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Degraded Forest Evaluation Using Vegetation Indices at Bandealit Resort, Meru Betiri National Park

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ABSTRACT

The forest degradation and deforestation was widely occurred in Indonesia and Meru Betiri National Park is one of the area with illegal loggings threats. Bandealit Resort as one of the resort in Meru Betiri National Park was reported as the area with high activity of illegal loggings specifically in 2020. Based on this information, this research study aims to evaluate the degraded level of the forests using Normalized Difference Vegetation Index and Enhanced Vegetation Index (NDVI and EVI) so it can be managed and evaluated in the future. This research use direct and indirect observation methods in three areas with different damage levels. Direct observation was done by counting the number of species and the stands trees, while the indirect observation was analyzing the Landsat 8 Imagery in 2020, 2021 and 2022. The results showed that the A area had the lowest density with only 45 remaining trees than two others with more than 150 trees. The greenness levels imply the quality level of tree stand density, as higher the tree stand density, the higher the greenness. NDVI and EVI showed that A area had the range from low greenness (sparse density) to high greenness (medium density) than two others area had the higher greenness and densities.

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INTRODUCTION

Forest degradation and deforestation have similar meanings, but there is a distinction between the two. Deforestation refers to the conversion of forested land into another land use or the reduction of tree canopy cover to less than 10% (Pacheco *et al*., 2021; Wahyuni & Suranto, 2021). In contrast, forest degradation is defined as the result of human activities that negatively impact the products and services of forests by damaging or destroying their composition, structure, and functions (Ghazoul *et al*., 2015; Vásquez-Grandón *et al*., 2018). Both forest degradation and deforestation at a large scale contribute to biodiversity loss, natural disasters, and climate change, driven by factors such as urban expansion, forest fires, agriculture, and plantations (Oljirra, 2019; Pacheco *et al*., 2021)

According to Austin *et al*. (2019), palm oil plantations have contributed to 23% of deforestation in Indonesia, followed by mixed plantations at 22%, land conversion at 20%, and illegal logging at 10%. In the Bandealit resort area of Meru Betiri National Park (MBNP), human activities have degraded the forest, with illegal logging as the primary cause. In 2020, illegal logging activities were monitored, showing that Teak trees (*Tectona grandis*) were frequently targeted due to their abundance and high market value. Forest degradation can be mitigated through timely monitoring, both by direct observation and remote sensing methods such as vegetation indices, which are commonly used to track changes in the forest canopy (Tacconi *et al*., 2019). Vegetation indices measure canopy greenness by calculating the ratio of specific wavebands. Two commonly used indices are the NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) (Elhag *et al*., 2021). NDVI uses two wavebands (red and near-infrared) to detect and map vegetation changes, while EVI is an optimized index that combines three wavebands (red, near-infrared, and blue) to reduce biases from the canopy background and aerosol variations (Huete, 2012). Both NDVI and EVI are valuable tools for monitoring vegetation canopy and land cover changes spatially and temporally (Gao *et al*., 2021; Hartoyo *et al*., 2021; Othman *et al*., 2018).

As mentioned earlier, forest degradation has occurred in the Bandealit Resort area (Budiarta, 2016). A survey conducted in September - October 2021 revealed that parts of the Bon Pantai forest, located within Bandealit Resort, MBNP, have been degraded due to illegal logging. The cleared areas were subsequently converted into agricultural land for crops such as elephant grass (*Pennisetum purpureum*), porang (*Amorphophallus muelleri*), bananas (*Musa* sp.), and cassavas (*Ipomoea batatas*). Given this situation, the condition of the Bon Pantai forest in Bandealit Resort, MBNP, needs to be evaluated using vegetation indices like NDVI and EVI. This research project aims to assess the greenness level of the degraded forest in the Bon Pantai area of Bandealit Resort, MBNP

MATERIALS AND METHODS

Study Area

The research study was conducted in three lowland tropical rain forest areas within the Bandealit Resort, MBNP, located administratively in Jember Regency, East Java, Indonesia (Figure 1). The national park is geographically positioned between coordinates 113° 037’ 23” - 113° 058’ 11” east longitude and 8° 020’ 31” - 8° 035’ 09” south latitude. The study focused on three forest areas with varying conditions to compared in their tree density, species composition, NDVI and EVI value. Area A is highly degraded due to illegal logging and land conversion activities into agricultural land. The area A was already cultivated since this observation and research started. Secondly, Area B was originally secondary forest and had moderate damage of degradation due to illegal logging but without any land conversion activities. Thirdly, Area C is an undisturbed primary forest and serving as the reference forest for this research study.

