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KARST ECOSYSTEM RESTORATION IN THE NGLIRIP CAVE NATURE RESERVE WITH ENDEMIC PLANTS

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Abstract:
The karst ecosystem of the Nglirip Cave Nature Reserve in Tuban Regency, East Java, plays a vital role as a water reservoir, carbon sink, and biodiversity hub. However, uncontrolled deforestation and human activities have disrupted the ecological balance, threatening the flora and fauna, as well as the local groundwater reserves. This study documents a collaborative restoration program initiated by PT PLN Nusantara Power Unit Pembangkit Tanjung Awar-Awar (UPTA), in partnership with the East Java BBKSDA (National Resources Conservation Agency) and the Tuban Regency Environmental Agency. The program aimed to rehabilitate the karst ecosystem through the planting of 1,000 endemic trees, which are Ficus benjamina and Ficus macrocarpa. These trees were chosen for their high-water absorption capacity and ecological suitability to the Nglirip Cave Nature Reserve. We implemented an innovative protection technique called "Ficus in Shield" by constructing cylindrical galvanized sheet metal under the tree trunks. This procedure was implemented to protect the saplings from damage by porcupines. The results show a measurable increase in biodiversity, evidenced by an increase in the Shannon-Wiener Biodiversity Index, and are expected to improve groundwater retention and ecosystem resilience. Beyond the ecological benefits, this initiative emphasizes the importance of public-private collaboration in biodiversity conservation and climate resilience. These findings highlight that endemic-based reforestation, combined with adaptive protection methods, is expected to effectively restore long-degraded karst ecosystems and serve as a model for sustainable conservation both in the Nglirip Cave Nature Reserve and elsewhere.

Keywords: Nglirip Cave Nature Reserve, Ficus in Shield, Ficus Benjamina, Ficus Macrocarpa, Biodiversity.

INTRODUCTION

PT PLN Nusantara Power Unit Pembangkit Tanjung Awar-Awar (UPTA) is committed to improving the environment through various activities, one of which is related to biodiversity efforts from the impact of power plant activities. In this paper, we are committed to conducting initiatives to minimize environmental impacts, increase the role of local ecosystems, and promote sustainable practices. UPTA contributes to a balance between energy production and environmental

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conservation by including biodiversity conservation in environmental improvement activities and making it a priority for society and the world.

In early 2024, UPTA started an environmental awareness program with attention to important biodiversity, focusing on restoring karst ecosystems in the Nglirip Cave Nature Reserve using local plants to protect karst, increase carbon sequestration, and increase biodiversity.

Background. As shown in Fig. 1, Nglirip Cave, located in Tuban Regency, is a karst cave that functions as a water reservoir, carbon sink, and ecosystem for various animal species. It has a geographical location of 06°57'26.8" South Latitude and 111°49'00.2" East Longitude. This area has a topography that tends to be flat to undulating, with an altitude of between 200 and 220 meters above sea level. Water percolates through limestone in karst caves, creating natural water filtration systems that help conserve the environment.

Furthermore, this type of environment provides habitat for endemic species. These specific caves also serve as carbon sinks, absorbing and storing carbon dioxide to slow down global warming. Deforestation and limestone mining currently pose a threat to the karst ecosystem.

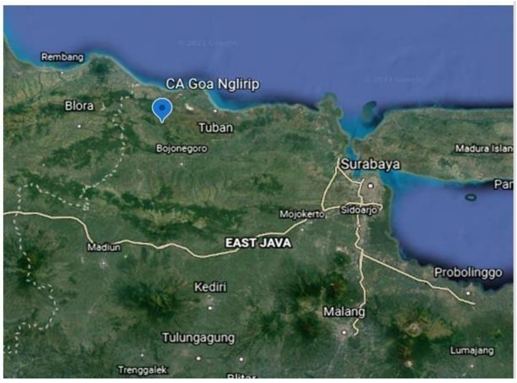

Figure 1. Location of Nglirip Cave in Tuban Regency, East Java

Deforestation or tree felling above the cave reduces the water previously absorbed by tree roots and stored in limestone. Furthermore, various species of birds, reptiles, insects, and small mammals will lose their homes if native trees are cut down. If this issue is not addressed immediately, it will disrupt the water supply flowing along the underground rivers in Tuban and the surrounding area. In addition, it will lead to the loss of biodiversity inhabiting the Nglirip Cave area. Furthermore, at the site, people can enter the cave area without permission, which has the potential to cause further damage to the cave ecosystem, and animal hunting includes hunting activities of swiftlets and bats by people for consumption, which can disrupt the balance of the cave ecosystem (Prayuda & Rahmawati, 2025).

