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SUSTAINABLE MANAGEMENT OF BIOLOGICAL NATURAL RESOURCES IN THE FREEPORT AREA, PAPUA

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ABSTRACT

This article aims to examine the sustainable management of biological natural resources in the Freeport mining area, Papua, which is home to diverse and fragile ecosystems ranging from mangroves to alpine zones. The study employs a qualitative descriptive method through document analysis, literature review, and field observation to explore environmental practices conducted by PT Freeport Indonesia. The findings show that while mining activities have caused significant ecological disturbances—including habitat loss, biodiversity degradation, and pollution—the company has also carried out various mitigation efforts. These include biodiversity monitoring, ecosystem reclamation, reforestation of the Grasberg mine, and conservation programs in partnership with local communities. More than 50,000 pig-nosed turtles and many endemic birds and mammals have been reintroduced into protected habitats. The paper contributes to the broader discourse on balancing industrial development with biodiversity protection, particularly in ecologically sensitive areas. It also provides insights into how conservation data from the mining area can support biodiversity management in adjacent protected zones like Lorentz National Park.

Keywords: biodiversity; Freeport; conservation; Papua; sustainability

INTRODUCTION

Biological natural resources are living-based resources such as plants, animals, and microorganisms. These resources play a critical role in ecosystems by providing food, medicine, and other human necessities.

According to Neolaka (2008), the diversity of biological natural resources must be preserved, as the rapid advancement of science and technology often leads to monoculture practices—cultivating only one or two types of plants or animals in large quantities. Such practices inevitably reduce biodiversity. If this trend continues unchecked, many species of plants and animals will face extinction due to human imprudence, despite the fact that these resources are inherently renewable.

In Indonesia, Papua—particularly Mimika Regency—is one of the regions with exceptionally high biodiversity. One of Mimika's unique features is its diverse range of ecosystems, from mangrove forests to alpine ecosystems with snow-covered peaks, all within a relatively short distance.

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Since the opening of the copper mine by PT Freeport Indonesia (PTFI) in 1969, Mimika has undergone rapid development. Its population has grown from around 1,000 in the early 1970s to over 150,000 today, with an estimated annual population growth of 9%, far above the national average of 1.35%.

Freeport's mining area in Papua has attracted significant attention due to its environmental impacts, especially on the sustainability of biological resources. PTFI operates in Mimika Regency, managing the Grasberg mine, one of the world's largest gold and copper mines. Its operations cover approximately 10,800 hectares, including open-pit and underground mines, processing facilities, and support areas. The company employs over 30,000 people—both local and national—and partners with local communities to support socio-economic development.

According to Supriatna (2008), biological natural resources include all forms of living-based resources that provide direct or indirect benefits to human life. This includes flora, fauna, and microorganisms that maintain ecological balance. Odum (1993) describes biodiversity in *Ecology and Environment* as a primary support system for life on Earth. Primack (1998), in *Biodiversity and Conservation*, emphasizes their ecological, economic, and cultural value.

Biological resources can be grouped into several categories. Plant resources consist of trees, shrubs, and undergrowth, which provide oxygen, timber, food, and medicinal ingredients. Animal resources include terrestrial and aquatic fauna that serve as protein sources, sources of labor, and ecosystem stabilizers. Microorganisms such as bacteria, fungi, and microalgae play essential roles in decomposition, nutrient cycling, and biotechnology. These living resources interact with their physical environment to form ecosystems that function as unified systems.

The legal foundation for managing biological resources in Indonesia includes several key regulations. Law No. 5 of 1990 on the Conservation of Biological Natural Resources and Ecosystems outlines the protection of life-support systems and the sustainable utilization of biological resources. Law No. 32 of 2009 on Environmental Protection and Management mandates environmental impact assessments (AMDAL) and requires proper waste management to avoid ecosystem damage. Additionally, Government Regulation No. 7 of 1999 on the Preservation of Plant and Animal Species focuses on protecting endangered species.

Made Putrawan (2014) posits that national development embodies the noble objective of fostering a prosperous, just, and equitable Indonesian society, encompassing both material and spiritual well-being. Development is frequently associated with industrialization, which seeks to meet fundamental human needs—a pursuit that remains viable only when supported by the adequate availability of natural resources.

Putrawan further emphasizes that the success of any development process is largely contingent upon the quantity and/or quality of these natural resources. This encompasses renewable resources—such as forests, water, and vegetation—which serve as primary raw materials for industry, as well as non-renewable resources—such as petroleum, coal, and copper—that function as critical inputs in industrialization.

