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Structural degradation of community-managed mangroves under illegal logging pressure in Lubuk Kertang, North Sumatra, Indonesia

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Abstract. *Onrizal, Ratua D. 2026. Structural degradation of community-managed mangroves under illegal logging pressure in Lubuk Kertang, North Sumatra, Indonesia. Biodiversitas 27 (4): d270440. https://doi.org/10.13057/biodiv/d270440*. Illegal logging is a major pressure on mangrove ecosystems, but field-based evidence that links ecological condition with community perception remains limited in Indonesia. This study assessed whether mangrove structure and health differed between two stations with contrasting disturbance levels in Lubuk Kertang Village, North Sumatra, and how local people perceived current mangrove condition and management priorities. Vegetation was sampled in nested seedling, sapling, and tree plots along two 300-m transects, and community structure, importance value index, and Mangrove Health Index (MHI) were calculated. Perceptions were analyzed from an 11-item Likert questionnaire administered to 52 respondents. Ecological differences between stations were evaluated using independent t-tests or Mann-Whitney U tests, depending on data distribution. Station I contained seven species and showed moderate condition (MHI 56.27%), whereas Station II contained six species and showed poor condition (MHI 32.95%). The disturbed station had significantly lower canopy cover, tree density, seedling abundance, basal area, mean stem diameter, and mean height, while felled stands occurred only at that station. Respondents strongly acknowledged mangrove benefits, recognized ongoing degradation, and supported stricter supervision, sanctions, and rehabilitation. Taken together, the results indicate that illegal logging in Lubuk Kertang is associated more strongly with structural degradation than with immediate local species loss. These findings support two near-term management priorities: stronger protection of remaining higher-integrity stands and hydrology-informed restoration of degraded and abandoned-pond areas.

Keywords: Community-based management, illegal logging, mangrove health index, North Sumatra, vegetation structure

INTRODUCTION

Mangrove forests support shoreline stabilization, wave attenuation, fisheries production, biodiversity, and very large ecosystem carbon stocks, making them central to both coastal resilience and climate-mitigation agendas (Barbier et al. 2013; Donato et al. 2011; Horstman et al. 2014). Mangroves are among the most carbon-rich tropical forests, with average ecosystem carbon storage of about 1023 Mg C/ha, much of it stored below ground in organic-rich soils (Donato et al. 2011; Alongi 2014). Loss or degradation of mangroves therefore has consequences that extend well beyond local timber extraction, including reduced habitat complexity, weaker coastal protection, and potentially large blue-carbon emissions (Alongi 2014; Murdiyarso et al. 2015; Hamilton and Friess 2018).

Indonesia is globally important for mangrove conservation, yet its mangroves have long been pressured by aquaculture expansion, timber harvesting, and other land-use change (Ilman et al. 2016; Hagger et al. 2022). A historical analysis showed that mangroves in Indonesia have been systematically exploited since the nineteenth century and that aquaculture remains the dominant driver of change, followed by other land conversion pressures (Ilman et al. 2016). At the global scale, social-ecological conditions strongly shape whether mangroves are lost or recovered, and community forestry can support mangrove expansion where governance and local institutions function effectively (Hagger et al. 2022; Damastuti et al. 2022).

Degradation by logging often affects stand structure more strongly and more rapidly than local species richness. Selective logging and other disturbances can reduce canopy cover, biomass, tree density, and habitat complexity, while shifting stands toward simplified composition (Nordhaus et al. 2019). Conversely, evidence from regulated production forests in Indonesia shows that managed selective logging may retain a large share of ecosystem carbon stocks, implying that unregulated and illegal cutting in community-managed sites is likely to be ecologically more damaging than formal, controlled harvest systems (Murdiyarso et al. 2021).

Ecological outcomes in mangroves are inseparable from local perceptions, governance quality, and the legitimacy of management rules. Stakeholder perceptions can reveal which pressures are socially salient, while clearly defined roles, benefit-sharing, and credible enforcement are repeatedly identified as prerequisites for durable mangrove management (Arumugam et al. 2020; Nyangoko et al. 2022). Community-based management in Indonesia can improve biodiversity outcomes, but only when local institutions, monitoring, and restoration actions are well aligned (Arifanti et al. 2022; Damastuti et al. 2022).

