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The Impact of Environmental Factors on Ecological Balance and the Bioactive Complexity of the Mangrove *Avicennia alba* in the Youtefa Bay Nature Tourism Area (YBNTA), Jayapura City

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ABSTRACT

The natural tourism area of Teluk Youtefa in Jayapura City is known for its mangrove forests, rich in biodiversity, particularly *Avicennia alba*. Mangroves serve as coastal buffers, pollutant filters, and habitats for various flora and fauna. However, climate change, pollution, and human activities can affect the ecological balance and bioactive compound content of *A. alba*, which has long been recognized as a potential source of medicinal and natural antioxidant compounds. Fluctuations in water quality, invasive species, and land-use changes may disrupt both the ecosystem and the complexity of its bioactive constituents. Understanding the impact of environmental factors on both aspects is crucial for effective and sustainable conservation. This study aims to explore the relationship between environmental factors and the production of bioactive compounds in mangroves. The research investigates how environmental changes influence the ecological balance and bioactive content of *A. alba*, and their implications for the sustainability of the Teluk Youtefa mangrove tourism area. Sampling was conducted using a purposive sampling method, focusing on environmental parameters such as temperature, salinity, pH, dissolved oxygen (DO), biological oxygen demand (BOD), and total suspended solids (TSS), along with laboratory analysis of bioactive compounds. The results show that the site with poor environmental quality (Site 1) recorded DO at 3.2 mg/L, BOD at 5.8 mg/L, and Pb at 0.07 mg/L. In contrast, the site with better environmental conditions (Site 3) showed DO at 5.5 mg/L, BOD at 2.1 mg/L, and salinity at 32.4 ppt. The bioactive compounds identified include Wagner's alkaloids, Dragendorff's alkaloids, flavonoids, terpenoids, saponins, and tannins. The polluted site (Site 1) yielded only three compounds—flavonoids, terpenoids, and saponins—whereas the conservation site (Site 3) revealed the full set of six bioactive compounds, including alkaloids and tannins. These findings indicate that environmental quality has a direct influence on the complexity of bioactive compounds and the ecological potential of mangrove ecosystems.

Key words: *Avicennia alba;* bioactive compounds; environment; mangrove

INTRODUCTION

The Youtefa Bay Nature Tourism Area (YBNTA) in Jayapura City is renowned for its rich mangrove forests, particularly the species *Avicennia alba* (Tuhumena *et al*., 2025). Mangroves play a crucial role as coastal environmental buffers, pollutant filters, and habitats for diverse flora and fauna (Naibaho *et al*., 2023). However, environmental changes such as climate change, pollution, and human activities threaten the ecological balance and bioactive complexity of these mangrove ecosystems (Sehol *et al*., 2023). The

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ecological stability of *A. alba* mangrove forests can be disrupted by fluctuations in water quality, invasive species, and land use changes (Kodhikara *et al*., 2023; Bhagarathi *et al*., 2024). Meanwhile, the bioactive complexity—referring to the diversity and potency of bioactive compounds within *A. alba* —may also be affected, influencing the overall ecosystem value and potential for natural resource utilization (Hussain *et al*., 2025). Therefore, understanding how environmental factors impact these two aspects in Youtefa Bay is essential for effective and sustainable conservation efforts.

Mangrove ecosystems, as unique coastal habitats, present intriguing biological and ecological complexities (Karim *et al*., 2023). Mangroves thrive in tidal zones with high salinity, exhibiting remarkable adaptations to harsh conditions such as elevated temperatures, tidal fluctuations, and muddy soils (So'o *et al*., 2024). The mangrove ecosystem in Youtefa Bay offers a distinctive environment for *A. alba* (Flassy *et al*., 2022), which endures extreme conditions including high temperatures, strong winds, tidal waters, high salinity, and anaerobic muddy soils (Bhagarathi *et al*., 2024). Globally, mangroves cover approximately 181,000 km² along coastlines in 121 countries and territories, representing nearly 25% of the world's coastline and making them a significant focus for ecological balance studies (Sawant, 2022). The diverse mangrove species provide habitats for various flora and fauna and deliver critical ecosystem services to humans, such as coastal protection from erosion and storms (Sihombing *et al*., 2024).

