Leaflet No-10-2020

The Republic of the Union of Myanmar

Ministry of Natural Resources and Environmental Conservation

Forest Department

Altitudinal Variations of Tree Community Structure and Composition in the Montane Forests in the Natma Taung National Park, Chin State, Myanmar

Kyaw Kyaw Htoo

Range officer

Nature and Wildlife Conservation Division

Forest Department , Nay Pyi Taw , Myanmar

2020 December

Table of Contents

Altitudinal Variations of Tree Community Structure and Composition in the Montane Forests in the Natma Taung National Park, Chin State, Myanmar

Kyaw Kyaw Htoo,Range officer

Forest Department

Abstract

Tropical montane forests (TMFs) are of a high conservation value because they are unique in terms of biological diversity, stand biomass, and carbon storage. Understanding how the forest structure, composition, and above ground biomass changed with elevation is crucial for the stability of the mountain forest ecosystem. Species diversity and forest structures along the mountain slopes are susceptible to anthropogenic pressures, and the establishment of protected areas and conservation enforcement may reduce anthropogenic disturbances and improve the condition of forests. This study aimed to document the forest structure and taxonomic composition tree communities encompassing several types of montane forests in Natma Taung National Park (NTNP) in western Myanmar and to examine their relationship with elevations and location relative to the park boundary. A total of 24 plots were established to cover the entire elevational range (ca. 500 to 3000 m ASL). Tree diameter, height, location, elevation, evidence of selective cutting, and fire were recorded in each sample plot. Results showed that stand basal area and above ground biomass increased with elevation, while tree diameter, height, and tree density showed no trend with the elevation. Species composition differed between inside and outside of NTNP, as well as with elevation. Community type distribution within NTNP showed substantial overlaps in similar elevations. Oak dominated forests stored a large amount of above ground biomass than secondary forests that dominated lower elevation outside NTNP. Non-metric multidimensional scaling (NMDS) analysis showed that environmental factors related to tree community composition included elevation, disturbance, above ground biomass, and basal area. Thus, forest structures, composition, and live AGB changed with altitudes depending on the past human disturbance and protection status. This study confirmed that the establishment of a protected area helped in conserving forest characteristics (diameter, height, basal area, and biomass). Findings from this study also suggested that tropical montane forests stored higher amount of live above ground biomass if they were well-preserved.

Keywords: Tropical Montane Forest; Altitude; Protection; Disturbance; Forest structure; Tree community composition

ချင်းပြည်နယ်၊ နတ်မတောင်အမျိုးသား ဥယျာဉ်အတွင်းရှိ အပူပိုင်းတောင်ပေါ် သစ်တောများ၏ ပင်လယ်ရေပြင်အမြင့်လိုက် သစ်မျိုးပါဝင်မှုများနှင့် သစ်တောများ၏ ပြောင်းလဲမှုအခြေအနေများလေ့လာခြင်း

ကျော်ကျော်ထူး၊ တောအုပ်ကြီး
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်းချုပ်

အပူပိုင်းဒေသ တောင်ပေါ်သစ်တောများသည် ဇီဝမျိုးစုံမျိုးကွဲကြွယ်ဝခြင်း၊ ကာဗွန် သိုလှောင်ထိန်းသိမ်းမှုများပြားခြင်း စသည့် ထူးခြားချက်များကြောင့် ထိန်းသိမ်း ရေးဆိုင်ရာ တန်ဘိုး မှာ မြင့်မားလျက်ရှိပါသည်။ အဆိုပါသစ်တောများ၏ ဂေဟစနစ်များ ရေရှည်တည် တံ့နိုင်ရေး အတွက် တောင်ပေါ်သစ်တောများ၏ ဖွဲ့စည်းတည်ဆောက်မှု ဆိုင်ရာ အချက် အလက် များ၊ တောအမျိုးအစားအလိုက်ပါဝင်ပင်များ နှင့် မြေဆီလွှာ အပေါ်ယံရှိ ဇီဝဖြစ်ထု များ ပင်လယ်ရေမျက်နှာပြင်အမြင့်အလိုက် ပြောင်းလဲဖြစ်ပေါ်နေမှု များကို သိရှိနားလည် ရန်မှာ အရေးကြီးလှပါသည်။ တောင်ပေါ်ဒေသရှိ မျိုးစိတ်များ ကွဲပြားခြားနားမှုများ နှင့် သစ်တောများ၏ ဖွဲ့စည်းတည်ဆောက်မှုများသည် လူသားတို့ ဆောင်ရွက်ချက်များမှ ဖြစ်ပေါ် လာသည့်ခြိမ်းခြောက်မှုများအပေါ် ခံနိုင်ရည်နည်းပါး လျက်ရှိသော်လည်း သဘာဝ ထိန်းသိမ်း ရေးနယ်မြေများ တည်ထောင်ခြင်းနှင့် ထိန်းသိမ်းရေးဆိုင်ရာ ဆောင်ရွက်မှု များသည် လူသားတို့၏ ခြိမ်းခြောက်မှုများကို လျော့ချနိုင်ရုံသာမက သစ်တောများတည်ရှိမှုအခြေ အနေများကိုပိုမိုတိုးတက်ကောင်းမွန်စေနိုင်ပါသည်။