Lubuk Kertang Village in Langkat District, North Sumatra, represents a relevant case because it combines community-based mangrove management, rehabilitation efforts, abandoned-pond landscapes, and renewed illegal logging pressure. Previous work in the same landscape showed that restored abandoned ponds can recover vegetation growth and carbon-storage potential (Amelia et al. 2023), but that line of work did not explicitly compare relatively intact stands with presently degraded stands or examine whether local perceptions are aligned with field-based ecological signals. The present study therefore advances the local evidence base by integrating direct vegetation and mangrove-health measurements with community perception data within the same management landscape. This combination is important because it helps distinguish whether degradation is expressed mainly through species loss or through structural simplification that has more immediate implications for canopy condition, regeneration, and management response. We specifically aimed to: (i) quantify mangrove composition, structure, and health at two stations with contrasting disturbance levels; (ii) evaluate community perceptions of mangrove condition, degradation drivers, and management; and (iii) derive management implications for protection and hydrology-informed restoration of degraded mangroves. We expected a priori that the station categorized as more disturbed would retain similar or only slightly lower species richness, but would show markedly lower structural condition, canopy cover, regeneration, and MHI than the relatively undisturbed station.

MATERIALS AND METHODS

Study area

Fieldwork was conducted from October 2023 to March 2024 within the working area of the Lestari Mangrove Fishers'-Farmers' Group (KTH Lestari Mangrove) in Lubuk Kertang Village, Brandan Barat Sub-district, Langkat District, North Sumatra, Indonesia (Figure 1). The community-managed mangrove area covers approximately 410 ha. The landscape includes relatively intact mangrove stands as well as disturbed areas affected by cutting and former aquaculture ponds. Based on field observation during site visits, the study area is a low-lying, tidally influenced mangrove landscape connected with creek channels and abandoned pond compartments, and the substrate in sampled stands was predominantly muddy to muddy-silty. These descriptors are ecologically relevant because tidal flushing, substrate condition, and ease of human access can influence regeneration, canopy closure, and the visibility of logging disturbance across stations.

Sampling design and vegetation measurements

Two stations were purposively selected to represent contrasting conditions: Station I (relatively undisturbed) and Station II (disturbed/degraded). The initial classification was established before detailed measurement using field evidence such as canopy openness, visible cut stumps or felled stems, accessibility, and supporting information from local community members regarding recent disturbance history. At each station, a transect of approximately 300 m was established. Thirty nested plots were arranged along each transect, comprising 2 x 2 m subplots for seedlings (height <1.5 m), 5 x 5 m subplots for saplings (height >= 1.5 m and DBH <10 cm), and 10 x 10 m plots for trees (DBH >= 10 cm). Accordingly, the effective sampled area per station was 120 m^2 for seedlings, 750 m^2 for saplings, and 3000 m^2 for trees. Species identity and abundance were recorded for each growth stage. For trees, diameter at breast height (DBH) and height were measured. Species were identified in the field using standard mangrove morphological characters and the identification guidance of Onrizal (2008); doubtful records were cross-checked using field notes and plot photographs before tabulation. Community structure was summarized using density, relative density, frequency, relative frequency, dominance (for trees), relative dominance, and importance value index (IVI) following standard mangrove vegetation analysis procedures (Onrizal 2008).