Avicennia alba, a vital mangrove species, typically grows in tidal zones with salinity levels ranging from 17 to 36.6 ppm. This group includes trees and shrubs belonging to various families, such as Avicenniaceae, Bombacaceae, Combretaceae, Maliaceae, Myrtaceae, Myrsinaceae, Pellicieraceae, Plumbaginaceae, Rhizophoraceae, Rubiaceae, and Sonneratiaceae. Mangroves are among the most ecologically diverse and productive wetland ecosystems globally, owing to the synthesis of numerous metabolites triggered by environmental stress (Kumar *et al*., 2014; Kumar & Pola, 2023).

Environmental factors like temperature, salinity, and soil quality play pivotal roles in shaping the bioactive complexity of mangroves. Previous research has shown that varying environmental conditions can lead to differences in the types and concentrations of bioactive compounds produced by mangrove species (Sanyal, 1983; Patra *et al*., 2011). Hence, comprehending the interactions between environmental variables and bioactive complexity is critical for understanding coastal ecosystem dynamics and optimizing their bioprospecting potential.

Recent studies have highlighted the phytoremediation potential of *A. alba* in mangrove forests. Juswardi *et al*. (2023) demonstrated the species' ability to remediate heavy metals like lead (Pb) and copper (Cu) in Jambi's mangrove areas through phytoremediation mechanisms including phytoextraction and phytostabilization. Additionally, Efriyeldi *et al.* (2023) found significant biomass and carbon storage potential in *A. alba* within a mangrove rehabilitation site in Kedaburapat Village, Riau. Their research identified a positive correlation between tree diameter and biomass/carbon storage, emphasizing the role of *A. alba* in climate change mitigation via carbon sequestration in mangrove ecosystems. Furthermore, Wintah *et al*. (2023) reported that mangrove species diversity, including *A. alba*, is strongly influenced by environmental conditions such as salinity, pH, and soil organic content in Kuala Bubon, West Aceh. This underscores the importance of understanding the relationships between environmental factors and mangrove community structure for sustainable coastal ecosystem management.

This study uniquely focuses on *A. alba* in Youtefa Bay, a conservation area in Papua that has been underrepresented in scientific research. The local ecosystem's distinctiveness and the region's specific environmental pressures provide a strong basis for this research to contribute meaningfully to the conservation of endemic mangrove ecosystem. The novelty of this work lies in its integrated approach, combining ecological balance and bioactive complexity—two aspects often studied separately—within a location-specific context. This integrated perspective aims to offer new insights into how environmental dynamics influence both the bioprospecting potential and the long-term sustainability of mangrove ecosystems. Moreover, the study is relevant to global challenges such as climate change, biodiversity conservation, and sustainable bioresource development, aligning with national and international environmental policies. Consequently, the findings from this research could serve as a scientific foundation for policymaking aimed at protecting coastal ecosystems in eastern Indonesia. The objective of this research was to understand how *A. alba* responds to environmental changes and to explore its relationship with the complexity of bioactive compounds.

MATERIALS AND METHODS

This study was conducted at the Youtefa Bay Nature Tourism Park in Jayapura City. The mangrove species *A. alba* in this area was selected as the research subject using a purposive sampling approach. Purposive sampling is a selective, judgment-based sampling technique that relies on the researcher's assessment to choose sampling units (Azzahra *et al*., 2020; Firmansyah & Dede, 2022). Sampling sites representing the entire study area were carefully chosen to ensure comprehensive coverage. The study focused on Bioindicator Analysis and Laboratory Analysis, with *A. alba* serving as a biological indicator to assess the sustainability of the mangrove ecosystem and the impacts of environmental changes (Suriadi *et al*., 2024).

