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ORIGINAL RESEARCH

Growth Performance of Exotic and Indigenous Tree Species Across Site Conditions in a Subtropical Hill Ecosystem

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ABSTRACT: Subtropical hill forests play vital roles in biodiversity, climate regulation, and soil stability. However, unsustainable land use and logging have caused soil degradation, threatening these ecosystems and hindering reforestation. Effective restoration requires selecting tree species suited to site conditions, but knowledge of native and exotic species performance across altitudinal gradients remains limited. To address this knowledge gap, this study aimed to evaluate the growth and survival of native and exotic tree species planted at three altitudinal zones (bottom hill: up to 25 m, middle hill: 25–45 m, and top hill: above 45 m mean sea level) within the Chittagong University campus hill ecosystem. Using systematic random sampling, 59 plots (20 m × 20 m) containing 886 trees representing 21 species were assessed for height, diameter at breast height (DBH), and survival at plantation ages ranging from 5 to 35 years. Species were categorized into short-rotation and medium-to-long rotation groups to analyze species-site interactions. Results demonstrated superior growth of Gmelina arborea at the top hill among short-rotation species, while native long-rotation species such as Dipterocarpus turbinatus and Elaeocarpus serratus showed maximum height and DBH at higher altitudes. Survival rates were significantly lower at the middle hill, correlating with frequent illegal felling, while top and bottom hills showed better species establishment. The findings highlight the critical importance of species-site matching and suggest that anthropogenic disturbances are a major constraint on reforestation success in subtropical hill forests. This study provides valuable empirical data to inform species selection and forest management strategies, ultimately supporting more sustainable afforestation efforts and ecosystem restoration in similar subtropical hill regions globally.

KEYWORDS: Exotic, growth performance, indigenous, species site interaction, survival rate.

1. Introduction

Forests are vital ecosystems that provide numerous ecological, economic, and social benefits worldwide. However, the definition of "forest" varies considerably among countries, shaped by ecological contexts and socio-political factors (Romijn et al., 2013). According to the Food and Agriculture Organization (FAO, 2020), a forest is defined as land spanning more than 0.5 hectares, covered by trees taller than five meters, with a canopy cover exceeding 10%, or trees capable of naturally reaching these criteria. Despite their significance, forests have been severely impacted by decades of deforestation and unsustainable land-use practices, resulting in widespread land degradation globally. Reforestation and afforestation efforts are recognized as critical strategies to mitigate these losses and restore ecological integrity while supporting human livelihoods.

However, a major challenge limiting the success of reforestation programs is the lack of comprehensive knowledge on tree species performance under different site conditions (Wishnie et al., 2007). Globally, many plantation initiatives rely heavily on monocultures, planting only a few economically important tree species (FAO, 2000). While monoculture plantations offer benefits such as simplified management and rapid biomass production, they have been criticized for negatively affecting biodiversity, reducing ecosystem services, and failing to meet the diverse needs of local communities (Lamb et al., 2005). In contrast, mixed-species plantations have demonstrated greater potential in enhancing ecosystem functioning and resilience (Cusack and Montagnini, 2004). Thus, understanding species-specific growth and survival in relation to environmental gradients is essential for designing sustainable forestry programs.

Bangladesh, endowed with rich vegetation and diverse forest species, faces significant forest degradation due to population pressure and unscientific forest management over the past decades (Dutta and Hossain, 2017). To address this, the country has increasingly focused on plantation of valuable timber species to restore heterogeneous natural forests (Hossain, 2008). Initiated in 1871 with *Tectona grandis* in the Chittagong Hill Tracts, plantation efforts have expanded to include species such as *Dipterocarpus turbinatus, Hopea odorata, Artocarpus chama, Anisoptera scaphula, Acacia auriculiformis, Acacia mangium,* and *Eucalyptus camaldulensis* under Bangladesh Forest Division programs. Building on this legacy, Chittagong University commenced its own plantation program in 1982, aiming to reduce forest degradation in hill areas and improve the availability of forest products for local communities. The university's forests fall within tropical wet evergreen and semi-evergreen forest types (Islam et al., 1979), with widely planted species including *Gmelina arborea, Dipterocarpus turbinatus, Acacia auriculiformis, Hopea odorata, Chuckrassia tabularis, Tectona grandis, and Swietenia macrophylla* (Sultana et al., 2025).