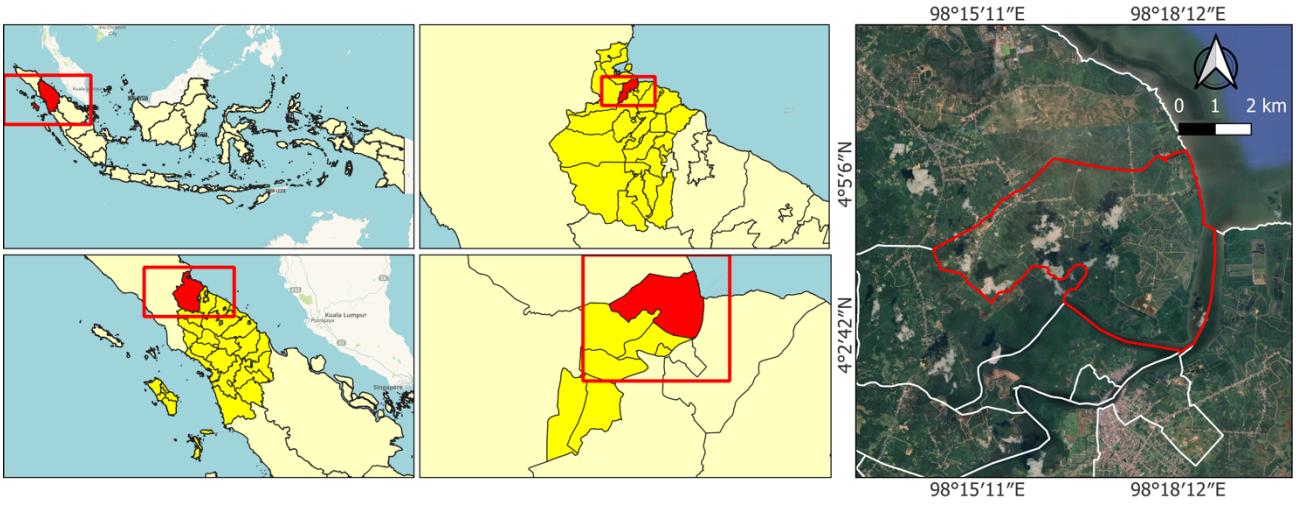

Figure 1. Study location map of Lubuk Kertang Village, Brandan Barat Sub-district, Langkat District, North Sumatra Province, Indonesia

Mangrove health assessment

Mangrove condition was assessed using the Mangrove Health Index (MHI) implemented in MonMang v2.0 (Dharmawan and Khoir 2020). The main inputs were canopy cover estimated from hemispherical photography, mean stem diameter of saplings and trees, and sapling density per plot. Canopy cover was estimated in MonMang v2.0 using hemispherical photography. Each plot was divided into 4-9 quadrants depending on stand density, and one upward-looking canopy photograph was taken in each quadrant. Photographs were taken vertically toward the sky and canopy at a position corresponding to one-third of stand height within the plot; in stands taller than 4 m, photographs were taken at breast height. Images were then converted from 8-bit to 1-bit in MonMang v2.0 to calculate canopy-cover percentage, which was accumulated automatically across quadrants. Supporting indicators included seedling abundance, evidence of cutting in the form of cut stumps or felled stands, and litter cover. In this study, felled-stand percentage refers to the proportion of sampled plots in which cut stumps and/or recently felled stems were recorded. Following MonMang guidance, MHI values were classified as poor (<33.33%), moderate (33.34%-66.67%), or good (>=66.68%).

Community perception survey

Community perceptions were collected using a closed-ended Likert questionnaire with five response categories ranging from strongly disagree (1) to strongly agree (5) (Budiaji 2013). The instrument contained 11 items grouped into three constructs: (i) mangrove existence and benefits (4 items), (ii) knowledge of mangrove degradation (3 items), and (iii) mangrove management and monitoring (4 items). The study population comprised all 108 members of the Lestari Mangrove Fishers'-Farmers' Group (KTH Lestari Mangrove). Sample size was determined using Slovin's formula with an error tolerance of 10%, resulting in 52 respondents. Item validity was tested using Pearson correlation against the total score at alpha = 0.01, and questionnaire reliability was evaluated using Cronbach's alpha together with corrected item-total statistics. Pearson item-validity coefficients ranged from 0.528 to 0.937, indicating that all 11 items were valid and significant at the 1% level. The questionnaire also showed excellent internal consistency (Cronbach's alpha = 0.949 for 11 items), with corrected item-total correlations ranging from 0.441 to 0.921; the reliability analysis used all 52 cases with no excluded responses.

Data analysis

Differences in health-related ecological parameters between stations were tested using independent t-tests for normally distributed variables and Mann-Whitney U tests for non-normal variables, with alpha = 0.05, after prior assessment of data distribution for normality. Perception data were summarized as item means and construct means and interpreted using Likert score ranges. The ecological and perception datasets were then interpreted jointly to identify practical priorities for community-based mangrove protection and restoration.