Natural resources thus constitute a fundamental pillar of industrialization, supplying essential materials, energy, and biodiversity, all of which are indispensable for the achievement of environmentally sound and sustainable development. Environmental considerations have therefore become integral to development strategies at national, regional, and even global levels. Within the economic domain, development must be pursued in accordance with ecological principles, with heightened attention to the

conservation of natural resources as the foundational raw materials for both economic and industrial activities.

Papua is recognized as one of the last frontiers of global biodiversity, harboring ecosystems that range from dense mangrove forests along its coasts to alpine meadows and glacial environments at the peaks of its highest mountains. This diversity is not only remarkable for its breadth but also for the high levels of endemism found across its flora and fauna. According to Conservation International, Papua's terrestrial and marine ecosystems are part of the Coral Triangle and the Australasian biodiversity hotspot, making them globally significant for conservation efforts. The Mimika Regency, where PT Freeport Indonesia (PTFI) operates, lies within this ecological tapestry and directly borders Lorentz National Park, a UNESCO World Heritage Site.

However, such ecological richness exists alongside significant industrial development, most notably large-scale mining operations. The Grasberg mine, one of the largest gold and copper mines in the world, has been central to the socio-economic transformation of Mimika since the late 20th century. While mining has brought substantial infrastructure, employment, and economic growth, it has also introduced ecological pressures, including habitat fragmentation, river sedimentation, and the displacement of species. These challenges underscore the delicate balance between resource extraction and environmental stewardship, especially in a region where ecosystem integrity is critical to cultural identity and local livelihoods.

In the context of environmental science, sustainable management of biological natural resources refers to practices that meet human needs while preserving ecosystem functions and biodiversity for future generations. This approach aligns with international conservation frameworks such as the Convention on Biological Diversity (CBD) and the United Nations Sustainable Development Goals (SDGs), particularly Goal 15, which emphasizes the protection, restoration, and sustainable use of terrestrial ecosystems. In resource-rich areas like Papua, achieving this balance requires a multi-disciplinary strategy that integrates ecological restoration, socio-economic development, and cultural preservation.

The interaction between local communities and their environment in Papua is deeply rooted in traditional ecological knowledge. The Amungme people of the highlands and the Kamoro people of the coastal areas have, for generations, developed sustainable resource use practices that maintain ecological balance. These practices include rotational hunting, seasonal fishing patterns, and the cultivation of diverse food crops. Incorporating such knowledge into contemporary biodiversity management is not merely a gesture of cultural respect but also a practical approach that can enhance the effectiveness of conservation initiatives.

From a policy perspective, Indonesia has established legal frameworks to safeguard biological resources, including Law No. 5 of 1990 on the Conservation of Biological Natural Resources and Ecosystems, and Law No. 32 of 2009 on Environmental Protection and Management. However, the implementation of these laws in mining-intensive regions often faces challenges related to enforcement capacity, economic pressures, and competing land-use priorities. Addressing these challenges requires not only regulatory oversight but also corporate commitment to environmental and social responsibility.

This paper situates the case of Freeport's operational area in Papua within this broader discourse, examining how large-scale industrial activities intersect with efforts to conserve one of the world's most ecologically significant regions. By analyzing both

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the environmental impacts and the mitigation measures undertaken—ranging from biodiversity monitoring to community-based conservation—this study aims to contribute to the growing body of literature on reconciling economic development with ecological sustainability.

METHOD

This study employs a descriptive qualitative approach using documentation studies, literature reviews, and limited field observations. Data sources include official PTFI reports, government policy documents on biodiversity conservation, and direct observations in the Grasberg reclamation and other conservation areas in Mimika, Papua.

RESULTS AND DISCUSSION

Development carries the noble objective of enhancing human well-being; however, the negative impacts it generates demand wise and thoughtful consideration. One of the consequences that has begun to attract serious global attention in the 21st century is the continuing decline in biodiversity. This trend is likely rooted in the flawed perception that natural resources are unlimited, thereby justifying their irrational exploitation in support of development. Such overexploitation, as noted by Gore in Putrawan (2014), is a key factor contributing to biodiversity loss.