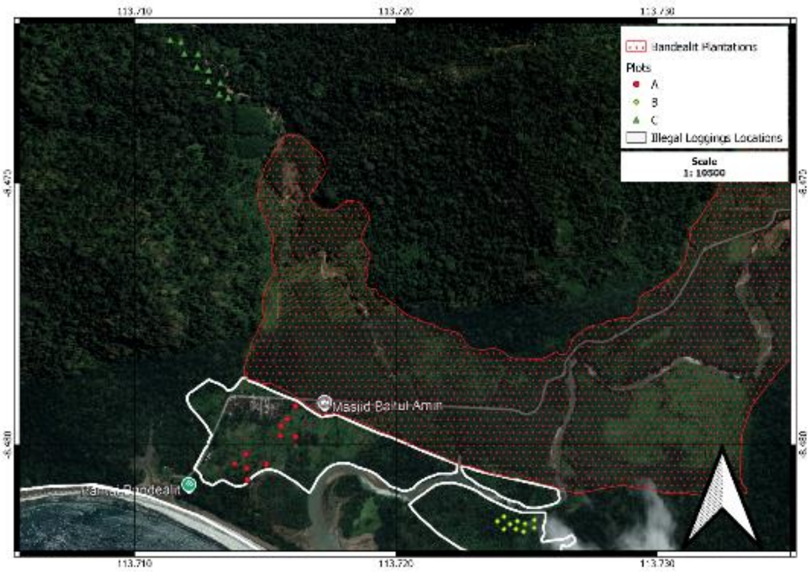

Figure 1. Research location based on Google Earth Imaginary on May 2020

Field Data Collection

The field survey was conducted to collect data on tree species and their numbers within 10 x 10 m2 plots. A total of 10 sample plots were selected purposively, taking into account the representativeness of forest cover conditions and field topography. Data were collected for all tree species with a diameter of ≥ 2 cm.

Greenness Level Estimation

The greenness level of the tree stand canopy was estimated using vegetation indices analysis, specifically NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index). These indices were analyzed using Landsat 8 imagery data from the period 2020 to 2022. The Landsat 8 imagery used was from path 117 and row 066, captured in August 2020, July 2021, and September 2022. The imagery data were processed using QGIS 3.22.7, with atmospheric correction applied to minimize distortions before analyzing the vegetation indices. These Landsat data was analyzed in NDVI and EVI to obtain the value of each plots to compared between area A, B and C which had different condition. NDVI was analyzed and calculated using Equation 1, while EVI using Equation 2. The results were classified into five categories for NDVI and six categories for EVI to simplify the result data (Sobhani *et al*., 2018; Solihin *et al*., 2020).

$$NDVI = \frac{N-R}{N+R} \qquad (1)$$

$$EVI = G\frac{N-R}{N+C_1R-C_2B+L} \qquad (2)$$

Where N, R, and B represent atmospherically corrected or partially corrected surface reflectances in the near-infrared, red, and blue bands, respectively; G is a gain factor, set at 2.5; C1 and C2 are the coefficients for the aerosol resistance term, which are 6 and 7.5, respectively; and L is the soil-adjustment factor, set at 1.

RESULTS AND DISCUSSION

Species Composition

The number of species found in Area C was higher than in Areas A and B (Table 1). Tree density in each area reflected different levels of degradation. In Area A, there were 45 standing trees remaining from illegal logging. These trees were identified by their large diameter trunks, which were similar in size to the stumps left behind. In contrast, both Areas B and C had a higher density of standing trees. Area B contained 198 standing trees, 158 of which had an average trunk diameter of 9.5 cm, while 40 were larger-diameter trees left from logging. Area C, predominantly filled with 198 standing trees, had an average trunk diameter of 12.4 cm. The loggers selectively cut the larger trees, leaving the smaller and medium-sized ones. This observation aligns with the results of this study, where the remaining trees were larger in diameter, and the stumps were of similar size. The success of illegal logging was facilitated by the cooperation between loggers, investors, and law enforcement. This is supported by (Nazia *et al*., 2013), who noted that loggers received permits and guarantees from law enforcement to avoid arrest during illegal logging in the forest. This issue continues to be a challenge in Indonesia's efforts to protect its forests, leading to degradation where only medium to small trees remain. Selective logging, where larger trees are targeted, can significantly alter the forest structure. Larger trees often play key roles in the ecosystem, providing habitats, maintaining canopy cover, and contributing to nutrient cycles. As mentioned by (Hosonuma *et al*., 2012), selective logging is responsible for 51 % of the forest disturbances in Asia and Latin America. The removal of these trees can lead to changes in microclimates, reduced biodiversity, and disruption of ecological processes (Santos *et al*., 2024). As smaller and medium-sized trees are left behind, they may struggle to grow in degraded environments where sunlight, water, and nutrient distribution are altered.

