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Variations in the Forest Productivity of *Pinus patula* Plantations in Tanzania: The Need for an Improved Site Classification System

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Abstract: The productivity of forests in sub-Saharan Africa is often summarized into large compartments or site classes. However, the classification of forest productivity levels based on the original site index model in Tanzania and the techniques applied to generate the model did not include the micro-toposequence variations within compartments. This may create false expectations of wood supply and hinder the estimation of sustainable harvesting processes. This study analyzed variations in forest productivity and the site index in *P. patula* stands in two forest plantations of Tanzania to assess the applicability and generality of the present site classification system. We used dominant height as a proxy for forest productivity in 48 plots at the Sao Hill forest plantation (SHFP) and 24 plots at the Shume forest plantation (SFP). We stratified the sampling plots in each site class along the soil catena and recorded the elevation, slope, and slope positions (summit, mid, and lower). Our results showed that the site classes did not generally match the previously assigned site classes and the productivity of a given site class varied between the two plantations. We found a consistently higher productivity than that implied by the original site index in SFP, while in SHFP, the productivity was both higher and lower than estimated in different compartments. Both elevations and slope significantly contributed to predicting the productivity variations within site classes. Overall, the results indicate that physiographic factors affect variations in forest productivity within the assigned site classes. We recommend a more comprehensive site productivity assessment that takes into account physiographic variations and hence provides more accurate information for sustainable forest plantation management in Tanzania and in the region at large.

Keywords: forest productivity; *Pinus patula*; mean annual increment; physiographic factors; site classes

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1. Introduction

Forest plantations were estimated to cover over 294 million ha by 2022 [1] and have been established to meet the increasing global demand for timber products [2,3]. Such plantations have the potential to supply the world with its entire wood needs [4–6]. However, the productivity of tropical forest plantations grown on short- to medium-term rotation lengths can vary significantly. Globally, the production of wood products in 2020 totaled 473 million m^3 of sawn wood, 368 million m^3 of wood-based panels, and 401 million tonnes of paper and paperboard [7]. The global demand for timber has seen a significant increase of over 30% in the last 10–20 years, driven by economic development, urbanization, and climate change mitigation efforts that rely on timber as a renewable resource [8]. Therefore, to be able to match wood demand, production, and plantation areas at the global, regional, and local scales, timely and accurate information on the productivity of plantation forests is essential [9].

Pinus patula is a forest tree species native to Mexico, widely cultivated in tropical and subtropical regions of the world [10]. In its natural range, *P. patula* grows from 18° to 24° North latitude and from 1800 to 2700 m above sea level. Its rainfall range is from a 750 to 2000 mm annual average. The species is largely used for plantations in tropical and subtropical regions of the world, including South America, Central and Southern Africa, Indonesia, Australia, and New Zealand [11]. The area of planted *P. patula* worldwide is approximately 1 million hectares, of which 95% corresponds to plantations in central, eastern, and southern Africa [11,12]. In Africa, plantations of this species have gained considerable interest, being represented in different African countries and probably being the most widely planted pine in tropical Africa. The demand for *P. patula* timber has increased in the last 10–20 years due to improvements in economic well-being and population growth, which have driven up the overall consumption of wood-based products.

The productivity of forests varies significantly, with the mean annual increment (MAI) ranging from as low as 1–2 m^3 ha^{-1} yr^{-1} to as high as 25–30 m^3 ha^{-1} yr^{-1} [13]. Eucalypts and tropical pines are the primary species in tropical timber plantations [13]. In southern Africa, the productivity of *P. patula* ranges from 18 to 28 m^3 ha^{-1} yr^{-1} [10]. In South Africa, *P. patula* planted in well-drained soils is expected to have a MAI range of 11 to 27 m^3 ha^{-1} yr^{-1}, with good stem form and wood properties [14]. Several factors can affect forest productivity, such as site quality, age, silviculture, type of planting materials, species, irradiance, physiography, and stable environmental factors like edaphic and micro-climatic factors [15–18]. Understanding forest productivity is crucial for sustainable forest management, as it helps land managers make informed decisions about species selection, rotation lengths, and silvicultural treatments [13].

Physiographic factors, including elevation, aspect, and slope, influence plant growth [19]. The effect of elevation and slope on forests has been widely studied [20], as they can be valuable indicators of the distribution of environmental conditions such as radiation, precipitation, temperature, and soil water and nutrient availability [21,22] that affect the composition and productivity of a species [23]. The effect of physiographic factors on forest productivity is closely linked with soil physical and chemical properties including soil depth, aeration, and nutrient and water availability [24]. Thus, differences in site conditions can result in variations in site index predictions, which can, in turn, affect estimates of forest productivity. Therefore, it is important to consider site variations based on physiographic factors when predicting MAI [25].

In many countries, especially in South Africa, Tanzania, the DRC, and Zimbabwe, the productivity of forest plantation estates is generally summarized within large compartments/site classes [26]. However, forest productivity estimates downscaled from larger spatial scales can give false expectations of wood supply at the local scale and prevent reasonable estimates of sustainable yields [25]. In many underdeveloped countries, the forest productivity estimates within site class are poorly developed and rarely used in practice. This may partly be due to changes within the site that can only be detected in the longer term [27]. Such changes can be caused, in part, by off-site anthropogenic factors such as the atmospheric deposition of nutrients, site degradation, or climatic change [28,29]. The physiography that characterizes mountainous terrain strongly influences local climate [30], soil characteristics [31], and disturbance regimes [32,33]. Despite the importance of forest productivity in developing countries, there have been few undertakings to capture fine-scale variations in forest productivity within typical management compartments in forest plantations in African countries. Variations in the accuracy of the site index for large compartments/site classes also affect local wood markets and sales of timber since these rely on volume predictions based on the site index.

