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Structure and Composition of Dry Deciduous Forests in Central Myanmar

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မြန်မာနိုင်ငံအပူပိုင်းဒေသရှိတောခြောက်များ၏သဘာဝပေါက်ပင်များ၊သစ်မျိုးစိပ်များရောနှောပေါင်းစပ်ဖွဲ့စည်းပုံနှင့်ပင်စုတည်ဆောက်ပုံများအားလေ့လာခြင်း

ဒေါက်တာညွန့်ခိုင်
လက်ထောက်ကထိက
သစ်တောတက္ကသိုလ်

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စာတမ်းအကျဉ်း

မြန်မာနိုင်ငံအတွင်းပေါက်ရောက်နေသောတောခြောက်သစ်တောများသည်ဂေဟစနစ်နှင့်လူမှုစီးပွားရေးတွင်အလွန်အရေးကြီးသောအခန်းကဏ္ဍမှပါဝင်နေကြောင်းတွေ့ရှိရပါသည်။ဒေသခံပြည်သူလူထု၏ရေရှည်အကျိုးစီးပွားအတွက်မြန်မာနိုင်ငံအပူပိုင်းဒေသသစ်တောများနှင့်ပတ်ဝန်းကျင်အားကာကွယ်ထိန်းသိမ်းရန်အလွန်အရေးကြီးပါသည်။မြန်မာနိုင်ငံအပူပိုင်းဒေသရှိတောခြောက်သစ်တောများရေရှည်တည်တံ့ခိုင်မြဲအောင်စီမံအုပ်ချုပ်နိုင်ရန်အတွက်အဆိုပါတောများ၏သဘာဝပေါက်ပင်များနှင့်သစ်မျိုးစိပ်များရောနှောပေါင်းစပ်ဖွဲ့စည်းပုံနှင့်ပင်စုတည်ဆောက်ပုံအားကောင်းစွာနားလည်ရန်လိုအပ်ပါသည်။သို့ဖြစ်ပါ၍ဤသုတေသနလုပ်ငန်းအား- (က) မြန်မာနိုင်ငံအပူပိုင်းဒေသရှိတောခြောက်သစ်တောများ၏သဘာဝပေါက်ပင်များနှင့်သစ်ပင်လုံးပတ်၊ရွက်အုပ်အတန်းအစားများအားလေ့လာဆန်းစစ်ရန်၊ (ခ) တောခြောက်သစ်တောများမှကြီးထွားမှုအကောင်းဆုံးနှင့်တွေ့ရှိရအများဆုံးသစ်မျိုးများအတွက်အသင့်လျော်ဆုံးသောအပင်အမြင့်နှင့်လုံးပတ်ဆက်စပ်မှုပုံသေနည်းများတွက်ချက်ပေးနိုင်ရန်နှင့် (ဂ) တောခြောက်သစ်တောများအားထိရောက်စွာစီမံအုပ်ချုပ်နိုင်ရန်ယုံကြည်စိတ်ချရသောကိန်းဂဏန်းအချက်အလက်များပံ့ပိုးထောက်ပံ့ပေးနိုင်ရန်အစရှိသည့်ရည်ရွယ်ချက်များဖြင့်လုပ်ဆောင်ခဲ့ပါသည်။မြန်မာနိုင်ငံအပူပိုင်းဒေသအတွင်းနေရာ (၄)နေရာ (သန်း-ဒဟတ်တော၊ရှားတော၊အင်တိုင်းတောနှင့်တယ်တော) ရွေးချယ်၍အပင်အမြင့်တိုင်းတာခြင်း၊သစ်ပင်လုံးပတ်တိုင်းတာခြင်း၊သစ်မျိုးခွဲခြားခြင်းအစရှိသည့်သုတေသနလုပ်ငန်းများလုပ်ဆောင်ခဲ့ပါသည်။ဧရိယာ (၀.၄ဟက်တာ) ရှိသောနမူနာကွက်အစုလိုက်ကောက်ယူသည့်ပုံစံအသုံးပြု၍ကောက်ယူရရှိသောကိန်းဂဏန်းအချက်အလက်များကိုသစ်မျိုး- ဧရိယာဆက်စပ်မှုရေးဆွဲဖော်ပြခြင်း၊တောခြောက်သစ်တောအမျိုးအစားတစ်ခုချင်းစီအလိုက်အရေးအကြီးဆုံးသစ်မျိုးရွေးချယ်ဖော်ပြခြင်း၊သစ်မျိုးစုံမျိုးကွဲများတိုင်းတာခြင်း၊ပုံသေနည်းအသုံးပြု၍အပင်လုံးပတ်နှင့်ပါဝင်ကြိမ်နှုန်းပြပုံစံရေးဆွဲခြင်း၊အပင်အမြင့်- သစ်ပင်လုံးပတ်ဆက်သွယ်မှုကိုပုံသေနည်းအသုံးပြုတွက်ချက်ခြင်းအစရှိသည့်သုတေသနလုပ်ငန်းများလုပ်ဆောင်ခဲ့ပါသည်။သုတေသနရလာဒ်များအရသစ်ပင်လုံးပတ် (၁၀)စင်တီမီတာနှင့်အထက်ကြီးသောအပင်ကြီးများအားတိုင်းတာတွက်ချက်ပါကတောခြောက်သစ်တောများတွင်တောအမျိုးအစားအလိုက်သစ်ပင်မျိုးရင်း (၄-၁၈)မျိုးနှင့်ပေါက်ရောက်သောသစ်မျိုး (၅-၂၃) မျိုးသာတွေ့ရှိရသဖြင့်မြန်မာနိုင်ငံတွင်တွေ့ရှိရသောအခြားသောသစ်တောအမျိုးအစားများထက်နည်းပါးကြောင်းတွေ့ရှိရပါသည်။၎င်းတွေ့ရှိရသောသစ်ပင်မျိုးရင်းများအနက်ပဲမျိုးရင်းသည်မြန်မာနိုင်ငံအပူပိုင်းဒေသအတွင်းကျယ်ပြန့်စွာပေါက်ရောက်မှုရှိကြောင်းတွေ့ရှိရပါသည်။ဤသုတေသနလုပ်ငန်းတွင်အသုံးပြုသောအပင်အမြင့်သစ်ပင်လုံးပတ်ဆက်သွယ်မှုပုံသေနည်းများသည်အသက်အရွယ်အတန်းအစားမတူညီသောသဘာဝတောများအတွက်ရည်ရွယ်တွက်ချက်ထားခြင်းဖြစ်ပြီးသစ်ပင်လုံးပတ်အတန်းအစားကျယ်ပြန့်စွာထည့်သွင်းတွက်ချက်ထားခြင်းဖြစ်ပါသည်။သို့ဖြစ်ရာအပင်အမြင့်

တိုင်းတာရန်အခက်အခဲရှိသောအခြေအနေများ၊အပင်အမြင့်သစ်ပင်လုံးပတ်ဆက်သွယ်မှုတွင်ယေဘုယျတိကျမှုလို
အပ်သောအခြေအနေများတွင်ဤသုတေသနလုပ်ငန်းမှတွက်ချက်ပေးထားသောပုံသေနည်းအားအသုံးပြုနိုင်ပါသည်။

Composition and Structure of Dry Deciduous Forests in Central Myanmar

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Abstract

Dry deciduous forests in Myanmar play an exceptionally important role from both an ecological and socio-economic point of view. Protecting and conserving the environment of central Myanmar is vitally important for the long-term benefits of local communities. A better understanding of tree species composition and forest stand structure is thus of foremost importance for the sustainability of a dry deciduous forests environment.This study was conducted with several main objectives: (a) specify the tree species composition and forest stand structure of drydeciduous forests; (b) present the most suitable height-diameter equations for the predominant species as the basic requirements of dry deciduous forest management; and (c) provide reliable information for a better management of the natural dry deciduous forests.Four research sites were chosen for the present study in central Myanmar. The measurements (diameter at breast height, total height, and species) were done. The data from a 0.4ha cluster sample plot were analyzedusing species-area curves approach, important value index (IVI), diversity indices, Weibull 2- and 3- parameters function for diameter distribution, height-diameter functions and IUFRO classification scheme for height distribution. The results indicated that the dry deciduous forests of Myanmar are less diverse than other forest formations. For trees with a dbh ≥ 10 cm, there are 5-23 tree species and 4-18 families found in the forests; among the tree families, Fabaceaedominated the area. The stand basal area per hectare for trees with a dbh ≥ 10 cm ranged from 9.4-39.7 m^2ha^{-1}. The hyperbolic height-diameter equation seems the best suited function for the dry deciduous forest tress species. The fitted functions utilized in this study are with regard to natural, uneven-aged forest stands and a wide range of tree diameters.This function is useful in field cases where tree height is particularly difficult to measure, as well as in those instances when generalized accuracy for height-diameter correlation is a requisite.