RESULTS AND DISCUSSION

Mangrove composition and structural degradation

Seven mangrove species were recorded at Station I and six at Station II (Table 1). *Sonneratia alba* occurred only at Station I, whereas *Avicennia marina*, *Bruguiera cylindrica*, *Bruguiera parviflora*, *Nypa fruticans*, *Rhizophora mucronata*, and *Xylocarpus granatum* occurred at both stations. Although Table 1 presents species occurrence only, the density and IVI summaries (Table 2-4) show that *R. mucronata* dominated across growth stages. This dominance likely reflects the combined influence of past rehabilitation planting, strong regeneration performance of *Rhizophora* in disturbed settings, and disturbance filtering that reduced the relative contribution of less abundant associated species.

Table 1. Mangrove species composition in Stations I and II

Species	Station I	Station II
Avicennia marina (Forssk.) Vierh.	Present	Present
Bruguiera cylindrica (L.) Blume	Present	Present
Bruguiera parviflora (Roxb.) Wight & Arn. ex Griff.	Present	Present
Nypa fruticans Wurmb	Present	Present
Rhizophora mucronata Poir.	Present	Present
Sonneratia alba Sm.	Present	Absent
Xylocarpus granatum J.Koenig	Present	Present

Table 2. Community structure at the seedling stage

Species	Density (ind/ha)	Rel. density (%)	Frequency	Rel. freq. (%)	IVI %)	Station
Avicennia marina	200.00	5.41	0.10	10.34	15.75	I
Bruguiera cylindrica	283.33	7.66	0.10	10.34	18.00	I
Bruguiera parviflora	166.67	4.50	0.10	10.34	14.84	I
Nypa fruticans	450.00	12.16	0.10	10.34	22.50	I
Rhizophora mucronata	1166.67	31.53	0.47	48.28	79.81	I
Sonneratia alba	1433.33	38.74	0.10	10.34	49.08	I
Avicennia marina	50.00	7.50	0.06	10.00	17.50	II
Bruguiera cylindrica	83.33	12.50	0.06	10.00	22.50	II
Rhizophora mucronata	533.33	80.00	0.53	80.00	160.00	II

Table 3. Community structure at the sapling stage

Species	Density (ind/ha)	Rel. density (%)	Frequency	Rel. freq. (%)	IVI (%)	Station
Bruguiera cylindrica	40.00	2.67	0.07	5.71	8.38	I
Bruguiera parviflora	20.00	1.33	0.03	2.86	4.19	I
Nypa fruticans	113.33	7.56	0.10	8.57	16.13	I
Rhizophora mucronata	1220.00	81.33	0.77	65.71	147.04	I
Xylocarpus granatum	106.67	7.11	0.20	17.14	24.25	I
Avicennia marina	40.00	6.00	0.06	9.09	15.09	II
Bruguiera cylindrica	186.67	28.00	0.10	18.18	46.18	II
Rhizophora mucronata	440.00	66.00	0.40	72.73	138.73	II

Table 4. Community structure at the tree stage

Species	Density (ind/ha)	Rel. density (%)	Frequency	Rel. freq. (%)	Dominance	Rel. dominance (%)	IVI (%)	Station
Avicennia marina	6.67	0.48	0.03	1.43	0.03	0.11	2.02	I
Rhizophora mucronata	1353.33	96.44	0.87	40.00	22.92	98.81	235.25	I
Sonneratia alba	26.67	1.90	0.07	2.86	0.05	0.21	4.97	I
Xylocarpus granatum	16.67	1.19	0.03	1.43	0.19	0.87	3.49	I
Avicennia marina	13.33	2.84	0.03	2.50	0.22	2.73	8.06	II
Bruguiera cylindrica	6.67	1.42	0.03	2.50	0.01	0.16	4.08	II
Bruguiera parviflora	3.33	0.71	0.03	2.50	0.01	0.10	3.31	II
Rhizophora mucronata	446.67	95.04	1.23	92.50	7.80	97.01	284.55	II

