Comparison of Community Structure and Productivity of Pinus Plantation and Natural Broadleaved Forest in Same Ecology

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Research

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Abstract

Both plantation and natural forests are distributed throughout the world and the same is the case in Nepal. Different structures are forms due to mode of forests' origin that requires a different approach for sustainable forest management. This compares community structure and production between naturally-regenerated broadleaved and the plantation *Pinus* from the same ecological region, at present and predicts the scenarios taking into consideration of biomass production and sustainable management perspective. A total of 89 plots trees were sampled of area 250 m² each for both forests forest on a random basis in Mid-hills of Nepal. The t-test, correlation test, Man-Kendall test and Sen's slope estimators, linear and polynomial regression analysis were performed to compare the forests. The result showed the significantly ($p < 0.05$) higher mean age, DBH, height, biomass density, carbon stock density and mean annual increment (MAI) in plantation forest but the forest had a very low level of undergrowth, a sign of frequent fire and absence of regeneration. The higher mean density of wood, stocking density (number - both trees and regeneration), under-growth biomass, absence of fire sign, good condition of regeneration were found in natural forests. Bell-shaped DBH-classes distribution having positive insignificant trend is found of plantation forest. Plantation forest hinders long-term sustainability though it showed significantly higher productivity (biomass). Result reveals that monoculture plantation forest can be managed either considering together with the naturally-regenerated forest of all age gradation or promote age (size-classes) gradation through management intervention in such forests for perpetuating yielding, otherwise, these forests lose ecological sustainability. On the contrast, naturally-regenerated forest comprises of all age gradation that they allow exercising active sustainable management without compromising continuous regeneration and sustainable production. The result could give insight for managing both plantation and natural forests sustainably.

Introduction

The area of the planted forest increased from 167.5 million ha to 277.9 million ha in the period of 15 years from 1990 to 2015 worldwide (Pyan et al. 2015). Throughout the world, *Pines* species are the main medium rotation utility species, primarily in the temperate and boreal zones and planted in the largest proportion (FAO 2020). Globally the extent and importance of plantation forest have been increasing and Nepal is no exception from this phenomenon. Latest forest resource assessment estimated around 5.96 million hectare forest area in Nepal (DFRS, 2015). This showed a significant increase in forest cover than the previous forest resource assessment. Various factors are responsible behind the substantial increase in forest cover but the plantation forest establishment is also one of a notable reason. After the initiation of large scale plantations in the 1980s till now around 370,000-hectare plantation forests have been established in Nepal mostly dominated by Pine (Dangal and Das 2018). Out of the total national forests of Nepal, more than one-third of these forests are managed by the local communities (GoN/MoFSC 2016). Almost all (97%) community forests (CFs) of Nepal are naturally regenerated whereas remaining 3% plantation as CFs (Kanel 2004) and are planted in a single year or within a short interval.

Forest vegetation and soils are viable sinks of atmospheric carbon and may contribute significantly to the mitigation of global climate change (Bajracharya et al. 1998; Phillips et al. 1998; Lal 2004; Smith 2004) irrespective of its mode of regeneration. Also, replenishing carbon in the terrestrial ecosystem provides a multitude of benefits by improving soil fertility, ecosystems, and biodiversity, which in turn has a series of other benefits attached (Janzen 2004). In the case of Nepal using locally enforced strict forest protection measures, CFs are recuperating ecologically and ultimately help in enhancing the carbon stock. CFs served the dual objectives of meeting forest product requirement of communities (Acharya and Sharma 2004; Kanel 2004) and forest condition improvement and biodiversity conservation (Acharya and Sharma 2004). Soil erosion has been mitigated and water sources were restored because of forest protection. However, it is uncertain that these benefits would receive in perpetuating or temporal. Sustainability largely depends on the regeneration condition, plant density, age or size (or class) gradation, biomass accumulation forest conditions to optimize biomass production, biodiversity management as well as getting incentives from carbon financing mechanism or other means. In this regard as a proxy measure, above-ground biomass is useful comparing structural and functional attributes of forest ecosystems across a wide range of environmental set-ups (Brown et al. 1999).