ထို့ကြောင့်အပူပိုင်းတောင်ပေါ် သစ်တော များ၏ အပင်အမြင့်များနှင့် ရင်စို့လုံးပတ် ပြောင်းလဲမှုများ၊ တောအမျိုးအစား ပြောင်းလဲမှုနှင့် သစ်မျိုးပါဝင်မှုများကို မှတ်တမ်းတင်ရန် နှင့် တောင်အမြင့်ပြောင်းလဲမှုများ၊ ဥယျာဉ်အတွင်း အပြင်ဆိုင်ရာ အချက်အလက်များနှင့် ၎င်းတို့၏ ဆက်စပ်နေမှု အခြေအနေ များ အား သိရှိနိုင်ရန် ရည်ရွယ်ချက်များဖြင့် ဤသုတေသနကို မြန်မာနိုင်ငံ အနောက်ဘက် ပိုင်းတွင် တည်ရှိသော အာဆီယံအမွေအနှစ်စာရင်းဝင် နတ်မတောင်အမျိုးသားဥယျာဉ်တွင် ဆောင်ရွက်ခဲ့ပါသည်။ သုတေသနလုပ်ငန်း ဆောင်ရွက်ရာတွင် တောင်အနိမ့်ပိုင်းမှစ၍ တောင်ထိပ်ပိုင်း အထိ ခြုံငုံမိစေရန် နမူနာကွက်များကို အမြင့်မီတာ ၅၀၀ ခန့်မှ မီတာ ၃၀၀၀ အထိ စုစုပေါင်း (၂၄) ကွက် ချမှတ်၍ ကောက်ယူခဲ့ ပါသည်။ သစ်ပင်များ၏ ရင်စို့လုံးပတ်၊ အပင်အမြင့်၊

တည်နေရာ၊ ပင်လယ်ရေပြင်အမြင့်၊ သစ်ငုတ်များတွေ့ရှိရမှု နှင့် မီးလောင်ခြင်း ဆိုင်ရာအချက်အလက်များကို နမူနာကွက်တိုင်းတွင် ကောက်ယူ မှတ်တမ်းတင်ခဲ့ပါသည်။ သုတေသနတွေ့ရှိချက်များအရ သစ်ပင်များ၏ ရင်စို့ဖြတ်ပုံ ဧရိယာနှင့် မြေဆီလွှာအပေါ်ယံရှိဇီဝဖြစ်ပုံများသည် တောင်အမြင့်အလိုက် ပြောင်းလဲမှုရှိသော်လည်း အပင်များ၏ ရင်စို့လုံးပတ်၊ အပင်အမြင့် နှင့် အပင်သိပ်သည်းမှု အရေအတွက် တို့မှာ ပင်လယ်ရေပြင် အမြင့် အလိုက် ပြောင်းလဲမှုမရှိသည်ကို တွေ့ရှိရပါသည်။ သစ်အယ်မျိုးစိတ်များလွှမ်းမိုးလျက်ရှိသော တောင်ပေါ်တောများသည် နတ်မတောင်ဥယျာဉ် အပြင်ဘက် တောင်၏ နိမ့်ပိုင်းတွင်ရှိသော တောနိမ့်များ၊ ထင်းရှူးတောများထက် မြေဆီလွှာအပေါ်ယံရှိ ဇီဝဖြစ်ထု များပိုမိုသိုလှောင်နိုင်ကြသည်။ Non-metric Multidimensional Scaling Analysis ရလဒ်များအရ အပင်မျိုးစိတ် ပါဝင်မှုများသည် အမျိုးသားဥယျာဉ် အတွင်းပိုင်း နှင့် အပြင်ပိုင်းသာမက အမြင့်အလိုက်ပါ ပြောင်းလဲမှုများ ရှိပြီး သစ်ငုတ်များတွေ့ရှိရမှု၊ ဇီဝဖြစ်ထု သိုလှောင်မှု နှင့် ရင်စို့ဖြတ်ပုံ များနှင့်လည်း ဆက်စပ်နေကြောင်းလေ့လာတွေ့ရှိရပါသည်။ ထို့ကြောင့် အပူပိုင်းတောင်ပေါ်သစ်တောများ၏ ဖွဲ့စည်းတည်ဆောက်မှုများနှင့် အပင်မျိုးစိတ် ပါဝင် မှုများ သည် တောင်၏ အနိမ့်အမြင့်အလိုက်သာမက လူတို့၏ နှောက်ယှက်ခဲ့မှုများနှင့် ထိန်းသိမ်းကာကွယ်မှု ဆိုင်ရာ အခြေအနေများအရပါ ပြောင်းလဲလျက်ရှိပါသည်။ ဤသုတေ သန သည် သဘာဝထိန်းသိမ်းရေး နယ်မြေများ တည်ထောင်ခြင်းသည် အပူပိုင်းဒေသ တောင်ပေါ်သစ်တောများ၏ အခြေခံ လက္ခဏာ များဖြစ်သော လုံးပတ်၊ အပင်အမြင့်၊ ရင်စို့ဖြတ်ပုံ ဧရိယာ နှင့် ဇီဝဖြစ်ထုများကို ထိန်းသိမ်းရာတွင် အထောက်အကူပြုကြောင်းကို အတည်ပြုနိုင်ခဲ့ပြီး လေ့လာတွေ့ရှိ ချက်များအရ အပူပိုင်းဒေသ တောင်ပေါ်တောများသည် ကောင်းမွန်စွာ ထိန်းသိမ်းကာကွယ်ပါက သစ်ပင်မျိုးစိတ်များ၊ သစ်တောအခြေအနေများနှင့် မြေဆီလွှာ အပေါ်ယံရှိ ဇီဝဖြစ်ထုများကိုပိုမိုသိုလှောင်ထိန်းသိမ်းနိုင်ကြောင်းကိုလေ့လာတွေ့ရှိခဲ့ပါသည်။