Table 6. Comparison of supporting health parameters between stations

Parameter	Station I	Station II	Test	P-value
Canopy cover (%)	74.05	9.88	Mann-Whitney U	p<0.001
Average stem diameter (cm)	10.97	8.19	Independent t-test	p<0.001
Average basal area (cm2/plot)	2426.19	721.59	Mann-Whitney U	p<0.001
Average tree height (m)	12.68	10.52	Mann-Whitney U	p<0.001
Average felled stands (%/plot)	0.00	68.13	Mann-Whitney U	p<0.001
Average seedlings (ind/plot)	3.70	1.43	Mann-Whitney U	p<0.001
Average saplings (ind/plot)	7.47	5.07	Independent t-test	p=0.016
Average trees (ind/plot)	14.03	4.70	Mann-Whitney U	p<0.001

Table 5. Summary of stand structure and Mangrove Health Index (MHI)

Metric	Station I	Station II
Species richness (no. species)	7	6
Seedling density (ind/ha)	3700.00	666.66
Sapling density (ind/ha)	1500.00	666.67
Tree density (ind/ha)	1403.34	470.00
Canopy cover (%)	74.05	9.88
Mean stem diameter (cm)	10.97	8.19
Mean tree height (m)	12.68	10.52
Basal area (cm2/plot)	2426.19	721.59
MHI (%)	56.27 (moderate)	32.95 (poor)

The contrast between stations was much stronger in stand structure than in species richness (Table 5). Species richness differed by only one species, but the structural contrast was ecologically large: compared with Station I, Station II showed approximately 82.0% lower seedling density, 55.6% lower sapling density, 66.5% lower tree density, 86.7% lower canopy cover, 70.3% lower basal area, and 41.4% lower MHI. Mean stem diameter and mean tree height were also lower at Station II by 25.3% and 17.0%, respectively. Station I showed substantially higher seedling density (3700.00 ind/ha), sapling density (1500.00 ind/ha), tree density (1403.34 ind/ha), canopy cover (74.05%), mean stem diameter (10.97 cm), mean tree height (12.68 m), and basal area (2426.19 cm2/plot) than Station II, where canopy cover collapsed to 9.88% and tree density to 470.00 ind/ha. MHI values classified Station I as moderate (56.27%) and Station II as poor (32.95%). All major health-related parameters differed significantly between stations, and evidence of cutting, expressed as the proportion of plots containing cut stumps or felled stems, was recorded only at the degraded station (68.13% of plots) (Table 6).

These patterns indicate that illegal logging pressure in Lubuk Kertang is associated more strongly with structural simplification and reduced ecological integrity than with immediate local extinction of mangrove species. In mangrove forests, several species can remain present after disturbance because residual adults, coppicing stems, or planted individuals continue to occupy the site, whereas canopy closure, tree density, basal area, and regeneration respond more quickly to cutting pressure. This interpretation is consistent with Indonesian evidence from Segara Anakan and broader national analyses showing that deforestation and disturbance first erode biomass, canopy structure, and habitat complexity before species lists become extremely simplified (Ilman et al. 2016; Nordhaus et al. 2019). The present data therefore show a classic degradation signal: modest change in richness, but severe decline in the structural attributes that most directly govern ecosystem functioning and recovery potential.

This interpretation is consistent with disturbance studies from other Indonesian mangrove systems. In South Sulawesi, mangrove harvesting altered composition, density, coverage, stem diameter, and tree biodiversity, showing that repeated wood extraction can simplify stand structure and ecosystem-service capacity even where mangrove cover persists (Malik et al. 2015). Likewise, long-term deforestation and land-use change in Segara Anakan, Central Java, were associated with reduced diversity, aboveground biomass, and habitat complexity, although remnant stands maintained spatial heterogeneity across the landscape (Nordhaus et al. 2019). At the national level, aquaculture expansion, timber extraction, and coastal development have been identified as dominant drivers of mangrove loss and degradation in Indonesia, indicating that the Lubuk Kertang case is locally specific but consistent with broader national disturbance pathways (Ilman et al. 2016).

