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Mining Site Reclamation in Ghana: A Comparative Assessment of Vegetation Dynamics

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ABSTRACT

Post-mining reclamation is an essential component of mine closure, aimed at restoring degraded lands to safe, stable, and sustainable conditions that support ecological integrity, community wellbeing, and the mining industry's long-term viability. This study evaluated the ecological effectiveness of a reclamation project undertaken by a large-scale mining company in Ghana, focusing on vegetation recovery two decades after reclamation in the Amansie West District, Ashanti Region. A comparative approach was used, assessing a reclaimed waste rock dump alongside an adjacent natural forest serving as a reference site. Twelve 25 m × 25 m plots were established in each site to record tree species with a diameter at breast height (DBH) ≥10 cm, while saplings (DBH <10 cm, height ≥1.5 m) and seedlings (height <1.5 m) were assessed using nested subplots. Results revealed marked differences in species richness and diversity between the two sites. The reclaimed site recorded 1,260 individuals representing 78 species and 34 families, compared with 1,454 individuals, 139 species, and 47 families in the reference forest. Tree diversity indices were considerably lower in the reclaimed site (1.08) compared with the reference site (2.25). Vegetation in the reclaimed area was largely dominated by exotic species, notably Acacia mangium, Senna siamea, Gliricidia sepium, and Leucaena leucocephala, which collectively contributed 78% of the total Importance Value Index (IVI). In contrast, the reference forest exhibited greater structural and compositional diversity, with indigenous species accounting for 54% of the IVI. Non-metric multidimensional scaling further indicated a moderate similarity in herbaceous species composition between the two sites. Overall, findings suggest that despite notable progress, two decades of reclamation have not fully restored the waste rock dump to natural forest conditions. These results highlight the need for improved species selection, prioritization of indigenous plants, and adaptive management strategies to enhance the long-term success of post-mining land rehabilitation in Ghana.

Keywords: *Post-mining reclamation, Vegetation recovery, Biodiversity, Exotic and indigenous species, Importance Value Index (IVI), Ecological restoration, Waste rock dump, Natural forest reference, Species diversity.*

1.0 INTRODUCTION

Gold mining and processing an important economic activity that contributes immensely to the sustainable development of many developing countries worldwide [1]. However, mining activities can have significant negative impacts on the environment, including land degradation, loss of biodiversity, and contamination of soil and water resources [2], [3] and [4]. Increases in these impacts over the last few decades as a result of growing mineral production and consumption have made post-mining reclamation one of the most essential features of the mining industry and a key requirement for mine closure globally [5], [6], [7] and [8]. Recent shifts toward opencast or surface mining in many parts of the world have further worsened the impacts of mining on the environment and led to a growing call for appropriate reclamation. Reclamation helps to restore soil fertility, prevent erosion, and promote the growth of plant species [9]. It also has the potential to restore some ecosystem functions and services previously disrupted by mining activities, including preserving biodiversity and protecting wildlife habitats [10] and [11], enhancing the aesthetic value of landscapes, and promoting eco-tourism [12] and [13]. When properly implemented, reclamation can also be an effective tool to minimize the negative impacts of mining on surrounding communities, such as loss of livelihoods, health risks, and social conflicts [14]. Effective reclamation is, thus, critical for the sustainability of the mining industry, the local community, and the environment, as it helps to restore degraded lands to a stable, safe, and sustainable condition [15] and [16].

Reclamation is a complex process that involves the management of soil disturbances (physical, chemical, and biological) to improve productivity and revegetation to reduce erosion and protect soil against further degradation [6]. Revegetation, which happens to be an important source of nutrients, is considered the most widely accepted and suitable way of enhancing mined soil quality [17] and [16]. Thus, reclamation of degraded mined lands should support the establishment, growth, and development of plant species to be deemed successful [16]. While most mines have often relied on nitrogen-fixing plants such as legumes [6], effective revegetation requires the establishment of a mixture of plant species to ensure that the reclaimed site provides opportunities for multi-purpose uses and conservation roles, mitigates climate change effects, and increases litter production and nutrient cycling, among others [17]. Successful revegetation also requires careful consideration of the roles of exotic or native plant species [18] and [16]. Thus, a thorough analysis of the vegetation composition of reclaimed mined land relative to that of adjacent reference forests can be an important tool for understanding the success of reclamation efforts.