The exploitation of the forest and limestone caves in the Nglirip Cave Nature Reserve plays a significant role in influencing the drought and meteorological humidity index in the Tuban area. According to BMKG data, the Tuban area experienced drought from November 2023 to January 2024, with several areas experiencing severe drought conditions (as seen in Fig. 2). Therefore, it is necessary to implement a karst ecosystem restoration program in the Nglirip Cave Nature Reserve area with endemic plants. This condition is so that the Tuban area's groundwater reserve capacity can be maintained and its existence guaranteed.

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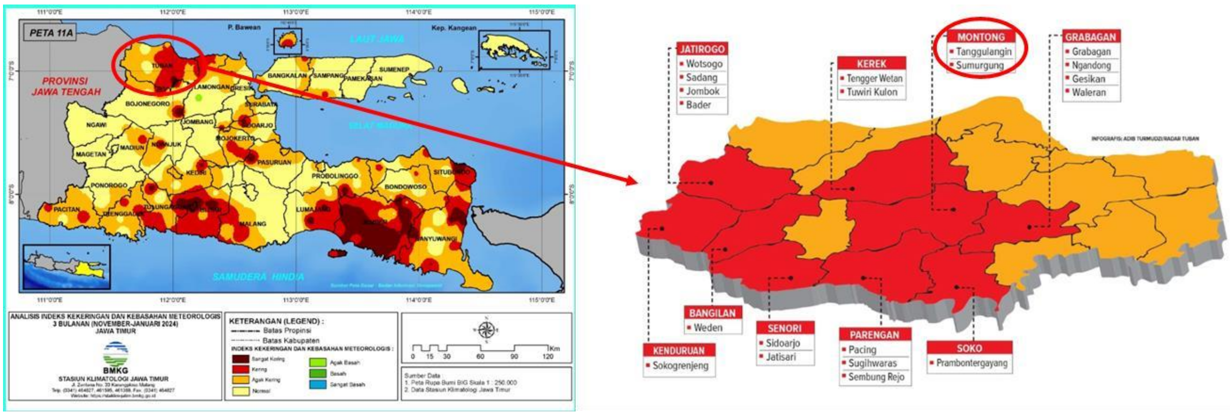

Figure 2. Meteorological drought and wetness analysis map of East Java, particularly the Tuban area, for the period November 2023 – January 2024

Origin of ideas or changes. The conservation environment initiative is an innovation from UPTA in collaboration with the East Java Natural Resources Conservation Agency (BBKSDA) for joint management of the Nglirip Cave Nature Reserve area. UPTA and BBKSDA have signed a Memorandum of

Understanding is evidence of this collaboration. A significant part of this innovation program is the involvement of the Tuban Regency Environmental Agency (DLH) in determining which endemic plants are suitable for plant cultivation in the Nglirip Cave Nature Reserve. Based on discussions with the East Java Natural Resources Conservation Agency (BBKSDA) and the Tuban Regency Environmental Agency (DLH), it has been determined that the Banyan (Ficus benjamina) and Kimeng Banyan (Ficus macrocarpa) are suitable plants for the Nglirip Cave Nature Reserve. These plants are plants have high water absorption capacity. Accordingly, this program aligns with its long-term goal of protecting water reserves in Nglirip Cave Nature Reserve, which flows along an underground river in Tuban and its surrounding areas. Due to deforestation, logging, and limestone mining, Nglirip Cave's vegetation has been significantly damaged.

Aside from the damage caused by the exploitation of forests and limestone caves, porcupines are also responsible for the destruction of plant life. The porcupine is an herbivore and feeds primarily on leaves and stems, particularly the bark of trees. Bark is crucial for transporting nutrients throughout the plant. Those plants that have their bark damaged or completely removed will likely suffer from a lack of growth, and may even succumb to death in the worst-case scenario. The presence of porcupines requires precautions in order to prevent damage and ensure proper growth and development of plants. One way to mitigate porcupine damage is the "Ficus in Shield" method. This method is an alternative method, which involves the installation of a protective fence made of galvanized sheet metal. This fence is installed around the plant's trunk and is appropriate for the plant's age and diameter.