Forest productivity potential often varies with site index [34]. The site index is defined as the average height of the dominant (Hdom) trees in a forest stand at a given reference age and is one of the most commonly used indicators of site productivity of even-aged stands [35]. This is a more consistent way of assessing site production potential than maximum MAI since Hdom is less affected by planting density and thinning [34]. Site index is influenced by spatial scale variations in environmental factors and their impact on tree growth [35]. Understanding how site-specific factors affect variations in productivity and Hdom in forest plantations is an essential prerequisite for attaining sustainable forest management and patterns of resource use [24]. Still, little knowledge is currently available in many African countries. Potentially, physiographic factors, including elevation, slope, slope positions, and site specificity, play a crucial role in determining variations in MAI and site index, which can lead to shifting or changing site classes within forest plantations [26]. Understanding how these factors affect forest productivity and the site index at smaller spatial scales than predicted using the practiced classification is crucial for effective forest management and sustainable practices.

We therefore studied variations in forest productivity and the site index in *P. patula* stands in two forest plantations located in different regions of Tanzania and aimed to assess the applicability and generality of the present site classification system. Specifically, we tested the following:

(i) Whether forest productivity and stand variables are consistent with the assigned site classes within plantations.
(ii) To what extent Hdom, as predicted by the assigned site classes, is consistent with the realized Hdom within and between plantations and whether the differences in Hdom are related to physiographic factors.
(iii) How physiographic factors represented by slope and elevation affect forest productivity (MAI) within management compartments, each categorized by a single site class.

2. Materials and Methods

2.1. Study Site Descriptions

This study was conducted within the Sao Hill and Shume forest plantations. Sao Hill forest plantation (SHFP) is situated in the Iringa Region in the southwest of Tanzania, between a latitude of 8°18′ and 8° 33′ S and a longitude of 35°6′ and 35°20′ E (Figure 1). The plantation spans an altitudinal range of 1400 to 2000 m above sea level (m.a.s.l.), with an average altitude of 1634 m.a.s.l. It experiences a mean annual rainfall ranging from 750 to 2010 mm between November and April and temperatures ranging from 15 °C to 25 °C per annum [36]. SHFP covers a total area of 135,903 ha, out of which 86,003 ha is used for commercial tree planting and 48,200 ha is reserved for natural forest, river valleys, and future expansion [37]. *Pinus patula* occupies the largest plantation area (40,000 ha), followed by other pines (*P. elliottii, P. caribaea*), with 14,070 ha, and the remaining area covered with cypress (*Cuppresus lusitanica*), Eucalyptus species (*Eucalyptus saligna*, *E. grandis*, *E. maidenii*), *acacias* (*Acacia melanoxylon*, *Acacia mearnsii*), and *Grevillea robusta* [37–39].

Shume forest plantation (SFP) is located in the western part of the Usambara Mountains in the Lushoto district of the Tanga region. This area is positioned at a latitude of 04°33′–04°42′ S and a longitude of 38°15′–38°16′ E, with altitudes varying between 1650 and 2120 m.a.s.l [40]. The region experiences two rainy seasons, from September to November and March to April, with an average annual rainfall spanning from 800 mm to 2000 mm. The temperature range is approximately 16–22 °C, with occasional minor and unreliable rain (Mluwati) occurring in August and September [41]. The total plantation covers about 4863 hectares and is divided into four plantation blocks, namely the Shume West (1906.7 ha), Shume East (1510.51 ha), Shagayu (693.21 ha), and Magamba blocks (752.84 ha). The main species planted include *Pinus patula*, *Pinus radiata*, and Cupressus *lustanica*.