Understanding the effectiveness of reclamation efforts is essential for promoting responsible mining practices and protecting the environment [19]. Such information would also be useful to stakeholders, including mining companies, local communities, and the scientific communities [20] and [21]. Data on the effectiveness of reclamation practices is essential for adaptive management and policy formulation [22]. The availability of data on the effectiveness of reclamation practices can help mining companies adapt their practices to better meet their environmental and social obligations. Moreover, this information can inform policy formulation by identifying best practices for reclamation and promoting sustainable mining practices [21].

In Ghana, mining activities are widespread, and the reclamation of degraded lands is a legal requirement for mining companies [23]. Large-scale mining companies in the country are required by law to reclaim all degraded areas within their concessions, using a mixture of exotic and native vegetation to ensure the recovery of biodiversity [24]. However, while all large-scale mining companies in the country have in place reclamation programmes at their sites, independent scientific studies that assess the effectiveness of these reclamation efforts are lacking. Without reliable data, it is difficult to determine if the reclamation efforts are meeting the regulatory requirements or achieving the desired ecological outcomes. The lack of data on the effectiveness of reclamation efforts also limits the ability of stakeholders, including local communities, civil society organizations, and policymakers, to hold mining companies accountable for their environmental performance. The objective of this study was, thus, to assess the effectiveness of the reclamation of a selected large-scale gold mining site in Ghana by comparing the vegetation characteristics of a reclaimed waste rock dump site to a reference site. It was predicted that the vegetation characteristics of the reclaimed mined site would approximate those of the adjacent forest ecosystems within the mining concession studied (Amansei West district.

2.0 MATERIALS AND METHODS

2.1 Description of the study area

The study was conducted at the concession of Asanko Gold Ghana Limited, one of the large-scale gold mining companies in Ghana in the year. The company is located in the Amansie West District in the Ashanti Region of Ghana on Latitude 6º 19'40" N and 6º 28' 40" N; and Longitude 2º 00' 55 W and 1º 55' 00" W (Figure 1). It is approximately 35 km southwest of the regional capital, Kumasi. Reclamation activities were initiated at the site in 2004, following the cessation of mining activities happening on the site. Before the reclamation process, the waste dump was profiled to a repose angle of 20º. After the profiling, layers of oxide material up to a depth of 50 cm and 30 cm of topsoil material from an undisturbed humic area were sequentially spread over the profiled area following the Ghana Environmental Protection Agency's post-mining reclamation guidelines.

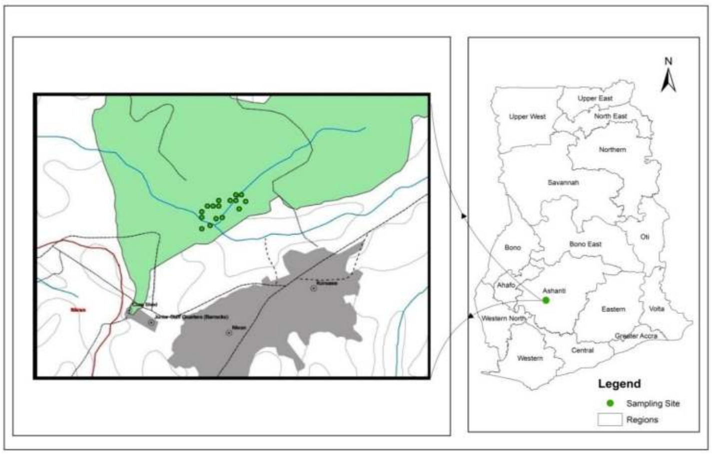

Figure 1: Map of the Asanko Gold Mine showing the reclaimed area and the sampling points

For successful phyto-stabilization in the initial stages of the reclamation process, soil amendments were required to create optimum growing conditions for re-vegetation, immobilize accumulated heavy metals and decrease their bioavailability to water sources or to the food web. Biochar (625 kg) and composts (1,250 kg) per 25 m by 25 m were applied to improve soil properties. Afterwards, seedlings of nitrogen-fixing *Acacia magium, Gliricidia sepium, Leucaena leucocephala and Senna siamea* were planted to expedite the process of succession.