Altitudinal Variations of Tree Community Structure and Composition in the Montane Forests in the Natma Taung National Park, Chin State, Myanmar

1. Introduction

Tropical montane forests (TMFs), generally found in the humid tropics with frequent cloud and mist cover, are of a high conservation value because they are unique in many aspects, and high in biological diversity, stand biomass, and carbon storage (Bubb et al., 2004; Spracklen & Righelato, 2014). Although they constitute only 2.5 % of the world's tropical forests, they are also important for the stability of mountain ecosystems, conservation of upland watersheds and water sources, provision of livelihood support to the local people (Hertel et al., 2003).

Taxonomic and structural attributes and ecosystem processes may vary not only with the environmental gradient (such as climate, soil fertility, rainfall) (Poorter et al., 2015) but also with topographic factors; elevation, slope, and aspect (Austin, 1980; Mokarram & Sathyamoorthy, 2015). Among these factors, elevation has been the most important variable in controlling forest structure, because vegetation responses to climate, soil quality, and nutrients change along elevation gradients (Sang, 2009; Wang et al., 2011; Halbritter et al., 2013). Aiba and Kitayama (1999) and Takyu and Kitayama (2002) in Bornean forests found that forest stature, tree species diversity, and floristic composition decreased with altitude depending on the type of geological substrates. Similarly, Homeier et al. (2010) in Ecuador found a gradual decrease in tree DBH and height from low elevation to high elevation and reported their positive associations with soil parameters. Lower temperatures, higher rainfall, soil acidity, nutrients shortage have been major limiting factors on the vegetation growth in high elevation areas. Pandey et al. (2018) in eastern Himalaya also observed that tree species diversity and basal area decline monotonically with elevation. However, the relationship between stand density and elevation differs among life forms, plant size classes, and taxonomic groups (Hernández et al., 2012; Pandey et al., 2018).

Depending on the broad matrix of environmental conditions along the elevation gradient, tree species, and community composition change. Along the altitudinal gradient of the Cordillera El Consuelo in the Andes of southern Ecuador, Lauraceae is the most important family, with typical lowland tree taxa (e.g., Chrysobalanaceae, Moraceae, Sapotaceae, Quiina, and Vochysia) occurring at lower elevations and typical montane taxa (e.g., Araliaceae, Ilex, Symplocos and Weinmannia) occurring at higher elevations (Homeier et al., 2010). In eastern Himalaya, *Abies densa* and *Sorbus microphylla* had wide distribution up to 3900 m (Pandey et al., 2018). In the same area, temperate species such as *Prunus bracteopadus and Magnolia campbellii* are found at the lower end, and *Rhododendron* species are found at the higher end of the elevation range surveyed (Pandey et al., 2018; Sinha et al., 2018). Although the distribution of species is elevation driven, vegetation growth within a given elevation range could be better on the shady side of the mountain where much less evapotranspiration (Jin et al., 2008). Furthermore, the abundance of tree species varies with habitat associations within the topographic gradient. Analysis of the intraspecific spatial distribution of the 42 species tropical montane forest in Mount Kinabalu, Borneo found

habitat association of 16 species with slope convexity, three species with the inclination, and one species with both (Aiba et al., 2004).