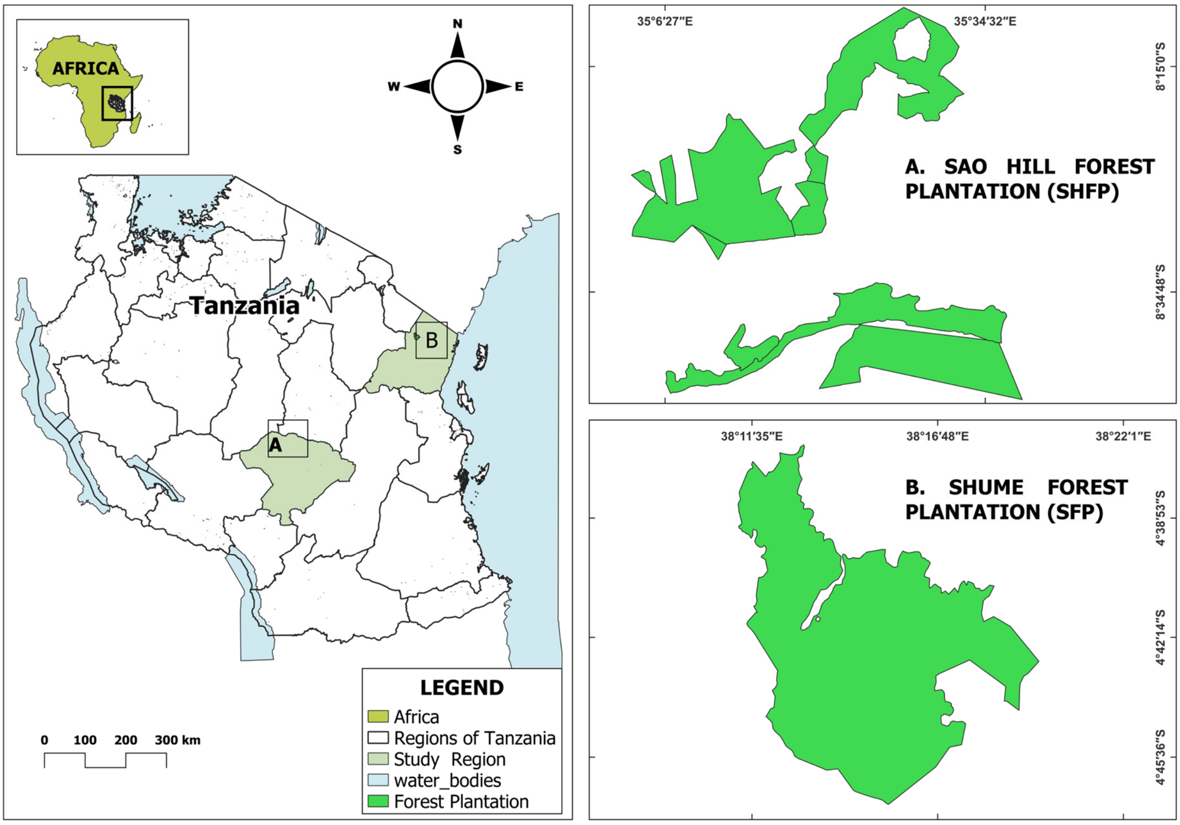

Figure 1. Location of study sites at Sao Hill and Shume forest plantations in Tanzania.

2.2. Sampling Design

We selected the two largest administrative divisions according to production potential, namely SHFP and SFP. Then, based on official management plan records, the original site index model (Equations (1) and (2)) that fits well for *P. patula* forest plantations in Tanzania, as described by Malimbwi [42], was used to divide the divisions into four compartments representing site classes (I, II, III, and IV), in ascending order of productivity (Figure A1). The site index model is a suitable generalized growth model for explaining height growth at a reference age for *P. patula* in Tanzania.

$$Hdom = a \times site \times (1 - \exp(b \times Age))^{c} \tag{1}$$

where *Hdom* = dominant height (m), *a*, *b*, and *c* are the coefficients to be estimated, and Site = site index, which is the dominant height at a reference age of 15 years.

This resulted in the following equation:

$$Hdom = 1.564354 \times site \times (1 - \exp(-0.092288 \times Age)^{1.571869} \tag{2}$$

The suitable site indices obtained through the site index curves at reference ages of 12, 15, 15, and 9 were 22.4, 21.8, 16.9, and 7.6 m (site classes I, II, III, and IV), respectively, at SHFP, while at SFP, they were 22.6, 21.8, 16.9, and 7.6 at reference ages of 12, 15, 15, and 13, indicating site classes I, II, III, and IV, respectively (Table A1).

In each site class, we stratified 12 and 6 quadrant plots measuring 20 m × 20 m (400 m^2) each, based on the slope position (i.e., summit, mid, and lower slopes) at SHFP and SFP, respectively (Figure 2). A total of 48 plots with 1960 individual trees and 24 plots with 942 individual trees were measured at SHFP and SFP, respectively (Table 1).

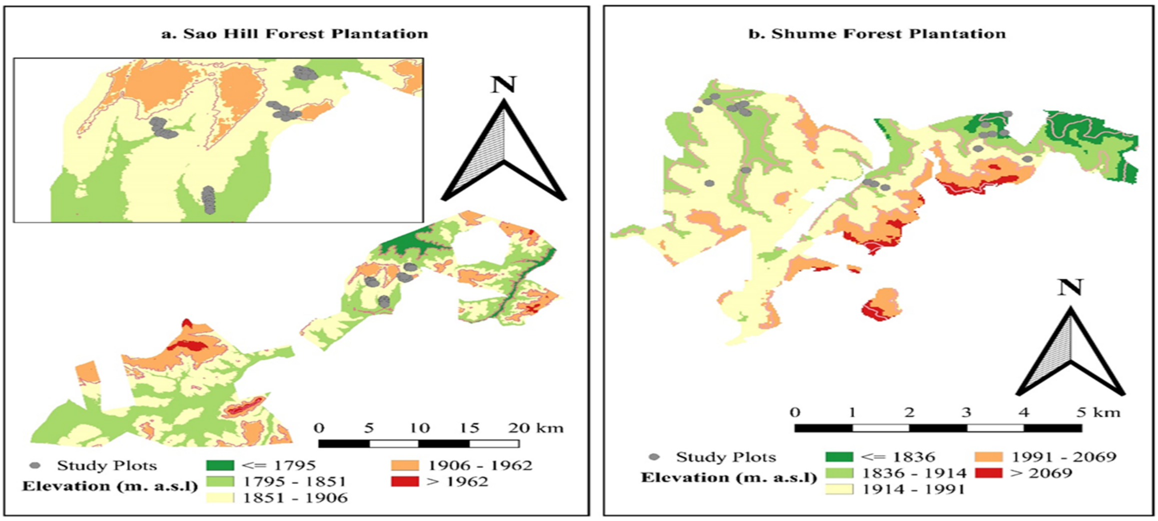

Figure 2. The location of sampling plots and elevations at Sao Hill and Shume forest plantations in Tanzania. Shaded dots in gray represent studied plots. Rectangles shaded green, pale green, yellow, orange, and red represent elevation range. The different intervals of elevation are influenced by different geographical locations of the plantations.