2.2 Floristic assessment

To evaluate the vegetation characteristics of the reclaimed site, 12 plots of size 25 m × 25 m were established in the reclaimed sites, and an adjacent forest (reference site), respectively. The plots were laid out with the help of a compass, and their geographic locations were recorded using the Garmin geographic positioning system (Garmin Model 66st) through Systematic Random Sampling. Data such as plants with a diameter at breast height, DBH ≥ 10 cm were collected from these plots. These plants were first identified, and their DBH were measured using a diameter tape. For the measurement of the saplings, 12 plots measuring 5 m × 5 m were demarcated and nested in the larger plots. Trees with DBH < 10 cm, height ≥ 1.5 m were considered. For seedlings measurement, another 12 plots of size 1 m × 1 m were demarcated with each 5 m × 5 m plot. Seedlings of height < 1.5 m were counted. Species were identified through the help of a plant taxonomist and the nomenclature was verified through the readily available online repository: The World Flora Online [25].

2.3 Data analyses

Vegetation attributes, including species richness, Shannon diversity index, evenness, and basal area, were calculated for both the reclaimed and reference forest sites using EstimateS software (version 9.10) [26]. Welch's two-sample t-test was performed to tease out the differences in Shannon diversity, evenness, and basal area between the reclaimed and reference plots. Additionally, relative values of density, frequency, and basal area were calculated for all species from their DBH measurements [27]. The importance value index (IVI) was computed for each species and aggregated for the various families identified. The IVI for the species was calculated by summing the relative density, relative basal area and relative frequency. Sample-based rarefaction and extrapolation curves were generated using the readily available online resource, Chao's iNEXT [28].

Differences in the floristic composition of the reclaimed site and the reference site were visualized using the non-metric multidimensional scaling technique. The analysis was done using the presence or absence data for the species. Trees/saplings and herbs were analysed separately. A diameter or size distribution graph was used to visualize and compare the structural differences between the reclaimed and reference forests. In addition to the IVI, indicator species analyses were also conducted to determine the key species that define each of the two studied sites. All analyses were performed using the R Studio Software [29]. Statistical tests were performed at a 5% significance level.

3.0 RESULTS

3.1 Composition and abundance of plant species

A total of 1260 individuals belonging to 78 species and 34 families were identified in the reclaimed plots. The species richness was lower than that of the reference site, where 1454 individuals, categorized into 139 species and 47 families, were encountered (Table 1).

Table 1. Summary characteristics of the reclaimed and reference vegetation at the studied area

Life form	Parameter	Reclaimed	Reference	P-value
Combined	Number of Individuals	1260	1454	
	Species richness	78	139	
	Families	34	47	
Trees	No. of Individuals	384	303	
	Species richness	19	62	
	Families	9	26	
	Mean basal area (m2/ha)	28.17±23.05	22.54±12.87	0.471
	Shannon index	1.08±0.26	2.25±0.38	< 0.001
	Shannon evenness	0.77±0.12	0.91±0.07	0.003
Saplings	No. of Individuals	707	882	
	Species richness	34	86	
	Family	17	35	
	Mean basal area (m2/ha)	1.68±0.68	2.19±0.87	0.124
	Shannon index	1.21±0.70	2.53±0.26	<0.001
	Shannon evenness	0.56±0.23	0.84±0.06	0.002
Herbs	No. of Individuals	169	269	
	Species richness	57	70	
	Family	25	31	
	Shannon index	2.09±0.58	2.60±0.23	0.012
	Shannon evenness	0.61±0.22	0.76±0.11	0.041

With respect to the tree species, the reclaimed site had more trees (384) than the reference site (303), although the latter was considerably richer (62 species, 26 families) than the former (19 species, 9 families). The mean basal area of trees per plot was approximately 28 m2/ha for the reclaimed site, whereas the reference forest recorded a lower value of 23 m2/ha. Despite the higher number of trees and basal area, the reclaimed site recorded a significantly lower Shannon diversity index (1.08) and evenness (0.77) compared to the reference site (2.25 and 0.91, respectively). The diversity of the saplings and herbs exhibited a similar pattern, being significantly higher for the reference site relative to the reclaimed site. Species richness and Shannon diversity index of the saplings were higher for the reference site (86 and 35, respectively) than for the reclaimed site (34 and 17). The saplings were also more evenly distributed in the reference site (0.84) compared to the reclaimed (0.56). Fifty-seven (57) herb species were recorded in the reclaimed site compared to 70 in the reference site. Rarefaction and extrapolation curves further indicated that the plant species in the reference site were far more diverse than those in the reclaimed sites (Figure 2).