Key words: Dry deciduous forests, Important value index,Species-area curves, Species diversity,Standstructure

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Composition and Structure of Dry Deciduous Forests in Central Myanmar

1. Introduction

Tropical dry forests grow on both sides of the equator, where the evapotranspiration rate is greater than that of precipitation (Lamprecht 1989). The world tropical regions include Asia, Africa, and Latin America; of these, Africa (Lamprecht 1989; Murphy and Lugo 1986) has the largest dry forest areas, whereas those tropical forests in Asia account for only 23% of the world's tropical forest (FAO 2003). Hegner (1979) and Lampercht (1989) describe the four dry forest areas in Asia as: (1) the western dry monsoon zone of the Indian subcontinent, consisting of most important species *Shorea robusta* and *Tectona grandis*; (2) the dry basin landscape of central Myanmar, characterized by *Tectona* spp. and Dipterocarpaceae; (3) the arid basin landscape of Thailand and the Khorat, with family Dipterocarpaceae as the predominating species; and (4) the arid monsoon zone of the Sunda Islands. The tropical dry forest structure and species composition vary from one forest type to another due to the wide distribution and divergence in ecological conditions (Lamprecht 1989). However, the species show common physiological characteristics of adaptation to extreme climatic conditions (Lamprecht 1989).

Myanmar has one of the largest forest areas in Southeast Asia (FAO 2009), a good representative part of which is dry deciduous forests (Songer et al. 2009). These forests are a niche for endangered and endemic species of wild *fauna* and *flora*, such as Eld's deer (*Cervus eldi thamin*), star tortoise (*Goechelone platynota*), and *Tectona hamiltoniana*. Despite the current status, this tree species is clearly known and, most likely endangered (FAO 1978, 1986). *Tectona hamiltoniana* grows only in the dry deciduous forests of Myanmar– incidentally, these forests are threatened by annual fires (FAO 1978; Anonymous 2007), firewood and pole harvestation, and agricultural lands expansion.

The distribution of dry deciduous forests is limited to central Myanmar. Less diverse than other forest types in term of species and structural diversity, dry deciduous forests are generally single-species dominated forests; the names of forest types come from the predominant co-occurring species. The most widely distributed forest is *Terminalia* forest; the representation of primary, secondary, and degraded forest conditions is conspicuous. *Acacia*, *Diospyros*, and *Dipterocapus* forests are important contributors of dry deciduous forests; the distribution of the latter forest type relies largely on soil types.

1.1 Objectives

Dry deciduous forests play an exceptionally important role from both an ecological and socio-economic point of view. A better understanding of tree species composition and forest stand structure is thus of foremost importance for the sustainability of a dry forests environment. Until now, the scientific researchers have emphasized teak (*Tectona grandis*) bearing, mixed deciduous forests, with only few studies focusing on dry deciduous forests. An overall evaluation of the dry deciduous forests composition, structure, and regeneration of dry deciduous forests is not available. This study was conducted with several main objectives: (a) specify the tree species composition and forest stand structure of drydeciduous forests; (b) present the most suitable height-diameter equations for the predominant species as the basic requirements of dry deciduous forest management; and (c) provide reliable information for a better management of the natural dry deciduous forests.

2. Materials and Methods

2.1 Research area selection and sample plot design

In general, there are seven different types of dry deciduous forests in central Myanmar(see Table 2.1). Among these, *Terminalia* and *Acacia* forests are the most widely distributed in the region.

It should be noted that while mixed deciduous forests can also be found, they represent only a small fraction of forest areas in central Myanmar; forests such as the *Euphorbia* semi-desert scrub and the dry savannah appear to be scrub lands of dispersed *Acacia* spp., *Euphorbia* spp., bushes, and scattered patches of grasses. Because the occurrence of tree species in the latter two types is similar to that in other types of dry forests, these types were excluded from the study. Four different sites consisting of *Terminalia*, *Acacia*, *Diospyros*, and *Dipterocarpus* forests, were, however, selected for theresearch.

The research sites, *Terminalia* and *Dipterocarpus* forests in Sagaing Region and *Acacia* and *Diospyros*forests in Magway Region (see Figure2.1),were chosen based on available information provided by the Forest Department, the Environmental Conservation and Wildlife Division, and local foresters. We referred to two criteria when selecting the research sites: (1) the site had to represent primary forest condition with minimal anthropogenic disturbances; and (2) the site had to cover a large area of central Myanmar. Both *Terminalia* and *Acacia* forests are old growth primary forests, within which a total of 11 and 5 tree species were found, respectively. Forests such as *Diospyros*and *Dipterocarpus*are primary forests of low disturbance intensities: in these, 11 tree species were recorded in the former and 24 species in the latter.

Cluster sampling with 8 sub-plots was used for vegetation analysis. This entailed a one-stage cluster sampling of a fixed area, in which all elements within the cluster were treated as sample elements (Lohr 1999). The center point of the cluster was laid down at random. Then, the 8 sub-plots were established at 45° intervals beginning with the northernmost point and going in a clockwise direction. At 17 m from the center point, a 50 m long sub-plot was set up by marking 5 m width boundary lines on both sides of the 50 m center line. A sub-plot covered an area of 500 m^2; the 8 sub-plots contributed to about 4000 m^2 of a cluster-plot.

2.2 Field data collection and analysis

The field inventory was carried out in February of 2010 during the late dry season, where, the tree species, diameter at breast height, total height, and the social condition of the various trees were recorded. For the forest tree species composition and structural analysis, relative abundance (RA), frequency (RF), and dominance (RD) (Cottam and Curtis 1956) were calculated, as well as the importance value index (IVI) (Curtis and McIntosh 1951; Greig-Smith 1957; Husch et al. 2003). Species-area curves were constructed based on Cain's (1938) method, diversity indices and similarity measures were analyzed to understand the heterogeneity of the forest stand.

To characterize silvicultural behavior of the most dominant species, the stem number-diameter distribution curves for *Terminalia oliveri*, *Tectona hamiltoniana, Acacia catechu*,and *Dipterocarpus tuberculatus* were constructed in STATISTICA 9 for Windows using Weibull 2- and 3-parameter functions. The smaller diameter class (i.e. saplings<10 cm dbh and >1.3 m tall) was added into the calculation to derive the stem number-diameter distribution curves. The three-parameter Weibull function given by Rennolls et al. (1985), Merganič and Sterba (2006), and Rinne (2009) was used. By assigning location parameter a = 0, the two-parameter Weibull function was obtained (Rennolls et al. 1985; Merganič and Sterba 2006; Rinne 2009).

Among the three parameters, the shape parameter 'c' represents the majority of Weibull distribution shapes. If the condition is $c < 1$, the distribution curve is shaped like a reverse 'J'; when $c = 1$, the Weibull function gives the exponential distribution. In the case of $1 < c < 3.6$, the function appears bell-shaped and skewed to the right. The distribution is assumed to be a normal distribution when $c = 3.6$, whereas if $c > 3.6$, the distribution is skewed to the left. Nonparametric test statistics, such as the Chi-square goodness of fit and Kolomogorov-Smirnov tests, were used to assess the performance of the function.

In order to specify the correlation between observed height and diameter for predominant tree species such as *Terminalia oliveri*, *Tectona hamiltoniana*, *Acacia catechu*, and *Dipterocarpus tuberculatus*, the most suitable functions for the height-diameter distributions of dry forest species were selected by plotting total tree height against the diameter at breast height in a spreadsheet in Microsoft Office Excel 2007. The selected functions were fitted in STATISTICA 9 for Windows using nonlinear estimation (least squares estimation, Levenberg-Marquardt method). Nonlinear regression was used due to the ease of prediction and the nonlinear relationship features of height and diameter at breast height (dbh). The fitted equations are shown in table (2.2). Tree stems numbered 103 for *Terminalia oliveri*, 64 for *Tectona hamiltoniana*, 135 for *Acacia catechu*, and 498 for *Dipterocarpus tuberculatus*. Those trees with broken tops were excluded in order to achieve consistently increasing functions.

The root mean squared error (RMSE) and *pseudo*-R^2 were provided to examine the performance of fitted functions. The RMSE (Packalén and Maltamo2008) and *pseudo*-R^2 equation (Velten 2009) used in this study are:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n}}\;, \quad R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Here, n is the number of observations of tree height, y_i is the observed tree height, $\hat{y}_i$is the predicted tree height, and $\bar{y}$ is the mean observed tree height. The IUFRO classification (Lamprecht 1989; Chirici et al. 2011) scheme was used to analyze and show a general overview of the forest's vertical structure.

3. Results

3.1 Sampling accuracy and species composition

In a vegetation analysis, the sample area must be large enough to represent the whole community (Pielu 1966a); doing so guarantees reliable information for further investigation. The species-area curve is a well-known approach to determine the minimal representative area of a particular community (Cain 1938; Gnanadesikan 1997; Ganderton and Coker 2005). Different construction measures of the species-area curve were developed in response to varying requirements and functions, however, the original form involves the allocation ofspecies found in sample plots on the y-axis in coordination with the corresponding area on the x-axis (Cain 1938). In this case, the curve rises sharply and then flattens out to become parallel with the x-axis (Cain 1938; Greig-Smith 1983); the minimal area is regarded as the point where the curve begins to flatten (Cain 1938; Greig-Smith 1983). As suggested by Cain (1938), the survey should be continued until the occurrence of new species remains below 10% with a 10% increasein the sample area (Cain 1938; Lamprecht 1989).

In all sampling sites, the species-area curves rise from the intersection of the x and y axes, before flattening to eventually become horizontal and parallel to the x-axis (see Figure 3.1). This point, where the curve tends to flatten, was considered the minimum sample sizefor consideration in the course of this study. The *Dipterocarpus* forest had the largest number of species, and occurrence of new species increased gradually in the successive sample plots. Five species were represented in the *Acacia* forest, where new species was rarely found. The species in the *Terminalia* and *Diospyros* forests were numbered 9 and 11 for trees ≥10 cm dbh, respectively. A total of 497 individuals belonging to 9 species were found in the *Terminalia* forest, 375 individuals of 5 species in the *Acacia*, 595 individuals of 11 species in *Diospyros*, and 1800 individuals of 22 species in the *Dipterocarpus*.