A fundamental question in forest ecology is how diverse tree species coexist and interact within complex ecosystems, especially in tropical forests characterized by high species richness (Bagchi et al., 2011). Over 100 ecological mechanisms have been proposed to explain species coexistence (Wright, 2002), yet identifying dominant processes under natural conditions remains challenging (Bagchi et al., 2011). Spatial distribution patterns of species provide critical insights into ecological processes such as dispersal limitation, habitat heterogeneity, and interspecific interactions (Fibich et al., 2016; Zhang et al., 2017). Moreover, species interactions influence growth, survival, and reproduction, thereby shaping forest community structure (Magrach et al., 2014). Competition and facilitation among neighboring trees further mediate species assembly and ecosystem function

(Callaway and Walker, 1997; Schöb et al., 2012).

Despite these advances, there remains a significant research gap regarding how exotic and indigenous tree species perform across variable site conditions, particularly altitudinal gradients in subtropical hill ecosystems. This gap limits the ability to optimize species selection and plantation design tailored to site-specific environments.

To address this, the present study investigates species-site interactions by evaluating growth parameters (height, diameter at breast height, and survival rate) of multiple native and exotic tree species planted at different altitudes within the hill sites of Chittagong University campus. The study sites were stratified into three altitudinal zones: Top hill (>45 m above mean sea level), Middle hill (25–45 m), and Bottom hill (<25 m). Measurements were conducted at five-year plantation intervals, ranging from 10 to 35 years of age. By analyzing species performance across these site conditions, this research aims to provide valuable data to guide future large-scale plantation programs, ensuring improved survival, growth, and ecosystem service delivery in subtropical hill forests.

2. Materials and methods

2.1 Description of the study site

The study was conducted in the Chittagong University campus (Figure 1) which is located at Fatehpur union under Hathazari upazila in Chattogram district. It lies between 22º27'30" and 22º29'0" North latitudes and 91º46'30" and 91º47'45" East longitudes. The campus lies some 12 miles north of Chattogram city, about 2 miles southwest of the Chattogram-Rangamati road, and a little closer to the Chattogram-Nazirhat railway branch lines (Akhtaruzzaman et al., 2020). Topographically, the campus is lodged at a safe elevation from seasonal flooding (Akter et al., 2022). Soils are yellowish brown to yellowish red and are sandy to clay-loam. More than 60% of soils are formed in moderately coarse to fine textured, folded tertiary hill sediments (Akhtaruzzaman et al., 2020). The mean monthly temperature ranges from 14.6 ºC to 26.3 ºC, and the mean annual rainfall is 2796 mm, with monthly variation from 6 mm to 583 mm. Information related to plantation of different species were collected from IFESCU library; IFESCU nursery, Botany nursery and the most recent information were collected from internet and published articles.

2.2 Experimental design

The study was conducted from June 2021 to February 2022. At first, the whole campus was assessed through simple random sampling, and data were collected from 59 different plots having a plot size of (20 m x 20 m). Some of these plots were at the top hill (above 45m from MSL), some were at the middle hill (25 to 45m from MSL), and some were at the bottom hill (lower than 25m from MSL).

*MSL = Mean sea level

2.3 Data collection

The number of quadrats was fixed considering the sample plot size (20 m x 20 m) to have a sampling intensity of more than 0.068% for quantitative measurement of the tree species throughout the sites.