Research on the environmental impact on the ecological balance and bioactive compound complexity of *A. alba* mangroves can be conducted through several stages:

Field Survey

The initial stage involves a field survey that includes direct observation within the *A. alba* mangrove area. During this phase, data on the distribution and abundance of mangrove populations are collected. The purpose of the survey is to obtain a general overview of the spatial distribution and population density of mangroves at the study site, which will serve as a

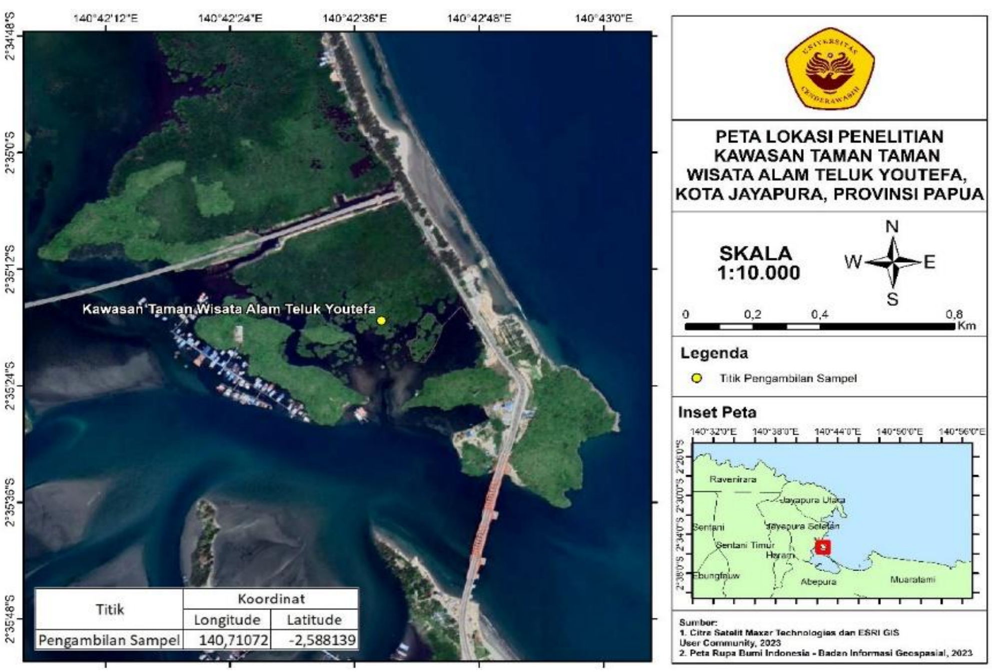

Figure 1. Map of the research location.

foundation for further analysis (Wulandari *et al*., 2023; Wijaya & Santojo, 2024).

Mangrove sample collection for laboratory testing

This stage involves collecting samples of *A. alba* mangrove plants from the survey locations for further laboratory analysis. The purpose of sampling is to evaluate the quality of the mangrove plants, their bioactive compound content, and other relevant factors through laboratory testing (Poncowati *et al*., 2022; Akasia *et al*., 2021).

Laboratory test

Samples collected from the previous stage will be tested for various parameters, including water quality analysis, soil analysis, physicochemical environmental parameters, and bioactive compound assays (Feng *et al*., 2024; Glevitzky *et al*., 2025).

Integration of field survey and laboratory test data

After collecting data from the field survey and laboratory tests, this stage involves combining and integrating the datasets. The analysis focuses on the relationship between the distribution and abundance of mangroves and the laboratory results to understand how environmental factors influence the ecological condition and bioactive complexity of the mangrove ecosystem (Segaran *et al*., 2023; Cid-Alvarado *et al*., 2024).

Figure 2. Sample of *A. alba.*

Figure 3. Laboratory testing process.

Data Analysis

This stage involves the integration of data and identification of patterns from field surveys and laboratory analyses of samples to understand the response of *A. alba* to environmental changes.

RESULT AND DISCUSSION

Environmental characteristics of the mangrove ecosystem in YBNTA

Environmental parameter measurements were conducted at three different locations, each representing varying levels of human activity (Table 1). Environmental parameters were measured at three distinct sites, selected based on varying degrees of human activity: Site 1 (adjacent to settlements and a harbor), Site 2 (a transitional zone with moderate activity), and Site 3 (a conservation area with no direct human interference). This sampling design aims to assess how differences in environmental quality influence the ecological condition of the *A. alba* mangrove ecosystem.

Temperature

Temperature across the three sites remained relatively stable, ranging from 29.1 - 30.4°C. These fluctuations are within the tolerance range for mangroves; however, the higher temperature observed at Site 1 is likely influenced by domestic wastewater runoff and human activities that contribute to elevated microclimate temperatures. Increased temperature can also accelerate the decomposition of organic matter, thereby raising the demand for dissolved oxygen (DO) in the water.