In combination with the species-area curve approach, the accuracy of sampling was assessed using the standard error of the mean basal area. Sampling errors occur in any procedure when a sample is drawn from an entire population. Standard error is a useful statistical indicator in determining whether a sample is representative of an entire population or not; the smaller the standard error, the better it represents an entire population. The acceptable standard error for vegetation analysis in this research was 10%, but across all sites the standard errors of mean basal areas fell below this limit(Table 3.1). The importance value index (IVI) is used as a tool to accurately indicate and identify (Curtis and McIntosh 1951) the important species in a community. This is determined via a combination of three parameters: relative abundance, relative frequency, and relative dominance.

In the *Terminalia* forest, *Terminalia oliveri* and *Tectona hamiltoniana* were the most important tree species based on IVI values (Table 3.2), representing approximately 90% of total species abundance and dominance in the forest stand. The former consisted of 275 individual trees with a basal area of 8.3 m^2 ha^{-1}, while the latter possessed 162 trees with a basal area of 6.2 m^2 ha^{-1}. The two species grew vigorously and attained larger diameters and heights in the forest stand; nonetheless, the heartwood of most of the stems was in decay. About 15 trees of *Tamarindus indica* were found at 37% frequency. Although the species is found locally and is widely distributed in Myanmar, it is difficult to find in natural forests. *Acacia catechu*, the commonly associated species, occupied about 1% of the basal area with only 2 individuals, both with stunted stems. A total of 15 *Heterophragma sulfuerum* and 22 *Lannea corromandelica* individuals, also commonly associated species in the dry deciduous forest of central Myanmar, were found in the forest stand. The lianas and associated bamboo species, *Dendrocalamus strictus,* were, however, absent. During the wet season, the forest floor was covered to some extent by small seedlings and bushes.

In the *Acacia* forest, the predominant species, *Acacia catechu*, accounted for 91% of the total abundance and 94% of the total dominance (Table 3.3). At 100% frequency, and the forest appeared to be a single species dominated stand, with *Acacia catechu* reaching larger dimensions and heights than the identical forest types growing on the drier sites. The other 4 species had lower tree densities, basal area, and IVI values.In addition, despite the principle association of *Acacia leucophloea*and,*Acacia catechu* in *Acacia* forests, natural occurrence and regeneration of the species barely occurred in natural stands of *Acacia* forests in the present days. In the research area, a total of 15 individuals per hectare of *Acacia leucophloea* were recorded, while 10 recorded individuals of *Tectona hamiltoniana* amounted to 37% frequency. The commonly associated species of this forest type, *Randia dumetorum* and *Limonia acdidissima*, represented a small number of individuals, and lianas species were completely absent. The forest floor was bare with the exception of some small patches of grass, but young seedlings were rarely found. The forest stand is frequently affected by water logging and water erosion in the wet season.

In the *Diospyros* forest, about 48% of the total abundance was represented by *Diospyros burmanica*, which contributed 58% of the total basal area (Table 3.4). *Terminalia oliveri*, with 105 individual stems, playedthe second-most important role in this forest stand, while *Hiptage candicans*, a small tree which grows widely in central Myanmar, had 58 stems and a 100% frequency. *Tectona hamiltoniana* also occured in this forest stand with 48 individuals. The associated species of the area were of fairly good density, and only one species, *Osyris wightiana,* had 5 stems per hectare. All trees in this forest stand had small diameters and stunted stems with the exception of some *Diospyros burmanica* and *Dalbergia paniculata* individuals. Three clumps of *Dendrocalamus strictus* were found in one hectare plot. The bamboos remained rather small, and the heights of culms (numbering 5-10 individuals) of the clump did not exceed 5 m. Bushes and lianas in the undergrowth were not found, and small grasses occurred sparsely in some of the sub-plots. The forest stand is prone to annual forest fires.

Dipterocarpus tuberculatus grows gregariously in the *Dipterocarpus* forest, and, as the most important species has both the highest percentage of abundance, frequency, dominance, and the greatest IVI value; in this research area, this species constituted more than 70% of the total tree density and basal area (Table 3.5). As the second-most important species, associated tree *Melanorrhoea usitata* consisted of approximately 250 individuals with a basal area of 6 m^2h^{-1} and a frequency of 100%. *Xylia xylocarpa*, a semi-shade bearer and additional commonly associated species in the *Dipterocarpus* forest, had a total of 48 observed adults per hectare. In the case of *Xylia* *xylocarpa*, a valuable timber species in Myanmar that can growup to 120 cm dbh and 35 m in height under favorable site conditions, the trees in this stand grew weresmall and stunted.

A total of 8 trees per hectare of *Shorea obtusa* were examined. It is worth noting that *Shorea obtusa* is typical species of the *Dipterocarpus* forest on drier sites in which *Dipterocarpus tuberculatus* is completely taken over by *Shorea obtusa* and *Shorea siamensis.* However, few individuals of the latter species were recorded in this forest stand. The other 18 species contributed only slightly to tree density, basal area, and the frequency percentage. The *Dipterocarpus* forest is a habitat for *Cervus eldi thamin* and, the associated fruit trees therefore play an important role in maintaining the biodiversity of the dry deciduous forests. *Strychnos acuminata*, a climber species, was very common in this forest stand, while *Dendrocalamus strictus* attained medium size and remained sparsely distributed. The forest floor was partially covered by seedlings and shrubssuch as *Strychnos nux-blanda*, *Gardenia* spp., and *Phoenix acaulis*, as well as grasses.

Frequency diagrams provide a general illustration of the homogeneity or heterogeneity of a forest stand (Lamprecht 1989). Based on the occurrence of the species in successive sample plots, the frequency can be organized into 5 classes covering ranges of 1-20%, 21-40%, ~~is~~ 41-60%, 61-80%, and 81-100% (Lamprecht 1989). If the species density falls into the lower frequency classes (class I and II), it can be assumed that the forest stand is heterogeneous. However, a higher number of species in frequency classes IV and V in tandem with a low number in classes I and II may depict the homogeneity of the stand (Lamprecht 1989).

The vast majority of species in the *Terminalia* forest were in the lower frequency classes, and only few species occupied the frequency class IV. Despite the fact thatthe species were missing in the IV-frequency class, the higher number of species represented the lower frequency class. Of the 9 species, 4 species(*Acacia catechu, Millettia brandisiana, Vitex limonifolia,* and *Balanites triflora*) represented the frequency class I, each with only 2 individuals. The two species characterizing this forest type, *Terminalia oliveri* and *Tectona hamiltoniana,* corresponded to frequency class V. In the *Acacia* and *Diospyros* forests, there were no species in classes I and III; however, *Tectona hamiltoniana*, *Randia dumetorum* and *Limonia acidissima* were found with class II frequency, while *Acacia leucophloea* and *Acacia catechu* were in frequency classes IV and V, respectively.

The *Dipterocarpus* forest had a complete representation of species in all frequency classes, with higher numbers of species being recorded in the classes I and II. Species of less economic interest, such as *Protium serratum, Grewia tiliifolia*, *Dillenia indica*, and *Bridelia retusa*were found in frequency class I. Nine of the 22 species occurred in frequency class II. *Dipterocarpus tuberculatus* and *Melanorrhoea usitata*,were found across the whole sampling area representing frequency class V.

3.2 Species diversity

Species diversity is a function of the number of species present (i.e. species richness) and the evenness with which the individuals are distributed among these species (Margalef 1958; Pielou 1966a; Hurlbert 1971; Lähde et al. 1999). In this study, indices were selected for use based on their fulfillment of two criteria: (1) the index must be widely-used, simple to apply, and easy to interpret; and (2) it must provide reliable results. The most well-known and widespread indices for diversity measurement are Shannon and Simpson diversity indices (Hurlbert 1971; Lyons 1981; Magurran 1988; Lande 1996). The Shannon index assumes that the samples are randomly selected from an infinite population and that all species in the community are included in the sample (Pielu 1966a; Magurran 1988). Additionally, the index weighs species richness and the relative evenness of the whole community (Whittaker 1972; Peet 1974; Magurran 1988).

Table (3.6) demonstrates the values of diversity indices used for analysis in the dry deciduous forests of central Myanmar. Among forest stands, the *Diospyros* had the highest values in the

Shannon and Simpson indices. Furthermore, the species in this forest type was fairly evenly distributed over the unit area. The *Acacia* forest was the most homogeneous stand, where the predominant species, *Acacia catechu*, represented 91% of the total abundance. The other two forest stands, *Terminalia* and *Dipterocarpus*, exhibited intermediate values of species diversity. In the *Terminalia* forest, *Terminalia oliveri* and *Tectona hamiltoniana* were found over the entire study area. *Acacia catechu* was both the predominant and most common species of the *Acacia* forest; *Diospyros burmanica*, *Terminalia oliveri*, and *Hiptage candicans*were the most common species in the *Diospyros* forest. Out of 22 species in the *Dipterocarpus* forest, two, *Dipterocarpus tuberculatus* and *Melanorrhoea usitata*, were the most frequently found.