Table 1. Number of plots used for tree growth variable data collection.

Forest Plantations	Compartments	Site Classes	Age (Years)	Plots	No. Trees
SHFP	ITIMBO 1	I	12	12	462
	ITIMBO 2	II	15	12	539
	ITIMBO 3	III	15	12	556
	ITIMBO 4	IV	9	12	403
	Total			48	1960
SFP	SHUME WEST 45, SHUME EAST 189	I	12	6	233
	SHUME WEST 35, SHUME EAST 187	II	15	6	226
	SHUME WEST 43A, SHUME EAST 164	III	15	6	255
	SHUME WEST 67, 181A	IV	13	6	228
	Total			24	942

2.3. Field Data Collection

In each plot, the diameter at breast height (DBH in centimeters) was measured for all trees. Six trees per plot, including those with the smallest, medium, and largest DBH, had their height measured to estimate the height of the other trees in each site class. Additionally, the dominant height of the five tallest trees per plot was measured (Hdom in meters) at both studied sites [43]. Tree DBH and height were measured using a vernier caliper and a vertex, respectively. We also measured the physiographic factors within each sample plot, including slope (%) and elevation (m.a.s.l) (Figure 2). Slopes were measured at four corners of each plot using a clinometer, and the average values were recorded. Slope positions were identified by observing contour lines, and their elevations were recorded using a global positioning system (Garmin GPSMAP 65 Series). The ages of the plantations were documented based on management records. Specifically, the ages of the plantations at SHFP ranged from 9 to 15 years, while those at SFP ranged from 12 to 15 years.

2.4. Data Analysis

2.4.1. Data Processing

Table 2 displays the calculated forest stand parameters, including tree height (H), basal area (G), tree volume (V), and mean annual increment (MAI). However, for both plantations, the same species-specific models are employed to estimate these attributes because they are tailored to specific forest tree species.

Table 2. Studied forest stand parameters for Sao Hill and Shume forest plantations in Tanzania.

Parameters	Model	Reference
Tree total height	$height = 1.3 + \frac{dbh^2}{13.63898+0.026482\times \mathrm{dbh}^2}$	Mugasha et al. [44]
Basal area	$G = 1/m \sum (gi/ai)$	Malimbwi et al. [45]
Single tree volume	V = exp(−9.04925 + 1.14781 × ln (Ht) + 1.5496 × ln*Dbh*	Malimbwi et al. [45]
Mean annual increment (MAI)	$MAIa = \frac{Ya}{a}$	Saka [46]

Note: Tree total height = estimated total tree height (m); dbh = measured diameter at breast height (cm); *G* = basal area per ha; (m^2/ha); *gi* = tree cross-sectional area ($gi = \pi \times Dbh^2/4$); m = number of sample plots; *ai* = plot area; MAI = mean annual increment (m^3 ha^{-1} yr^{-1}); Y_a is yield at age *a* and *a* is the age.

The Mean Dominant Height (Hdom) was estimated using the height of the five tallest trees of good form in each plot, as described by Vatandaşlar et al. [47].

Stand volume (m^3/ha) was estimated in a similar way to the basal area per ha, as described by Malimbwi et al. [45]. The mean annual increment (MAI) of a forest stand was typically measured through the cumulative volume production over time as described by Saka [46] and Matthews et al. [47].

2.4.2. ANCOVA, the Generalized Linear Model, and the Linear Mixed-Effects Model

As some of the stands had different ages, we analyzed the differences in forest productivity and stand variables under different site classes using Covariance Analysis (ANCOVA), in which stand age served as a covariate. With all the trees combined in plots for a given site class, the Generalized Linear Model (GLM) was used to examine the effect of each site class on the forest productivity and stand variables. Then, where significant differences were observed, Student–Newman–Keuls (SNK) post hoc tests were used to determine which means were significantly different at $p \leq 0.05$ [48,49]. We also examined the variations between the predicted and realized dominant heights (Hdom) based on the slope positions, one of the physiographic factors, using site index curves in the *P. patula* forest plantation yield table, as described by Malimbwi et al. [44], to observe shifts in the site classes at SHFP and SFP. Moreover, a linear mixed-effect model (LMM) was used to test whether physiographic variables (slope % and elevations) could account for the heterogeneity of MAI within site classes as described in Equation (3). However, slope percentage and elevations were used as the independent variables.

$$MAI_{ij} = \beta_0 + \beta_1 \cdot \mathrm{Slope}_{ij} + \beta_2 \cdot \mathrm{Elevation}_{ij} + \gamma_k + \epsilon_{ij} \quad (3)$$

where MAI_{ij} is the response variable for the I (th) observation in the (*j*) plot.

β_0 is the intercept. β_1 and β_2 are the fixed-effect coefficients for slope and elevation, respectively. γk represents the random effect for the (k)th plot. ϵ_{ij} is the error term.

The model allows us to partition the total variance in MAI into the variance explained by the fixed effects (slope and elevation) and the random plot-level effect. This can help determine how much of the heterogeneity in MAI is accounted for by the physiographic variables versus other unobserved site-level factors. Only significant parameters ($p < 0.05$) were retained. All statistical analyses were conducted and tables and figures made using SAS 9.4 (2011, SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Forest Productivity and Stand Variables for Assigned Site Classes within Sao Hill and Shume Forest Plantations in Tanzania

The ANCOVA results indicated that at SHFP, the forest productivity and stand variables for site classes (SCs) I and III were similar and lower than for SC II, while Hdom was significantly higher in SC II (Figure 3a). For SFP, the results indicated significant variation in forest productivity between site classes, with the forest productivity and stand variables decreasing from SCs I to IV, as expected. Unlike at SHFP, the stand variables at SFP decreased consistently with SC, except for Hdom and BA, which did not differ significantly between SCs I, II, and III (Figure 3b). For each corresponding SC, the stand variables were consistently lower at SHFP than at SFP (Figure 3a,b).