Salinity

Salinity levels across the study sites ranged from 26.7 ppt at Site 1 to 32.4 ppt at Site 3. The lowest salinity at Site 1 suggests dilution of seawater by freshwater inflow or domestic wastewater. In contrast, Site 3—located far from human activity—exhibited a more natural and stable salinity level, ideal for the growth of *A. alba*, which requires high salinity conditions to maintain normal metabolic functions.

pH

The pH values across all sites varied from 6.8 to 7.4, remaining within a neutral range. However, Site 1 showed a slightly more acidic condition, likely due to the decomposition of organic material from household waste and port-related activities. Lower pH levels can affect the enzymatic activity of mangrove plants and soil microorganisms.

Dissolved oxygen (DO)

Dissolved oxygen levels varied significantly, with the lowest recorded at Site 1 (3.2 mg/L) and the highest at Site 3 (5.5 mg/L). The low DO at Site 1 indicates high organic pollution, which increases microbial oxygen consumption during decomposition. In contrast, the higher DO levels at Site 3 provide better support for aquatic life and photosynthetic processes in mangrove ecosystems.

Biological oxygen demand (BOD)

The highest BOD level was recorded at Site 1 (5.8 mg/L), while the lowest was at Site 3 (2.1 mg/L). High BOD indicates a large amount of organic matter that requires decomposition by microorganisms, which in turn depletes dissolved oxygen in the water. This reflects significant pollution pressure at Site 1, likely due to domestic wastewater discharge and maritime activities.

Total suspended solids (TSS)

TSS values followed a similar trend to BOD. Site 1 recorded the highest TSS level (45 mg/L), indicating a high load of suspended particles such as silt, organic waste, and detritus. Elevated TSS levels can reduce light penetration, hinder photosynthesis, and negatively affect mangrove growth and aquatic organisms.

Lead (Pb)

Heavy metal contamination, particularly lead (Pb), also varied considerably across sites, with the highest concentration at Site 1 (0.07 mg/L) and the lowest at Site 3 (0.01 mg/L). The elevated Pb levels at Site 1 suggest contamination from marine transportation and small-scale industrial activities. Lead is a toxic metal that can impair physiological processes in mangroves and aquatic fauna.

These data indicate that Site 1 has significantly poorer environmental quality compared to Site 3, which serves as a conservation zone. Pollutants such as BOD, TSS, and Pb are prevalent in high human-activity areas, while parameters like DO and salinity are more stable and healthier in the conservation zone. This disparity influences the ecological balance and the production of bioactive compounds in *A. alba*, which will be further elaborated in the discussion section.

Mangrove ecosystem of Youtefa Bay

Youtefa Bay in Papua hosts an extensive mangrove ecosystem, playing a vital role in maintaining environmental balance. Mangroves protect shorelines from erosion, serve as habitats for diverse flora and fauna, and provide numerous ecosystem services such as supporting fisheries, supplying raw materials, sequestering carbon, protecting coastlines, purifying water, serving as breeding grounds, and offering nature-based recreation (Qudenhoven *et al*., 2015). However, the mangrove ecosystems in Youtefa Bay are increasingly affected by various environmental stressors, including climate change, human activities, sedimentation, water quality degradation, and land-use changes. Studies have shown that both the quality and quantity of mangroves in the region have declined over the years (Hamuna *et al*., 2018).

Global climate change has significantly impacted mangrove ecosystems. Rising temperatures and sea level pose serious threats to their survival. Sea level rise may lead to saltwater intrusion further inland, potentially harming mangrove species that are sensitive to excessive salinity.

Human activities such as land clearing, settlement development, and deforestation for fuel or infrastructure often lead to the degradation of mangrove ecosystems. In Youtefa Bay, the expansion of coastal settlements poses a serious threat to the preservation of mangrove forests. Pollution from domestic and industrial waste further intensifies the pressure on these ecosystems. Additionally, sedimentation in Youtefa Bay's waters—often resulting from upstream erosion—can bury mangrove root systems, block water flow, and hinder nutrient and oxygen absorption. Such conditions diminish the productivity of the ecosystem and reduce biodiversity.