3.3 Forest stand structure

3.3.1 The diameter frequency distribution

Forest stand structure can reflect the interaction between vegetation growth habit and environmental conditions, management practices, and natural/human disturbances. Forest structure, a product and driver of biological diversity and the ecosystem process (Spies 1998), encompasses various ecological attributes (Spies 1998; Zenner and Hibbs 1999). Husch et al. (2003) and Newton (2007) define forest structure as the distribution of species or tree sizes within a stand or forest area, but the term can also refer to the spatial arrangement of various components of the ecosystem, e.g., heights of various canopy levels and tree spacing (Franklin et al. 1981; McElhinny et al. 2005). Forest structure can be additionally defined via two components: (1) the horizontal arrangement of stems; and (2) the vertical arrangement of individuals and their foliage (McEvoy et al. 1980). Based on the latter requirement, the diameter frequency distribution and height-diameter distribution were analysed, as these parameters play important roles in characterizing the condition of various forest stands (Van Laar and Akça 2007; Podlaski and Zasada 2008; West 2009).

The diameter frequency distribution is both a required parameter in describing the characteristics of the forest stand (Bailey and Dell 1973; Maltamo et al. 2000), and the fundamental variable in forest stand table construction, stand volume estimation and end products evaluation (Van Laar and Akça 2007). Many mathematical functions for stem diameter distribution have been developed and applied in forestry. Among them, the Weibull function is widely used (Bailey and Dell 1973; Biging et al. 1994; Green et al. 1994; Cao 2004; Bullock and Boone 2007) due to its simplicity and reliability (Bailey and Dell 1973), as well as its trademark flexibility in the shape of diameter distributions (Merganič and Sterba 2006; Gove and Fairweather 1989) and the ease of parameter estimation (Biging et al. 1994).

The Weibull distribution was initially introduced for the reliability of materials in the engineering sciences (Weibull 1989; Van Laar and Akça 2007; Rinne 2009), but it was widely applied to many other fields beginning in 1951 (Johnsonet al. 1994). Bailey and Dell (1973) propagate the use of the Weibull distribution in modeling the diameter distribution of the forest stand (Rennolls et al. 1985) and confirm the function's superior performance (Bailey and Dell 1973). In this study, the diameter frequency distribution curves for all forest stands depicted variations of bell-shaped distributions with positively skewed, right-tailed curves (Figure 3.2).

The skewness values ranged from 0.33-0.62 and the shape parameters for the Weibull 3-function fell between 1.40 and 2.10. In the case of the Weibull 2-function, the shape parameters varied from 1.67-2.37. The tree densities in the smaller diameter classes were slightly higher than those in the middle classes of the *Terminalia*, *Acacia*, and *Diospyros* forests. In the *Dipterocarpus* forest, tree density was higher in the lower and middle diameter classes.Based on Rollet's (1974) findings, Richards et al. (1996) describe the seven types of stem diameter distribution for individual species as either 'bell-shaped' and right-skewed, when the species is light-demanding, or 'erratic', adistribution with an L-shaped curve on the short base (Richards et al. 1996). As is common, light demanding species can regenerate under special circumstances (Baur 1968), such as when trees in the smaller diameter classes are minimal or absent. Consequently, diameter distribution patterns vary greatly under diverse site conditions and among different locations (Richards et al. 1996).

In analyzing the ecological guilds of individual species, the diameter frequency distribution curves exhibited variations of mound shape diameter distribution with relatively large number of trees in the middle diameter classes. *Terminalia oliveri* and *Dipterocarpus tuberculatus* had bell-shaped distribution curves that were more or less skewed to the right. *Tectona hamiltoniana* and *Acacia catechu*demonstrated distortions in their bell-shaped distributions. The diameter frequency distribution curves for *Diospyros burmanica* and *Melanorrhoea usitata* provided in this study ranged in skewness values from 0.07 to 0.85 and were right-tailed. The shape parameter 'c' fell between 1.0 and 2.2 for Weibull 3-function and 1.5 and 2.5 for Weibull 2-function.

The goodness of fit test provides valuable information in determining the distribution function which is the best suited to the observed data. The Chi-square test performs well with the nominal data (Bernstein and Bernstein 1999; Zar 2010), whereas the Kolmogorov-Smirnov test is better for continuous datasets. Both tests are, normally, hypothesis statistics which report the test outcome as a p-value (Meilke 2010); the higher the p-values, the better suited the estimated function is to the data. A p-value of 0.05 is generally acceptable (Meilke 2010; McGarrigle et al. 2011). The goodness of fit tests confirm that some functions better fit a number of tree species and the *Acacia* forest. Parameters of the Weibull function, and skewnessare given in tables(3.7). The Chi-square goodness of fit test for the Weibull 3-function is proven a poor fit (i.e., $p < 0.05$) in the function's observed distribution for all tree species and forest stands, with the exception of *Acacia catechu* and the *Acacia* forest.

The K-S test for the Weibull 3-function revealed that the observed diameter distributions were conformed to the function for *Tectona hamiltoniana*, *Acacia catechu*, and the *Acacia* forest. The Weibull 2-function, however, fitted the diameter frequency distributions of the dry deciduous forest and tree species better than the Weibull 3-function. The Chi-square and K-S test exhibited a poor fit to the diameter frequency distribution for *Dipterocarpus tuberculatus*, *Diospyros burmanica*, *Melanorrhoea usitata*, and the *Terminalia*, *Diospyros*, and *Dipterocarpus* forests.

3.3.2 The height-diameter distribution

Stand height is fundamental in tree-improving research, silvicultural experiments, and predicting site index, stand volume, and stand growth (Van Laar and Akça 2007). Height-diameter functions are effective and useful measurements for predicting tree height in forest mensuration. To address the many constraints in measuring individual tree height in practice, various functions have been developed to determine the nearest estimation of height based on the observed diameter. Diameter at breast height becomes the supreme parameter for field measurement thanks to two distinct advantages of the method: simplicity and accuracy (Fang and Bailey 1998; Colbert et al. 2002). The height of the tree is predicted from this variable, although in some instances, the total heights of the sample trees are measured and a model of height-diameter distribution is developed. Although tree height and diameter at breast height over bark strongly correspond, this correlation varies depending on the locality, site, and species. Therefore, the predicted functions should be flexible, ending at the x-y interception (Fang and Bailey 1998) and consistently expanding with increasing diameter (Van Laar and Akça 2007). This study provided the best suited functions for the predominant dry forest tree species of Myanmar. These height-diameter functions covered diameter ranges of 10-37 cm for *Terminalia oliveri*, 10-47 cm for *Tectona hamiltoniana*, 10-49 cm for *Acacia catechu*, 10-33 cm for *Dipterocarpus tuberculatus*, and 10-25 cm for *Diospyros burmanica*.

A total of 5 functions were selected to fit the height-diameter distributions for the most predominant tree species in the dry forests. *Terminalia oliveri* and *Tectona hamiltoniana* had similar height-diameter distribution curves (Figure 3.3), with maximum heights at approximately 15 m. The former had a mean diameter at breast height and standard deviation of 18.9 cm ± 5.9, the latter, 20.5 cm ± 8.4. The height curve and observed height distribution pattern of *Acacia catechu* were in accord with the forms of *Terminalia oliveri* and *Tectona hamiltoniana*; the tallest trees attained a height of about 15 m, and the mean dbh and standard deviation were 24.4 cm ± 9.4. The distribution pattern for *Dipterocarpus tuberculatus* was somewhat different from that of the other species, in that the wide variations of tree heights were noticeable in all corresponding diameters at breast height.

Dipterocarpus tuberculatus had a maximum height of approximately 11 m, with a mean dbh and standard deviation of 15.7 cm ± 6.1. *Diospyros burmanica*, with its regularly increasing height-diameter distribution, grew to a median size, with the largest trees developing to a maximum height of 7 m. The largest height for *Acacia catechu* was about 13 m, and the mean dbh and standard deviation was 13.2 cm ± 5.5. The performance of the fitted functions was assessed using *pseudo*-R^2, RMSE, and the appearance of the resulted curves. Instead of R^2, the coefficient of determination which is best suited to linear regression, *pseudo*-R^2 is used to evaluate the model performance in nonlinear regression (Velten 2009). Although *pseudo*-R^2 are effective in evaluating several functions fitted withthe same observed data set (Hox 2010), their interpretations are nevertheless similar to the coefficient of determination in linear models (Cameron and Trivedi 1998); the values are smaller than R^2, and acceptable prediction results can be expected in the range of *pseudo*-R^2 values 0.2-0.4 (Hox 2010).

Like *pseudo*-R^2, RMSE, is also computed as an alternative method of estimating model validation, where smaller RMSE values better fit the estimated function to the observed data (Table 3.8). Despite the providing satisfied results, not all the distribution curves either ended at the x-y interception or, as monotone curves. Regarding the *pseudo*-R^2 and RMSE values, the parabolic equation demonstrated to be the best fitting function for all species; however, the distribution curves did not come up to the x-y interception.

The hyperbolic equation provided acceptable *pseudo*-R^2 and RMSE values as well as the best illustration of height-diameter distribution curves for all species (Figure 3.3). This function was monotone increasing with increasing diameter and passed through the x-y origin. For all fitted functions, *Acacia catechu* displayed the highest *pseudo*-R^2 values with the smallest RSME, *Tectona hamiltoniana* and *Dipterocarpus tuberculatus* exhibited an intermediate fit, and *Terminalia oliveri* provided the smallest *pseudo*-R^2 values with the largest RSME. The regression coefficients were significant at 0.05 p-value, with the exception of equation (1) and (5) for *Terminalia oliveri*, and equation (5) for *Tectona hamiltoniana* and *Acacia catechu*. All estimated parameters in the fitted equations for *Dipterocarpus tuberculatus* were significant from zero atp <0.05.