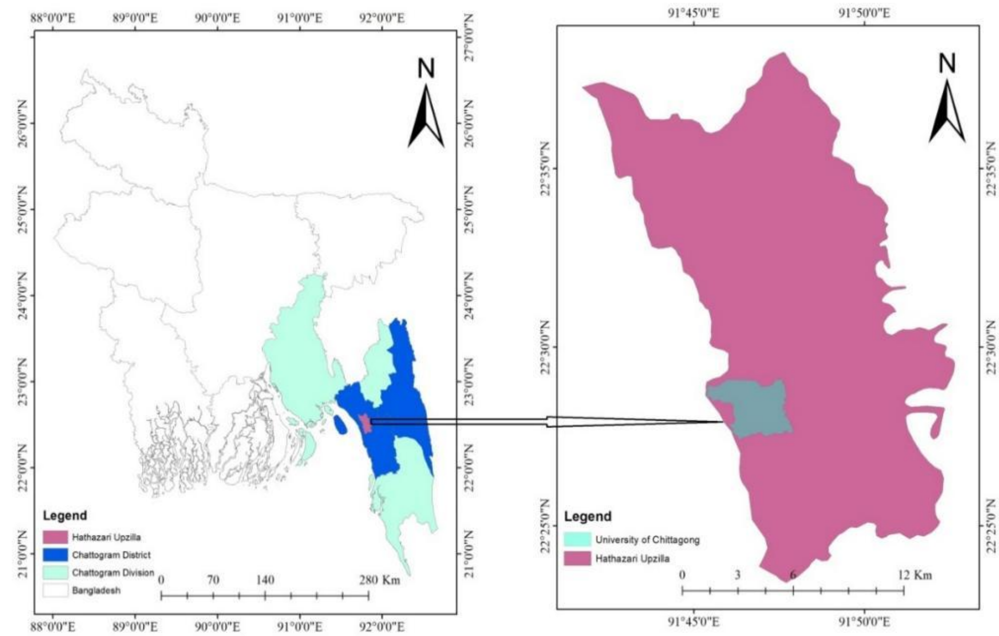

Figure 1. Study Area Map (*Study area map was prepared by using Arc GIS software.

All trees having ≥ 2 cm DBH were identified, counted by individuals and measured in the quadrats.

2.4 Statistical analysis

Collected data were divided into short rotation species and medium to long rotation species for both exotic and indigenous tree species. Statistical data analysis and graphical representation were done by MS Excel (Version 2018)

3. Results

3.1 Growth performance

A total of 59 plots, each measuring 20 m × 20 m, contained 886 tree stems representing 21 different species. These tree species are categorized into two rotation classes: short rotation and medium to long rotation to measure their growth performance and survival rate.

3.2 Growth performance of short rotation species

From Table 1, 10 year old plantation of short rotation species shows that *Acacia mangium* attained the best height and DBH at three altitudes having the highest height (18.22 m) and DBH (20.4 cm) at the middle hill following the lowest height (13.7 m) and DBH (14.1 cm) in *Gmelina arborea* at the bottom hill. *Acacia auriculiformis* possessed better height and DBH at three altitudes of hill.

On the other hand, *Gmelina arborea* showed the highest height (20.2 m) and DBH (23.5 cm) at the top hill in 15 years old plantation. Both *Acacia auriculiformis and Melaleuca leucodendron* attained better growth performance at three altitudes of hill at the age of 15 years. On the other hand, *Eucalyptus camaldulensis* possessed comparatively lower height and DBH at three altitudes of hill than that of other species.

Overall, *Gmelina arborea,*

Table 1. Growth performance of short rotation species.

Nature of the species	Species name	Age (Year)	Top hill		Middle hill		Bottom hill	
			Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)
Exotic	*Acacia auriculiformis*	10	15.50	17.80	16.00	14.42	15.15	16.50
		15	18.45	21.54	16.50	22.33	18.00	19.98
	Acacia mangium	10	17.50	19.00	18.22	20.40	17.35	19.40
	Eucalyptus camaldulensis	15	18.00	20.50	15.50	17.89	16.00	18.55
	Melaleuca leucodendron	10	15.92	19.50	14.50	16.33	14.90	18.27
		15	18.50	20.50	17.00	22.30	15.70	17.59
Native	*Gmelina arborea*	10	16.21	15.50	15.33	18.00	13.70	14.10
		15	20.20	23.50	18.66	22.50	19.00	20.34

Note: Ht-height of tree, DBH- Diameter at Breast Height

Table 2. Growth performance of medium to long rotation species

Nature of the species	Species name	Age (Year)	Top hill		Middle hill		Bottom hill	
			Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)
Native	*Albizia odoratissima*	20	18.00	31.20	16.55	21.70	18.50	25.40
	Albizia procera	20	18.00	40.50	15.50	29.20	17.32	32.40
	Alstonia scholaris	20	16.66	22.20	15.90	24.10	15.50	23.65
		25	16.50	24.60	16.00	22.70	18.20	24.33
	Anisoptera scaphula	20	19.00	23.50	18.50	17.55	20.30	20.90
		25	22.50	27.10	22.00	18.30	21.90	23.50
	Aphanamixis polystachya	20	17.33	31.20	15.50	23.66	17.00	27.73
	Artocarpus chama	25	16.00	26.20	16.50	22.80	17.20	25.89
		30	19.57	33.40	17.16	25.55	18.74	26.36
		35	20.20	35.10	18.77	28.30	19.00	29.50
	Bombax ceiba	25	19.50	33.70	17.23	28.55	20.50	34.32
	Chuckrasia tabularis	20	17.50	29.48	15.75	22.20	17.00	29.19
		25	16.87	28.56	18.00	25.52	18.50	30.25