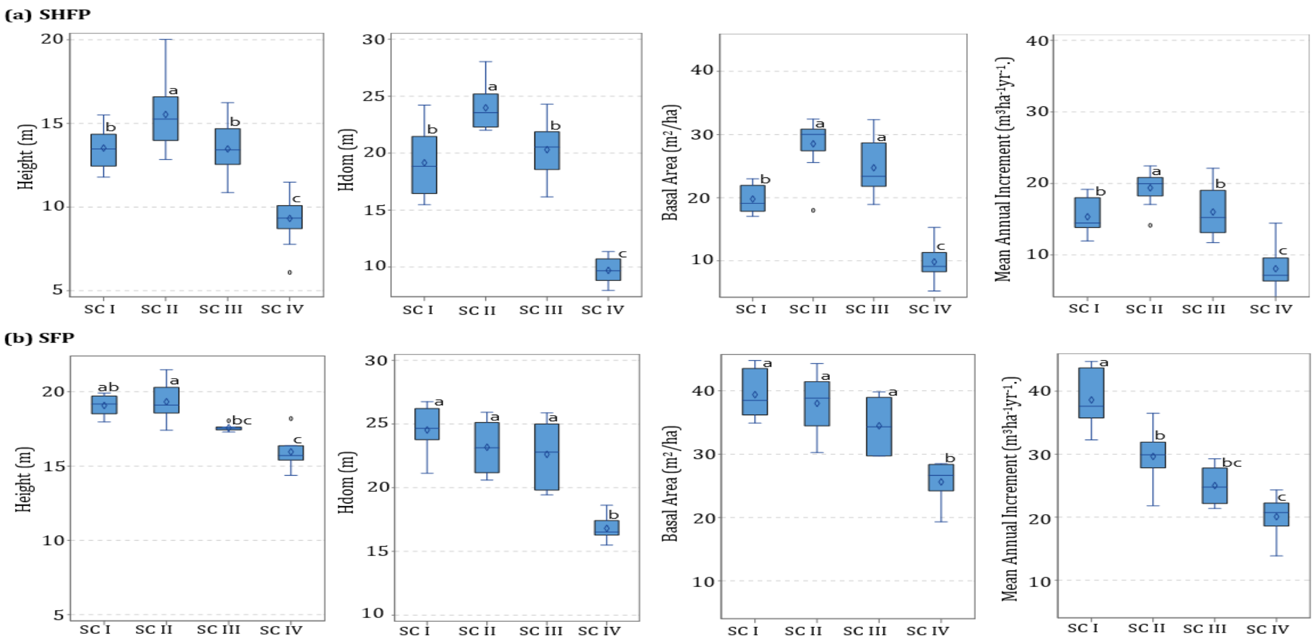

Figure 3. Variability in forest productivity estimates and other stand variables as indicated by letter a, b and c with respect to site classes at Sao Hill (SHFP) and Shume forest plantations (SFP) in Tanzania. The vertical line outside the box represents the minimum and maximum values. Means denoted with the same letter are not significantly different (α = 0.05). SC I = site class I; SC II = site class II; SC III = site class III; SC IV = site class IV.

3.2. Dominant Height (Hdom) as Related to Physiographic Factors and the Shift in Site Classes at Sao Hill and Shume Forest Plantations in Tanzania

Hdom exhibited unexpected shifts in both directions contrary to what was predicted from the original site classes at SHFP and SFP, resulting in shifting site classes (Figure 4a,b). Furthermore, SC I displayed variations at SHFP due to physiographic factors (slope positions). Specifically, Hdom at the summit slope position shifted to site class III, while the mid-slope position shifted to site class II (Table A1). The remaining three SCs did not vary with the slope positions. In contrast, SC II at SFP changed to SC III in the mid-slope position, while SC III shifted to SC II at a lower slope (Table A1). Interestingly, SC IV changed to SC III in all slope positions at SFP.

3.3. Effects of Elevations and Slope Percentage on Forest Productivity within Site Classes at Sao Hill and Shume Forest Plantations in Tanzania

The LMM for the entire dataset showed remarkable evidence for the effect of the elevation and slope factors on MAI (Table 3). Notably, MAI exhibited a significant positive correlation with slope and elevation and hence influenced productivity variations within the forest plantations (Table 3, Figures 5 and 6). The effect of slope depended on the elevation-indicated variations in a forest's mean annual increment, whereby MAI at SHFP decreased with elevation at a slopes between 8 and 17% (Figure 5a,b) and MAI increased as slope and elevation increased (Figure 5c), while at SFP, MAI increased with elevation at a 7.1%–9.0% slope but decreased with elevation at a 9.1 to 11.0% slope (Figure 6a,b).