3.3.3 Vertical floristic composition

The vertical structure of a forest stand is the arrangement of above-ground vegetation from forest floor to canopy (Brokaw and Lent 1999) and is of utmost importance in a wide range of forest management, from tree growth modeling and yield table construction to wildlife conservation (Latham et al. 1998). Vertical structure has been described as the allocation of tree heights in a particular forest stand by Zimble et al. (2003), expressed as either measured height or on the basis of crown position by Huch et al. (2003). Numerous definitions and techniques have been proposed in the stratification of the forest canopy into superimposed layers; according to Oliver and Larson (1996), it can be described as the ranking of forest canopy into different strata based on tree height. Although numerous methods have been proposed to stratify the forest canopy into various layers, it is important to consider the flexibility or availability of stratification methods and the dynamic nature of the canopy.

Watt (1925) initiated the profile diagram approach (Baker and Wilson 2000) to illustrate fruit dispersal and beech seedlings development under the tree canopy, a method which has since become the most traditional and widely used method in classifying forest canopy layers (Baker and Wilson 2000). Other well-known approaches are the identification of the social position of trees (Kraft 1884) and the IUFRO classifications scheme (Lamprecht 1989; Chirici et al. 2011), a combination of social position of the trees, tree vigor, and tree growth (Chirici et al. 2011). The classification scheme itself can provide some ecological consequences for a particular forest stand at the time of field measurement.

The IUFRO classification scheme divides total tree height into three components, or stories (Lamprecht 1989): upper (tree height $>^2/3$top height), middle ($^2/3$ > tree height $>^1/3$), and lower story ($<^1/3$ of top height). According to Lamprecht (1989), a species which occurs in all story layers can be described as a ‘species with a regular vertical distribution’. For those species, natural regeneration is absolutely assured, and a sustained yield can be expected. On the contrary, species restricted to the middle and lower canopy layers are of less economic interest because of their small diameters. When a species is found only in the upper story, the natural regeneration and sustainability of forest stand appears uncertain. This study applied the IUFRO classification system in order to allocate the canopy into layers.

In the *Terminalia* forest, a total of 4 species represented the upper story, 9 were the middle story, and 2 made up the lower story. Although nearly equal tree densities were recorded in the upper and middle layers, the higher basal area (71%) was to be expected from the upper canopy story. The *Acacia* forest was the second highest forest stand, and a remarkable amount of basal area (88%), composing 66% of the total tree density, was found in the upper canopy story. Of 5 species found in the forest, 3 and 5 were recorded in the upper and middle stories, respectively, while only few species contributed the lower story.

The *Diospyros* forest, a type of dry scrub forest where the highest tree reached a maximum height of 7 m, had only approximately 6% of its total tree density represented in the upper story while the majority of the individuals had twisted stems of inferior quality. About 188 trees belonged to the middle story, accounting for 43% of the total basal area. A total of 370 stems (62%) and the largest basal area (45%) made up the lower story. In the *Dipterocarpus* forest, a 6 of 22 species were recorded in the upper story, 21 species in the middle, and 12 species in the lower. Here, the occurrence of species, tree density, and basal area were the highest in the middle story.

The predominant tree species in the three forest stands had a regular vertical distribution; *Terminalia oliveri* in the *Terminalia* forest, *Diospyros burmanica* in the *Diospyros* forest, and *Dipterocarpus tuberculatus* and *Melanorrhoea usitata* in the *Dipterocarpus* forest. Natural regeneration for those species is certain and long term sustainability can be expected. Another important associated species, *Tectona hamiltoniana*, was not found in the lower story of the *Terminalia* forest. In *Acacia* forest, the representation of tree species with dbh ≥ 10 cm in the lower story layer was absent. The two associated species of *Acacia* forest, *Acacia leucophloea* and *Tectona hamiltoniana*, occurred only in the upper story.

In the *Diospyros* forest, only *Diospyros burmanica* had a regular vertical distribution, with three other dominant tree species of the dry forest, *Terminalia oliveri*, *Tectona hamiltoniana*,and *Acacia catechu,* occupying the middle and lower story layers. All dominant species had a regular vertical distribution in the *Dipterocarpus* forest, the corresponding layers of which are found in table (3.9).

4. Discussion

The species area curves affirmed that the decidedsampling area was enough for this study. The importance value index (IVI) indicated *Terminalia oliveri* and *Tectona hamiltoniana* as the most critical species for the *Terminalia oliveri-Tectona hamiltoniana* forest, *Acacia catechu* for the *Acacia* forest, *Diospyros burmanica* for the *Diospyros* forest, and *Dipterocarpus tuberculatus* for the *Dipterocarpus* forest. The dry deciduous forests of Myanmar are less diverse than other forest formations: for instance, a total of only 9 woody species are found in the *Terminalia oliveri-Tectona hamiltoniana* forest; 5 species in the *Acacia* forest; 11 species in the *Diospyros* forest; and 23 species in the *Dipterocarpus* forest. A complete frequency diagram can therefore only be seen in the *Dipterocarpus* forest. In the other forest stands, one or two frequency classes are missing in the diagrams, possibly due to homogeneity of species and the effect of the sample plot size.

In every forest stand, it is common for one or two species to grow all over the area. Forest stands are most likely to be single species-dominant; the other associated species, which represent a smaller number of tree density and frequency percentage, are considered a part of the dry deciduous forest community. Diversity indices indicated that the *Diospyros* forest was the most heterogeneous of the forest stands. As the indices depend on the abundance of a particular species and the total abundance for all species in a given forest stand, smaller values are the results of more variation in species abundance. The *Acacia* forest was the most homogeneous stand according to the diversity indices. The intrusion of a new species is most likely impossible in this environment given the old growth fragmentation and location along the river bank.

The observed diameter frequency distributions of *Terminalia oliveri*, *Acacia catechu*, *Diospyros burmanica*, *Melanorrhoea usitata*, and the *Acacia* forest showed a similar proportion of trees occurring in the diameter classes between 5 to 30 cm, indicating irregular diameter frequency distributions. With regards to the observed diameter distributions, it appears that none of the functions show a better fit to the aforementioned species and forest. These irregular diameter frequency distributions are most likely due to the nature of the forest dominated by a single species with a few associated tree species and species-specific response patterns or the indication of disturbances in the past.

The predominant species of the dry deciduous forests, *Tectona hamiltoniana* and *Dipterocarpus tuberculatus*, demonstrate the characteristics of shade intolerance.The diameter distribution curve of *Dipterocarpus tuberculatus* depicts bell-shaped distribution, indicating the inadequate representation of small trees in the lower diameter classes. It is possible that the disturbance in seed germination and seedling establishment in these forest stands is due to the constraints in water availability as well as frequent forest fires.

The fitting of height-diameter distribution is carried out to manage the basic requirements of dry deciduous forest tree species in Myanmar's central dry zone. Until now, literature concerning the height-diameter distribution for dry deciduous forest tree species has been unavailable. The hyperbolic equation seems to bethe best suited function for the dry deciduous forest tress species, partlybecause it better illustrates those curves with reasonably high *pseudo*-R^2 and RMSE values. This finding affirms Latifah's (2005) study of height-diameter distribution for tropical rainforests in Indonesia; however, her height curves are fitted for either all tree species or certain families.

The fitted functions utilized in this study are in the context ofnatural, uneven-aged forest stands and a wide range of tree diameters. Despite the exclusion of certain parameters, such as site quality, stand age, or basal area, the function's fitted equation for a particular species is adequate, for planning purposes,in estimating height from a measured diameter at breast height. This function is useful in field cases where tree height is particularly difficult to measure, as well as in those instances when generalized accuracy for height-diameter correlation is a pre-requisite. One should take several aspects into consideration before using the proposed function, including the maximum diameter that can be covered by the function, the possibility of an available height data set, and the required accuracy of prediction.

Based on the resulting height-diameter curves, variation in tree height is visible in the deciduous dipterocarp forest stand, possibly due to tree growth positions and the space between the individuals. In the deciduous dipterocarp forest, *Dipterocarpus tuberculatus* and other associated species grow gregariously, greatly influencing the competition for light and other resources. Trees in the clusters attain larger heights than those in wider spaces, although this may be the result of inaccurate height measurements taken in the field.

Despite the vague nature of the term, stratification remains a useful tool in generally expressing an overview of the forest vertical structure; the IUFRO classification system in particular can explain some aspects of ecological processes in a particular forest stand. A few predominant species in the dry forests have regular vertical distribution, and natural regeneration for such species is certain. One of the most important tree species of the *Terminalia oliveri-Tectona hamiltoniana* forest, *Tectona hamiltoniana*, is represented in the middle and upper stories only, suggesting that the natural regeneration and sustainability of this species is in question.

In two old growth forest stands, *Terminalia oliveri-Tectona hamiltoniana* and *Acacia* forest, a number of tree species occupy the upper story, which itself shares more than two-third of the total stand basal area. Although the middle story has the highest amount of species' distribution, the basal area accounts for less than 30%. Tree density, species occurrence, and basal area for the lower story are negligible in these forest stands, in a situation similar to Lamprecht's (1989) description of vertical structure.