Furthermore, species diversity and forest structures along the mountain slopes are susceptible to anthropogenic pressures (Becker et al., 2007; Anderson et al., 2018). Extraction of timber and non-timber forest products, shifting cultivation, and firewood cutting are common disturbances in hillside forests, and such disturbances affect forest conditions, tree diversity, and species composition (Phyu Lwin & Kanzaki, 2017). Not only that, but the consequences of human-driven canopy opening, and global climate change also lead to vegetation shifts and compositional changes of disturbance-, light- or drought-intolerant species. For instance, analysis on the trend of vegetation index from 1982 to 2006 in the Qilian Mountains in China found that the normalized difference vegetation index (NDVI) values increases in higher elevations due to the range shifts driven by increasing temperatures over the period (Wang et al., 2011).

The establishment of protected areas and conservation enforcement may reduce anthropogenic disturbances and improve the condition of forests. According to the global analysis of deforestation between 2001 and 2018, forest loss inside protected areas is comparatively lower than outside, due to a lower level of disturbance in the former (Wade et al., 2020). Dao et al., (2016) also found that the protection level of nature reserve influences the structural and compositional characteristics of montane forests. These authors found that tree species richness and DBH were higher in the high-elevation core zone than the low-elevation buffer zone of Ta Xua Nature Reserve in the Vietnamese montane forest.

Nonetheless, tropical montane forests often received less conservation attention than other types of tropical forests (Bubb et al., 2004; Homeier et al., 2010). Montane forests remain understudied although they are environmentally and ecologically irreplaceable. Baseline information is still very limited in these forests (Spracklen & Righelato, 2014). In Myanmar, most forestry studies have been done on the deciduous forests which were commercially important. Therefore, this study was conducted in Natma Taung National Park (NTNP) to understand the distribution and characteristics of montane forests in western Myanmar.

1.1 Problem statement

Natma Taung National Park, centered around Mt. Natma Taung also known as Mt. Victoria, is located in Chin State, which is the least developed among the States in Myanmar. On rough mountainous terrain in Chin state, indigenous Chin ethnic communities have traditionally been practicing shifting cultivation and home-garden. Forests surrounding local communities have been major livelihood sources. Forest products not only provide subsistence need but also provide cash income to the local households (Aung et al., 2015). Unstainable land-use practices, as well as overharvests of NTFPs and fuelwood, are putting pressures on the forests surrounding the park. The resultant deforestation and land fragmentation impair the ecological functioning and integrity of the park's ecosystem (Istituto Oikos & BANCA, 2011).

In this area, there have been previous studies on plant taxonomy **(**Tanaka, 2005, Fujikawa et al., 2012, Fujikawa et al., 2015, Ding et al., 2019), vegetation differences between primary and degraded forests (Myat, 2016), biomass storage of secondary forests

after shifting cultivation (Chan & Takeda, 2016), and species range shifts in response to climate change (Thang et al., 2020). However, no studies have been conducted regarding forest structure and composition, or their relationships with environmental factors along the altitudinal gradient. This study is the first attempt to fill this gap for better conservation of NTNP's montane forests.

1.2 Objectives

The study aimed to document the following aspects of structure and taxonomic composition of several types of montane forests in NTNP and to examine their relationship with elevation and location relative to the park boundary. More concretely, the study quantified the following aspects:

1) Forest structure, in terms of DBH, height, basal area, stem density, and biomass of trees
2) Tree community composition, in terms of species, genera, and family of trees
3) Signs of disturbance, in terms of stumps remaining and signs of fire.

2. Materials and methods

2.1 Study area

The study was conducted in Natma Taung National Park (NTNP) in the Southern Chin State of Myanmar (Fig. 1). It is located in the north-western part of Myanmar (latitude 21˚13' N, and longitude 93˚53' E). The park encompasses 71,346.07 ha and shared its boundary in three townships; Kanpalet, Mindat, and Matupi (Forest Department, 2017).

The study area experiences a tropical monsoon climate with the rainy season from May to October (Sein et al., 2015). Precipitation is particularly high between June and September (Kine, 2018). The mean annual temperature is 20.5°C, and annual precipitation is 1530 mm according to the data collected from the Department of Hydrometeorology, Myanmar during 1985-2017 (Thang et al., 2020). In this area, the reddish-brown soil was formed by weathering of alkaline parent material (Makino & JICA, 2013). Chin hill's complex soils and red-brown forest soils are mostly low in fertility (Forest Department, 2017).

The study area is located at the transition zone between tropical and temperate regions of Southeast Asia, with both tropical and temperate species are found (Tanaka et al., 2005; Ashton & Zhu, 2020). The mountainous landscape of the NTNP ranges in elevation from 740 m to 3200 m ASL (Thang et al., 2020). At the lowest elevation zone, the original vegetation is hill evergreen Dipterocarp forests, but the secondary forests resulting from repeated clearance of the shifting cultivation are more common in recent times. At the next elevation zone, pine forests are extensive, above which the vegetation shifts from laurel, oak and Rhododendron forests to open meadow near the highest summit (Fujikawa et al., 2015).