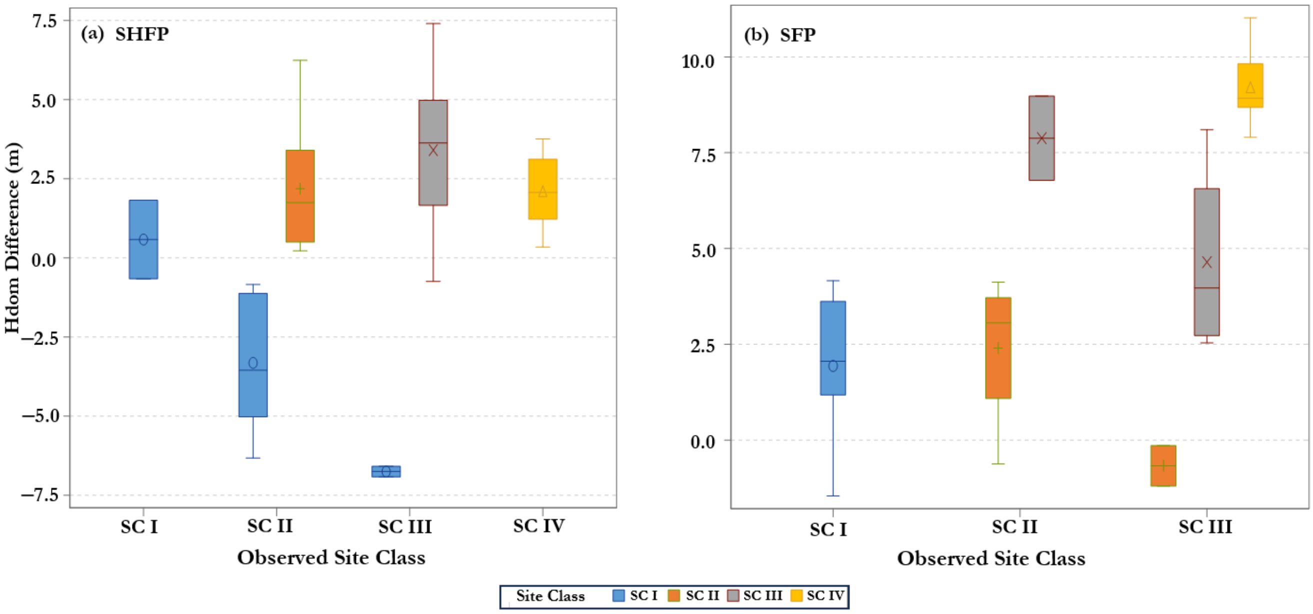

Figure 4. Shift in site classes at Sao Hill forest plantation (SHFP) and Shume forest plantation (SFP) in Tanzania: the difference between the predicted and realized Hdom allows for site class shifts at SHFP and SFP compared to those reflected in the original site index model. The color indicates site classes. SCI = site class I; SCII = site class II; SCIII = site class III; SC1V = site class IV. The site class I at SHFP been distributed to SC II and SCIII while at SFP there is an interchange in SCII and SCIII but SCIV been completely shifted to SCIII.

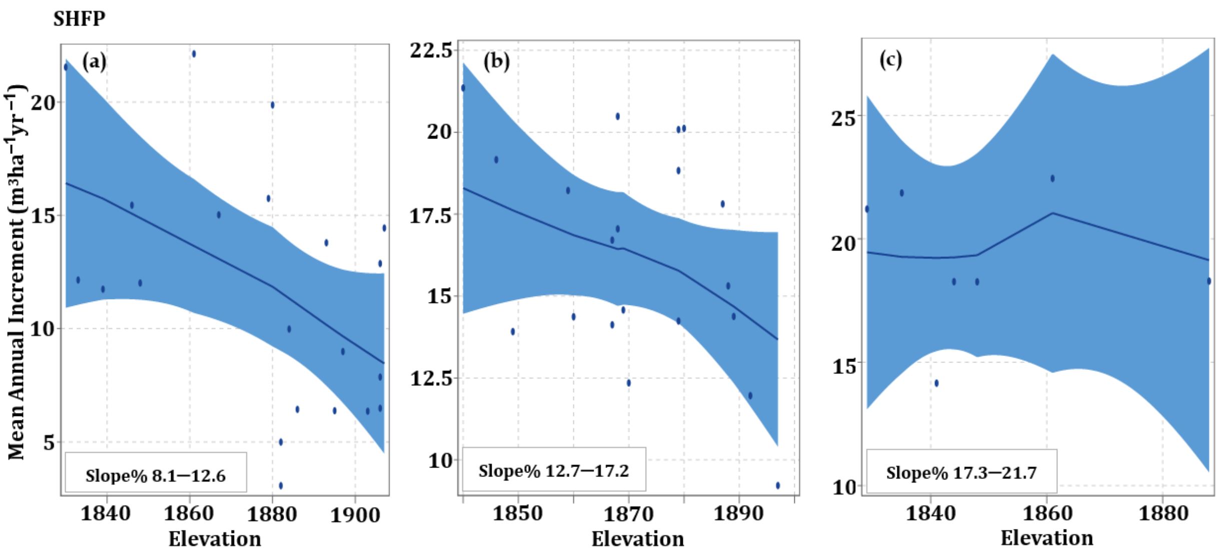

Figure 5. Mean predicted variations in response variable over the different observed ranges of slope percentages and elevation interactions in Sao Hill forest plantation (SHFP) in Tanzania. The blue area around the fitted line shows the confidence region. (**a**,**b**) MAI decreased with elevation at a slopes between 8 and 17% while (**c**), MAI increased as slope and elevation increased (**c**).

Table 3. Results of LMM in estimating the variation in MAI as a dependent variable with elevation and slope as predictive variables at Sao Hill forest plantation (SHFP) and Shume forest plantation (SFP) in Tanzania.