Table 1. the number of found species and trees in three research area

Area	Number of Species	Number of Trees				
		ø>10	5< ø<10	2< ø<5	ø <2	Total
A	14	42	3	0	0	45
B	20	40	30	120	8	198
C	25	47	49	36	26	158

Small trees (diameter <10 cm) were predominantly found in Area B, comprising 79.8% of the trees in the plots. This indicates that the early stages of the succession process following logging are already underway. Small trees are often pioneer species that can quickly establish themselves in disturbed areas (Goodale *et al*., 2012). They typically possess adaptations such as fast growth rates and high seed dispersal capabilities, which enable them to take advantage of the newly available resources after logging. In Area C, the average trunk diameter was 12.4 cm, suggesting that succession is approaching a more stable condition with reduced competition among species. In forest ecosystems, trunk diameter is often used as a proxy for tree age and health, with larger diameters typically reflecting older, more established trees. The research study revealed that Area B experienced higher levels of disturbance from logging and other human activities, as indicated by the presence of Teak trees, which were of similar size to those in Area A. In contrast, no Teak trees were found in Area C, leading to fewer disturbances from human activities. This observation is supported by Lutz *et al*. (2013); Oo *et al*. (2021), and Zaytsev *et al*. (2019), who noted that trees in less disturbed areas tend to have larger trunks and fewer seedlings due to competition and dominance by larger trees. Conversely, disturbed forests typically have a higher proportion of smaller trunks and a greater number of seedlings, reflecting the early stages of the succession process. This is a result of the disturbance event (e.g., logging, natural disasters) that removes larger, mature trees, thereby allowing smaller trees and seedlings to dominate the landscape. The smaller trunks represent the early stages of growth and recovery following disturbance.

Evaluation of the forest degraded level using Vegetation Indices (NDVI and EVI)

The greenness levels of these areas were analyzed using the NDVI and EVI indices at every coordinate within each plot. In 2020, illegal logging began in Areas A and B, while Area C remained untouched and was designated as a recovery forest due to its abundance of small to medium-sized tree trunks. The findings indicated a sharp decline in the absence of vegetation, a minor decline in sparse vegetation, and a significant rise in dense vegetation. These results were depend on its abundance and dense the vegetation canopy, more dense and abundance the vegetation will cover the soil surface and increase the NDVI value due to its calculation on soil surface reflection (Khairunnisa *et al*., 2024). The same results were found in EVI as mentioned by Hasanah *et al*. (2020) that in area with high tree density will increase the EVI value. NDVI and EVI results in this research was obtained from August 2020 showed that Area A exhibited high greenness, although some patches displayed brighter colors, indicating lower greenness. In contrast, Areas B and C showed greener hues, suggesting a higher tree density than Area A. The brighter green in Area A showed that the vegetation cover was lower than two Areas due to the logging that cleared the area from the herbs and shrubs for the initial land conversion into agricultural land. Area B had more green colors due to less disturbance as the logger pay more attention to area A that had more Teak trees than in area B while in area C with no Teak was remain untouch.

One year after logging in July 2021, revealed that Area A had brighter colors compared to the other two areas, implying that illegal logging significantly impacted all areas, including Area C, albeit to a lesser extent. The bright patches in Area A were primarily due to land conversion for agriculture, while Areas B and C maintained their greener appearance as they began to recover naturally through ecological succession. The greenness of an area, as indicated by NDVI and EVI values, serves as an important proxy for assessing forest health and vitality, brighter patches indicating lower tree density and lower canopy cover. As mentioned by Morales-Gallegos *et al*. (2023), the health of forest could be detected by its canopy conditoin such as canopy density and the vegetation indices such as NDVI and EVI could detect and analyzed the tree density and canopy density, as more dense the forest and its canopy, increase the NDVI and EVI value. Both indices showed that all three areas were affected by illegal logging, with Area A displaying more bright patches than the others. These results showed that the health of area A as a forest was in bad or poor condition while the area B and C area was showed in good health condition due to the growth of young vegetation.