Water pollution, caused by both chemical and organic waste, can damage the soil structure around mangroves, impair plant growth, and harm wildlife that depends on this habitat. The decline in water quality can also result in mass die-offs of mangrove vegetation. Land-use changes, such as converting mangrove forests into agricultural or aquaculture zones, have further contributed to ecosystem degradation. Shrinking mangrove areas weaken their ecological functions—such as carbon sequestration, pollutant filtration, and providing shelter for fish and wildlife. When mangrove ecosystems lose these essential roles, ecological imbalances arise—for instance, the loss of spawning grounds disrupts the life cycles of aquatic organisms and diminishes the resources available to humans (Witomo, 2018).

In 1994, the mangrove area in Youtefa Bay, Jayapura, covered approximately 392.45 hectares. By 2017, this area had shrunk to 233.12 hectares—a reduction of 159.34 hectares or about 40.59% over 23 years. This decline is largely attributed to anthropogenic factors such as logging, conversion of mangrove areas for roads, bridges, and settlements, as well as natural environmental changes (Hamuna *et al*., 2018).

The role of *A. alba* mangroves in maintaining ecological balance

Avicennia alba plays a vital role in maintaining ecological balance in coastal areas. This mangrove species serves not only as a natural barrier against coastal abrasion but also functions as an effective carbon sink. Its extensive and robust root system stabilizes coastal soils and helps prevent erosion caused by tides and wave action, acting as a natural buffer that protects shorelines from degradation.

Moreover, *A. alba* provides essential habitat for various fauna, including fish, crustaceans, and birds. The ecosystem supports breeding, foraging, and sheltering activities, thereby contributing to high biodiversity. Among mangrove species, Avicennia alba is one of the most widespread and is known for its effectiveness in mitigating pollution within mangrove forests (Bana *et al*., 2019).

This species is also recognized for its high carbon sequestration capacity. Through photosynthesis, *A. alba* reduces atmospheric greenhouse gases, making it a significant player in climate change mitigation. Additionally, mangroves serve as natural biofilters. They trap pollutants such as heavy metals and harmful chemicals, particularly through their roots. The complex root systems of Avicennia alba are capable of absorbing heavy metals, effectively reducing contamination in coastal waters (Rachmawati *et al*., 2018).

By trapping sediments and filtering pollutants before they enter marine ecosystems, *A. alba* helps maintain water quality. Furthermore, its leaf litter contributes to nutrient cycling, supporting the productivity of nearby marine ecosystems. These nutrients feed primary producers like plankton, which form the base of the marine food web and sustain a wide array of aquatic life.

Bioactive complexity of *A. alba* mangrove

Mangrove plants thrive in coastal ecosystems and have significant potential across various sectors due to their rich content of bioactive compounds. *A. alba*, one of the dominant mangrove species, is known for its high bioactive potential. This species is well-adapted to harsh environmental conditions such as high salinity and muddy substrates. Beyond its ecological importance in maintaining coastal ecosystem balance, *A. alba* has drawn scientific attention due to its diverse bioactive compounds, including flavonoids, tannins, and alkaloids, which have demonstrated antioxidant, antibacterial, anti-inflammatory, and anticancer properties.

The bioactive compounds of *A. alba* have been evaluated through laboratory testing. These tests aim to assess the plant's biochemical potential and its ecological responses to environmental stress in the mangrove ecosystem of Youtefa Bay. The results of the laboratory analysis of *A. alba* bioactive compounds are presented in Table 2.

Bioactive compound testing on *A. alba* leaves

The bioactive compound analysis of *A. alba* leaves collected from three different sites revealed significant variation among locations, particularly in alkaloid content. This suggests that environmental quality strongly influences the plant's ability to synthesize secondary metabolites.

Alkaloids (Wagner and Dragendorff Tests)

Alkaloids are nitrogen-containing organic compounds known for their broad biological activities, including antimicrobial and anticancer properties. The test results showed that both Wagner and Dragendorff-type alkaloids were detected only at Site 3 (the conservation zone), while no alkaloids were found at Site 1 or Site 2. The presence of these alkaloids at the site with the best environmental quality suggests that stable, low-pollution conditions support the biosynthesis of complex secondary compounds.