Two other forest stands, the dry *Diospyros* and deciduous dipterocarp forests, do not share similar characteristics with the aforementioned forest stands. In the dry *Diospyros* forest, the highest number of tree density, species occurrence, and tree basal area are found in the lower story, along with the three most important species in the area, *Terminalia oliveri*, *Tectona hamiltoniana*, and *Acacia catechu*. Most likely, soil qualityhasstrong influence on them: the stems of these species are stunted and of inferior quality, with branching occurring below 1.3 m.

In the case of the deciduous dipterocarp forest, the proportion of tree density, species occurrence, and tree basal area is higher in the middle story than in the upper story, although these differences are not significant (51% and 46%, respectively). This situation is explained by taking into account the history of the forest's growth; the deciduous dipterocarp forest is either a young growth forest stand or in the intermediate stage between young and old growth.

5. Conclusions and Recommendations

The dry deciduous forests of Myanmar are less diverse than other forest formations in terms of tree species and families. The Fabaceae family dominated the central area of Myanmar. Of thedry deciduous forest tree species, *Acacia catechu*, *Tectona hamiltoniana*, and *Terminalia oliveri* are widely distributed over all of central Myanmar.Theirregular diameter frequency distributions of dry deciduous forests and their tree species are most likely due to either the nature of the single species-dominant forest with a few associated tree species and species-specific response patterns or the indication of disturbances in the past. This study recommends that the hyperbolic equation function is useful in field cases where tree height is particularly difficult to measure, as well as in those instances when generalized accuracy for height-diameter correlation is a pre-requisite.

The dry deciduous forest in central Myanmar has long been a basic resource heavily relied upon by the local people for food, shelter, energy, medicine, and livestock fodder. Therefore, the following options are recommended for the sustainability of natural dry forests.

1. The protection of dry deciduous forests is of vital importance to maintain the diameter-frequency distribution of forests and tree species as regularly as possible, since the regular distributions are only possible under forest conditions without disturbances.

2. One should take several aspects into consideration before using the proposed height-diameter function, including the maximum diameter that can be covered by the function, the possibility of an available height data set, and the required accuracy of prediction.
3. Additional scientific research on dry deciduous tree species' and families' adaptation to dryland environmental conditions to understand the dominating capacity of tree families is recommended.

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Tables

Table 2.1. The classification of dry deciduous forest types in central Myanmar, after Kermode (1964).

Forest types	Rainfall (mm/a)	Soil	Dominant species
Zonal forest formation			
a) Dry mixed deciduous forest	890-1270	Variety of soils	*Vitex* spp., *Dalbergia* spp., *Albizzia* spp., *Terminalia* spp.
b) Cutch thorn forest	500-760	Sandy alluvium, poor shallow soils	*Acacia catechu*, *Acacia leucophloea*
c) *Euphorbia* semi-desert scrub forest	No data	Shallow, rocky and alkaline soils	*Euphorbia antiquorum*
Azonal forest formation			
a) *Terminalia oliveri*-*Tectona hamiltoniana* forest	890-1016	Clay soils	*Terminalia oliveri*, *Tectona hamiltoniana*
b) Dry *Diospyros* forest	< 1016	Light and sandy soils	*Diospyros burmanica*
c) Deciduous dipterocarp forest	> 890	gravelly and laterite soils	*Dipterocarpus tuberculatus*, *Shorea siamensis*, *Shorea obtusa*
Transition to grassland			
a) Dry savannah forest	500-1270	Variety of soils	*Terminalia oliveri*, *Tectona hamiltoniana*, *Diospyros burmanica*

Table 2.2. The fitted height-diameter functions for the most dominant species in the dry deciduous forests, in central Myanmar.

Functions	Form	Sources
$h = a+bd+cd^2$	Parabolic equation	Fang and Bailey (1998)
$h = d^2 / (a+bd)^2$	Hyperbolic equation	Fang and Bailey (1998)
$h = e^{(b_0+b_1*1/d)}$	Exponential equation	Van Laar and Akça (2007)
$h = 1.3+b_1*d+b_2*d^2$	Second-degree equation	Van Laar and Akça (2007)
$h = 1.3+\frac{d^2}{b_0+b_1*d+b_2*d^2}$	Prodan's (1944) equation	Van Laar and Akça (2007)

Table 3.1. Sampling accuracy (stand basal area in m²) in vegetation analysis in the dry deciduous forest of central Myanmar, single plot size 0.05 ha.

Sampling Site	$\bar{x} \pm$ SD*	SE %	n
Terminalia forest	2.02 ± 0.24	8.5	8
Acacia forest	2.58 ± 0.28	9.9	8
Diospyros forest	1.18 ± 0.17	5.8	8
Dipterocarpus forest	4.96 ± 0.13	4.6	8

* = mean stand basal area per sub-subplot and standard deviation

Table 3.2. The species composition and importance value index (IVI) for all trees ≥10 cm dbh in the *Terminalia* forest, in central Myanmar, 1 ha.

Species	**Abundance [Nha^{-1}]**	**Dominance [m^{2}ha^{-1}]**	**Frequency [%]**	**IVI [%]**
Terminalia oliveri	275	8.3	100	132
Tectona hamiltoniana	162	6.2	100	97
Tamarindus indica	15	0.4	37.5	15
Acacia catechu	2	0.1	12.5	4
Millettia brandisiana	2	0.1	12.5	4
Heterophragma sulfuerum	15	0.4	50	19
Lannea corromandelica	23	0.6	50	21
Vitex limonifolia	3	0.1	12.5	4
Balanites triflora	3	0.1	12.5	4
Total	500	16.1		300

Table 3.3. The species composition and importance value index (IVI) for all trees ≥10 cm dbh in the *Acacia* forest, in central Myanmar, 1 ha.

Species	**Abundance [Nha^{-1}]**	**Dominance [m^{2}ha^{-1}]**	**Frequency [%]**	**IVI [%]**
Acacia catechu	340	18.2	100	219
Acacia leucophloea	15	1.0	62.5	34
Tectona hamiltoniana	10	0.9	37.5	22
Randia dumetorum	5	0.3	25	13
Limonia acidissima	5	0.2	25	12
Total	375	20.6		300

Table 3.4. The species composition and importance value index (IVI) for all trees ≥10 cm dbh in the *Diospyros* forest, in central Myanmar, 1 ha.

Species	**Abundance [Nha^{-1}]**	**Dominance [m^{2}ha^{-1}]**	**Frequency [%]**	**IVI [%]**
Diospyros burmanica	285	5.5	100	120
Terminalia oliveri	105	1.1	100	43
Hiptage candicans	58	0.6	100	29
Tectona hamiltoniana	43	0.6	87.5	25
Sideroxylon assamicum	25	0.3	75	18
Dalbergia paniculata	23	0.5	75	19
Acacia catechu	15	0.2	37.5	10
Miliusa velutina	15	0.2	37.5	10
Boscia variabilis	13	0.2	62.5	12
Terminalia crenulata	10	0.2	37.5	9
Osyris wightiana	5	0.1	25	5
Total	595	9.4		300

Table 3.5. The species composition and importance value index (IVI) for all trees ≥10 cm dbh in the *Dipterocarpus* forest, in central Myanmar, 1 ha.

Species	**Abundance [Nha^{-1}]**	**Dominance [m^{2}ha^{-1}]**	**Frequency [%]**	**IVI [%]**
Dipterocarpus tuberculatus	1280	28.6	100	155
Melanorrhoea usitata	250	6.1	100	41
Xylia xylocarpa	48	0.7	87.5	14
Syzygium fruticosum	40	0.8	50	10
Lophopetalum wallichii	35	0.5	63	10
Buchanania lanzan	30	0.4	63	10
Bombax insigne	28	0.4	63	10
Albizia procera	13	0.4	25	5
Schleichera oleosa	13	0.2	25	4
Gardenia erythroclada	10	0.2	50	7
Strychnos nux-blanda	8	0.1	25	4
Shorea obtusa	8	0.1	37.5	5
Careya arborea	5	0.2	25	4
Terminalia chebula	5	0.2	25	4
Lannea coromandelica	5	0.1	25	3
Heterophragma sulfureum	5	0.1	25	3
Protium serratum	5	0.1	12.5	2
Vitex pubescens	5	0.05	25	3
Diospyros burmanica	3	0.2	12.5	2
Grewia tiliifolia	3	0.2	12.5	2
Dillenia indica	3	0.03	12.5	2
Bridelia retusa	3	0.02	12.5	2
Total	1800	39.7		300

Table 3.6. The diversity indices for the dry deciduous forests in central Myanmar, 1 ha.

Study area	**Diversity indices**	
	Shannon index[H´]	**Simpson index[1/D]**
Terminalia forest	1,13	2,41
Acacia forest	0,43	1,21
Diospyros forest	1,71	3,58
Dipterocarpus forest	1,18	1,90

Table 3.7. The parameters of Weibull functions for the individual species and the dry deciduous forests, in central Myanmar, 1 ha.