Sites	Parameter	Estimate	Standard Error	t-Value	*p*-Value
SHFP	Intercept	−24.066	5.375	−4.477	0.024
	Slope%	1.687	0.486	3.472	0.016
	Elevation	0.013	0.003	4.496	0.024
	Slope% × Elevation	−93.27	2.638×10^{-4}	−3.385	0.018
SFP	Intercept	−40.159	8.51	92.74	<0.001
	Slope%	4.483	0.927	90.904	<0.001
	Elevation	0.022	0.005	115.685	<0.001
	Slope% × Elevation	−0.002	5.107×10^{-4}	90.074	<0.001

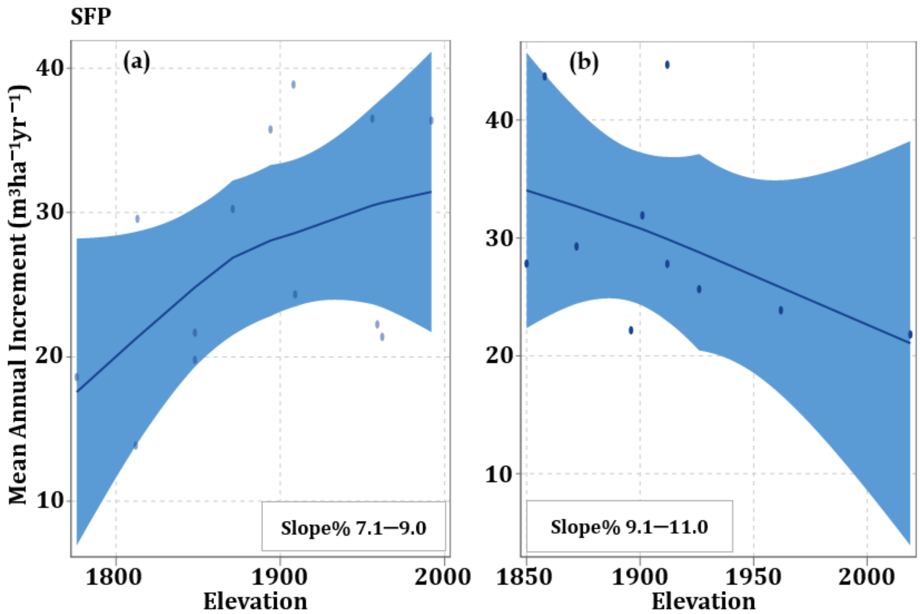

Figure 6. Mean predicted variations in response variable over the different observed ranges of slope percentages and elevation interactions in Shume forest plantation (SFP) in Tanzania. The blue area around the fitted line shows the confidence region. (**a**) indicates that MAI increased with elevation at a 7.1%–9.0% slope while (**b**), MAI decreased with elevation at a 9.1 to 11.0% slope.

4. Discussion

This study demonstrated variations in forest productivity and stand variables for the assigned site classes within the Sao Hill and Shume forest plantations. Our results indicate that MAI and other stand variables vary inconsistently within and between the assigned site classes. Specifically, we found that MAI was significantly higher in SC II at SHFP, while it was significantly higher in SC I at SFP (Figure 3a,b). The differences in the stand variables between site classes could be attributed to a combination of factors, such as superior soil quality, including soil fertility and the availability of moisture [50–53]; management factors; and other environmental factors, such as light availability and microclimate conditions [34]. Fu et al. [54] suggest that soil moisture content, weather conditions, and crop growth stage are also important fine-scaled factors that can predict production variations. Stendahl [55] reported that detailed fine-scaled information at the regional and small scales within forest stands might lead to better use of forest resources and better information about productivity prediction.

By comparing the measured Hdom based on variations in the slope positions as one of the physiographic factors with sigmoid-shaped curves of the original site index (Figure A1), our results indicated that, in most cases, the measured Hdom did not agree with the previously predicted site class from the original site index model, leading to a change in site class (Figure 4a,b). These findings suggest that variations in Hdom within the stands cause changes in site classes and ultimately influence productivity variations [56,57]. The reasons for this include changes in microclimate patterns, such as increased precipitation or temperatures, which are influenced by different altitudinal gradients [58–60]. This also contributes to better conditions for the growth of trees in terms of height and other associated growth attributes, resulting in a gap between the expected volume and the realized volume.

The slope positions contribute to the shift in site classes (Table A1), as they create microhabitats with unique microclimates [61] that may cause stand growth variables to vary [62–64]. We found that Hdom differed along the slope position, with the mid and lower slopes recording the highest variations. Steep slope areas, probably due to high soil erosion, often have poorer soil nutrients and a lower water supply than gentle slope areas, and the different amounts of resources trees need to grow will affect the productivity of the trees. Rohner et al. [65] reported that tree growth is higher in gentler and lower-slope areas.

Furthermore, studies by Mgoo et al. [66] and Gumadi et al. [67] reported that changes in site classes within forest plantations can be attributed to a range of natural (pest and disease outbreaks) and human-induced factors (e.g., wildfires). Additionally, unfavorable soil properties, including low fertility, acidic pH, low humus content, poor conditions for mycorrhizal associations, high bulk density and poor soil structure, and fluctuating groundwater levels, may lower forest tree variables [68–71]. Alterations in soil quality due to erosion, nutrient depletion, or contamination can also influence specific tree species' growth, consequently impacting site class shifts [72]. This argument is supported by other studies that slope affects the soil properties along elevation gradients [21,73].