This finding aligns with environmental parameters at Site 3, such as higher dissolved oxygen (5.5 mg/L) and lower lead levels (0.01 mg/L), which are more favorable for physiological processes and secondary metabolite production. In contrast, the absence of alkaloids at Sites 1 and 2 likely reflects metabolic inhibition caused by environmental stressors, including elevated biological oxygen demand (5.8 mg/L) and lead contamination (0.07 mg/L), which may interfere with enzymatic pathways involved in alkaloid synthesis.

Flavonoids, terpenoids, saponins, and tannins

Flavonoids, terpenoids, saponins, and tannins were detected across all sampling locations, including areas impacted by human activity and the conservation zone. This suggests that these compounds are relatively common secondary

Table 1. Characteristics of Environmental Parameters at YBNTA in Jayapura City, Papua

Parameters	Point 1 (Near Settlement)	Point 2 (Tourist zone)	Point 3 (Conservation zone)	Quality Standards (PP No. 22/2021)
Temperature (°C)	30.2	29.5	28.7	28–32
Salinity (ppt)	28.5	30.1	32.4	28–34
pH	6.7	7.1	7.4	6.5–8.5
DO (mg/L)	3.2	4.1	5.5	≥ 5
BOD (mg/L)	5.8	4.3	2.1	≤ 2
TSS (mg/L)	45.0	30.0	18.0	≤ 30
Pb (mg/L)	0.07	0.04	0.01	≤ 0.03

Description: *Site 1:* reflects a more polluted environment, with BOD and Pb levels exceeding environmental quality standards. *Site 3* demonstrates the best water quality, meeting standard thresholds.

Table 2. Test results for the content of bioactive compounds in *A. alba*.

No.	Senyawa bioaktif	Point 1	Point 2	Point 3
1.	Alkaloids Wagner	None	None	Available
2.	Alkaloids Dragendroff	None	None	Available
3.	Flavonoid	Ada	Ada	Present
4.	Steroids	None	None	None
5.	Terpenoids	Present	Present	Present
6.	Saponins	Present	Present	Present
7.	Tannins	Present	Present	Present

metabolites and that *A. alba* can still produce them even in suboptimal environments.

- *Flavonoids* are known for their strong antioxidant activity. Their consistent presence across all sites indicates that the plant maintains its defense against oxidative stress, regardless of varying environmental pressures.
- *Terpenoids*, volatile compounds involved in defense against pathogens and environmental adaptation, were also found at all sites, supporting their role in basic plant resilience.
- *Saponins and tannins* function as natural defenses against microbes and herbivores. Their widespread presence suggests that *A. alba* maintains essential protective systems across different environmental conditions.

However, it is likely that the complexity and concentration of these compounds are higher at Site 3 (the conservation zone), and further chromatographic or spectrometric analyses could confirm this.

Steroids

Interestingly, steroid compounds were not detected at any site. This absence may be due to the limitations of the detection method or the naturally low levels of steroids under current environmental conditions. Steroid production is often associated with specific tissues or environmental triggers that may not be present at the sampling sites.

These results highlight that environmental quality affects the presence of certain bioactive compounds, especially alkaloids. More complex and pharmacologically valuable compounds like alkaloids appear to be optimally produced only in stable, low-pollution environments. Therefore, maintaining environmental quality in Teluk Youtefa is vital not only for preserving mangrove ecosystems but also for sustaining their bioactive potential as a resource for pharmaceuticals and local bioeconomy development.

Based on Table 2, it is evident that *A. alba* in Teluk Youtefa contains several bioactive compounds. Site 3, the conservation area with better environmental conditions, exhibited a wider variety of bioactive compounds, including Wagner and Dragendorff alkaloids, flavonoids, terpenoids, saponins, and tannins. Only steroids were absent across all samples. Similar findings have been reported by Das (2020), who noted the presence of alkaloids, phenolics, flavonoids, tannins, diterpenes, triterpenes, sterols, saponins, and carbohydrates in *A. alba*, though lacking glycosides, proteins, and reducing sugars. Mitra *et al*. (2022) also confirmed that the phytochemicals in *A. alba* serve vital physiological and stress-related functions, with high levels of carbohydrates, tannins, alkaloids, flavonoids, terpenoids, steroids, and phenolic compounds.