Continued Table 2

Nature of the species	Species name	Age (Year)	Top hill		Middle hill		Bottom hill	
			Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)
	Dipterocarpus turbinatus	20	17.00	16.20	17.50	14.63	16.88	15.79
		25	20.00	24.96	19.61	21.89	17.50	17.14
		30	20.67	27.47	19.00	25.88	21.17	28.27
		35	23.46	31.72	22.26	28.63	22.38	30.55
	Elaeocarpus serratus	20	16.36	22.72	16.00	20.78	18.00	29.55
		25	19.00	42.25	16.80	31.70	18.33	33.28
	Hopea odorata	20	10.06	13.88	17.54	14.72	16.00	14.82
		25	14.44	18.29	13.57	21.25	15.00	23.19
		30	15.88	28.23	17.92	25.67	13.50	20.78
		35	18.83	29.43	21.00	25.22	16.00	23.68
	Lagerstroemia speciosa	20	13.00	14.20	11.55	18.72	13.00	15.70
		25	15.60	18.36	12.77	16.39	14.35	20.30
	Swintonia floribunda	25	21.00	32.76	20.25	31.10	20.00	33.40
	Syzygium firmum	25	14.00	17.55	12.88	14.31	13.83	21.23
	Terminalia bellirica	30	18.00	17.63	12.70	20.74	15.00	24.35
Exotic	*Samanea saman*	20	13.83	13.63	14.00	17.43	14.50	20.50
		35	18.67	29.50	14.83	23.00	15.67	24.87
	Swietenia macrophylla	25	13.53	20.10	16.50	18.55	14.33	20.93
		30	15.44	23.65	14.36	21.56	14.78	21.76
	Tectona grandis	20	12.17	18.39	13.00	18.56	16.00	20.21
		30	20.00	29.65	19.00	27.30	21.50	29.43

Acacia auriculiformis, Acacia mangium and *Melaleuca leucodendron* grew well at three altitudes of hill.

3.3 Growth performance of medium to long rotation species

A 20 years old plantation of medium to long rotation species showed that *Albizia procera* obtained the highest height of 18m and highest DBH of 40.5 cm at the top hill among the native species. On the other hand, highest height (16 m) and DBH (20.21cm) was obtained in *Tectona grandis* at the bottom hill among the exotic species. But the growth performance of *Tectona grandis* was not satisfactory at top and bottom hill. *Lagerstroemia speciosa* possessed the lowest height and DBH at three altitudes of hill at 20 year old plantation. 25 years old plantation showed a variety of differences among the height and DBH of both native and exotic species. The highest height (22.5 m) was attained by *Anisoptera scaphula* at top hill where highest DBH (42.25 cm) obtained by *Elaeocarpus serratus* at top hill. *Dipterocarpus turbinatus* and *Swintonia floribunda* showed better growth performance at three altitudes of hill than that of other species where *Lagerstroemia speciosa* and *syzygium firmum* possessed lower growth performance at the age of 25. On the other hand, the highest height obtained by *Tectona grandis* which was 21.5 m at bottom hill and highest DBH of 33.4 cm was found in *Artocarpus chama* at top hill at the age of 30 years old. *Dipterocarpus turbinatus, Hopea odorata* and *Swietenia macrophylla* possessed satisfactory growth performance at three altitudes of hill while *Terminalia bellirica* did not. In 35 years old plantation of medium to long rotation species, *Dipterocarpus turbinatus* attained the highest height of 23.46m at top hill and highest DBH was found in *Artocarpus chama* of 35.1cm at top hill. *Samanea saman* possessed comparatively lower growth performance than that of other species at three altitudes of hill at the age of 35 (Table-2).

Overall, *Tectona grandis* performed well at the lower altitudes of hill where *Dipterocarpus turbinatus, Hopea odorata* and *Artocarpus chama* showed good performance at three altitudes of hill at different ages.