The growth of vegetation after logging was evidenced by the NDVI and EVI analyses in July 2021 (Figure 2b). The NDVI analysis indicated that Area A changed from partially green in August 2020 to brighter in July 2021 due to land conversion, while Areas B and C displayed more bright green patches than in August 2020. Similar results were observed in the EVI analysis, with brighter patches in Area A being more extensive than those in Areas B and C. The clearer patches in Area A were already converted for agriculture, featuring crops like Porang (*Amorphophallus muelleri*), bananas (*Musa* sp.), and cassava (*Ipomoea batatas*). In Area B, seedlings and shrubs were growing due to the succession process. Badraghi *et al*. (2023) stated that the initial of succession will had more diverse in number of species and seedlings. Area C showed changes in vegetation cover related to seasonal variations transitioning into summer. These findings align with Baratto *et al*. (2024), which noted that NDVI and EVI can be influenced by changes in climate, seasonal temperature, and total rainfall**.**

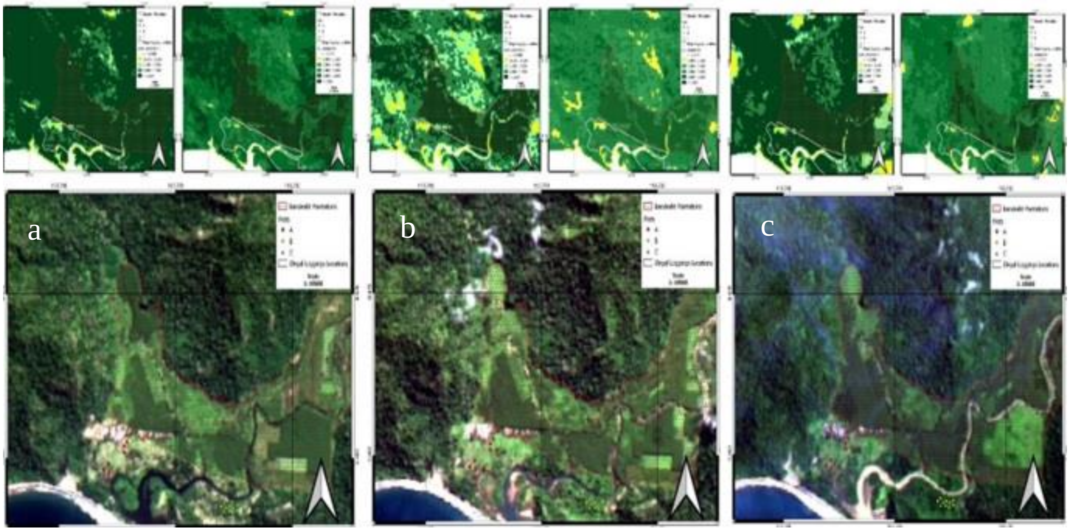

Figure 2. Landsat 8 Imagery (below), NDVI (left), EVI (right) in August 2020 (a) in July 2021 (b), in September 2022 (c)

Recently captured Landsat imagery data from September 2022 revealed changes in the NDVI, EVI, and the imagery itself (Figure 2c). The NDVI and EVI results indicate that these three areas became greener in 2022 compared to 2021. This increase in greenness in Area A is attributed to the growth of agricultural plants, as local communities predominantly cultivate shrubs and herbs for their cattle. In contrast, Areas B and C experienced significant growth of seedlings and younger trees, which nearly covered the land surface as they competed for nutrients in the soil. These two areas can be categorized as undergoing a succession process that has led to more stable ecological conditions. As forest patches develop, species diversity in secondary forests may increase, eventually reaching the high species diversity characteristic of late successional mixed deciduous forests (Verburg *et al*., 2001), which can be visualized using NDVI and EVI metrics. Dense vegetation affects the brightness of the green levels, as illustrated in Figure 2. These changes in the areas are also visible in the Landsat imagery as the loss of major trees in area A and B while in C had no changes.

The Landsat 8 imagery from September 2022 indicated that Area A had become greener, although the loss of trees remained visible and distinguishable from the agricultural shrubs and herbs. The B forest area exhibited a notable improvement in greenness compared to the previous year, indicating a positive response to environmental conditions and conservation efforts. This enhancement in vegetation was primarily due to the active growth of shrubs, herbs and especially the younger trees, which are playing a crucial role in recovering the tree cover that had been lost due to disturbances (Nikolova *et al*., 2019). These young trees are not only increasing the overall biomass of the forest but also contributing to the ecological balance by providing habitat and resources for various species. As they mature, these trees will further enrich the forest structure, promoting greater biodiversity and resilience in the ecosystem. In contrast, the C forest area continued to maintain a good and green condition with the abundance of younger trees will keep consistent with the previous two years and could be increase in the next year.

A comparison of the NDVI and EVI values for each plot across the three areas revealed that the values in Area A tended to be lower than those in the other two areas, reflecting its lower greenness and tree density (Table 2). These low values suggest that logging activities have contributed to a decrease in vegetation cover and tree density. Hall *et al*. (2003) note that logging impacts forest structure and composition, leading to reduced tree density and promoting a shift in floristic composition by favoring the regeneration of pioneer species. This analysis can illustrate the historical conditions of the forest areas before and after logging, based on the measured greenness values.Although the NDVI value was slightly more accurate than the EVI, both values conveyed similar meanings. This finding aligns with the statements of Situmorang *et al*. (2016) and Yudistira *et al*. (2019), which noted that both NDVI and EVI exhibit high accuracy in detecting and analyzing vegetation changes.