Many studies have been published worldwide concerning biomass estimation, carbon estimation, monitoring and assessment issues (NRFMI 2011). Some studies have been carried out in CFs in a Nepalese context too on aforementioned areas (e.g.: Upadhyay et al. 2005; Banskota et al. 2007; ANSAB 2010; Subedi et al. 2010; Pandey and Bhusal 2016; Tripathi et al. 2017). In addition to these, some of the studies have covered area outside the CFs and looked at patterns of in DBH-classes and distribution of woody species concerning species recruitment and disturbance (e.g.: Vetaas 2000; Måren and Vetaas 2007). However, there is a dearth of study about a comparison of planted and natural forest from the perspective of ecological sustainability and biomass production and potentiality. Thus, this study aims to compare the community structure and characteristics of naturally regenerated broadleaved forests and planted *Pine* for the same environment. The output of this research will contribute to comparative ecological knowledge of *Pine* plantation and natural plantation forest. This study would be very important for ensuring ecological sustainability, harnessing climate change and sustainable forest management.

The Study Area

The study was carried out in Gorkha district which extends between 27°15'-28°45'N latitude and 84°27'-84°58'E longitude (Fig. 1). The district is located in the Mid-hills and High Mountains of the Gandaki Province of Nepal covering an area of 3614.70 km², with an elevation range of 228 m to 8,163 m above sea level (asl). Gorkha district possesses five distinct types of vegetation zones based on the altitudinal range – viz. tropical, subtropical, temperate, sub-alpine, and alpine – offering a wide array of vegetation. The district receives an average annual rainfall of 1776 mm and average annual maximum and minimum temperature are 26.1°C and 15.9°C, respectively (DDC 2011).

The study was concentrated on two CFs, namely Ghaledanda Ranakhola Community Forest (GRCF) and Ludi Damgade Community Forest (LDCF) (CFUG 2008). A total of 269 ha of forest has been studied taking a sampling intensity of 0.83% that covers an area of 2.23 ha. A brief description of CFs is presented here.

Natural Forest

The natural forests were mainly covered by three species- *Shorea robusta*, *Schima wallichii* and *Castanopsis indica* as naturally-regenerated broad-leaved forests. Associated common species are *Cleistocalys species*, *Syzygium cumini*, *Lyonia ovalifolia*, *Wendlandia coriacea*, and *Engelhardtia spicata*. The forests are facing in all aspects and elevation ranges between 700–1000 m above sea level (asl).

Plantation Forest

There were two patches of plantation forests *Pinus roxburghii* about 20 ha in total and 10 ha of each forest belongs in GRCF and LDCF between the broadleaved forests within Ludi Khola watershed area. This forest faced mostly towards the east, but also south-east and north-east in a few sample plots were recorded. The forest was in a gently sloping area with approximately two-thirds crown cover and elevation ranges between 850–1000 m asl.

Materials And Methods

Sampling Design

A map of the study area was laid on the table and randomization was performed up to the required number of sample frame using geographic points. Then a list of geographic position uploaded in geographical positioning system instruments (GPS). Finally, the sampling plots were tracked to the forest using GPS to layout concentric circular sample plots (CCSP) throughout the forest. Altogether 89 plots were with a radius of 8.92 m for tree measurement (≥ 5 cm DBH), 5.56 m radius nested plots for saplings measurement (DBH < 5 cm) and 1 m radius nested plots for seedling (height < 1.30 m) count. Among all the sample plots, 20 were fell in plantation forests and 69 remained in naturally regenerated broadleaved forests in the study area. The main reason for selecting circular plots as they were easy for layout, covering a greater area with lesser perimeter which reduces the bias on the boarder trees whether to measure or not as observed by Subedi et al. (2010).

Measurements

Trees were first marked starting from the edge and working inwards to prevent accidental double counting. All the trees marked were then numbered from the middle to the edge starting at north and heading in a clockwise direction. Each tree was recorded, together with its species name. Trees on the border were included if > 50% of their basal area fell within the plot and excluded otherwise. All the trees

were measured at 130 cm above the ground-level from the up-hills side. The total height of the tree was measured by using Vertex IV and Transponder. The wood density of individual species was obtained from secondary literature (Tamrakar 2000).