Research Objectives. In this study, the following research objectives are being pursued:

a) Assessing the effectiveness of a karst ecosystem restoration program through the planting of endemic plants in the Nglirip Cave Nature Reserve.
b) The study also aims to increase the biodiversity of flora and fauna, while also maintaining groundwater reserves in the Tuban region.

Research Significance. This research holds five significant implications:

a) Conservation of Karst Ecosystems: Through this program, critical karst ecosystems are protected, which serve as water reservoirs and habitats for a variety of species. Deforestation

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and mining have disrupted the area's ecological function. Planting endemic plants is expected to restore this function.

b) Enhancement of biodiversity: The planting of 1,000 banyan trees (Ficus benjamina and Ficus macrocarpa) will increase the biodiversity index for both flora and fauna. It is crucial for recreating habitat for avifauna, insects, and small mammal species displaced by environmental degradation.
c) Water Resource Management: This program plays an important role in maintaining groundwater reserves for the Tuban area and its surroundings. By increasing the number of trees in the area, water is expected to be absorbed more efficiently, and frequent droughts will be prevented.
d) Innovative Plant Protection Methods: The use of the "Ficus in the Shield" method to protect seedlings from porcupine infestation demonstrated an innovative approach to plant management. This method can serve as a model for other restoration programs in the same sector.
e) Multistakeholder Collaboration: This program involves collaboration between PT PLN, BBKSDA East Java, and the Environmental Agency, demonstrating the importance of collaboration in addressing complex environmental issues.

Karst Ecosystem. The karst ecosystem in Indonesia is a unique and complex environment characterized by limestone formations, caves, and rich biodiversity (Aprilia et al., 2021). These ecosystems are primarily found in regions such as Sumatra, Java, and Sulawesi, where geological processes have created distinctive landscapes (Sisriany & Furuya, 2024). The karst topography not only supports a variety of flora and fauna but also plays a crucial role in local water systems, acting as natural aquifers that store and filter water (Zerga, 2024). The biodiversity within these ecosystems includes numerous endemic species, making them critical areas for conservation efforts.

Figure 3. An interior view of Karst Nglirip Cave

Despite their ecological importance, Indonesian karst ecosystems face significant threats from human activities such as mining, agriculture, and urbanization. The extraction of limestone for cement and other industries has led to habitat destruction and degradation, impacting both the species that inhabit these areas and the local communities that depend on them (Torres et al., 2022). Furthermore, land-use changes have resulted in increased pollution and altered hydrological patterns, exacerbating the vulnerability of these ecosystems. Conservation initiatives are essential to mitigate these impacts, focusing on sustainable management practices that balance economic development with ecological preservation. Fig. 3 shows limestone stalactites and stalagmites in the Nglirip Cave Karst. Formed from water droplets containing mineral deposits, these stalactites are composed of calcite. Stalagmites grow on the cave floor as water droplets fall from the stalactites.

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Research on Indonesian karst ecosystems has highlighted the need for comprehensive studies to understand better their ecological dynamics and the services they provide. Studies have shown that these ecosystems are not only vital for biodiversity but also contribute significantly to carbon storage and climate regulation (Xiong et al., 2023; Zhang et al., 2024). Collaborative efforts among scientists, local communities, and policymakers are crucial for developing effective conservation strategies. By integrating traditional knowledge with scientific research, it is possible to enhance the resilience of karst ecosystems in Indonesia, ensuring their protection for future generations.

Impacts of Deforestation and Mining. Deforestation and mining have profound and often irreversible impacts on forest ecosystems, leading to the degradation of biodiversity, disruption of ecological processes, and loss of ecosystem services. The removal of forest cover not only eliminates habitats for countless species but also alters microclimates, reduces carbon storage capacity, and increases vulnerability to soil erosion and flooding.

Deforestation in karst regions disrupts this delicate ecological balance, leading to severe soil erosion, groundwater contamination, and habitat fragmentation (Wang et al., 2019). Unlike other forest types, karst landscapes have thin soil layers and complex underground drainage systems, making them especially vulnerable to surface disturbances. The removal of forest cover accelerates the loss of topsoil, reduces vegetation resilience, and increases the vulnerability of endemic species to extinction (Lindenmayer, 2023). Moreover, the loss of forest in karst areas contributes to altered microclimates and decreases in carbon sequestration potential, further compounding global climate challenges.