The study area has been preserved as a reserve forest since 1936, and the large part of it became gazetted as a national park in 2010. NTNP is counted among the 200 globally important ecoregions of the world (Fleming, Edrington, & Bennett, 2008), as it consists of unique forest communities with a high level of plant species endemism (Myat, 2016). NTNP contains important habitats for endemic birds (BirdLife International, 2020) and threatened and endangered mammals such as hoolock gibbon (*Hylobates hoolock*), tiger (*Panthera tigris*), clouded leopard (*Pardofelis nebulosa*), leopard (*Panthera pardus*), sun bear (*Ursus*

malayanus), eld deer (*Cervus eldii*), and gaur (*Bos gaurus*). Furthermore, the Mt. Natma Taung is culturally and spiritually important for indigenous Chin communities (Istituto Oikos & BANCA, 2011). For its biological and cultural significance, it became recognized as the Association of Southeast Asian Nations-ASEAN Heritage Park in 2012.

2.2 Field survey

I designed the study to cover the entire elevational range of the NTNP on the basis of the previously published information on vegetation distribution along the elevation (Fujikawa et al., 2012). Locations of the study plots were determined by 1) elevation, 2) forest type, and 3) accessibility. I conducted the field survey from November 2019 to December 2019, during which a total of 24 plots (0.1 ha each) were established and sampled.

Following Fujikawa et al. (2015), the study plots were pre-classified to five forest types by physiognomy and their relationship to the three altitudinal zones; seven plots were at less than 1800 m, eight plots were between 1800 and 2400 m, and nine plots were at 2416 m and above (see Table 1 for the information about study plots' elevation and pre-classified forest types). As my original intention was to document the relationship of the original forest vegetation to elevation, I chose locations with good forest characteristics, i.e. undisturbed old-growth forests with closed canopy cover were selected as much as possible. This was possible inside NTNP. However, it was not possible to find undisturbed forests that were easily accessible outside NTNP, especially below 1700 m. Most areas outside the park boundary were dominated by secondary forests with open canopy from shifting cultivation and other forest use by people. Relatively undisturbed forests could be found only in some areas preserved by villagers as water sources. Furthermore, plots located in very remote areas and steep slopes were not selected due to their infeasibility to conduct the survey. There were 7 study plots outside the NP and 17 study plots inside the NP. The distribution of sample plots is presented in Fig. 1 and the distribution of vegetation types with elevation were presented in Fig. 2.

For an efficient survey, I adopted the concentric circular plot design that is used widely in forest inventories, with the advantage of reducing the edge effects (Paudel & Mandal, 2019). Each sample plot consisted of three concentric circles within which trees of different sizes were identified and measured. Trees greater than 1 cm DBH were measured in the innermost circle of the radius of 5.64m (0.01 ha), those with DBH $\geq$ 5 cm were measured in the middle-sized circle of 11.28 m (0.04 ha) radius, and those with DBH $\geq$ 18 cm were measured in the largest circle of 17.84 m (0.1 ha) radius (Fig. 3). For all stems above these threshold sizes, I recorded their location, height, and diameter at breast height (DBH) at 1.3 m above ground.

In the middle-sized and largest circular area of each plot, all trees > 5 cm diameter at 1.3 m above the ground level were tagged, respectively, with a numbered tape for repeated monitoring. Tree heights were measured with Vertex Hypsometer (VI, Haglof Company Group, Sweden). The fifteen-meter telescopic pole was used to collect leaves, fruits, and flowers for taxonomic identification. A handheld GPS (Garmin 64s, Garmin International, Inc., USA) was used to record locations and altitudes of each plot with an accuracy within 5 to 10 meters. At each plot, I recorded weather conditions, latitude, longitude, elevation, slope, and aspects (Appendix for the survey form used). Environmental conditions such as evidence

of human disturbances (i.e. selective cutting) and information about fire found at the given plot were also noted. I also took photos of each plot as a visual reference.

Voucher specimens were collected, identified, and deposited at the Herbarium of Forest Research Institute, Forest Department, Myanmar. "A checklist of Trees, Shrubs, Herbs, and Climbers of Myanmar" by Kress et al. (2003) and Angiosperm Phylogeny Group III System by APG III (2009) were used as references for taxonomic identification. Local technical assistance provided by park rangers who had previously became trained in multiple botanical surveys helped onsite identification and identification of fresh voucher specimens. Samples were identified to the lowest taxonomic level possible whether species, genus, or family.

2.3 Data analysis

Forest inventory data from all subplots were compiled together to examine the differences and trends among plots. Tree height and DBH measurements were plotted after log-transformation using the standardized major axis slope (SMA) fitting to verify the allometric relationship. Quantile regression analyis was used to test whether the forest parameters (DBH and tree height) were changed with elevation or not.