Data Analysis

The data were analyzed using the guideline prescribed by ANSAB (2010) for measuring carbon stocks in community-managed forests following predictive allometric equations (models). Based on that guideline in estimating above-ground tree biomass (AGTB), the biomass model developed by Chave et al. (2005) to estimate forest biomass density was used. As Gorkha district falls in the moist category, the corresponding recommending allometric model $[AGTB = 0.0509 \cdot (\rho D^2 H)]$; where, ρ is wood density, D = DBH, and H is the total height of trees] for the site was employed for AGTB estimation. The biomass stock density of a sampling plot has been converted to carbon stock density using IPCC default carbon fraction of 0.47 (IPCC 2006). The sapling biomass is calculated by using national allometric biomass tables (Tamrakar 2000). Measurements of root biomass are indeed highly uncertain, and the lack of empirical values for this type of biomass in forest ecosystem. To simplify this process for estimating below-ground biomass, the study used the root-to-shoot ratio of 1:5 (MacDicken 1997). Biomass on leaf litter, grasses, dead wood, and stumps in Nepalese forests is less than 1% (DFRS 2015), so they were excluded for analysis.

All the analysis and tests were performed in R (R Core Team 2018). Study parameter of regeneration status, biomass and carbon density, ground cover, present biomass (carbon) and future perspective, growth performance, DBH-classes distribution and feasibility for sustainable management were compared and discussed between *Pinus* plantation forest and naturally-regenerated broadleaved forests. Other tests such as correlation test, Man-Kendall test and Sen's slope estimators, and regression analysis were performed as appropriate to test the variables.

Results

Characteristics of Forests

Almost a dozen parameters were considered for the comparative study between two types of forests. The characteristic of such variables are illustrated in the following table (Table 1)

Table 1

The characteristics of natural and plantation forest forests from the study area [MAI is mean annual increment; other variables have their usual meaning]

Variables	Plantation forest	Natural forest	Remarks
Mean age (years)	24	16	Age of natural forest has estimated from Jackson, (1994) by interpolation of mean DBH and height of trees)
Mean height (m)	15.73	6.7	
Mean DBH (cm)	23.13	10.47	
Mean wood density (kg/m ³)	0.65	0.83	
Biomass (t/ha)	409.76	133.87	Used root-shoot ratio 1:5
MAI (t/ha)	17.07	8.37	<i>Pinus</i> MAI was obtained from the coring sample and natural forests' MAI obtained from Jackson (1994) by interpolation and adjustment
Carbon Stock (t/ha)	189.77	62.82	
Stocking (number/ha)	1080 - trees 100 - reg.	1557 - trees 35217 - reg.	Reg. = regenerations
Undergrowth	Nil or nominal	Profound	Source: field survey
Fire signs	Present	Absent	Source: field survey
Natural regeneration	Absent	Present	Source: field survey

The result showed higher mean age, DBH, height, biomass density, carbon stock density and mean annual increment (MAI) in plantation forest but the forest had very few undergrowths, signs of frequent fire, lower wood density and absence of regeneration. Meanwhile, the higher mean density of wood, stock per hectare (both trees and regeneration), under-growth biomass, absence of fire sign, and good condition of natural regeneration was found in natural forest (Table 1).

The mean value of all continuous variables (Table 1) between plantation and natural forest were significantly different (Table 2) for a given site. The test result showed that the significant ($p < 0.05$) difference in biomass production concerning the type of forests (Table 2).

Table 2
Comparison between variables using t-test and their respective standard deviation for plantation and natural forests from the study area [SD forests for forested deviation; other variables have their usual meaning]

Variables	p-value	SD- plantation forest	SD- natural forest
Base girth at 15 cm	< 0.05	23.66	26.08
Girth at breast height	< 0.05	20.65	21.18
DBH	< 0.05	6.57	6.74
Total height	< 0.05	2.52	6.74
Wood density	< 0.05	0	0.08
Biomass per tree	< 0.05	170.24	246.83
Carbon per tree	< 0.05	80.01	116.01

The highest variability between plantation and the natural forest was found in biomass content per plant in the study area whereas the lowest was in wood density as indicated by the standard deviation of the respective variables. More interestingly, the study found that almost similar variation in DBH distribution variation between plantation and natural forests (Table 2).

Figure 3: Frequency distribution of DBH and height of planted and natural forests from the study area [Almost unimodal distribution of DBH for plantation forest (top left) and height for natural forest (bottom right); the negative skewed-distribution of height for plantation forest (bottom left) and positively skewed DBH distribution for natural forest (top right)]

The DBH-height relationship showed a wide variability but a high degree of positive correlation ($r = 0.71$) and was significant ($p < 0.05$) was observed. In plantation forest, there are larger sized trees in terms of both mean DBH and height (Fig. 3), as a result, higher biomass (or biomass carbon) was found in the plantation forest than in the naturally regenerated broadleaved forest. But the lower regeneration and density of trees, absence of under-growth, and smaller coverage diminish the future potentiality of the plantation forest for continuous carbon sequestration (Table 1, Fig. 4). The plantation *Pinus* forest had significantly higher biomass production and increment than naturally regenerated broadleaved forests (Table 2).