Community perceptions and management implications

Respondents were predominantly farmers (67.31%), male (65.38%), and educated mainly to primary-school level (42.31%). Despite this profile, awareness of mangrove values and threats was high (Table 7). Construct means were 3.70 for mangrove existence, 4.25 for mangrove degradation, and 4.16 for mangrove management, with an overall mean of 4.01 (Table 8). Responses at the construct level indicate consistently high recognition of mangrove values, degradation, and management needs (Table 8). The questionnaire also showed strong measurement quality: Pearson item-validity coefficients ranged from 0.528 to 0.937 (all significant at the 1% level), Cronbach's alpha was 0.949 for 11 items, and corrected item-total correlations ranged from 0.441 to 0.921. Because the reliability output used all 52 cases with no exclusions, these statistics can be interpreted directly for the full respondent set. These statistics indicate that all items contributed positively to the internal consistency of the instrument, although the strength of contribution varied among items. This pattern suggests that practical ecological knowledge can remain high even where formal schooling is limited, particularly in coastal communities whose livelihoods depend on fisheries, farming, and direct exposure to mangrove change.

The perception results reinforce the ecological findings. High scores for the degradation and management constructs indicate broad support for stronger protection, monitoring, and rehabilitation (Table 8). Similar perception studies have shown that communities living close to mangroves often identify illegal harvesting as a primary driver of degradation and that local views are highly informative for determining realistic management priorities (Arumugam et al. 2020; Nyangoko et al. 2022). At the same time, support for sanctions and patrols should not be interpreted as evidence that local interests are uniform. In community-managed landscapes, some actors may simultaneously depend on mangrove protection for fisheries or coastal safety while also benefiting from opportunistic timber extraction under economic pressure; this social contradiction is important for understanding why nominal community support does not automatically translate into effective enforcement.

For Lubuk Kertang, the important management message is that community-based management exists, but enforcement is still insufficient to prevent structural degradation of accessible stands. International evidence suggests that participatory mangrove management performs best when local authority is clear, responsibilities are well defined, benefits are tangible, and enforcement is credible (Arifanti et al. 2022; Damastuti et al. 2022). In the present case, the dominance of farmers and fishers among respondents suggests that low-cost local monitoring, rapid reporting, and benefit-linked participation may be more realistic than reliance on external enforcement alone. Strong support for patrols and sanctions is therefore encouraging, but it should be matched with governance arrangements that reduce incentives for illegal cutting rather than treating enforcement as a purely punitive measure.

Table 7. Respondent characteristics (n = 52)

Characteristic	Category	n	%
Gender	Male	34	65.38
	Female	18	34.62
Age class (year)	18-31	15	28.85
	32-45	18	34.62
	46-59	11	21.15
	60-73	8	15.38
Main job	Fishers	17	32.69
	Farmers	35	67.31
Education	Out of school	11	21.15
	Elementary school	22	42.31
	Junior high school	10	19.23
	Senior high school	7	13.46
	University	2	3.85

Table 8. Construct mean perception scores (Likert 1-5)

Construct	Mean score	Interpretation
Mangrove existence	3.70	Good
Mangrove degradation	4.25	Very good
Mangrove management	4.16	Good
Overall mean	4.01	Good

This governance interpretation is also supported by Indonesian social-ecological evidence. In South Sulawesi, mangrove decline has been linked not only to ecological damage but also to livelihood trade-offs, showing that community dependence on mangrove resources can coexist with continued degradation when short-term benefits from extraction or conversion remain attractive (Malik et al. 2017). By contrast, Damastuti et al. (2022) showed in Central Java that community-based mangrove management can positively influence biodiversity when maintenance is regular, local roles are clear, and long-term stewardship is supported. Compared with that case, Lubuk Kertang appears to face a more pronounced implementation gap between strong community awareness and consistently effective field-level protection.

Implications for carbon, restoration, and future monitoring

The structural contrast between stations also implies a strong difference in likely biomass carbon storage and ecosystem functioning, although carbon was not measured directly in this study. Because mangrove carbon stocks are closely tied to biomass, stand basal area, and the integrity of organic-rich soils, the degraded condition at Station II is reasonably interpreted as having lower carbon-storage capacity than Station I (Donato et al. 2011; Alongi 2014). Global syntheses show that mangrove degradation and conversion can generate disproportionately large carbon emissions relative to area lost (Pendleton et al. 2012; Hamilton and Friess 2018). The carbon discussion should therefore be read as an ecological inference grounded in measured structural variables, not as a direct carbon-stock estimate.