The basal area (m^2) of each stem was calculated as below:

$$\text{Basal area} = \frac{\pi\,(\text{DBH}/2)^2}{10000}$$

where DBH is the diameter at breast height in centimeter. The total basal area for each plot was calculated as below.

$$BA_{total}(m^2/ha) = \frac{\sum BA_{>18}}{0.1} + \frac{\sum BA_{5-18}}{0.04} + \frac{\sum BA_{1-5}}{0.01},$$

where $BA_{>18}$, $BA_{5\text{-}18,}$ and $BA_{1\text{-}5}$ denotes the basal area of trees whose DBH was more than 18 cm, between 5 and 18 cm, and between 1 and 5 cm respectively.

The total number of stems per ha was calculated for each plot as follows:

$$No.\,of\ stems/ha = \frac{\sum stems_{>18}}{0.1} + \frac{\sum stems_{5-18}}{0.04} + \frac{\sum stems_{1-5}}{0.01},$$

where $\Sigma stems_{>18}$, $\Sigma stems_{5\text{-}18,}$ and $\Sigma stems_{1\text{-}5}$ denotes the number of stems whose DBH was more than 18 cm, between 5 and 18 cm, and between 1 and 5 cm respectively.

The structural heterogeneity of the stem size was evaluated by the Gini index (*G*). The Gini coefficient has been used for the measurement of size hierarchies in plant populations (Weiner & Solbrig, 1984). In forestry applications, it has been used for its sensitivity to variation in sample size distribution (e.g. Staudhammer & LeMay, 2001; Valbuena, et al. 2012). The size hierarchy at the plot level is displayed by the Lorenz curve. To calculate *G*,

all trees require to be ranked by size in ascending order with a consideration of concentric circular plot design (normalized per 1 ha, which means individuals in the larger circle are multiplied by 10 times, those in the medium circle by 25 times and those in the small circle by 100 times). The values are continuous and constrained within the interval 0 and 1. The Gini index can be calculated by the following formula (Damgaard & Weiner, 2000):

$$Gini = 2\frac{\sum_{i=1}^{n} ig_i}{nG} - \frac{n+1}{n}$$

Above ground biomass (AGB) was estimated with an allometric equation that considers DBH, height, and wood density. Wood density was estimated from the Global Wood Density Database (Chave et al., 2009). For trees for which only genus- or family-level information was available, the mean wood density of the genus or family was used, respectively. For trees that could not be identified even at the family level, the mean wood density of all trees was used. AGB of each tree was estimated with the following allometric equation developed by Chave et al. (2005), which has been used in a wide range of tropical moist forests. AGB was calculated as below:

$$AGB = 0.0509\rho D^2 H$$

where ρ represents specific wood density, D is the diameter at breast height and H is tree height. The plot-level AGB (Mg ha^{-1}) was estimated by integrating all AGB of trees in each plot as follows:

$$AGB_{total}(Mg/ha) = \frac{\sum AGB_{>18}}{0.1} + \frac{\sum AGB_{5-18}}{0.04} + \frac{\sum AGB_{1-5}}{0.01}$$

where $\Sigma AGB_{>18}$, $\Sigma AGB_{5\text{-}18}$, and $\Sigma AGB_{1\text{-}5}$ denotes the total above-ground biomass of trees whose DBH was more than 18 cm, between 5 and 18 cm, and between 1 and 5 cm, measured in respective concentric circles. Pearson correlation test was done to see the correlation of AGB and elevation in both inside and outside of NP.

Non-metric multidimensional scaling (NMDS) analysis was performed to understand the differences in taxonomic compositions and their relationships with environmental factors. NMDS is an ordination method based on a distance or dissimilarity matrix. In this study utilizing concentric circular plot design, species presence-absence data including the morpho species were used. For NMDS analysis, three plots (P07, P12, and P21) at a low level of identifications (Table 2) were excluded. As required by NMDS, the data were analyzed by two distinct matrices: the species matrix and the matrix of environment variables. The species matrix contained species presence/absence vs. plot identity, and the environmental variables matrix contained elevation, basal area, above ground biomass, disturbance, and fire. For disturbance and fire, presence or absence (1 or 0) was used in the NMDS analysis. I used the "metaMDS" function in the "vegan" package in R and environmental variables were overlaid by the "envfit" function (Dixon, 2003), and the "ordiellipse" function was used to represent pre-classified forest types. However, for secondary forest plots, this function was not able to draw the circle as there were only two plots. All the analyses were conducted in RStudio software (R Core Team. 2016).

3. Results

3.1 Forest structural analysis

3.1.1 Stand level forest characteristics

Both inside and outside NTNP, a higher number of individuals were found at the lowest diameter classes (< 5cm DBH) (Fig. 4A). The number of individuals declined with increasing DBH. Big trees (more than 18 cm DBH) were more abundant inside the park. However, the middle size (5-18 cm DBH) trees were abundant outside the NP. In both outside and inside NTNP, trees bigger than 18 cm DBH contributed to the majority of the total basal area (Fig. 4B).