Mining operations, especially limestone quarrying and bauxite extraction, pose an even more immediate and irreversible threat to karst forests. The excavation process physically destroys cave systems and alters subterranean hydrological flows that sustain both surface and underground biodiversity (Ensley et al., 2021). Additionally, the use of explosives and heavy machinery causes vibrations and sediment runoff, impacting water quality and aquatic species in nearby streams and sinkholes. Studies have documented that mining activities in karst regions often precede long-term ecological degradation, social displacement, and the collapse of local ecosystem services (Chi & He, 2023).

In several locations in Manuk 2 Cave (Goa Lawa), damage was found on the cave floor. This damage was caused by widespread phosphate mining in several parts of the cave. Phosphate mining can lead to the destruction of delicate ecosystems within the cave, disrupting habitats for unique cave-dwelling species. The mining process often involves the removal of large amounts of rock and sediment, which can alter water flow patterns and decrease water quality.

METHODS

Research Location. This research was conducted at Nglirip Cave Nature Reserve. It is located in Tuban Regency, East Java, Indonesia, and is a unique karst landscape renowned for its ecological, geological, and cultural significance. The reserve features limestone formations, underground caves, and springfed rivers that form part of a fragile karst ecosystem.

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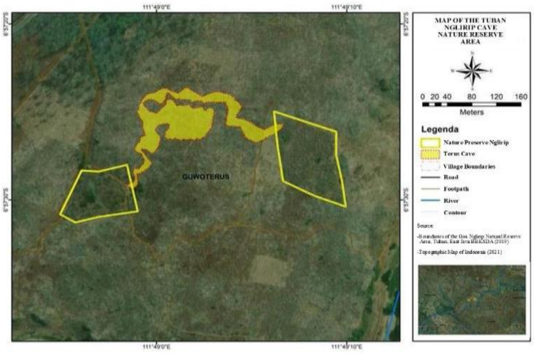

Figure 4. Map of the Nglirip Cave conservation area

The map illustrates the Nglirip Cave Diversity Area in Tuban Regency, East Java, highlighting its ecological boundaries and surrounding features. The reserve, marked in yellow, includes the Terus Cave area, which is a critical karst ecosystem supporting water introduction and biodiversity. The map also delineates village boundaries (Guwoterus Village), roads, footpaths, rivers, and contour lines, showing both natural and human-made elements that interact with the protected area. The spatial depiction emphasizes the proximity of human settlements to the conservation zone, underlining the importance of integrated management between local communities and conservation efforts. This visual representation, sourced from BBKSDA (2019) and the Topographic Map of Indonesia (2021), serves as a reference for planning restoration and biodiversity conservation programs within the karst ecosystem (as seen in Fig. 4).

Research Design.

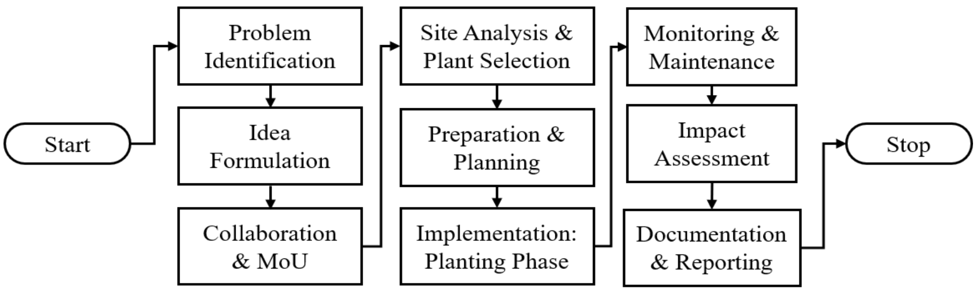

Figure 5. Research design

Fig. 5 shows that the process begins with problem identification. This stage is important because we can see the degradation of karst ecosystems due to deforestation & mining at Nglirip Cave. The idea formulation is to restore ecosystems using endemic water-retaining plants for environmental issues affecting the site: reduced groundwater storage and disruption of biodiversity. Responding to this problem, UPTA initiated an innovation program focused on ecological rehabilitation through the planting of native tree species known for their hydrological functions. This idea was developed collaboratively with key stakeholders, including BBKSDA East Java and the DLH, leading to the formalization of the program through a Memorandum of Understanding (MoU). Once the program was formalized, the team conducted site analyses to identify suitable plant species. Based on the suggestion from the government, we selected Ficus benjamina and Ficus macrocarpa due to these plants' strong root systems and high water-retention capacity.