These compounds offer substantial environmental and medicinal benefits. As secondary metabolites, they help plants adapt and survive in stressful environments. Alkaloids act as toxins against insects and herbivores, regulate plant growth, and serve as nitrogen reserves (Wink, 2008). Flavonoids function as antioxidants and protect plants from environmental damage and pathogens while contributing to color, taste, and aroma (Mierziak *et al*., 2014). Terpenoids support defense against herbivores and microbes, attract pollinators, and promote symbiosis with soil microbes. They also act as phytoalexins—antimicrobial compounds produced in response to stress (Singh & Sharma, 2015; Li *et al*., 2015).

Saponins have diverse industrial uses: in aquaculture (as shrimp pest control), textiles (as eco-friendly detergents), and cosmetics (as foaming agents in shampoos) (Putri *et al*., 2023). Tannins, widespread in the plant kingdom, help protect against predation and regulate growth (Das *et al*., 2020).

In the health sector, alkaloids have effects on the nervous system, blood pressure, and antimicrobial resistance (Widi & Indriati, 2007). Flavonoids prevent lipid peroxidation, protect tissues from oxidative damage, and inhibit harmful enzymes (Latifah, 2015). Terpenoids disrupt bacterial nutrient channels, hindering growth or causing cell death (Suhendar & Fathurrahman, 2019). Saponins demonstrate potential against leukemia, paralysis, asthma, inflammation, and rheumatism (Purnobasuki, 2005). Tannins possess astringent, antibacterial, antidiarrheal, and antioxidant properties (Malangngi, 2012).

Extracts from *A. alba* leaves, stems, and roots have been tested against various pathogens. This species is traditionally used to treat serious health issues (Mitra *et al*., 2022), including HIV, cancer, hepatitis, diarrhea, diabetes, inflammation, and oxidative stress. Its resin has applications in childbirth, abscess treatment, skin disease, and tumor management (Pambudi & Haryanto, 2022).

Impact of human activities on the mangrove environment in Teluk Youtefa

Human activities in Teluk Youtefa have had a significant impact on the mangrove ecosystem. Rapid infrastructure development—including roads, bridges, and settlements—has led to the conversion of mangrove areas into built-up zones. This land-use change has reduced the extent of mangrove forests, which play a crucial role in coastal protection and serve as vital habitats for various species. Unsustainable activities such as mining and overfishing have also contributed to ecosystem degradation by damaging mangrove root systems and increasing sedimentation, which inhibits mangrove growth.

In Teluk Youtefa, approximately 984 hectares of mangrove forests have experienced escalating degradation each year. The primary drivers of this damage include the conversion of mangrove forests into shrimp ponds, industrial zones, and coastal settlements—particularly in the Entrop area. This land degradation is further exacerbated by pollution from residential areas in Jayapura City, which drains into nearby rivers including the Ampera River, Entrop River, and Acay Stream (Paulangan, 2014).

The mangrove ecosystem within the TYNTA, which is located near urban areas, is directly affected by various anthropogenic activities. The exploitation of mangrove wood for fuel, construction materials, and other uses has led to a decline in ecosystem quality. Additionally, land reclamation for aquaculture, housing, and industry—along with rising pollution and sedimentation from urban runoff—has further stressed the ecosystem. Waste from domestic and industrial sources discharged into mangrove waters contributes to environmental pollution, reducing water quality and negatively affecting mangrove health.

These impacts have resulted in decreased biodiversity and ecosystem productivity, thereby disrupting ecological balance in the area. Conservation efforts and sustainable management practices are urgently needed to protect and restore this critical ecosystem. Mangroves in Teluk Youtefa are not only ecologically important but also provide substantial economic benefits to local communities. However, ongoing environmental degradation has led to a notable decline in community income, from IDR 5.65 billion to IDR 3.61 billion per year—a reduction of IDR 2.05 billion. Overall, the degradation of Teluk Youtefa's mangrove ecosystem could have been prevented through better development planning and a stronger understanding of the ecological and economic functions of mangroves by all stakeholders (Handono *et al*., 2014).