Table 2. Comparison between NDVI and EVI Value in Three Research Area

Plots	NDVI	Greenness	EVI	Density
2B	0,1794	Low	0,2184	Sparse
1B	0,2137	Low	0,2656	Sparse
7A	0,2986	Moderate	0,3154	Sparse
10A	0,3001	Moderate	0,6119	Dense
3B	0,3137	Moderate	0,3866	Sparse
1A	0,3383	Moderate	0,4989	Moderate
9A	0,3508	High	0,5271	Moderate
2A	0,3559	High	0,3678	Sparse
8A	0,3800	High	0,5930	Moderate
3A	0,3838	High	0,5596	Moderate
4A	0,3903	High	0,5682	Moderate
5C	0,3939	High	0,6041	Dense
6A	0,4027	High	0,6118	Dense
1C	0,4037	High	0,6865	Dense
5A	0,4091	High	0,6465	Dense
4C	0,4127	High	0,6274	Dense
3C	0,4210	High	0,6565	Dense
4B	0,4218	High	0,3872	Sparse
5B	0,4280	High	0,6444	Dense
6C	0,4331	High	0,6992	Dense
7C	0,4412	High	0,7185	Dense
2C	0,4446	High	0,7018	Dense
9C	0,4478	High	0,7306	Dense
8B	0,4500	High	0,7487	Dense
7B	0,4617	High	0,7410	Dense
6B	0,4635	High	0,6446	Dense
10C	0,4724	High	0,7408	Dense
10B	0,4737	High	0,7815	Dense
8C	0,4837	High	0,7313	Dense
9B	0,4930	High	0,7859	Dense

Both the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) are widely recognized for their high accuracy in detecting and analyzing vegetation changes. NDVI is a measure that utilizes the red and near-infrared bands of the electromagnetic spectrum to assess vegetation health. It effectively highlights the contrast between the high reflectance of healthy vegetation in the near-infrared range and the lower reflectance in the red range. This sensitivity allows NDVI to detect and assess the vegetation cover, Biomass, growth and plant vigor (Xue & Su, 2017). This useful vegetation index was often used and being a valuable tool in ecological and agricultural studies due to simplyfication the complex data and could provide useful data (Huang *et al*., 2021). EVI, on the other hand, is designed to improve upon NDVI by reducing atmospheric interference and soil background effects. By incorporating additional spectral bands, EVI provides a more nuanced understanding of vegetation cover and dynamics, particularly in densely vegetated areas where NDVI being saturated (Huang *et al*., 2021; Zhang *et al*., 2023). This capability makes EVI particularly useful for monitoring changes in vegetation in various ecosystems, including tropical and subtropical regions. Both indices have been extensively validated through ground-truthing and remote sensing studies, demonstrating their reliability in assessing vegetation changes over time. For instance, studies have shown that NDVI and EVI can accurately reflect seasonal variations in vegetation, detect responses to environmental stressors, and monitor the effects of land-use changes such as deforestation or agricultural expansion.

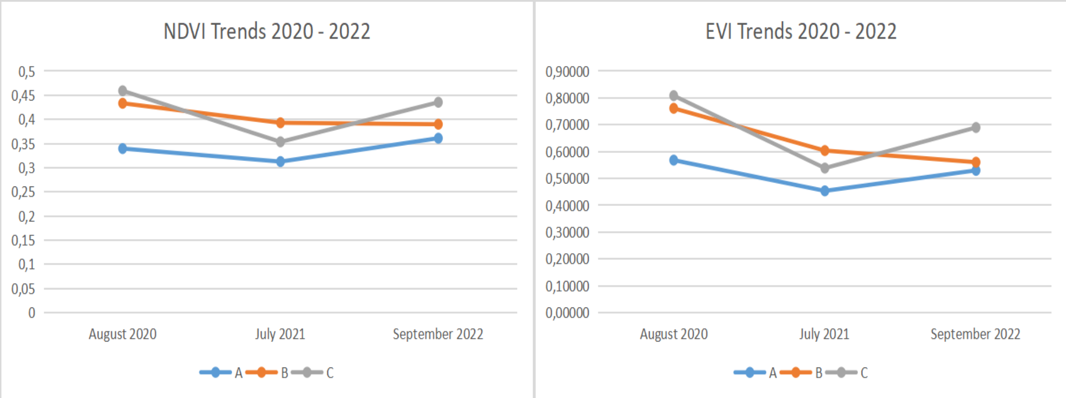

Figure 3. Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI)Trends in 2020 – 2022