According to McNeely, there are six principal obstacles to biodiversity conservation: (1) in monetary terms, national development programs tend to "undervalue" biological resources; (2) overexploitation of biological resources disproportionately benefits industrialists and factory owners who are able to externalize environmental costs, while local communities bear these costs as a consequence of excessive exploitation; (3) many species and ecosystems upon which humans depend remain insufficiently studied; (4) scientific research often fails to address the actual needs of natural resource managers in protected areas; (5) conservation activities tend to have an overly narrow focus; and (6) institutions responsible for biodiversity conservation lack adequate financial resources and organizational capacity to effectively carry out their mandates.

These challenges are faced not only by developing nations but also by industrialized countries—many of which are, in fact, responsible for excessive exploitation of tropical nations for investment purposes, reaping substantial profits without making corresponding investments in conservation or contributing to the compensation of environmental costs resulting from their activities.

Groups, types, and characteristics of resources:

Group	Type	Characteristic
Physical	Air	Almost unlimited, can be recycled
	Water	Limited, can be recycled
	Land, space	Very limited, cannot be recycled
	minerals	Limited, can be recycled, some are harmful to humans
Biological	Plants/vegetation	Limited, renewable, can become extinct, some are harmful to humans
	Animals, including humans	Limited, renewable, can become extinct, some are harmful to humans
	Decomposers	Limited, renewable, can become extinct, some are harmful to humans

Socio-cultural	Knowledge, technology	Limited, can develop
	Workforce	Limited, can be misused by humans
	Sosial and cultural values, arts	Immeasurable, can develop
	Reason, intellect, morality, conscience	Strongly determines motivation, can develop
	Religions, beliefs	Spriritual, can play a decisive role

Sources: M. Soerjani dan Surna T. Djajadiningrat.

The Freeport area in Mimika Regency, Papua, is ecologically rich and borders Lorentz National Park, a UNESCO World Heritage site since 1999. Mining activities in the area have significantly altered the landscape through land clearing, river sedimentation, and tailings disposal, all of which affect biodiversity and lead to habitat loss for numerous species. Animal smuggling is also prevalent in Papua, often tied to high population migration and the demand for wildlife as souvenirs.

Notable plant species include Papua orchids, matoa trees, and ironwood, while key animal species include birds-of-paradise, cassowaries, long-necked turtles, pig-nosed turtles, endemic birds, and the rare New Guinea singing dog (NGSD). The region's rivers and swamps support native fish like rainbowfish, hardyhead, pipefish, gudgeons, and gobies, as well as freshwater prawns like *Cherax* (red claw) and *Macrobrachium* (giant prawn). Swamp ecosystems are particularly biodiverse, even more so than lowland rivers, with rare species like Blue Eyes, Glass Fish (*Ambassis*), and *Glossamia*. Non-native species such as snakeheads, tilapia, and Toraja snakeheads are also present. These aquatic resources serve as income sources for local communities.

Freeport's biodiversity report documented 408 species of mammals and birds, including two newly identified species. Reptiles and amphibians accounted for 188 species, with 25 new discoveries and three new species recorded for Indonesia. Aquatic insects totaled 101 species, including 45 new species, while terrestrial insects reached 488 species, with 37 new species and one new genus.

Biodiversity studies began with an environmental impact assessment survey between 1995 and 1997. Botanical surveys were carried out by the KEW Royal Botanic Garden from 1997 to 2000. Bird surveys occurred in 2002, followed by a herpetofauna survey in 2005 and mangrove biodiversity studies in 2008. Between 2016 and 2019, Freeport documented a healthy population of NGSDs. In 2020, a dragonfly diversity study was conducted by LIPI (now BRIN).

Plant biodiversity research includes a 1990 KEW-led survey across coastal to alpine zones, which collected around 5,000 herbarium specimens stored in KEW, Leiden, Bogor, Manokwari, and PTFI. This study identified 1,935 plant species within 698 genera, with 700 species found above 3,000 meters elevation. It led to the discovery of one new taxon, one new genus, and 28 newly identified species, and the publication of a field guide on alpine flora. In 2002, an ethnobotanical study of the Kamoro people was conducted with LIPI and UNIPA, analyzing chemical contents such as polyphenols, saponins, steroids, alkaloids, triterpenoids, and flavonoids. UNIPA's Double Levee vegetation study found over 1,035 plant species in the area.

After the Grasberg open-pit mine ceased operations in 2020, PTFI initiated reclamation efforts. The reclaimed areas are now supporting a recovering NGSD population. Observations recorded 15 individuals in 2016, 18 in 2018, and over 40 in 2022.

Currently, 60% (570 hectares) of the targeted 920 hectares has been reclaimed. Freeport's 5-year roadmap targets 65 hectares in 2024, 35 hectares in 2025, and 35

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hectares in 2026. Reclamation costs are estimated at USD 200,000 per hectare, with USD 6.3 million spent as of 2023.