3.1.2 Plot level forest characteristics along the altitudes

There was a wide variation in plot-level forest characteristics (DBH, height, stem density, and basal area) along the elevational gradient.

DBH

The 95 % quantile regression showed that there was no relationship with DBH and elevation outside the national park ($p=0.487$). However, inside the national park it resulted that there was positively significant relationship with DBH and the range of DBH expanded with elevation ($p<0.001$), and most of the biggest diameter were found between 2350 m to 2631 m (Fig. 5A).

Height

For the plots outside national park, the 95 % regression showed that there was no significant relationship between tree height and elevation ($p=0.837$) while it showed negatively significant relationship with increasing elevation inside the national park ($p<0.001$) and the range of tree height contracted with elevation. Most of the tallest trees occurred around 2500 m elevation inside NTNP (Fig. 5B).

Basal area and stem density

The basal area showed an increasing trend with elevation across the national park boundary (Fig. 5C). The highest value was observed inside NTNP at 2367 m. There was no relationship between stem density per hectare with elevation. Both inside and outside NTNP, stem density per hectare ranged from 375 to 4205 (Fig. 5D). The Lorenz curve showed that large trees contribute disproportionately more to the stand basal area. For example, among 17 plots inside NP, about 20% of the stems were responsible for > 80 % of the total basal area in 14 plots. However, among 7 plots outside NTNP, only 3 plots showed such trends (Fig. 6). Gini indices varied from 0.50 to 0.94 and Laurel oak, Hill evergreen, and Oak rhododendron forests had the largest *G* values while secondary forests comparably low *G* value (Fig. 7).

Relationships between DBH and height

The diameter-height relationship differed significantly between inside and outside NP ($p=0.0057$) with 95 % confidence interval (0.68 (0.66~0.71)) for outside and inside national park 0.64 (0.62~0.66) (Fig. 8).

3.1.3 Estimation of above ground biomass (AGB)

As shown in Fig. 9, AGB stocks increased with elevation, both inside and outside of NTNP. AGB inside NTNP ranged from 188.89 Mg ha^{-1} to 801.46 Mg ha^{-1}, exceeding 600 Mg ha^{-1}at two plots. At the low elevation range (< 1700 m ASL) outside the park, however, the AGB was low (23.96 to 324.55 Mg ha^{-1}) (Fig. 9). AGB was not correlated with elevation inside NTNP (r = 0.3, p = 0.25) and also in the lower elevation range outside NTNP (r = 0.47, p = 0.29) (Fig. 9). The majority of AGB was contributed by trees greater than 18 cm DBH inside and outside of NTNP (Fig. 10). Oak dominated and hill evergreen forests had the highest AGB, while secondary and pine forests exhibited substantially lower AGB compared to other forest types (Fig. 11).

3.2 Forest community composition

Overall, 1493 stems with DBH > 1 cm were recorded in 24 study plots. Among them, 1277 stems were identified to 118 species, 92 genera, and 48 families. However, 216 stems could not be identified at any taxonomic level. The identification rate varied from 23.9 % to 100 % at all levels among the study plots. The detailed information on taxonomic identification levels of species, genus, and family are presented in Table 2. Results of the NMDS analysis showed the sorting of community types along the elevation gradient within NTNP with substantial overlap among them (Fig. 12). Species composition differed between inside and outside of NTNP, as well as with elevation. The qualitative characteristics of each type of community are explained below.

Secondary forests

Secondary forests were found at lower elevations (less than 1200 m), and associated species were *Wendlandia tinctoria*, *Xylia xylocarpa*, *Millettia* species, *Dipterocarp* species, and *Tectona grandis* (Teak), and *Shorea* species.

Pine community

Pine communities were found between 1600 m and 2400 m as a separate group. It is dominated by *Pinus kesiya*, *Glochidion* species, and *Millettia* species, often including *Lyonia ovalifolia*, *Alnus nepalensis*, and *Lithocarpus xylocarpus*.

Hill evergreen community

In the elevation range between 1600 m and 2600 m, hill evergreen forests were found. The characteristic species were *Betula alnoides*, *Castanopsis* species, *Prunus cerasoides*, *Turpinia nepalensis*, *Taxus wallichiana* (Temperate conifer), *Schima wallichii*, and *Engelhardtia spicata* with the continued presence of Lauraceae species.

Laurel and oak forest

Laurel and oak species dominated forests were found from 1900 m to 2900 m. However, there was no clear-attitudinal distinction between hill evergreen and laurel and oak dominated forests because laurels such as *Neolitsea zeylenica*, *Litsea* spp., were associated in both forest communities.