The NDVI and EVI analyses of each plot in these three areas revealed a downward trend in 2021, followed by an increase in 2022 (Figure 3). In 2021, the observed decline in these indices signifies a significant impact of illegal logging disturbances, which likely led to substantial changes in the forest structure. As logging activities were carried out, there was a marked decrease in greenness and canopy cover between 2020 and 2021. This reduction can be attributed to the removal of mature trees, which are vital for maintaining forest density and health. The loss of these trees not only diminished the overall biomass but also disrupted the habitat for various species, leading to increased vulnerability of the remaining vegetation (Arzoo *et al*., 2022). However, the subsequent increase in NDVI and EVI values in 2022 suggests a positive response from the ecosystem. This recovery could be attributed to the natural regrowth of vegetation, which includes the emergence of younger trees and understory plants that began to reclaim the disturbed areas. The increase in greenness indicates that ecological processes, in this case is natural succession, on its process, allowing the forest to gradually recover its structure and biodiversity (Yuniasih, 2009). This condition was align with Berveglieri *et al*. (2021) who mentioned that the vegetation indices could be used as the monitoring tools to assess the succession process. This upward trend highlights the resilience of the ecosystem and underscores the importance of monitoring vegetation changes over time to assess the long-term effects of disturbances like illegal logging.

Although there was an improvement in greenness in 2022, it fell short of the levels recorded in 2020. This indicates that while recovery processes were underway, the ecosystem had not fully regained its former vitality. The overall decline in greenness during 2021 reflects the significant impact of disturbances, such as illegal logging, which altered the forest structure and reduced overall canopy cover. Despite some recovery in 2022, the NDVI and EVI analyses show that greenness levels remained lower compared to those from two years prior, reinforcing the notion that the forest's ecological balance had been disrupted. The changes in vegetation health and structure are also vividly illustrated in the Landsat 8 imagery, which provides a visual representation of the forest's condition over time. These images complement the quantitative data obtained from NDVI and EVI analyses, together forming a comprehensive understanding of the forest dynamics following disturbances.

In light of these findings, it is crucial for government and national park authorities to evaluate and implement effective conservation strategies aimed at enhancing forest density and promoting the recovery of greenness to previous levels. Such strategies may include reforestation efforts, protection of remaining forest patches, and monitoring programs to assess the effectiveness of restoration initiatives. By prioritizing these actions, authorities can help ensure the long-term health and resilience of the forest ecosystem, safeguarding it against future disturbances.

CONCLUSIONS AND SUGGESTION

Based on NDVI and EVI, the A forest area have lower greenness levels than those of the B and C forest area. The Landsat 8 Imagery real image showed that A area was the brightest area than two others with only a few big trees canopy in sight and followed by B area with the more cover of canopy from the younger trees, and C area with the complex canopy of young-old trees. It means that A area need to be managed and conserved by planting more trees to increase its tree density and greenness level. Both A and B forest areas need to be monitor regularly to guarantee their sustainability as secondary forest areas. For the future research, the observation of soil temperature, annual rainfall total, and more data annual of NDVI and EVI were needed to improve the data and information of this research.

REFERENCES

Arzoo, E., Bhatia, R., Singh, M. C., Singh, L., & Gowthami, G. V. (2022). Conservation of old trees – A review. *Journal of Ornamental Horticulture*, *25*(1and2), 97-104. https://doi.org/10.5958/2249-880x.2022.00015.9

Austin, K. G., Schwantes, A., Gu, Y., & Kasibhatla, P. S. (2019). What causes deforestation in Indonesia? *Environmental Research Letters*, *14*(2), 024007. https://doi.org/10.1088/1748-9326/aaf6db

Badraghi, A., Krůček, M., Král, K., Reitschmiedová, E., Šálek, V., Kotápišová, M., Novotná, B., & Frouz, J. (2023). Woody species succession and spontaneous forest development in post-mining sites after coal mining in the Czech Republic. *Ecological Engineering*, *194*, 107051. https://doi.org/https://doi.org/10.1016/j.ecoleng.2023.107051

Baratto, J., Terassi, P. M. de B., & Galvani, E. (2024). Changes in vegetation cover and the relationship with surface temperature in the cananéia–iguape coastal system, São Paulo, Brazil. *Remote Sensing*, *16*(18), 3460. https://doi.org/10.3390/rs16183460

Berveglieri, A., Imai, N. N., Christovam, L. E., Galo, M. L. B. T., Tommaselli, A. M. G., & Honkavaara, E. (2021). Analysis of trends and changes in the successional trajectories of tropical forest using the Landsat NDVI time series. *Remote Sensing Applications: Society and Environment*, *24*. https://doi.org/10.1016/j.rsase.2021.100622