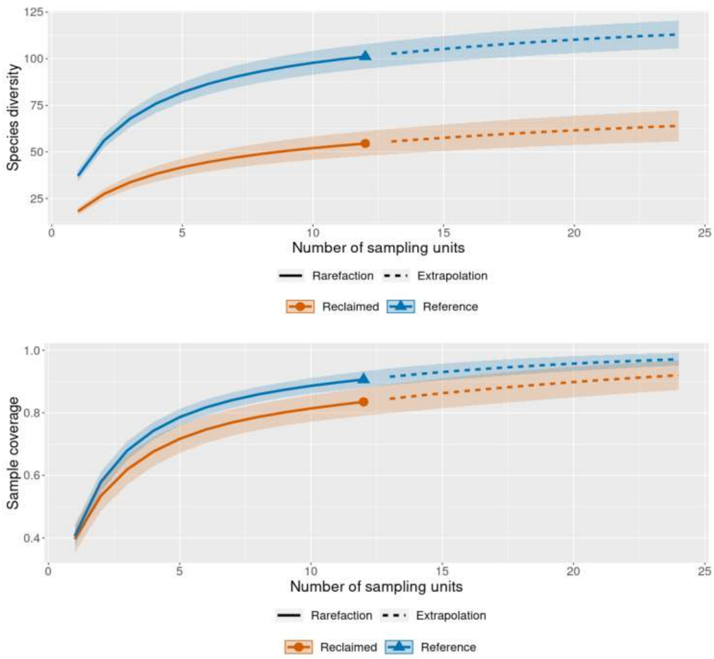

Figure 2: Rarefaction and extrapolation curves for species identified in the reclaimed and reference sites in the study area

The results also showed that the sites were adequately sampled, with sample coverage exceeding 80% at both sites. The abundance and dominance of plant species varied significantly between the two studied sites, with both tree and sapling layers in the reclaimed sites being overly dominated by fewer species than expected compared to the reference plots (Table 2). In the tree layer, for example, four (4) invasive plant species*: Acacia mangium, Senna siamea, Gliricidia sepium, and Leucaena leucocephala*, were very dominant and accounted for 74% of the importance value index (IVI) of species in the reclaimed sites. The remaining 15 tree species in this site recorded a total IVI of 26%. On the other hand, the top 10 most dominant tree species in the reference forest ecosystem were all indigenous (including *Albizia zygia, Macaranga barteri, Musanga cecropioides, and Elaeis guineensis)* and accounted for only 43% of the IVI, whilst the remaining 52 species shared a total of 55% of the IVI. The sapling layer exhibited a similar pattern of species abundance and dominance as observed for the tree layers; the reclaimed site was largely dominated by invasive species *(S. siamea, G. sepium, L. leucocephala, and A. mangium*), which accounted for 61% of the IVI, whereas *Baphia nitida and Rauvolfia vomitoria* (both native species) dominated the reference site with a combined IVI of 20%. Unlike in the tree and sapling layers, plant species in the herb layer were more evenly distributed in both the reclaimed and reference sites.

Table 2. Importance value indices of species compared for the reclaimed and reference sites in the study area

Layer/Growth Form	Reclaimed		Reference	
	Species	IVI (%)	Species	IVI (%)
Trees	*Acacia mangium*	41.24	*Albizia zygia*	7.88
	Senna siamea	27.62	*Macaranga barteri*	5.51
	Elaeis guineensis	13.95	*Musanga cecropioides*	5.47
	Gliricidia sepium	3.36	*Elaeis guineensis*	5.26
	Funtumia africana	1.60	*Discoglypremna caloneura*	5.11
	Leucaena leucocephala	1.55	*Albizia adianthifolia*	4.48
	Psydrax subcordata	1.01	*Distemonanthus benthamianus*	3.19
	Musanga cecropioides	0.98	*Rauvolfia vomitoria*	3.06
	Alstonia boonei	0.86	*Pycnanthus angolensis*	2.97
	Bombax buonopozense	0.85	*Trichilia monadelpha*	2.56
	Others (9 spp.)	6.98	*Others (52 spp.)*	54.60
Saplings	*Senna siamea*	47.18	*Baphia nitida*	13.45
	Funtumia Africana	7.40	*Rauvolfia vomitoria*	6.46
	Gliricidia sepium	5.36	*Macaranga barteri*	6.12
	Leucaena leucocephala	4.47	*Millettia zechiana*	4.46
	Blighia sapida	3.72	*Elaeis guineensis*	3.77