The biomass (and biomass carbon) was concentrated on medium-sized trees in case of plantation forest whereas the smaller-sized trees posed the main weight of biomass (Fig. 4). The Man-Kendall test showed that there was no significant DBH-classes distribution trend for plantation forest and the Sen's slope value was positive. On the contrary to this, the naturally-generated forest found significant ($p < 0.05$) negative trend of DBH-classes distribution which signifies the formation of reverse J-shaped curved and consistence size gradation of the trees (Fig. 3).

Biomass Modelling For Plantation And Natural Forests

The log₁₀-based biomass was explained by the height response using linear regression explains only 39% (adjusted R-square: 0.3884, DF: 3426 and p-value: <0.05) and found to be significant (Fig. 5). Prediction of biomass (thus biomass carbon) is the function of DBH, height and density of the wood. The biomass (kg) was explained by the DBH linear function about 79% (adjusted R-square: 0.7863, DF: 3425 and p-value: <0.05) as presented in Fig. 6. The distinct prediction lines for biomass to DBH were observed for plantation and natural forests employing linear function (Fig. 6).

Similarly, though the biomass calculating allometric equation has not contained the polynomial response of total height (Biomass = $0.0509 * pD^2H$), a high degree of the relation of the polynomial response of height upon log₁₀-based function to biomass for the given data set was observed (Fig. 7). This relationship was highly significant ($p < 0.05$) and explained about 77% (R-adjusted: 0.77, DF: 3424) variation in biomass. The polynomial regression response of DBH to log₁₀-based biomass explain to be quite higher than the linear function (adjusted R-square: 0.8728, DF: 3424 and p-value: <0.05) as shown in Fig. 8. The plot showed the sigmoid curve for both types of forests for biomass to DBH (Fig. 8).

Figure 5: Log₁₀-based biomass (kg) modelling on linear response of height of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid linear line) [The graphs indicate the height has a similar and significant effect on biomass production for both forests type in the study area. It is very hard to distinguish different regression lines due to overlapping one upon other]

Figure 6: Prediction of biomass (kg) based on linear relation with DBH of trees for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the DBH has similar but the differential response for plantation (lower line) and higher potential for natural forest (solid-upper line in the graph) in the study area]

Figure 7: Log₁₀ based biomass (kg) modelling against height in the response of using polynomial equations of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the total height has similar but the differential response for plantation (lower line) and higher potential for natural forest (solid-upper line in the graph) in the study area]

Discussions

Forest is a renewable natural resource which is generated either naturally or anthropogenic intervention. Livelihood linkage in various forms with forest to mankind is inseparable in developing country as most of the population live in countryside like Nepal (CBS 2020) and a large proportion of these people directly rely on the forest resources for their livelihood options (Aryal et al 2020). The forest community structure analysis and assessing the characteristics of a different mode of origin of forests is a key for sustainable forest resource management (Pandey and Pokhrel 2020) and mitigating the global climatic issue. The results reveal the sustainable management of forest resources base on the mode of origin of the forests.

This analysis would be a significant way forward towards sustainable forest management to the country and community relying on forest resources and often contested in the utilization of these resources for livelihood or commercial utilization.

Naturally regenerated trees have greater potential to sequester carbon (Table 1, Fig. 3) as they have a larger number of younger trees and plenty of natural regeneration. Good regeneration condition ensures the sustainability of generation in the forest ecosystem. Consistent with this finding Terakunpisut et al. (2007) reported that old-growth forests have less potential for carbon sequestration as the older trees cease to grow. Absence of regeneration in *Pinus* plantation area indicates the little potential for biomass increment in the long run (Table 1, Fig. 6) as old-growth forest hardly sequester the carbon and perform the biomass addition (Kongsager et al. 2019). Beyond the maturity, trees generally have marginal carbon sequestration capability (Lal and Singh, 2000). On the other hand, the role of small trees in naturally regenerated forests would enhance the future carbon stock because of their high carbon sequestration potentiality (Baishya et al., 2009) provided some improved management practices to maintain a fixed proportion of density or size-classes as suggested by Leuschner (1992). Therefore, CFs having a greater number of smaller trees have advantages to emission reduction as small trees growing up and add carbon in the forms of biomass as primary productivity. This sort of forests invites simple management practices to maintain proportionate numbers of trees of different sizes in the area for perpetuating carbon sink and materials returns for sustainability.