3.4. Survival rate (%)

3.4.1. Survival rate of short rotation species

Acacia auriculiformis obtained the highest survival (90%) at the top hill at the age of 10 years old while the lowest survival was noticed in Gmelina arborea (65%) at the middle hill at the age of 15 years old. *Acacia mangium, Eucalyptus camaldulensis* and *Melaleuca leucodendron* showed satisfactory rate ranges from 75% to 85% for both 10 and 15 years old plantation at top, middle and bottom hill (Table-3).

Table 3. Survival rate of short rotation species.

Nature of the species	Species name	Age (Yr)	Hill Top (%)	Middle hill (%)	Bottom hill (%)
Exotic	*Acacia auriculiformis*	10	90	80	88
		15	87	76	82
	Acacia mangium	10	82	73	78
	Eucalyptus camaldulensis	15	84	80	85
	Melaleuca leucodendron	10	88	85	79
		15	80	72	77
Native	*Gmelina arborea*	10	82	70	74
		15	76	65	70

Note: Yr-year

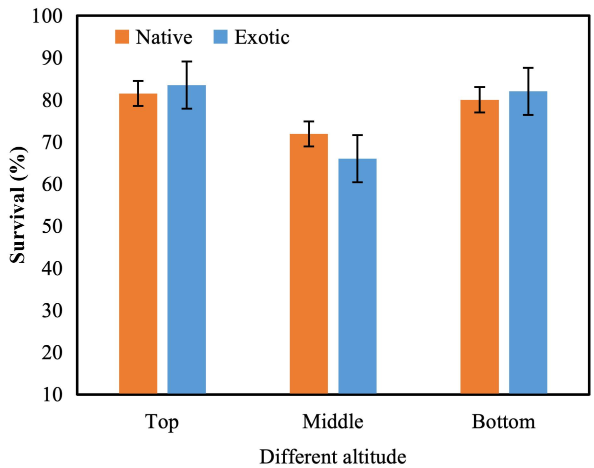

Figure 2. Average survival rate of exotic and native species at the age of 10 years.

Figure 2 stated that exotic and native species had little difference at high and low altitudes but exotic showed poor survival rate at middle altitude of hill than native tree species. It is due to the illegal fuel wood collection from the middle hill as short rotation fast growing tree species is a great source of fuel wood.

3.4.2. Survival rate of medium to long rotation species

Dipterocarpus turbinatus possessed the highest survival rate of 87% at top hill at the age of 20 years among the native tree species where *Tectona grandis* attained the highest rate of 85% at 20 years old plantation among the exotic tree species.

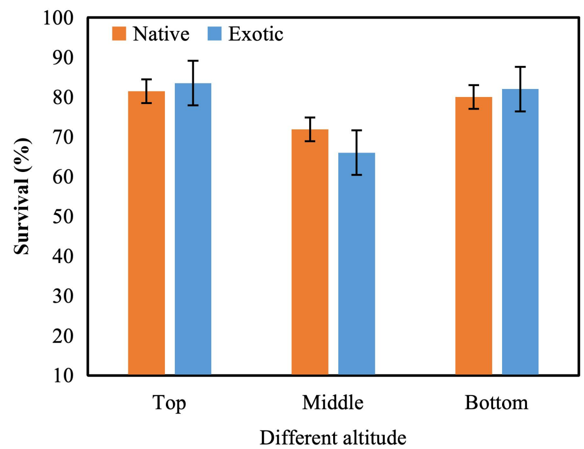

Figure 3. Average survival rate of exotic and native species at the age of 20 years.