Implementation involved procuring 1,000 saplings and protecting them using the "Ficus in Shield" method—galvalum-based barriers designed to prevent porcupine damage. The innovation

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progressed into a planting phase, followed by continuous monitoring and evaluation. It was done to assess plant survival, biodiversity changes, and groundwater impact. The outcome was a notable increase in the flora biodiversity index (H'), demonstrating the program's success in enhancing ecological resilience.

Selection of Endemic Plants. The team selected plants for the restoration program of the karst ecosystem carefully. It was based on ecological studies involving collaboration between UPTA, BKSDA, and the DLH. The plants chosen were the Banyan (Ficus benjamina) and the Kimeng Banyan (Ficus macrocarpa) because of their high-water absorption capacity and suitability to karst environmental conditions, which require protection of groundwater reserves and vegetation preservation, as shown in Fig. 6. Vegetation preservation plays a crucial role in ecosystem restoration by stabilizing soil, reducing erosion, and enhancing biodiversity. It helps maintain an ecological balance by providing habitat and food for various species.

Additionally, preserving vegetation aids carbon sequestration, improving air quality and mitigating climate change impacts. Ficus benjamina is a promising natural source of antioxidants and antimicrobial agents with potential medicinal applications. It has identified several types of antioxidants, mainly phenolic acids and flavonoids. Antimicrobial tests showed significant inhibition against bacterial strains (Bacillus cereus, E. coli, Pseudomonas aeruginosa, and B. subtilis) and fungal strains (Aspergillus niger and Candida albicans), with methanol and n-butanol fractions being the most effective [benjamina]. Ficus macrocarpa bark fibers (FMB) are a promising eco-friendly alternative to synthetic reinforcements for lightweight structural composites, owing to their enhanced physical, chemical, thermal, and mechanical performance. FMB serves as a sustainable reinforcement material for polymer composites, with a focus on the effect of alkali treatment (5% NaOH). The untreated fibers had an average diameter of 253.8 µm, which decreased to 223.3 µm after treatment. Additionally, the cellulose content increased from 48.4% to 59.7%, while amorphous constituents such as hemicellulose, lignin, and wax were significantly reduced (Tengsuthiwat et al., 2024).

a. Banyan (Ficus benjamina) (Bastana, 2025)

b. Kimeng Banyan (Ficus macrocarpa) (indiamart, 2025)

Figure 6. The types of Ficus benjamina and Ficus macrocarpa

The selection of these two banyan tree species was based on their deep and spreading root morphology. It allows for optimal water absorption and supports the karst cave ecosystem's hydrological function. These plants were also chosen for their ecological role as protectors against soil erosion and as habitat providers for various species of birds, reptiles, insects, and small mammals.

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The Importance Value Index (IVI) for trees is a parameter used in ecology and silviculture to measure the relative contribution of a tree species to a forest community. The IVI indicates the importance or dominance of a tree species based on three main factors: 1) Frequency: How often the tree species is found in the observed area. 2) Density: The number of individuals of a tree species in a given area. 3) Diameter: Tree size, usually measured by diameter above ground level (DBH). The Importance Value Index is calculated by combining these three factors to provide a numerical score that reflects the importance of the tree species in the forest ecosystem. The higher the IVI score, the more dominant the species is in the observed forest community. The IVI is used for forest management, conservation, and ecological research.