	Acacia mangium	3.65	*Myrianthus arboreus*	3.61
	Elaeis guineensis	3.47	*Lecaniodiscus cupanioides*	2.89
	Baphia nitida	3.21	*Discoglypremna caloneura*	2.58
	Celtis mildbraedii	3.05	*Microdesmis puberula*	2.57
	Albizia zygia	2.20	*Trichilia heudelotii*	2.52
	Others (24 spp.)	16.28	*Others (76 spp.)*	51.56
Herbs	*Paullinia pinnata*	12.21	*Geophila obvallata*	10.08
	Blighia sapida	6.74	*Culcasia scandens*	6.75
	Baissea baillonii	4.97	*Griffonia simplicifolia*	6.22
	Brachiaria deflexa	4.88	*Baphia nitida*	5.89
	Secamone afzelii	4.35	*Leptaspis cochleata*	5.55
	Clerodendrum umbellatum	3.84	*Millettia zechiana*	5.35
	Strophanthus preussii	3.21	*Adiantum vogelii*	3.87
	Leucaena leucocephala	2.58	*Elaeis guineensis*	3.01
	Senna siamea	2.49	*Baissea baillonii*	3.01
	Discoglypremna caloneura	2.43	*Sphenocentrum jollyanum*	2.75
	Others (47 spp.)	52.31	Others (60 spp.)	47.52

Regarding the dominance hierarchy of the plant families, *Leguminosae* overly dominated both the tree and sapling layers of the reclaimed sites, with IVI values of 78% and 69%, respectively (Figure 3).

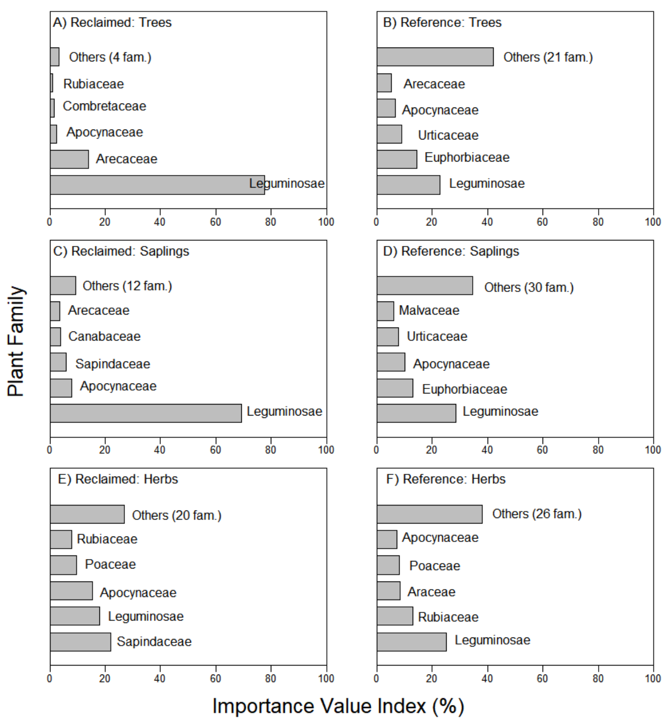

Figure 3: Family dominance based on the importance value index compared between the reclaimed and reference sites

For both layers or growth forms, *Apocynaceae* came in a distant second with approximately 14% (among the trees) and 8% (saplings) of the IVI. *Arecaceae*, a family that contains the native palm species, *Elaeis guineensis*, was also observed to be of greater importance value in the reclaimed site, accounting for 13.95% of the IVI. At the herb layer in the reclaimed site, however, the *Leguminosae* (IVI = 18.11%) was supplanted by *Sapindaceae* (IVI = 21.94%) in dominance. For the reference site, *Leguminosae* was found to be the most important plant family across all growth forms. However, its dominance was not as strong as in the reclaimed site, with IVI ranging between 22.86% (for the tree layer) and 28.61% (for the sapling layer).