The plantation forest was dominated by *Pinus roxburghii* whose approximate age of the forests can be found by counting the whorls of branches. This can also apply to some broadleaved trees (eg. *Bombax ceiba*, *Ceiba pentandra*) but many of the broadleaved species have neither annual branching whorls (Jackson 1994) nor can they be cored for age determination. Thus, naturally-regenerated forests are lacking forest management by age gradation rather size-class distribution. Thinning at an early stage of forest growth creates a variety of growth patterns that have a greater option for growth. Most of the forest forests reach their economic maturity before biological maturity that creates carbon sinks (Alexandrove 2007) as observed in most of the natural forests. Removal of matured or deformed or suppressed trees creates the opening for sunlight and reduce the resource competition in the ground for newly growing stems that required thinning regimes. Some older trees of *Shorea robusta* and *Schima wallichii* creates a source of seeds for regeneration, but subsequent removal after seed fall or sprouting regeneration allows for utilization of products for the livelihood of the locals.

The stock density was higher in the natural forest than those of plantation one. In the case of plantation forest, the biomass stock will be reduced drastically in long run (see DBH distribution: Fig. 3) because of the bell-shaped distribution of DBH. Besides that nil or nominal regeneration, acidic nature of *Pinus* needle and frequent fire invade natural regeneration to grow as future trees. This discontinuity in forest structure of *Pinus* plantation will diminish the future potentiality of carbon sink and biodiversity enhancement. However, the biomass density is higher in plantation forest than natural one at existing state. A similar result of higher biomass density in plantation forest than the natural forest has been found by Baishya et al. (2009) in north-east India. The higher biomass density in the plantation forest

than natural forest may be attributed to more or less uniform forest structure and of middle-aged trees that resulted from a combination of site factors, species characteristics (fast-growing - *Pinus*), and management practices adapted such as pruning. On the contrast, natural forest structure with wide variation in structure and composition, higher plant density creates resource competition and composition of slow-growing trees leads to having lower biomass density.

Plantation forest has higher biomass density and will have higher potential for a greater amount of carbon sequestration than natural forest forests, in the short period of 5 to 10 years, under different prediction scenarios (Fig. 6). As the mean stand age found 24 years in the study and the rotation is recommended to be 45 years for *P. roxburghii* (Dangal and Das 2015), but to maximize the volume of the products, 30–35 years is recommended for final felling of that trees in plantation area of Nepal. After a decade or slightly more time in plantation forests, the condition would be further where the field observation found an absence of regeneration and nominal undergrowth attributed by the frequent fire, dense canopy cover and acidic nature of *Pinus* needle invades regeneration in plantation forests. This situation entails diminishing potentiality of the carbon sink in long run from such forests. In this regard, *Pinus* plantation forest requires intense management practices. This practices could be canopy opening - thinning, pruning, and needle collecting, enrichment planting and promoting natural seed germination for the maintenance of continuous forest structure. Other perpetuate ecosystem services hardly could be achieved from these sorts of forests. This result would be beneficial for 3% planted area of forest of Nepal (Kanel, 2004) or whole forest area in the country (44.74%) (DFRS 2015) and beyond for sustainable management of the forest to receive perpetuate ecosystem services from this resource. Similar research is recommended in the various region to affirm the results.

Conclusion

The lower level of regeneration, less density of trees, bell-shaped DBH distribution, low level of undergrowth, lesser extend or area coverage of *Pinus* plantation reduce the potentiality of biomass production and carbon sink from these forests. In contrast, naturally regenerated broadleaved forests have diverse species composition but slower growth rate as compared to planted *Pinus*. Despite lesser carbon density at the moment of naturally-generated broadleaved forest in the study area, it poses several benefits associated with sustainable management as lower regeneration cost - continuous natural regeneration, higher biodiversity, proportional and consistent size-gradation, a lesser degree of threat to that of monoculture *Pine* plantation, young and mature trees facilitate to promote sustainable management and perpetuate benefits returns through intermediate interventions. The study suggests that both types of forests have their own merits and pitfalls in different aspect of socio-economic and environmental perspective, however, to optimize the ecosystem services and sustainable management of forests, the consideration of these both type of forests (natural and planted) as a unit of manage would provide synergy effect in optimizing ecosystem services and sustainability of forest ecosystem. Hence, this study recommends the combination of both planted and natural forest as an entity for forest management wherever relevant and applicable for sustainability to livelihoods of people and the ecosystem itself.