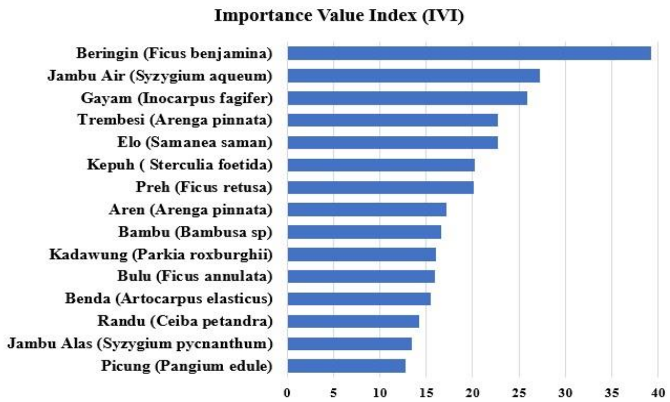

Figure 7. Importance Value Index (IVI) for trees

Figure 7 shows the IVI score for each tree that has been observed in the previous research (Yuliantoro & Frianto, 2019). Their research focused on the types of vegetation around springs in the lowlands and highlands of Wonogiri Regency and identified 8 types of families. Of the 8 types of families, the Moraceae family was the family with the largest number of species found; there are 4 species. The Moraceae family is dominated by the genus Ficus. Other families that were frequently found were the Fabaceae and Malvaceae families, each represented by 3 plant species. Based on the results of the vegetation structure analysis, which indicated that the types of vegetation with a large IVI were categorized as the main components of the vegetation community around springs in the highlands and lowlands of Wonogiri Regency. These types were found in all sample plots/plots at the research location. The Importance Value Index of vegetation types in a community is one parameter that indicates the role of the vegetation type in its community. The presence of a type of vegetation in an area indicates the ability to adapt to the habitat and a large tolerance to environmental conditions.

Ficus in Shield Method. The implementation of the "Ficus in Shield" method by installing protective galvanized sheet metal around the plant trunk. It was implemented as an innovation to prevent damage to the plants by animals such as porcupines. This change replaces the previous passive conservation system with an active system based on ecological restoration and adaptation to local threats.

As shown in Figure 8, (a) we illustrate the concept of the ficus in a galvanized shield to prevent damage to the plants by animals such as porcupines, and (b) the implementation of the ficus in a galvanized shield. Animals cannot damage the ficus because the galvanized shield provides a durable barrier.

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(a) Illustration of ficus in galvanized shield method

(b) implementation of ficus in galvanized shield method

Figure 8. The galvanized shield protects the tree from porcupines

The "Ficus in Shield" method requires a galvalume plate with a minimum width of 37 cm to 47 cm (according to the average body size of an adult porcupine) and a minimum length of 100 cm for Banyan tree seedlings. Due to the material's strength, rust resistance, and flexibility, galvalume plates are preferred as porcupine barriers because they are resistant to damage, rust-resistant, and can be shaped to fit the diameter of the plant. The plant can be treated by this method until the stem diameter reaches approximately 30 centimeters after transplantation. Plants with this size stem are considered capable of enduring damage from porcupines; however, regular monitoring of the plant's condition is still required to make sure that it does not deteriorate.

Data Collection. We obtained this information from a research report published in 2021 on the monitoring of biodiversity in Nglirip Cave Nature Reserve. Yayasan Konservasi Elang Indonesia and the BBKSDA conducted the research. UPTA supported it in updating data for the Nglirip Cave Nature Reserve Conservation Area. Data from the Meteorology, Climatology, and Geophysics Agency (BMKG) from November 2023 to January 2024 indicated that the Tuban area was experiencing drought, with some areas even experiencing severe drought.

The knowledge of biodiversity components is crucial for the development of conservation management policies. The Nglirip Cave Nature Reserve was designated by Decree of the Governor of the Dutch East Indies, GB No. 6 St.Bl. 90, dated February 21, 1919, with 3 hectares. This nature reserve is located in Guwoterus Village, Montong District, Tuban Regency.

Biodiversity Analysis. The Shannon-Wiener Diversity Index (H') is a method of diversity analysis used to measure species diversity, which measures species diversity by taking into account the number of species and their relative distribution. The formula for Shannon-Wiener:

$$H' = -\sum(p_i \cdot \ln{(p_i)})$$

Where pi is the proportion of species i in the total number of species present.

RESULT AND DISCUSSION

Initial Problems in Nglirip Cave. The initial problems in Ngirip Cave arise from the deteriorating condition of its karst ecosystem, particularly due to the degradation of both biotic and abiotic components. Phosphate extraction's destruction of the cave body has compounded this decline, threatening the delicate ecosystem balance. The surrounding environment, especially the exokarst area, has been affected by reduced essential vegetation. This situation supports the overall biodiversity of the cave area. The lack of proper land use management in the surrounding karst region further exacerbates this issue, with limited efforts to maintain ecological sustainability in the area.