Table 3. Indicator species of trees and saplings identified in the reclaimed and reference, with their indicator values and their corresponding p-value

Reference Site			**Reclaimed Site**		
Species	**Indicator value**	***P-value***	**Species**	**Indicator value**	***P-value***
Rauvolfia vomitoria	0.957	0.001	*Acacia mangium*	1.000	0.001
Baphia nitida	0.941	0.001	*Senna siamea*	0.997	0.001
Millettia zechiana	0.918	0.001	*Leucaena leucocephala*	0.803	0.009
Albizia adiantifolia	0.866	0.001	*Blighia sapida*	0.720	0.018
Amphimas pterocarpoides	0.816	0.001	*Gliridia sepium*	0.645	0.04
Discoglypremna caloneura	0.764	0.023			
Macaranga barteri	0.764	0.01			
Microdesmis puberula	0.754	0.009			
Ceiba pentandra	0.707	0.018			
Anthonotha macrophylla	0.688	0.046			
Alchornea cordifolia	0.645	0.046			
Allanblackia parviflora	0.645	0.038			
Baphia pubescens	0.645	0.032			
Calpocalyx brevibracteatus	0.645	0.031			
Cola nitida	0.645	0.039			
Discoglypremna caloneura	0.645	0.044			
Margaritaria discoidea	0.645	0.04			

In general, plant species composition differed substantially between the reclaimed site and the reference sites as depicted by the non-metric multidimensional scaling (NMDS) ordination plot (Figure 4).

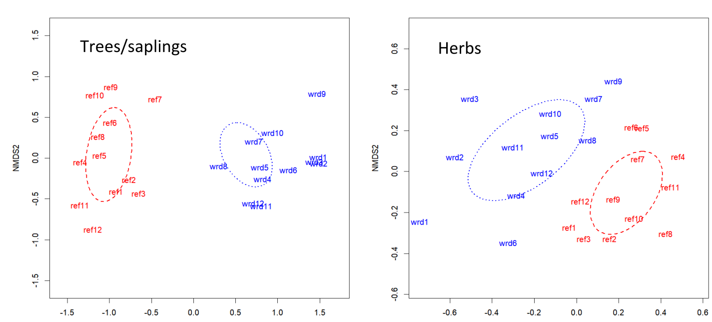

Figure 4: Non-metric multidimensional scaling (NMDS) of plots based on the presence or absence data of trees/saplings and seedlings for the studied sites

This compositional difference between the reclaimed and reference sites was more pronounced at the tree and sapling layers, where clear separations were discernible. Greater ecological distances were also observed among the reference plots than for the reclaimed plots. While the compositional differences were detectable between the reclaimed plots and reference plots, those within the former appeared to be more dissimilar than those of the former.

Table 4. Indicator species of herbs identified in the reclaimed and reference, with their indicator values and their corresponding p-value

Reference Site			Reclaimed Site		
Species	Indicator Value	p-value	Species	Indicator Value	p-value
Millettiazechiana	0.838	0.001	*Blighia sapida*	0.816	0.001
Griffonia simplicifolia	0.824	0.007	*Paullinia pinnata*	0.696	0.036
Baphia nitida	0.813	0.004	*Secamone afzelii*	0.679	0.049
Culcasia scandens	0.764	0.007			
Microdesmis puberula	0.764	0.008			
Geophila obvallata	0.732	0.017			
Sphenocentrum jollyanum	0.687	0.046			

3.2 Size distribution of plants

The size distribution of plant species in the two studied sites reflected the typical inverse J-shaped curve, with more individuals in the lower diameter class compared to the higher diameter classes (Figure 5).