Tailings—the fine waste material left after ore processing—are managed through the Modified Ajkwa Deposition Area (Mod ADA), an engineered riverine system approved by the government. This system includes containment embankments, regular evaluations, monitoring, and structural improvements. After mining ends, this area could be reclaimed for natural vegetation or converted for agriculture, forestry, or aquaculture. Annual tailings management costs average USD 120 million.

Soil improvements have been made using composting over 15–20 years, allowing for the cultivation of vegetables, chili, tomatoes, papayas, and cocoa. Cocoa farming involves 347 partner farmers, 55% of whom are local Papuans.

Since 1994, PTFI has invited national and international researchers to study the area's flora and fauna, leading to the discovery of dozens of new species, from aquatic organisms to terrestrial animals and plants.

These research findings also support the management of Lorentz National Park. With its 2.4 million hectares, it is Southeast Asia's largest national park and borders PTFI's concession. Freeport's data can serve as a valuable reference for park management.

Conservation facilities include an ecosystem diorama, botanical garden, butterfly breeding center, bird transit cages, and a herbarium lab. These facilities also serve educational purposes, particularly for students in Mimika from kindergarten to university level.

PTFI works with government agencies (e.g., BKSDA, quarantine, and local government), NGOs, the military, and communities to release protected and endemic animals back into their natural habitats. Between 2006 and 2022, PTFI facilitated the release of 50,000 pig-nosed turtles, 29 dusky pademelons, 5 Papuan crocodiles, 12 double-wattled cassowaries, 42 endemic snakes and lizards, 121 parrot species, 139 black-capped lories, 7 yellow-crested cockatoos, 21 forest kangaroos, 2 copper-tailed cuscuses, and 1 spotted cuscus.

Since 1998, Arabica coffee cultivation has been promoted in four Amungme valleys—Tsinga, Hoea, Aroanop, and Banti Opitawak—with 170 farmers working on 39 hectares and producing 1.2 tons of coffee beans per year. In 2023, 15,000 Arabica seedlings were distributed to highland villages including Jila, Bela, and Alama, while 50,000 Robusta seedlings were distributed to seven lowland districts.

The sustainable management of biodiversity faces several challenges. Papua's difficult terrain often delays conservation efforts. Public awareness about conservation remains low, particularly in remote communities. Additionally, economic pressures often conflict with conservation objectives, as short-term profits are prioritized over long-term ecological sustainability.

To address these challenges, stricter enforcement of environmental regulations is required. Multi-stakeholder collaboration between the government, private companies, and local communities is also crucial. Developing real-time ecosystem monitoring systems can further enhance biodiversity protection and management efforts.

Post-mining ecosystem restoration in the Freeport area of Papua is a complex process that requires a long period of time and an integrated strategy. Restoration ecology studies show that the success rate of recovery largely depends on the initial condition of the land, the type of damage, and the reclamation techniques applied (Suding et al., 2015). In the Ajkwa and Otomona watershed areas, tailings sedimentation presents a major

challenge as it alters river morphology, reduces water quality, and changes aquatic habitats. High sedimentation can reduce light penetration, decrease primary productivity, and disrupt aquatic food chains.

Restoring hydrological function requires interventions such as dredging sediment in critical areas, constructing diversion channels to reduce flooding, and planting riparian vegetation to bind soil. Riparian cover vegetation, such as *Barringtonia asiatica* and *Terminalia catappa*, plays an important role in reducing erosion and improving habitat quality for fish and invertebrates.

Mountain forest ecosystems affected by Grasberg's open-pit mining exhibit relatively slow natural succession. Without intervention, the recovery of endemic vegetation at elevations above 3,000 meters can take more than 50 years. This is due to cold climate conditions, nutrient-poor soils, and limited seed sources. Therefore, planting pioneer species such as *Miscanthus floridulus* and *Deschampsia klossii* is the initial strategy before introducing native mountain forest species like *Nothofagus* and *Podocarpus*.

Fauna also require time to return. PTFI observation data show that after reclamation, the number of New Guinea singing dogs (NGSD) increased from 15 individuals in 2016 to more than 40 in 2022. The return of NGSD is an indicator that the food chain is beginning to recover, as this species sits at the top of the trophic pyramid. In addition, the presence of birds-of-paradise in reclamation zones suggests that suitable habitats for Papua's iconic species are starting to form.