Additionally, the conservation focus of the Cagar Alam Gua Nglirip has primarily been on the cave complex itself. In contrast, the surrounding forest and exokarst ecosystems, which play a vital role in supporting the cave's ecological functions, have been overlooked. Such neglect has led to a mismatch in ecosystem diversity and composition between the cave's interior and its surrounding areas. The imbalance in vegetation, particularly the depletion of tree cover, significantly impacts the ecological stability of the cave and its catchment area. This condition affects both the cave fauna and the infiltration of water and minerals. These environmental challenges necessitate comprehensive conservation strategies to restore and protect the entire ecosystem.

With the aim of improving the ecological function of the cave area, the surface area of the Nglirip Cave Nature Reserve needs to be planted with tree species typical of the karst ecosystem.

Implementation of the Restoration Program. The implementation of the restoration program involves a strategic approach to address environmental degradation, particularly within the karst ecosystem of the Gua Nglirip Nature Reserve. UPTA, in collaboration with the BBKSDA, launched a restoration program in early 2024. This program focuses on the reforestation of the area with endemic plant species, specifically the Beringin (Ficus benjamina) and Beringin Kimeng (Ficus macrocarpa), to help restore the natural ecosystem. The aim is to enhance the capacity of the area's groundwater reserve, restore biodiversity, and improve carbon absorption, which had been threatened by deforestation and limestone mining activities. The project is part of a larger conservation effort, utilizing both scientific collaboration and local expertise to bring about long-term environmental benefits.

The implementation process began with collaboration between the various stakeholders, formalized through a memorandum of understanding (MoU). After securing approval, the planting of 1,000 trees took place, with ongoing monitoring and maintenance. To protect these newly planted trees from wildlife damage, a protective "Ficus in Shield" method was used, involving metal shields around the trunks of saplings to deter landak (porcupines) from damaging the trees. Following the initial planting phase, continuous monitoring will track the health of the plants, measure improvements in biodiversity, assess carbon sequestration, and evaluate the health of underground water systems, ensuring the effectiveness of the program. A year after the trees were planted, the project will undergo an evaluation to assess the outcomes and inform future phases.

Plant Protection Methods. The plant protection methods outlined in the report focus on safeguarding newly planted trees in the Gua Nglirip conservation area. One of the primary methods used is the “Ficus in Shield” technique. The use of selected tree species like Ficus benjamina and Ficus macrocarpa is intentional due to their high-water retention capabilities. These species are particularly effective in restoring the area's water balance, which is critical in maintaining the underground water reserves in the region. This feature is particularly relevant in areas experiencing drought, as indicated by meteorological data for the Tuban region. The project focuses on planting 1,000 trees, which, through their robust root systems, are expected to help improve the water retention capacity of the soil and restore biodiversity in the area.

Environmental Impact of the Program. The environmental impact of our program will be significant in the future, as it directly addresses the damage caused by deforestation and limestone mining. By planting endemic plants, such as Ficus benjamina, we can enhance the local ecosystem. Ficus macrocarpa aims to restore the ecosystem by improving water retention, supporting biodiversity, and increasing carbon absorption. This initiative not only aids in the stabilization of the karst ecosystem but also mitigates the harmful effects of soil erosion and loss of wildlife habitats caused by previous deforestation. The program has contributed to the overall improvement of the area's biodiversity index, demonstrating progress in the restoration of both flora and fauna diversity. The increased tree coverage helps provide shelter for avifauna, insects, and small mammals while also replenishing crucial groundwater supplies for the Tuban region and its surrounding areas. The "Ficus in Shield" method, which protects young plants from herbivores like land snails, ensures the long-term growth and sustainability of these trees. The positive environmental effects can be observed through the upward trend in the biodiversity index, reflecting the success of the restoration efforts in the Cagar Alam Gua Nglirip.

Flora Diversity Index. The karst ecosystem restoration initiative within the Nglirip Cave Nature Reserve, employing the use of endemic plant species, has introduced systemic alterations that significantly influence the flora biodiversity index of the region. As a foundational measure in launching this program, a total of 1,000 Banyan (Ficus benjamina) and Kimeng (Ficus macrocarpa) trees were introduced through planting activities (as shown in Table 1). These initiatives aim to restore the natural habitat, improve soil stability, and enhance the overall ecological balance. By prioritizing endemic species, the initiative supports long-term sustainability and strengthens the resilience of the karst ecosystem against environmental degradation and human impact.