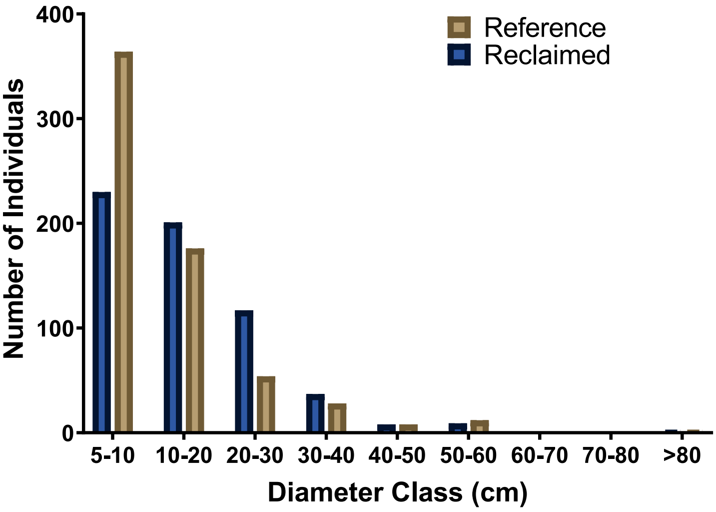

Figure 5: Size distribution of plants compared for the reclaimed and reference forests.

Within the small-sized class (< 10 cm), the recorded considerably fewer individuals relative to the reference site. However, the number of plants in the 10-20 cm, the 20-30 cm, and the 30-40 cm size classes was higher in the reclaimed site than that of the reference site. Beyond the 30-40 cm diameter class, however, no significant differences in the size distributions were found between the reclaimed and the reference forests.

3.3 Indicator species of the studied sites

The reclaimed site varied considerably from the reference sites in terms of its indicator species (Tables 3 and 4). At the reclaimed site, for example, the tree/sapling layers recorded only five indicators, four of which were exotic invasive plant species (namely, *Acacia mangium, Senna siamea, Leucaena leucocephala, and Gliricidia sepium*). A. mangium, in particular, was exclusive (Indicator Value = 1.000), while S. siamea was almost exclusive (Indicator Value = 0.997) to the reclaimed site. By contrast, a total of 17 species characterized the reference site, the most important of which were Rauvolfia vomitoria, Baphia nitida, and Millettia zechiana. Among the seedlings or herbaceous plants, Blighia sapida, Paullinia pinnata, and Secamone afzelii were the only three indicator species found for the reclaimed site (Table 4). However, the reference site recorded seven (7) indicator species. It is noteworthy that none of the indicator species observed in the reference site and within the seedling/herb layer of the reclaimed site were exotic.

4.0 Discussion

Plant species composition is an important indicator of reclamation success [16]. When well implemented, reclamation is expected to result in the establishment of a self-sustaining plant community that is compositionally and structurally diverse, devoid of non-native invasive plant species, and capable of carrying out multiple ecological functions. In the current study, a much lower diversity of plant species (78) of all growth/life forms (trees, saplings and seedlings/herbs) was observed in the reclaimed site relative to the reference site (139), consistent with several other studies conducted in Ghana [30] and [16]. For example, [16] recorded between 96 and 126 species for three reclaimed gold mined sites in the south-western part of Ghana while [30] observed 31 species from a mined site within the same area. This finding shows that reclamation, which started more than two decades ago, has yet to restore ecological conditions in the mined site to pre-disturbance states or to approximate the adjacent natural forest ecosystem. This assertion supports the view that reclamation or restoration of degraded mined land is a slow process that requires more time [31]; [32] and [33]. The slow pace of development of a diverse and complex plant community on the studied reclaimed site could be attributed to several factors including the lack of rich and viable seed banks as well as the use of exotic species at the initial stages of the reclamation process [34]; [30] and [32]. [32], for instance, argued that the use of high restoration interventions, including the introduction of exotic plant species, though would increase vegetation coverage over time, tends to suppress native plant growth and development and ultimately affect diversity, richness and evenness of restored ecosystems. On the other hand, a higher number of individuals and greater basal area recorded in the tree layer at the reclaimed site suggest higher productivity when compared to the reference site. Similar results were reported by [30], who recorded an exceedingly high density of trees (3057) in three reclaimed habitats compared to control sites (150). This result is not surprising considering the high abundance or rapid vegetative growth of exotic or invasive plant species at the reclaimed site [33]. Moreover, while fewer number of herb species were observed at the reclaimed site, the overall species richness of this growth form, contrary to the trees/saplings layers, compared somewhat more favourably with that of the reference site.