Physiographic factors represented by slope and elevation played a significant role in determining the variation in the forest productivity of the *P. patula* plantations ($p < 0.05$). We found that elevation and slope significantly but inconsistently affect the productivity within site classes (Table 2). Werner and Homeier [74]; Pierick et al. [21]; Fortunel et al. [75]; and Jucker et al. [76] reported similar findings that elevation and slope variation in forests could be strong drivers that affect productivity in several tropical forests. Hemingway and Kimsey [77] found that forest productivity varies with elevation. Micro-environmental heterogeneity influences the microclimate and short-range soil fertility changes, e.g., the soil fertility tends to be higher at lower elevations, hence improved productivity [22,78]. Physiographic factors also affect microhabitat heterogeneity, which limits light availability, space, soil nutrients, and water, among others [79]. Forest productivity is affected by elevation through associated changes in temperature, moisture, light, and soil properties [80,81]. Also, different slopes can provide valuable insights into the biophysical determinants of maximum productivity and the mechanisms controlling yields. The results indicated that a gentle slope below 20% and elevation below 1900 m.a.s.l (Figures 5 and 6) represent the most optimal slope for the growth and development of *P. patula*. Our findings highlight the importance of linking physiographic factors to variations in forest productivity to enhance decision-making in sustainable forest management.

5. Conclusions

This study provides valuable insights into the variation in forest productivity and dominant height (Hdom) within the site classes of *Pinus patula* at the Sao Hill and Shume forest plantations in Tanzania. By assessing variations in forest productivity (mean annual increment (MAI)) and Hdom in relation to physiographic factors in the *P. patula* stands, based on the site index model originally used to classify productivity, the researchers revealed inconsistencies in the present site classification system used in Tanzania. This study shows that physiographic factors, including elevation and slope, significantly contributed to predicting productivity variations within *P. patula* stands in Tanzania. Therefore, adopting a more comprehensive and accurate site classification system that accounts for these factors can help practitioners and policymakers make informed decisions regarding management practices, eventually contributing to sustainable forest resource utilization. To address the inconsistencies in the current site classification system for Tanzania's plantations, it is critical to review the models and methodologies that were originally applied to assess site productivity. Hence, there is a need to revise forest management plans by developing specific prescriptions based on the observed variations in the site classes to attain sustainable forest production. The results emphasize the importance of further research for an improved site classification system elsewhere that considers the influence of physiographic and other environmental factors on the variability of forest productivity.

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Appendix A

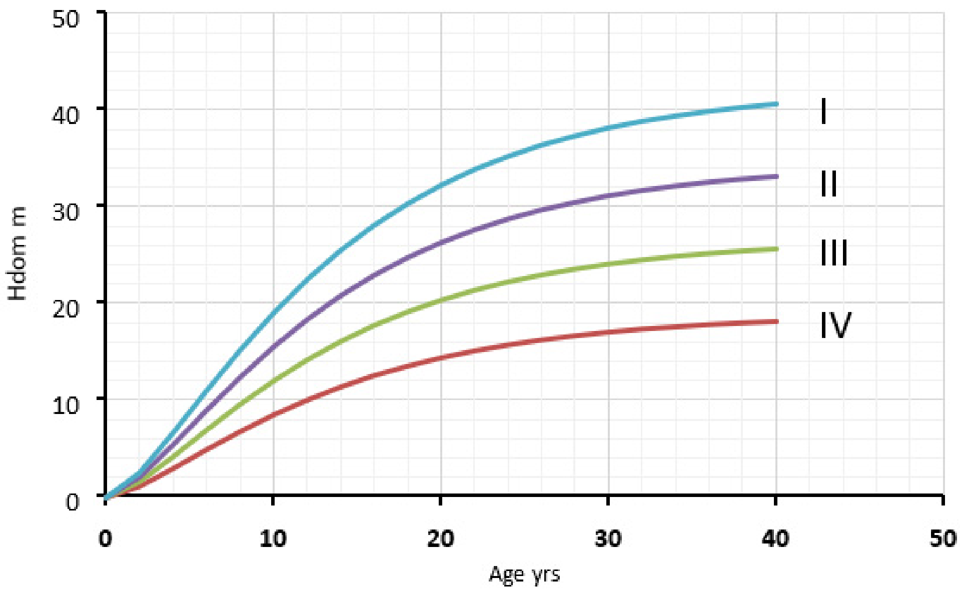

Figure A1. Site index curves for *P. patula* in Tanzania.

Table A1. Predicted and measured attributes for the site classes at SHFP and SFP.

Sites	Predicted Attributes			Measured Attributes		
	Original Site Class	**Age**	**Predicted Hdom**	**Realized Hdom**	**Slope Positions**	**Micro-Site Classes (Shifted Site Classes)**
SHFP	SC I	12	22.4	15.65	Summit	III
				19.08	Mid	II
				22.98	Lower	I
	SC II	15	21.8	22.65	Summit	II
				24.79	Mid	II
				22.07	Lower	II
	SC III	15	16.9	19.14	Summit	III
				20.39	Mid	III
				21.90	Lower	III
	SC IV	9	7.6	10.08	Summit	IV
				9.68	Mid	IV
				9.27	Lower	IV
SFP	SC I	12	22.6	22.46	Summit	I
				25.54	Mid	I
				25.61	Lower	I
	SC II	15	21.8	22.89	Summit	II
				21.13	Mid	III
				25.52	Lower	II
	SC III	15	16.9	20.87	Summit	III
				22.22	Mid	III
				24.78	Lower	II
	SC IV	13	7.6	16.03	Summit	III
				16.85	Mid	III
				17.55	Lower	III

Note: SC means site class obtained from administrative records.

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