. Soria-Barreto M, Rosela PC, Zaldívar-Jimenez A., Fernandez RG. Assessment of aquatic food web and trophic niche as a measurement of recovery function in restored mangroves in the Southern Gulf of Mexico. PeerJ. 2023; 11(15422). DOI: 10.7717/peerj.15422
51. Sudharaka A, Rupasinghe A, Thilakarathne D, Chathuranga D, Weerakoon SN, Pabasara M, et al. Sesarmid crabs as key contributors to the soil organic carbon sedimentation in tropical mangroves. Wetlands Ecology and Management. 2023; 31: 757-773. DOI: 10.1007/s11273-023-09947-y.
52. Surbakti H, Nurjaya IW, Bengen DG, Prartono T. Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia. Biodiversitas. 2023; 24: 1502-1510. DOI: 10.13057/biodiv/d240320.
53. Tongunui P, Kuriya Y, Murata M, Sawada H, Araki M, Nomura M, et al. Mangrove crab intestine and habitat sediment microbiomes cooperatively work on carbon and nitrogen cycling. PLoS ONE. 2021; 16(12): e0261654. DOI: 10.1371/journal.pone.0261654.

54. Usman AHA, Hartoyo APP, Kusmana C. Use of Rhizophora apiculata and its cut-propagule seedling method for mangrove rehabilitation in Indonesia. Earth and Environmental Science. 2022; 1109(1): 012093: (IOP Conference). DOI: 10.1088/1755-1315/1109/1/012093.
55. Van Vinh T, Marchand C, Linh TVK, Vinh DD, Allenbach M. Allometric models to estimate above-ground biomass and carbon stocks in Rhizophora apiculata tropical managed mangrove forest (Southern Viet Nam). Forest Ecology and Management. 2018; 434: 131-141. DOI: 10.1016/j.foreco.2018.12.017.
56. Wahyudi AJ, Afdal NS, Adi NS, Rustam A, Hadiyanto, Rahmawati S, et al. Potensi Cadangan dan Serapan Karbon Ekosistem Mangrove dan Padang Lamun Indonesia. Jakarta: Pusat PenelitianOseanografi, Lembaga IlmuPengetahuan Indonesia (P2O-LIPI), Pusat Riset Kelautan, Badan Riset dan Sumber Daya Manusia, Kementerian Kelautan dan Perikanan (PUSRIKEL-BRSDMKKP), Pusat Penelitian Laut Dalam; 2018.
57. Wambrauw O, Ilham. Conditions and management strategies for mangrove ecosystems as an effort to improve the economy of youtefa bay coastal communities, Jayapura City. Formosa Journal of Science and Technology. 2023; 2: 1049-1062. DOI: 10.55927/fjstv2i4.3835.
58. World Economic Forum. Insight report: global risks 2015. 10th ed. Swiss; 2015. Available: https://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf
59. World Wildlife Fund. What is the sixth mass extinction and what can we do about it?; 2018. Available: https://www.worldwildlife.org/stories/what-is-the-sixth-mass-extinction-and-what-can-we-do-about-it
60. Zainal S, Febriawan A, Sabran M. Association of aquatic biota with mangrove plants in the land transfer area of Lino Tolongano Village, South Banawa District, Donggala Regency and as a media for public information. JurnalBiologiTropis. 2021; 21(3): 829–837. DOI: 10.29303/jbt.v21i3.2956.

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