A useful Indonesian contrast comes from regulated selective logging systems, where mangrove production forests have been shown to retain 70%-75% of total ecosystem carbon stocks after harvest and regain part of that stock over time (Murdiyarso et al. 2021). The Lubuk Kertang results differ because the observed cutting is illegal, spatially concentrated, and accompanied by very low canopy cover and abundant felled stands, which together indicate weaker control and higher ecological risk. They also differ from restoration-focused work in the same landscape, where abandoned ponds that were reconnected and rehabilitated showed encouraging vegetation growth and carbon-recovery potential (Amelia et al. 2023). Taken together, these comparisons suggest that the main local challenge is not whether recovery is possible, but whether remaining intact stands can be protected while degraded patches are restored before repeated cutting locks the system into a low-canopy state.

Additional Indonesian carbon literature reinforces the inference that structural degradation at Station II likely corresponds to substantial carbon loss. A synthesis of 249 mangrove sites across Indonesia reported a clear gradient in total ecosystem carbon stocks from aquaculture to degraded, regenerated, and undisturbed mangroves, with total ecosystem carbon increasing in line with rehabilitation status and losses of approximately 52% in degraded mangroves relative to undisturbed baselines (Murdiyarso et al. 2023). In the Mahakam Delta, conversion of mangroves to shrimp ponds caused about 62% loss of extensive mangrove area and carbon losses equivalent to 226 years of soil-carbon accumulation in natural mangroves (Arifanti et al. 2019). Although the present study did not quantify carbon directly, these Indonesian comparisons make it reasonable to interpret the marked reductions in canopy cover, basal area, and tree density at Station II as ecologically meaningful warning signs of reduced blue-carbon capacity.

Management should therefore prioritize two linked strategies. First, remaining higher-integrity stands, especially those resembling Station I, should receive stronger protection through regular patrols, rapid reporting of cutting, and enforcement of locally legitimate rules. Second, degraded mangrove areas and abandoned ponds should be restored using hydrology-informed approaches rather than planting-only interventions. This is important because mangrove restoration often fails when tidal exchange, inundation regime, and site geomorphology are ignored (Lewis III 2005; Bayraktarov et al. 2016; Lovelock et al. 2022). In Lubuk Kertang, this recommendation is directly relevant to abandoned pond compartments and other disrupted sites where restoring tidal connectivity, drainage pathways, and appropriate microtopography is likely to be more decisive than planting alone. Previous local work showing vegetation and carbon recovery in restored pond sites supports this site-specific restoration pathway (Amelia et al. 2023).

A more local comparison also strengthens the restoration argument. In the same landscape, Amelia et al. (2023) documented measurable growth and carbon-storage potential in restored mangroves established on an abandoned pond in Lubuk Kertang, showing that ecological recovery is possible when degraded sites are actively managed. More broadly, rehabilitated mangroves in Sulawesi have shown recovering community structure and carbon stocks, but trajectories remain strongly dependent on site conditions and management history (Cameron et al. 2019). Together, these studies suggest that restoration in Lubuk Kertang should prioritize hydrological repair, protection from renewed cutting, and longer-term monitoring rather than planting success alone.

This study was intentionally focused on rapid ecological diagnosis and social perceptions. Future work should add repeated MHI monitoring, remote-sensing analysis of canopy change, direct biomass and soil-carbon estimation, and assessment of who conducts illegal cutting and why. Such additions would improve causal interpretation, allow formal reporting of carbon consequences, and help translate community support for protection into measurable conservation outcomes.

In conclusion, this study shows that illegal logging pressure in Lubuk Kertang is associated with severe structural degradation of community-managed mangroves. Compared with the relatively intact station, the disturbed station retained only slightly lower species richness but showed very large declines in canopy cover, tree density, basal area, regeneration, and overall mangrove health. The strongest scientific contribution of the study is therefore the demonstration that structural attributes were more sensitive indicators of degradation than species richness in this

community-managed landscape. Community perceptions were broadly aligned with the field evidence, respondents recognized that mangroves are highly beneficial, judged the current condition to be poor, and supported stricter monitoring, sanctions, and rehabilitation. The most defensible management priorities are to protect remaining higher-integrity stands from further cutting and to restore degraded and abandoned-pond areas through hydrology-informed interventions supported by local institutions.

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