Category	**N**	**Skewed**	**Weibull 3-function**			**Weibull 2-function**	
			a	**b**	**c**	**b**	**c**
Terminalia oliveri	435	0.07	1.65	16.71	1.88	18.96	2.46
Tectona hamiltoniana	592	0.85	0.80	13.48	1.08	15.07	1.30
Acacia catechu	480	0.41	3.20	22.06	1.98	25.80	2.42
Dipterocarpus tuberculatus	1700	0.84	1.20	15.34	2.10	16.75	2.34
Diospyros burmanica	545	-0.13	2.00	12.48	2.03	14.82	2.62
Melanorrhoea usitata	370	0.51	1.50	15.01	1.79	16.97	2.19
Terminalia forest	1240	0.46	0.80	15.56	1.45	16.80	1.67
Acacia forest	565	0.33	2.25	23.23	2.09	25.80	2.37
Diospyros forest	2713	0.49	2.00	8.31	1.39	10.88	1.95
Dipterocarpus forest	3090	0.62	1.40	13.74	1.68	15.58	2.04

Table 3.8. The parameters, *pseudo*-R^2, and RMSE values of the fitted height-diameter functions for the predominant tree species in the dry deciduous forests, in central Myanmar, 1 ha.

Function	**Regression coefficients***						**R^2**	**RMSE**
	a	**b**	**c**	**b_0**	**b_1**	**b_2**		
Terminalia oliveri								
Parabolic equation^{+}	4.309	0.420	-0.004^{ns}	-	-	-	0.73	0.958
Hyperbolic equation^{+}	1.330	0.229	-	-	-	-	0.71	0.993
Exponential equation^{++}	-	-	-	2.868	-8.54	-	0.70	1.012
Second-degree equation^{++}	-	-	-	-	0.72	-0.010	0.70	1.008
Prodan's (1944) equation^{++}	-	-	-	-5.629^{ns}	1.68	0.030	0.73	0.958
Tectona hamiltoniana								
Parabolic equation^{+}	3.843	0.443	-0.004	-	-	-	0.83	0.884
Hyperbolic equation^{+}	1.403	0.229	-	-	-	-	0.81	0.930
Exponential equation^{++}	-	-	-	2.876	-9.05	-	0.80	0.964
Second-degree equation^{++}	-	-	-	-	0.66	-0.008	0.79	0.975
Prodan's (1944) equation^{++}	-	-	-	-2.694^{ns}	1.38	0.041	0.83	0.895
Acacia catechu								
Parabolic equation^{+}	0.095^{ns}	0.193	3.570^{ns}	-	-	-	0.93	0.509
Hyperbolic equation^{+}	1.514	0.240		-	-	-	0.92	0.530
Exponential equation^{++}	-	-	-	2.786	-9.42	-	0.91	0.568
Second-degree equation^{++}	-	-	-	-	0.55	-0.006	0.87	0.690
Prodan's (1944) equation^{++}	-	-	-	0.224^{ns}	0.55	-0.471^{ns}	0.87	0.690
Dipterocarpus tuberculatus								
Parabolic equation^{+}	-1.082	0.462	-0.005	-	-	-	0.94	0.412
Hyperbolic equation^{+}	3.349	0.239		-	-	-	0.94	0.413
Exponential equation^{++}	-	-	-	2.582	-15.22	-	0.93	0.422
Second-degree equation^{++}	-	-	-	-	0.19	-0.001	0.91	0.476
Prodan's (1944) equation^{++}	-	-	-	0.241^{ns}	0.19	-4.141^{ns}	0.91	0.476
Diospyros burmanica								
Parabolic equation^{+}	0.648^{ns}	0.054^{ns}	0.005	-	-	-	0.90	0.280
Hyperbolic equation^{+}	5.995	0.216		-	-	-	0.89	0.292
Exponential equation^{++}	-	-	-	2.321	-19.92	-	0.87	0.322
Second-degree equation^{++}	-	-	-	-	-0.03	-0.007	0.90	0.282
Prodan's (1944) equation^{++}	-	-	-	0.099^{ns}	0.03	-10.08^{ns}	0.90	0.282

*****Regression coefficients are significant at $p = 0.05$; ^{ns} = non-significant at $\alpha=0.05$ level.

$^{+}$Fang and Bailey (1998), $^{++}$Van Laar and Akça (2007)

Table 3.9. Vertical floristic composition and ecological traits of tree species for all trees ≥10 cm dbh in the dry deciduous forests, in central Myanmar, 1 ha.

Terminalia **forest**	***Acacia*** **forest**	***Diospyros*** **forest**	***Dipterocarpus*****forest**
Canopy Story			
[US+MS+LS]*			
A. Species with a regular vertical distribution			
Terminalia oliveri	no individual	*Diospyros burmanica*	*Dipterocarpus tuberculatus,* *Melanorrhoea usitata ,* *Xylia xylocarpa,* *Syzygium fruticosum*
[US+MS and MS only]**			
B. Species with partially assured regeneration			
Acacia catechu, *Balanites triflora,* *Lannea corromandelica,* *Millettia brandisiana,* *Tamarindus indica,* *Tectona hamiltoniana,* *Vitex limonifolia*	*Acacia catechu* *Randia dumetorum* *Limonia acidissima*	*Terminalia crenulata*	*Albizia procera,* *Careya arborea,* *Dillenia indica,* *Diospyros burmanica,* *Grewia tiliifolia,* *Lannea coromandelica,* *Protium serratum,* *Shorea obtusa,* *Terminalia chebula*
[US only]$^{+}$			
C. Species with uncertain natural regeneration			
no individual	*Acacia leucophloea* *Tectona hamiltoniana*	*Dalbergia paniculata*	no individual
[MS+LS and LS only]$^{++}$			
D. Species with no economic interest			
Heterophragma sulfuerum	no individual	*Acacia catechu,* *Boscia variabilis,* *Hiptage candicans,* *Miliusa velutina,* *Osyris wightiana,* *Tectona hamiltoniana,* *Terminalia oliveri,* *Sideroxylon assamicum*	*Bombax insigne,* *Bridelia retusa,* *Buchanania lanzan,* *Gardenia erythroclada,* *Lophopetalum wallichii, Schleichera oleosa, Strychnos nux-vomica,* *Vitex pubescens*

* = Species occurred in all story layers, i.e. upper, middle and lower story

**= Species found in the upper and middle story; species in the middle story only

$^{+}$=Species represented in upper story only

$^{++}$= Species belonged to middle and lower story and species in the lower story only

Figures

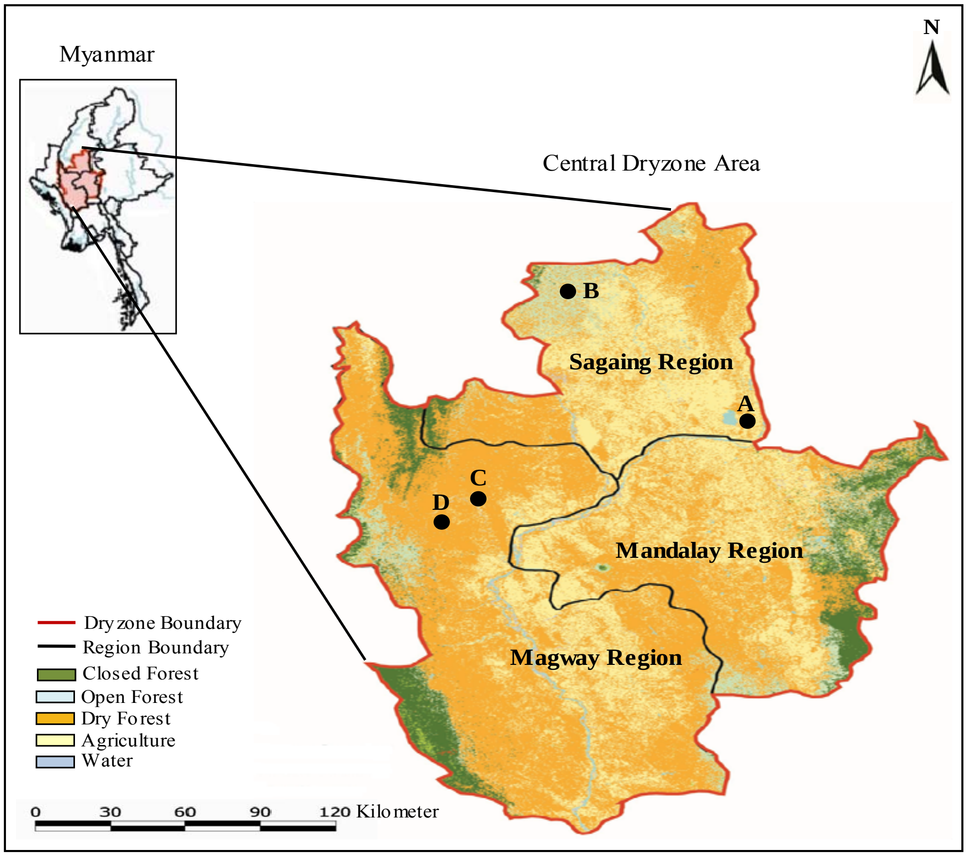

Figure 2.1. The location of study sites in the dry deciduous forests in central Myanmar.