Budiarta, I. W. (2016). *Penegakan hukum pelaku tindak pidana kehutanan oleh penyidik pegawai negeri sipil kehutanan di balai taman nasional meru betiri*. JURNAL RECHTENS. files/31/122-Article Text-235-1-10-20170614_2.pdf

Elhag, M., Boteva, S., & Al-Amri, N. (2021). Forest cover assessment using remote-sensing techniques in Crete Island, Greece. *Open Geosciences*, *13*(1), 345-358. https://doi.org/10.1515/geo-2020-0235

Gao, Y., Quevedo, A., Szantoi, Z., & Skutsch, M. (2021). Monitoring forest disturbance using time-series MODIS NDVI in Michoacán, Mexico. *Geocarto International*, *36*(15), 1768–1784. https://doi.org/10.1080/10106049.2019.1661032

Ghazoul, J., Burivalova, Z., Garcia-Ulloa, J., & King, L. A. (2015). Conceptualizing forest degradation. *trends in ecology & evolution*, *30*(10), 622-632. https://doi.org/10.1016/j.tree.2015.08.001

Goodale, U., Ashton, M., Berlyn, G., Gregoire, T., Singhakumara, B., & Tennakoon, K. (2012). Disturbance and tropical pioneer species: Patterns of association across life history stages. *Forest Ecology and Management*, *277*. https://doi.org/10.1016/j.foreco.2012.04.020

Hall, J. S., Harris, D. J., Medjibe, V., & Ashton, P. M. S. (2003). The effects of selective logging on forest structure and tree species composition in a Central African forest: Implications for management of conservation areas. *Forest Ecology and Management*, *183*(1-3), 249–264. https://doi.org/10.1016/S0378-1127(03)00107-5

Hartoyo, A. P. P., Sunkar, A., Ramadani, R., Faluthi, S., & Hidayati, S. (2021). Normalized Difference Vegetation Index (NDVI) analysis for vegetation cover in Leuser Ecosystem area, Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, *22*(3). https://doi.org/10.13057/biodiv/d220311

Hasanah, A., Supriatna, & Indrawan, M. (2020). Assessment of tropical forest degradation on a small island using the enhanced vegetation index. *IOP Conference Series: Earth and Environmental Science*, *481*(1). https://doi.org/10.1088/1755-1315/481/1/012061

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, *7*(4), 044009. https://doi.org/10.1088/1748-9326/7/4/044009

Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. In *Journal of Forestry Research* (Vol. 32, Issue 1). Northeast Forestry University. https://doi.org/10.1007/s11676-020-01155-1

Huete, A. R. (2012). Vegetation Indices, Remote Sensing and Forest Monitoring. *Geography Compass*, *6*(9), 513–532. https://doi.org/10.1111/j.1749-8198.2012.00507.x

Khairunnisa, S., Pamoengkas, P., Permatasari, A., & Hartoyo, P. (2024). *Journal of Natural Resources and Environmental Management Analysis of NDVI and Plant Vegetation Diversity in the Traditional Zone, Mount Halimun Salak National Park, Bogor*. https://doi.org/10.29244/jpsl.14.1.109

Lutz, J. A., Larson, A. J., Freund, J. A., Swanson, M. E., & Bible, K. J. (2013). The importance of large-diameter trees to forest structural heterogeneity. *PLoS ONE*, *8*(12), e82784. https://doi.org/10.1371/journal.pone.0082784

Morales-Gallegos, L. M., Martínez-Trinidad, T., Hernández-de la Rosa, P., Gómez-Guerrero, A., Alvarado-Rosales, D., & Saavedra-Romero, L. de L. (2023). Tree health condition in urban green areas assessed through crown indicators and vegetation indices. *Forests*, *14*(8). https://doi.org/10.3390/f14081673

Nazia, Z., Nugroho, R., Atikah, W., & Kalimantan, J. (2013). *Legal study about illegal logging in forest areas*. 11. files/49/Nazia et al. - 2013 - Legal Study About Illegal Logging In Forest Areas.pdf

Nikolova, P. S., Rohner, B., Zell, J., & Brang, P. (2019). Tree species dynamics in Swiss forests as affected by site, stand and management: A retrospective analysis. *Forest Ecology and Management*, *448*, 278–293. https://doi.org/10.1016/j.foreco.2019.06.012

Oljirra, A. (2019). The causes, consequences and remedies of deforestation in Ethiopia. *Journal of Degraded and Mining Lands Management*, *6*(3), 1747–1754. https://doi.org/10.15243/jdmlm.2019.063.1747