Strategies for conservation and management of mangroves in the TYNTA

Conserving mangroves in the Teluk Youtefa Nature Tourism Area requires a holistic approach involving multiple stakeholders, including local governments, conservation organizations, and the surrounding communities. A key strategy is the establishment of strictly protected mangrove zones to prevent land conversion and habitat destruction. These efforts are supported by rehabilitation programs, including regular mangrove replanting initiatives aimed at restoring degraded ecosystems. Moreover, continuous environmental monitoring and consistent enforcement of regulations—particularly against illegal logging and pollution—are essential to ensuring long-term mangrove conservation.

For sustainable management of the Teluk Youtefa tourism area, integrating ecotourism principles is crucial to achieving economic benefits without compromising environmental integrity. Tourism development must take into account the carrying capacity of the mangrove ecosystem, and include training for local tour guides and businesses on environmentally friendly practices. Educating visitors about the importance of mangroves and the impacts of human activities on coastal ecosystems is also a vital part of this strategy. Collaboration between government, local communities, and the private sector is expected to create an effective management model that supports conservation efforts while enhancing the overall visitor experience.

Environmental management strategies can be categorized into technical and non-technical approaches. Technical strategies include the construction of wave breakers, reforestation of forests and mangrove areas, the establishment of waste disposal sites (TPS), implementation of waste screening systems, the application of the 3R (reduce, reuse, recycle) waste management method, and the development of wastewater treatment plants (WWTP) and drainage systems. Meanwhile, non-technical strategies involve community education programs and the provision of financial support for small businesses around the TYNTA (Alfons, 2018).

CONCLUSION

This study aimed to explore the relationship between environmental factors and the ecological balance and bioactive compound production of *Avicennia alba* in the TYNTA, Jayapura City. The findings indicate that environmental quality significantly affects both the stability of mangrove ecosystems and the complexity of their bioactive content.

Sites with poor environmental quality, such as Site 1 (near residential areas), were characterized by high BOD levels (5.8 mg/L), elevated lead (Pb) concentrations (0.07 mg/L), and low dissolved oxygen (DO) (3.2 mg/L). These conditions correlated with a reduced capacity of *Avicennia alba* to produce bioactive compounds, as only three types of bioactive metabolites were detected through phytochemical analysis.

In contrast, Site 3 (a conservation zone) with better environmental conditions (DO 5.5 mg/L, BOD 2.1 mg/L, salinity 32.4 ppt) exhibited the presence of six types of bioactive compounds, including important groups such as flavonoids, terpenoids, saponins, and tannins. These results suggest that environmental degradation directly impacts the ecological balance and bioactive potential of *A. alba*. Polluted environments tend to suppress the diversity and abundance of bioactive compounds, whereas healthier ecosystems promote optimal mangrove growth, enhance pharmacological potential, and support the long-term sustainability of the Teluk Youtefa mangrove tourism area.

The detected bioactive compounds offer various ecological benefits, including defense mechanisms against pathogens and herbivores, and support adaptation to environmental stressors. Alkaloids serve as natural toxins against insects and herbivores, flavonoids act as antioxidants and contribute to pigmentation and aroma in plant tissues, while terpenoids enhance stress resistance. Saponins and tannins strengthen plant defense systems and have significant potential for applications in health, cosmetics, and industrial sectors.

In conclusion, environmental factors play a crucial role in shaping the complexity and composition of *A. alba*'s bioactive metabolites, underscoring the species' ecological significance and bioeconomic potential in coastal ecosystems. Therefore, effective conservation measures and pollution control are vital to ensuring the continued ecological function and sustainable resource use of the Teluk Youtefa mangrove area.

Based on the findings of this study, it is recommended to conduct regular monitoring of key environmental factors such as water quality, pollution levels, and land-use changes. Conservation efforts involving local stakeholders are essential to maintain the stability and sustainability of the mangrove ecosystem. Furthermore, future research focusing on the interactions between environmental factors and the diversity of bioactive compounds could provide deeper insights into the adaptive mechanisms of mangroves. Such studies would also contribute to developing effective mitigation strategies for protecting mangrove habitats from the impacts of climate change and human activities.

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