[A=old-growth *Terminalia oliveri-Tectona hamiltoniana* forest (N21° 53', E 95° 59'); B= deciduous dipterocarp forest (N23° 3', E 95° 12'); C= cutch thorn forest (N21° 24', E 94° 42'); D= dry *Diospyros* forest (N 21° 13' and E 94° 29')]

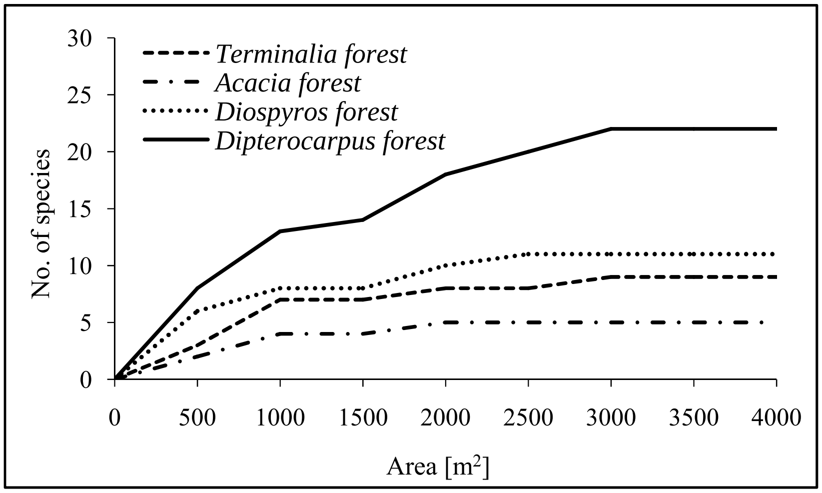

Figure 3.1. Species area-curves for all trees ≥10 cm dbh in the dry deciduous forests, in central Myanmar (accumulated number of tree species in accumulated area).

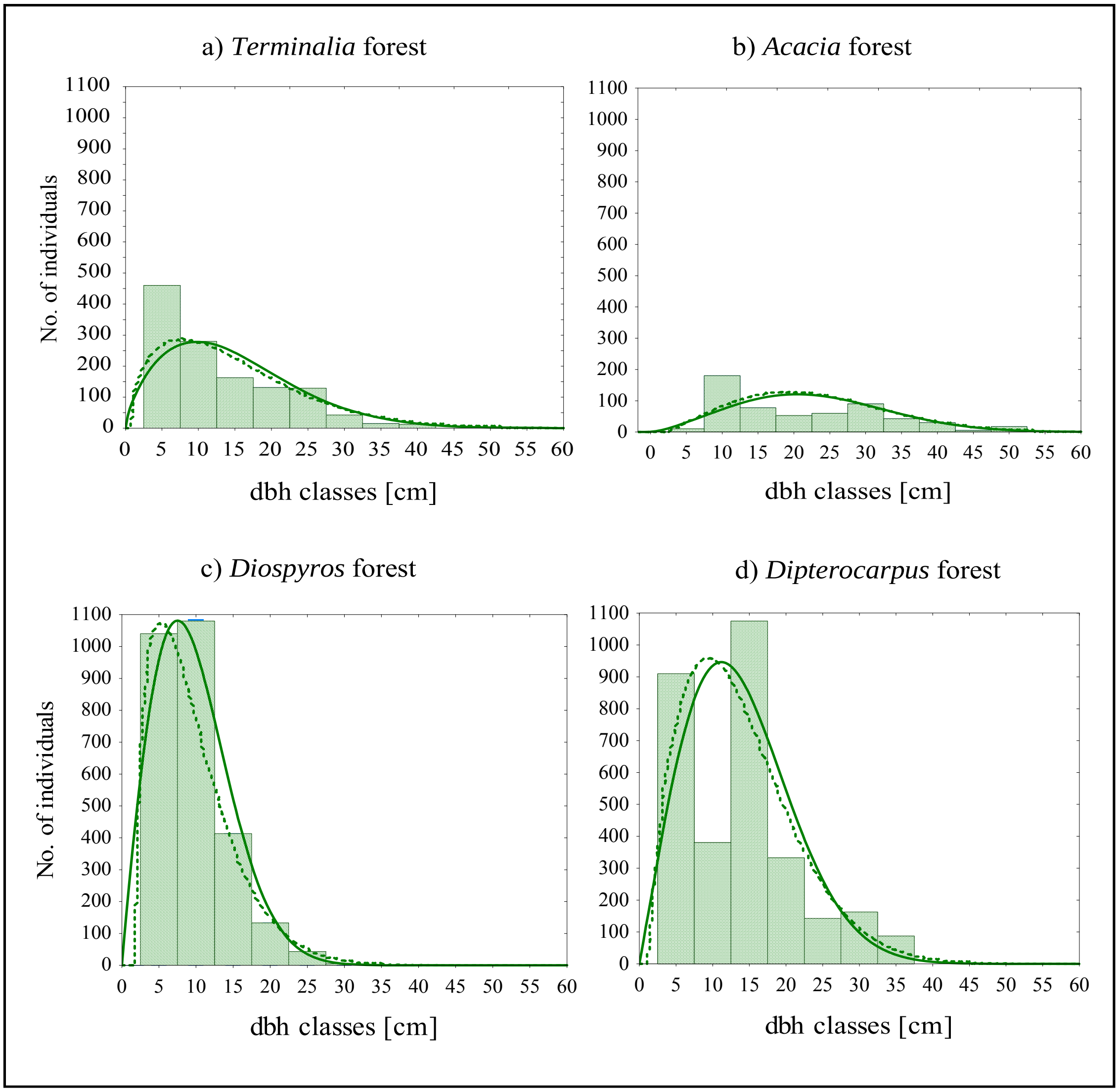

Figure 3.2. Diameter-frequency distribution for all trees including adult ≥10 cm dbh and sapling <10 cm dbh and >1.3 m height, in the dry deciduous forests of central Myanmar: a) the *Terminalia* forest; b) the *Acacia* forest; c) the *Diospyros* forest; d) the *Dipterocarpus* forest. [3-parameter Weibull function (dotted line); 2-parameter (solid line), and observed values (histograms)].

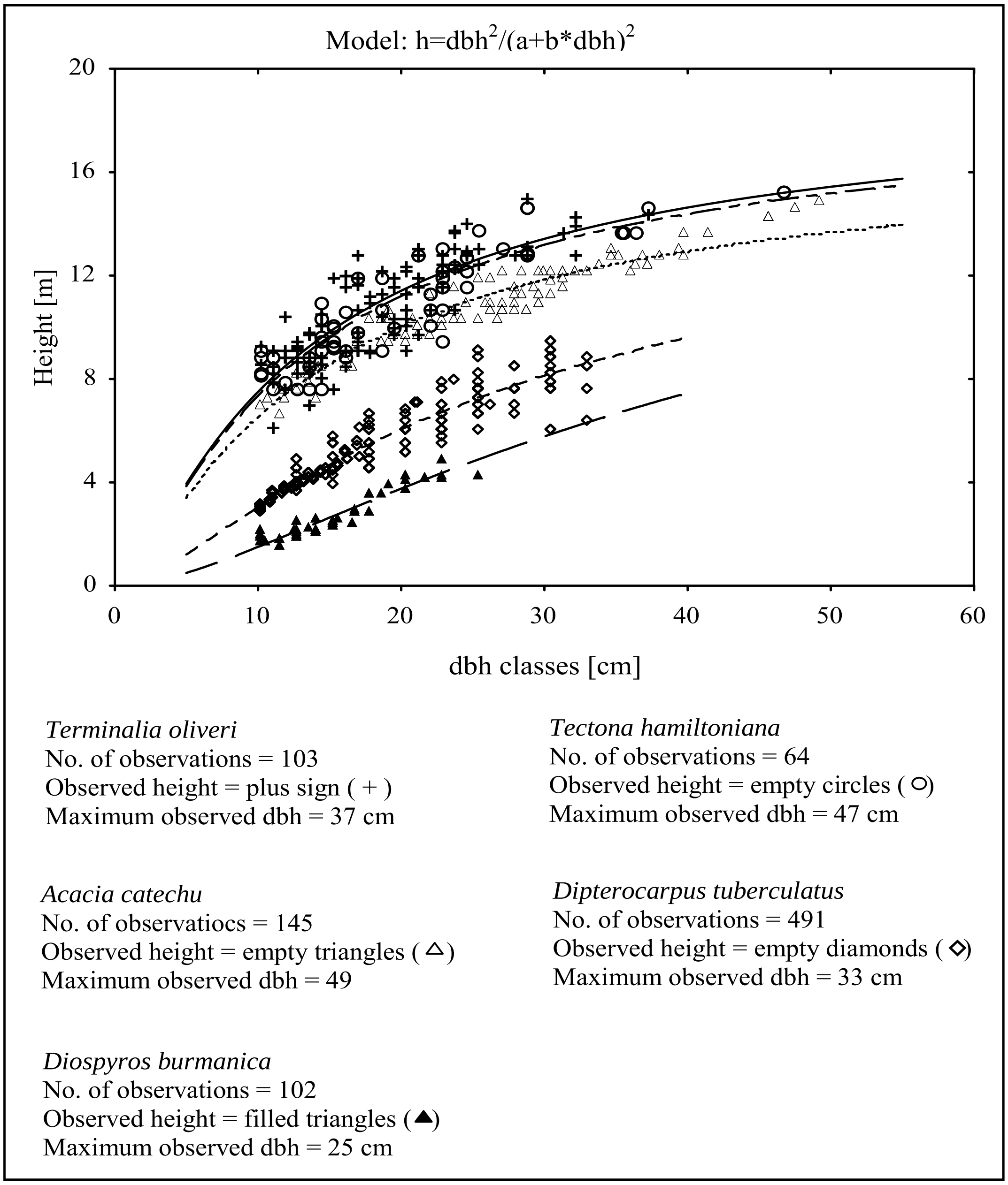

Figure 3.3. The height-diameter distribution curves for the predominant tree species in the dry deciduous forests, in central Myanmar, 1 ha. [The hyperbolic equitation: $h=dbh^2/(a+b*dbh)^2$ was fitted]