Declarations

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Conflict of Interest

Author declare that there is no competing interest associated with this publication or data presented in the article.

Author's Contribution

Both author contributed equally to finalize the manuscript but first author conceived the research and collected the data.

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Figures

Figure 1

Map showing the study area [The digit in Nepal's map indicates the name of provinces i.e. 1 = Province 1, 2 = Province 2, 3 = Bagmati Province, 4 = Gandaki Province, 5 = Province 5, 6 = Karnali Province, and 7 = Sudurpachhim Province] Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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DBH-Height Relation of Planted and Natural Forest

Figure 2

DBH-height relationship of plantation and natural forest in the study area [The triangular points are for plantation forest relationship for DBH to height and circular plots show the DBH to height relationship of natural forest]

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Figure 3

Frequency distribution of DBH and height of planted and natural forests from the study area [Almost unimodal distribution of DBH for plantation forest (top left) and height for natural forest (bottom right); the negative skewed-distribution of height for plantation forest (bottom left) and positively skewed DBH distribution for natural forest (top right)]

Figure 3

Frequency distribution of DBH and height of planted and natural forests from the study area [Almost unimodal distribution of DBH for plantation forest (top left) and height for natural forest (bottom right); the negative skewed-distribution of height for plantation forest (bottom left) and positively skewed DBH distribution for natural forest (top right)]

Figure 4

Biomass and carbon density distribution in planted and natural forests in the study area [Almost unimodal distribution of biomass and carbon for plantation forest (top and bottom left); the positive skewed-distribution of biomass and carbon density for natural forest forest (top and bottom right)]

Figure 4

Biomass and carbon density distribution in planted and natural forests in the study area [Almost unimodal distribution of biomass and carbon for plantation forest (top and bottom left); the positive skewed-distribution of biomass and carbon density for natural forest forest (top and bottom right)]

Prediction of Biomass Based on Height for Different Forests Type

Figure 5

Log10-based biomass (kg) modelling on linear response of height of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid linear line) [The graphs indicate the height has a similar and significant effect on biomass production for both forests type in the study area. It is very hard to distinguish different regression lines due to overlapping one upon other]

Prediction of Biomass Based on Height for Different Forests Type

Figure 5

Log10-based biomass (kg) modelling on linear response of height of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid linear line) [The graphs indicate the height has a similar and significant effect on biomass production for both forests type in the study area. It is very hard to distinguish different regression lines due to overlapping one upon other]

Prediction of Biomass Based on DBH for Different Forests Type

Figure 6

Prediction of biomass (kg) based on linear relation with DBH of trees for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the DBH has similar but the differential response for plantation (lower line) and higher potential for natural forest (solid-upper line in the graph) in the study area]

Prediction of Biomass Based on DBH for Different Forests Type

Figure 6

Prediction of biomass (kg) based on linear relation with DBH of trees for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the DBH has similar but the differential response for plantation (lower line) and higher potential for natural forest (solid-upper line in the graph) in the study area]

Prediction of Biomass Based on Height for Different Forests Stand

Figure 7

Log10 based biomass (kg) modelling against height in the response of using polynomial equations of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the total height has similar but the differential response for plantation (lower line) and higher potential for natural forest (solid-upper line in the graph) in the study area]

Prediction of Biomass Based on Height for Different Forests Stand

Figure 7

Log10 based biomass (kg) modelling against height in the response of using polynomial equations of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the total height has similar but the differential response for plantation (lower line) and higher potential for natural forest (solid-upper line in the graph) in the study area]

Prediction of Biomass Based on DBH for Different Forests Type

Figure 8

Polynomial regression model for predicting log10-based biomass (kg) against DBH of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the DBH has similar but the differential response for plantation (lower-dotted line) and natural forest (solid-upper line in the graph) in the study area]

Prediction of Biomass Based on DBH for Different Forests Type

Figure 8

Polynomial regression model for predicting log10-based biomass (kg) against DBH of forests for plantation (triangular points and dotted line) and natural forest (circular points and solid line) [The graphs indicate the DBH has similar but the differential response for plantation (lower-dotted line) and natural forest (solid-upper line in the graph) in the study area]