Technology plays an important role in accelerating ecosystem recovery. One approach used is bioengineering, which combines civil engineering techniques with vegetation to control erosion and improve soil stability. For example, installing geotextiles planted with vetiver grass can reduce erosion rates by up to 60% compared to bare soil (Bussière et al., 2020).

In addition, phytoremediation is used to reduce heavy metal content in soil and water. Plants such as vetiver (*Vetiveria zizanioides*) and water spinach (*Ipomoea aquatica*) have the ability to absorb copper and cadmium from their growth medium. Research in the Timika mining area shows that using these plants can reduce copper content by up to 40% within six months.

Technology-based monitoring systems are also a mainstay. Drones equipped with multispectral cameras can map vegetation cover, detect critical areas requiring intervention, and periodically monitor landscape changes. Camera traps installed at various locations utilize AI algorithms to recognize wildlife species, facilitating real-time identification and population monitoring.

In the aquatic sector, the use of real-time water quality monitoring systems enables continuous measurement of parameters such as pH, turbidity, and heavy metal content. This data is connected to a control center and can trigger early warnings if water quality declines.

The indigenous Amungme (highlands) and Kamoro (coastal) communities possess ecological knowledge passed down through generations. This wisdom includes determining hunting prohibition zones, timing the harvest of non-timber forest products, and methods for using medicinal plants. For example, the Kamoro people know that certain flowers bloom only when certain fish migrate, serving as a natural indicator of a sustainable fishing season.

Integrating local knowledge into PTFI's conservation program is carried out through the Indigenous Conservation Forum, where community leaders and scientists sit

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together to formulate habitat management strategies. This approach not only increases community acceptance of conservation programs but also enriches the methods used.

Educating the younger generation is key to sustainability. The "School for Nature" program, involving high school students in Timika, combines the formal curriculum with field training at botanical gardens, butterfly breeding centers, and PTFI's herbarium laboratory. In this way, ecological and cultural values can be passed on to the next generation.

Environmental management practices at the Grasberg mine can be compared with those at other mines in sensitive areas. The Yanacocha gold mine in Peru, for example, applies progressive rehabilitation with staged reclamation from the beginning of operations. This approach has reduced closure costs by up to 25% and accelerated the recovery of native vegetation.

The Voisey's Bay nickel mine in Canada applies a collaborative monitoring model with the Inuit and Innu communities. All biodiversity data is shared openly, thereby increasing transparency and public trust. This model is relevant to Papua, given the presence of indigenous communities with customary land rights and a spiritual connection to their land.

Conversely, large-scale gold mining in the Brazilian Amazon provides an important lesson on the risks of management failure. The absence of a clear reclamation plan has led to widespread deforestation, mercury pollution in rivers, and a drastic decline in local fish populations. This shows that long-term commitment and strict oversight are essential to avoid permanent damage.

The Freeport case offers the lesson that national regulations need to align with global agendas such as the Convention on Biological Diversity (CBD), Sustainable Development Goals (SDGs), and Environmental, Social, and Governance (ESG) principles, which are increasingly becoming benchmarks for international investors.

Some policy recommendations that can be adopted include strengthening Environmental Impact Assessments (EIA) with biodiversity data that include cumulative long-term impact analysis, not just direct impacts; implementing biodiversity offset mechanisms that require companies to restore ecosystems outside the mining concession as compensation for biodiversity loss; allocating a minimum of 30% of CSR funds for conservation in high-biodiversity areas; fostering international research collaboration to access advanced reclamation technologies and build local human resource capacity; and implementing participatory monitoring involving indigenous communities in data collection and field supervision.

If these recommendations are applied consistently, Papua has the potential to become a model for sustainable natural resource management in tropical regions, while also strengthening Indonesia's position in global environmental forums.

CONCLUSION

Sustainable management of biological natural resources in Freeport's operational area in Papua presents significant challenges that require cooperation from various stakeholders. With strong regulations, technological innovations, and active involvement of local communities, the negative impacts of mining activities can be reduced. This approach aims to preserve Papua's biodiversity for future generations.

The sustainable management of biological resources in the Freeport area is not solely about land reclamation, but also encompasses ecosystem reconstruction, community empowerment, technological application, and policy alignment with global agendas.

Current efforts show progress; however, long-term challenges remain, particularly in maintaining a balance between economic gains and ecological preservation.
By integrating modern science, local wisdom, and transparency-based governance, former mining areas in Papua can be transformed into productive landscapes that continue to preserve their ecological functions.

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