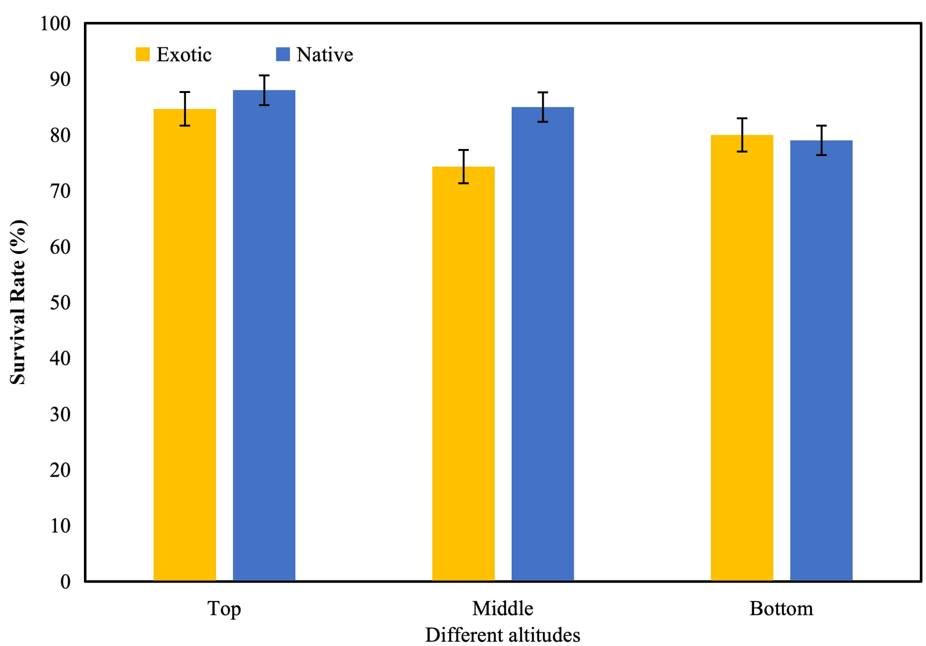

Figure 4. Average survival rate of exotic and native species at the age of 30 years.

Table 4. Survival rate of medium to long rotation species.

Nature of the species	Species name	Age (Year)	Top hill (%)	Middle hill (%)	Bottom hill (%)
Native	*Albizia odoratissima*	20	80	67	78
	Albizia procera	20	82	70	80
	Alstonia scholaris	20	75	59	65
		25	70	62	65
	Anisoptera scaphula	20	80	75	83
		25	77	65	70
	Aphanamixis polystachya	20	84	80	88
	Artocarpus chama	25	85	76	80
		30	72	56	68
		35	73	55	65
	Bombax ceiba	25	78	70	74
	Chuckrasia tabularis	20	84	71	86
		25	82	68	79
	Dipterocarpus turbinatus	20	87	82	85
		25	82	76	79
		30	80	69	75
		35	77	68	80
	Elaeocarpus serratus	20	82	73	80
		25	75	60	68
	Hopea odorata	20	86	80	83
		25	82	75	80
		30	78	68	73
		35	75	60	73
	Lagerstroemia speciosa	20	75	62	72
		25	70	57	66
	Swintonia floribunda	25	82	75	80
	Syzygium firmum	25	78	70	82
	Terminalia bellirica	30	74	75	80
Exotic	*Samanea saman*	20	82	67	80
		35	69	55	65
	Swietenia macrophylla	25	82	70	85
		30	74	69	75
	Tectona grandis	20	85	65	84
		30	83	59	78

The lowest rate was found in *Artocarpus chama* (55%) at the middle hill among the native species and *Samanea saman* (55%) at the middle hill among the exotic tree species (Table 4). Figure-3 and 4 show that average rate of survivability of both exotic and native tree species was higher in top hill and bottom hill as compared to middle hill. Illegal felling of tree species of timber value is more at the middle hill than that of top and bottom hill. Difficulty in overtopping the higher altitude of hill and remaining the people at the lower portion of the hill are the main causes of doing frequent illegal felling at the middle altitude of hill.

4. Discussion

The findings of this study highlight notable differences in the growth performance and survival rates of various short- and medium- to long-rotation tree species across different altitudinal zones in a hill ecosystem. These variations can be attributed to species-specific adaptability, environmental conditions, and anthropogenic influences. The outcomes support existing literature while also providing new insights into species-site interactions in such complex terrains.

The superior performance of Gmelina arborea at higher elevations aligns with previous findings by Dutta and Hossain (2017), who emphasized its suitability for upland plantations and mixed-species forestry systems. Likewise, *Acacia auriculiformis, Acacia mangium, and Melaleuca leucodendron* showed adaptability across diverse elevations, which confirms their potential for short-rotation forestry, as previously reported by Sikder & Khair, (2011). These species have been widely recognized for their rapid growth, soil-enriching properties, and tolerance to varying site conditions, making them valuable for degraded land restoration and fuelwood production.