Table 1. Absolute Table of Karst Ecosystem Restoration Program in the Nglirip Cave Nature Reserve Area with Endemic Plants

No	Activities	In numbers over the year		Unit of measurement
		2020-2023	2024	
	Ecosystem restoration program			
1	Banyan (Ficus benjamina)	-	500	Stem
2	Kimeng (Ficus macrocarpa)	-	500	Stem

The increase in the flora biodiversity index within the Nglirip Cave Nature Reserve reflects a gradual recovery of the ecosystem, which had previously suffered from forest and limestone cave exploitation. As depicted in Fig. 9, the index demonstrates a notable rise in 2024 relative to 2023, with an increase of 0.847.

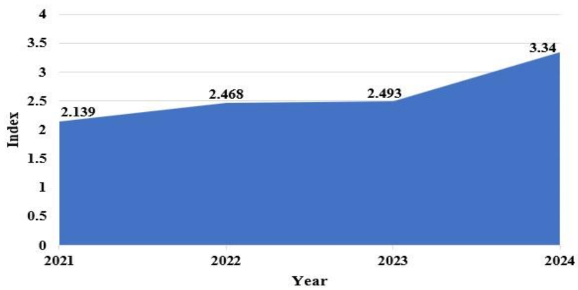

Figure 9. The trendline of the biodiversity index (H') for flora within the karst ecosystem restoration program in the Nglirip Cave Nature Reserve highlights the presence of endemic plant species

Budget. The restoration program is allocated a budget of IDR 453,278,653 to cover the procurement and planting of 500 banyan trees (Ficus benjamina) and 500 Kimeng banyan trees (Ficus microcarpa), as well as area maintenance, monitoring, and the provision of other supporting facilities.

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CONCLUSION

The restoration program implemented in the Nglirip Cave Nature Reserve has shown promising results in improving the local karst ecosystem, which had been severely impacted by deforestation and limestone mining activities. The planting of 1,000 endemic plants, including Ficus benjamina and Ficus macrocarpa, has successfully enhanced the biodiversity index for both flora and fauna. The introduction of these species has not only contributed to the restoration of the ecosystem but has also improved water retention capacity, supporting the sustainable management of groundwater reserves. The use of innovative plant protection techniques, such as the "Ficus in Shield" method, has ensured the survival and growth of these plants, mitigating damage from herbivores like porcupines. Through these efforts, the program has made significant progress in addressing the ecological challenges faced by the Nglirip Cave Nature Reserve and surrounding areas, demonstrating the effectiveness of collaborative, multi-stakeholder initiatives in restoring karst ecosystems.

In conclusion, the restoration program has successfully contributed to the revitalization of the Nglirip Cave ecosystem, improving both ecological stability and biodiversity. The increase in the flora biodiversity index highlights the success of the intervention in restoring the natural habitat and supporting various species. Additionally, the program's focus on water conservation and carbon sequestration offers long-term benefits for the region, mitigating the effects of drought and contributing to climate change resilience. The positive outcomes of the program serve as a model for future restoration projects in similar karst environments, emphasizing the importance of protecting biodiversity, maintaining water reserves, and ensuring ecosystem sustainability.

Recommendations for Further Research. Future research should focus on expanding the monitoring and evaluation processes to assess the long-term ecological impacts of the restoration program on both the flora and fauna of the Nglirip Cave Nature Reserve. It is essential to conduct a more detailed investigation into the specific roles that endemic plants, such as Ficus benjamina and Ficus macrocarpa, play in restoring the water retention capacity of the karst ecosystem. Additionally, further studies should explore how these plants interact with other species within the ecosystem, particularly in relation to improving biodiversity and stabilizing soil. Long-term data collection on the survival rates of these plants, their growth patterns, and their influence on local wildlife will provide valuable insights into the sustainability and effectiveness of the restoration efforts over time.

Another avenue for future research is the evaluation of the "Ficus in Shield" plant protection method. While this innovative approach has shown promise, further studies are needed to explore its applicability and effectiveness in different environmental contexts, particularly in areas with varying degrees of herbivore pressures. Researchers should also examine the economic feasibility and scalability of this method, considering its potential for wider application in other restoration programs. Lastly, it would be beneficial to investigate the socio-economic impacts of the restoration program on the local communities, including any changes in local livelihoods, awareness of environmental issues, and involvement in conservation activities. This holistic approach will ensure that the program not only restores the ecological balance but also contributes to the well-being of the surrounding communities.

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