Oo, Y., Suanpaga, W., & Meunpong, P. (2021). Assessment of forest degradation condition in Natmataung National Park Watershed, Myanmar. *Biodiversitas Journal of Biological Diversity*, *22*(3). https://doi.org/10.13057/biodiv/d220336

Othman, M. A., Ash'Aari, Z. H., Aris, A. Z., & Ramli, M. F. (2018). Tropical deforestation monitoring using NDVI from MODIS satellite: A case study in Pahang, Malaysia. *IOP Conference Series: Earth and Environmental Science*, *169*(1). https://doi.org/10.1088/1755-1315/169/1/012047

Pacheco, P., Mo, K., Dudley, N., Shapiro, A., Aguilar-Amuchastegui, N., Ling, P. Y., Anderson, C., & Marx, A. (2021). *Deforestation fronts: Drivers and responses in a changing world*. WWF International. https://wwfint.awsassets.panda.org/downloads/deforestation_fronts___drivers_and_responses_in_a_changing_world___full_report_1.pdf

Santos, E. G., Svátek, M., Nunes, M. H., Aalto, J., Senior, R. A., Matula, R., Plichta, R., & Maeda, E. E. (2024). Structural changes caused by selective logging undermine the thermal buffering capacity of tropical forests. *Agricultural and Forest Meteorology*, *348*, 109912. https://doi.org/https://doi.org/10.1016/j.agrformet.2024.109912

Situmorang, J. P., Sugianto, S., & . D. (2016). Estimation of carbon stock stands using EVI and NDVI vegetation index in production forest of lembah seulawah sub-district, Aceh Indonesia. *Aceh International Journal of Science and Technology*, *5*(3), 126–139. https://doi.org/10.13170/aijst.5.3.5836

Sobhani, B., Abad, B., & Kefayat Motlagh, O. M. (2018). Identification of vegetation coverage seasons in Iran using Enhanced Vegetation Index (EVI). *Applied Ecology and Environmental Research*, *16*(4), 3861–3872. https://doi.org/10.15666/aeer/1604_38613872

Solihin, M. A., Putri, N., Setiawan, A., Siliwangi, D., & Arifin, M. (2020). Karakteristik indeks vegetasi pada berbagai penggunaan lahan di hulu sub DAS Cikapundung melalui interpretasi citra satelit landsat 8. *Kultivasi*, *19*(3). https://doi.org/10.24198/kultivasi.v19i3.28625

Tacconi, L., Rodrigues, R. J., & Maryudi, A. (2019). Law enforcement and deforestation: lessons for Indonesia from Brazil. *Forest Policy and Economics*, *108*, 101943. https://doi.org/10.1016/j.forpol.2019.05.029

Vásquez-Grandón, A., Donoso, P., & Gerding, V. (2018). Forest degradation: When is a forest degraded? *Forests*, *9*(11), 726. https://doi.org/10.3390/f9110726

Verburg, R., Heil, G. W., & Baas, P. (2001). *Secondary forest succession of rainforests in East Kalimantan: a preliminary data analysis*. https://www.researchgate.net/publication/46609591

Wahyuni, H., & Suranto, S. (2021). Dampak deforestasi hutan skala besar terhadap pemanasan global di Indonesia. *JIIP: Jurnal Ilmiah Ilmu Pemerintahan*, *6*(1), 148-162. https://doi.org/10.14710/jiip.v6i1.10083

Xue, J., & Su, B. (2017). Significant remote sensing vegetation indices: A review of developments and applications. In *Journal of Sensors* (Vol. 2017). Hindawi Limited. https://doi.org/10.1155/2017/1353691

Yudistira, R., Meha, A. I., Yulianto, S., & Prasetyo, J. (2019). Perubahan konversi lahan menggunakan NDVI, EVI, SAVI dan PCA pada citra landsat 8 (Studi Kasus : Kota Salatiga). *Indonesian Journal of Computing and Modeling*, *1*, 25–30.

Yuniasih, B. (2009). *Suksesi Vegetasi Gunung Merapi Meggunakan Indek Ndvi Succession Of Vegetation In Merapi Volcano Using NDVI Index*.

Zaytsev, D. A., Danilov, D. A., & Navalihin, S. V. (2019). The effect of tree distribution by diameter classes on the density of pine and spruce trees in mixed coniferous forest stands without forestry impact. *IOP Conference Series: Earth and Environmental Science*, *226*, 012066. https://doi.org/10.1088/1755-1315/226/1/012066

Zhang, P., Liu, H., Li, H., Yao, J., Chen, X., & Feng, J. (2023). Using enhanced vegetation index and land surface temperature to reconstruct the solar-induced chlorophyll fluorescence of forests and grasslands across latitude and phenology. *Frontiers in Forests and Global Change*, *6*. https://doi.org/10.3389/ffgc.2023.1257287