Exotic plant species, particularly legumes, are commonly used for the reclamation of degraded mined sites due to their ability to fix nitrogen and enhance soil fertility [6]; [17] and [34]. However, concerns are growing regarding their potential to invade ecosystems and reduce the opportunity for recruitment of new species [33]; [35] and [16]. The use of exotic plant species at the initial stages of the reclamation affected the abundance and dominance patterns of the species in the reclaimed site. The greater abundance of *A. mangium, S. siamea, G. sepium and L. leucocephala* in the reclaimed site (accounting for approximately 78% and 61% of the importance value index (IVI) of all species, respectively for the tree and sapling layers) provides further evidence of the ecological distances (higher degree of dissimilarity) between these two sites, reflecting the negative impacts of exotic plant species on the composition and structure of the reclaimed site. This disproportionate dominance by fewer species as opposed to the reference site, which was dominated by indigenous plants, can have serious implications for achieving the desired successional trajectory and ecological integrity of this site.

The larger number of small-sized species in the reclaimed site relative to the reference site shows the structural dissimilarity between the two sites, further demonstrating the impacts of use of a few fast-growing exotic plant species for reclamation on vegetation establishment. On the contrary, the reclaimed forest was compositionally more similar to the reference forest at the herb layer than the tree/sapling layer as only two of the non-native invasive plant species made it into the top 10 most important species. These results suggest that with more time and the appropriate adaptive management measures, the desired composition (one similar to the reference forest ecosystem) may be achieved.

The dominance of *Leguminosae, Apocynaceae* and *Arecaceae* in both studied sites, particularly in the overstory (tree) and mid-story (sapling) strata, is not surprising as they are documented to be among the most dominant families in tropical forest ecosystems. However, the extremely high dominance of *Leguminosae* relative to other families within the tree/sapling layer in the reclaimed site is quite telling and reflects the greater abundance of the leguminous plants (*A. mangium, S. siamea, G. sepium, and L. leucocephala*) which were planted as part of the initial mix of species for the reclamation. It is equally interesting to note that the same exotic plant species that were deliberately planted at the reclaimed site emerged as the key indicator species (the only exception being *Blighia sapida*) for the tree/sapling layer. Compared to the reference site which recorded 17 indicator species, these results further support the call for a careful consideration of the role of exotic invasive plant species in reclamation as they often become monocultures and impede the development of local native species.

5.0 Conclusions and Management Implications

This study was designed to assess the effectiveness of revegetation in establishing a self-sustainable, structurally and functionally diverse native forest on degraded mined land within the tropical forest region of Ghana. Results of the study indicated a much lower diversity and complexity of the vegetation (especially within the upper vegetation strata) in the reclaimed site compared to the reference forest after two decades. Compositionally, the reclaimed site also varied substantially from the local reference site, being dominated by exotic invasive plant species. Indicator species analysis revealed the same species planted during the initial stages of the reclamation programme (i.e. *A. mangium, S. siamea, L. leucocepha, and G. sepium)* as the key indicator species for reclaimed sites. The results are generally consistent with previous reports that reclamation of degraded mined lands requires more time. This study also demonstrates that despite their potential to improve vegetation cover within a reasonably short time [17], invasive plant species can also slow the recovery of local native biodiversity, and thus, progress towards restoring the original forests in a degraded mined area. These outcomes highlight the need for careful consideration of the use of exotic plant species for reclamation, and the need for implementation of proper adaptive management systems if the objective of long-term restoration of a resilient native forest ecosystem capable of performing multiple functions, including sequestering carbon, controlling erosions and plant invasion, improving hydrology and serving wildlife habitats, are to be achieved.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

AUTHOR CONTRIBUTIONS

E. Darko and C. Afriyie-Debrah were responsible for searching the bibliography, selecting the relevant references, coding the references, writing the initial manuscript draft, synthesizing the manuscript, and revising the final manuscript version. E. Darko was responsible for conceptualizing the draft, analyzing the references' coding, and reviewing the whole manuscript. A. K. Anning and B. Fei-Baffoe were responsible for the work plan preparation, defining the bibliographic search, conceptualizing the draft, and reviewing the whole manuscript. D. Osei Twumasi and A. K. Keteku were responsible for selecting the relevant references, analyzing the coding of the references, and reviewing the analysis in the manuscript.

AVAILABILITY OF DATA AND MATERIAL

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Negative AI Statement

The author(s) declared that no AI tools or services were not used or not highly applied during the preparation of this work.

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