Our results also affirm the suitability of Tectona grandis for lower-elevation sites. This is consistent with earlier recommendations by (Sikder & Khair (2011) , who identified T. grandis as an ideal species for social forestry due to its timber value, growth potential, and broad adaptability in lowland areas. Furthermore, the successful establishment of species such as *Dipterocarpus turbinatus, Hopea odorata,* and *Artocarpus chama* at higher altitudes corroborates findings from Sakai et al. (2014), who suggested that these native dipterocarps thrive in open hill sites and can serve as foundation species in native forest restoration.

The observed differences in survival rates between native and exotic species are also noteworthy. Our study supports the findings of Subiakto et al. (2016) and Olukoye et al. (2003), which demonstrated that native tree species generally have higher survival rates under local ecological conditions. Native species often exhibit greater ecological compatibility, pest resistance, and adaptability to site-specific stresses, which contributes to their higher survivability. This is further supported by Arcos-LeBert et al. (2021), who emphasized the role of native species in enhancing long-term ecosystem resilience and biodiversity conservation. Similarly, Islam et al. (1999) recommended the use of native species in reforestation initiatives, especially in environmentally sensitive or degraded landscapes.

The relatively poor survival of exotic species at middle altitudes in this study can be largely attributed to anthropogenic pressures, particularly illegal fuelwood collection. Fast-growing exotic species are often targeted due to their commercial value, and mid-hill zones are more accessible to local communities. These socio-ecological dynamics underscore the need for integrated forest management that accounts not only for ecological suitability but also for social behavior and resource dependency in adjacent communities.

Moreover, the trend of lower survival and growth in the mid-hill areas compared to top and bottom hills suggests a potential "disturbance gradient" caused by human activities. This is especially important for forestry programs aiming to ensure long-term sustainability and ecological function. It indicates that passive protection strategies alone may be insufficient, and active community involvement and surveillance may be necessary to reduce pressure on vulnerable sites.

In light of these findings, species selection for reforestation and afforestation in hill ecosystems should not only consider growth performance but also survival potential under prevailing site conditions and external pressures. While fast-growing exotics may yield short-term benefits in terms of biomass, the long-term ecological success and sustainability of plantations are more likely to be achieved through the use of well-adapted native species.

Finally, the differential performance of species across elevations reinforces the importance of site-species matching in forest management. Elevation, microclimate, soil type, and human accessibility must be considered collectively when designing plantation schemes. Hill ecosystems are highly heterogeneous and susceptible to both climatic extremes and human interference; therefore, strategic planning must be adaptive, evidence-based, and context-specific.

5. Conclusion

Species site interaction is a major thinking before going on a plantation program. A forester or related authority should know the suitable site for a species where it can grow well and survive for a long period of time. This study has shown various growth performances (height, DBH, survival rate) of several species at different altitudes (top, middle, bottom) of hill of Chittagong University campus in different year of plantations i.e. 5, 10, 15, 20, 25…years. A comparative study on the growth performance of short rotation species has shown that fast growing exotic species i.e. *Acacia auriculiformis, A. mangium* has the ability to grow well at three altitudes of hill but *Gmelina arborea* performs well at the high altitude of hill. Another study on medium to long rotation species has shown that *Tectona grandis* is suitable for better growth performance at bottom hill. Among the native tree species *Dipterocarpus turbinatus, Hopea odorata* and *Artocarpus chama* has possessed better height and DBH at top hill. Survival percentage has been found very low at middle altitude of hill. Lots of stumps have been noticed during field survey. Of course, those tree species have been cut illegally as cutting tree is banned in Chittagong University campus. Those stumps were mostly found at the middle altitude of the hill. As one needs to face difficulty to reach the top hill and to carry the logs from the top, he finds comfort to cut trees at middle hill because no one can see him from the roadside. As a result, survival rate is poor at the middle altitude of hill. Lack of silvicultural treatments such as thinning, pruning, weeding, gap filling etc. have been observed in these plantation plots. Lots of branching reduced the height and DBH of the desired species. As a result, we cannot get proper production of timber.

Author contributions

Conceptualization: Tania Sultana, Mohammed Kamal Hossain; methodology: Mohammed Kamal Hossain, Tania Sultana formal analysis: Tania Sultana, Md. Habibul Hasan; writing—original draft preparation: Tania Sultana; writing—review and editing, Mohammed Kamal Hossain. All authors have read and agreed to the published version of the manuscript.

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Not applicable

Conflicts of interest

The authors declare no conflict of interest.

Availability of data and materials

Data will be available on a formal request from the corresponding authors.

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