Oak and rhododendron forest

Oak-rhododendron forests were found at higher elevations (greater than 2600 m). Although they were clearly distinguished from hill evergreen forests, they had some elements of laurel oak forests. *Quercus semecarpifolia*, *Rhododendron arboreum*, *Acer*, *Symplocos,* and *Viburnum* species were dominating up to the forest limit (approximately 3060 m).

Major canopy tree species greater than 50 cm DBH included *Quercus semecarpifolia*, *Taxus wallichiana, Symplocos species, Rhododendron arboreum, Cephalotaxus mannii, Lithocarpus xylocarpus, Pinus kesiya, Neolitsea zeylenica,* and *Macropanax dispermus*.

3.3 Relationships between forest characteristics and disturbance in and outside the national park

The NMDS analysis of community data resulted in a stress value of 0.121 and indicated that the most important factors explaining the community composition of the tropical montane forest included elevation, disturbance, above ground biomass, and mean basal area ($p \leq 0.05$ for all variables; Fig. 13). The NMDS axis 1 represents the gradient from low AGB and low BA at a lower elevation to greater AGB and high BA at a higher elevation (Fig. 13). The basal area was positioned similarly to the NMDS axis 1 as AGB. The disturbance had negative associations with elevation, as they were more prevalent at lower elevations, and it showed a significant association with the taxonomic composition of the plots.

4. Discussion

4.1 Changes in forest structure with elevation

The results are shown in Fig. 4A indicates that stem diameter distribution is in the reverse J shape, which is often considered to indicate a stable population structure and/or active juvenile recruitments in the community. Culmsee et al. (2010) in Indonesia and Gebeyehu et al. (2019) Ethiopia found a similar pattern at the community level. In this study, stem density outside NTNP was comparatively low than inside the park in the smallest diameter class (DBH < 5 cm). In contrast, the stem density in the middle size class (1-18 cm DBH) were higher outside NTNP. These show different regeneration dynamics in disturbed communities outside NTNP from protected forests inside.

Generally, canopy height decreases with elevation in most studies of Southeast Asian tropical montane forests (e.g. Aiba et al., 1999; Kitayama et al., 2002; Takyu et al., 2002; Culmsee et al., 2010). The current study did not find decrease of tree height with elevation outside the national park (elevation range from 510 to 1706 m). However, within the national park (elevation range from 1961 to 3049 m) such a montonic decrease could be found. I found a wide variety of tree height among different plots. The tallest trees were found around 2500 m, above which the maximum tree height gradually decreased beyond that elevation. It is possible due to the effects of cloud immersion at the highest altitudes. Although montane cloud forests may typically occur between 2000 to 3500 m on inland mountains, clouds and fogs can limit the amount of light received for the plants (Bubb et al., 2004; Bruijnzeel et al., 2011). As a result, photosynthetic rates and tree growth rates decline (Chi et al.s, 2015).

The results showed a positive relationship between basal area and elevation both inside and outside the park. The basal area was higher at high elevation areas (inside the park) than in low elevation areas (outside the park). Although there were many stems of small trees in NTNP, stand basal area was mostly determined by a small number of big trees. A similar phenomenon was reported by Tran, Osawa, and Nguyen (2011) in Vietnam and their study observed that old-growth forests exhibit much higher stand basal area than young-generated forests where the size of individuals is more homogeneous. Other studies in Asia and around the world also confirmed our findings (Aiba, 1999; Carpenter, 2005; Lovett et al., 2006; Culmsee et al., 2010). High tree diameters and basal areas at higher elevations may be related due to fewer human disturbances. High elevation areas fall inside the national park, and they were impacted less from human activities as a result of steep topography and protection. Our finding is further supported by the tree ring analysis by Thang et al. (2020) in the same study area, who confirmed that long-lived trees (*Rhododendron arboreum*) occurred in old-growth forests with the low level of major disturbances.

Although other studies reported that AGB declines with increasing elevation; Leuschner et al.,2007; Girardin et al., 2010; Miyamoto et al., 2018; Gebeyehu et al., 2019), this study found that AGB increased with increasing elevation. Findings from this study are in agreement with Alves et al. (2010) in Brazil and Chi et al. (2015) in Taiwan who reported that increases in AGB with elevations. Variations in AGB could be related to the heterogeneous distribution of large diameter classes (> 50 cm) in the study forests. Furthermore, the use of both stem height and tree diameter as predictors of AGB should have improved the predictive power of this study. Chave et al. (2005) and Girardin et al. (2010) confirm that the use of tree height as a predictor in estimating AGB in tropical montane forests should improve the accuracy of AGB estimates compared to the models that use only tree diameter. Interestingly, in this study, the oak-dominated forest exhibited higher values of AGB than other studied forests.

In the present study, past forest use by local people at lower elevation areas may partly explain the heterogeneity of AGB among sites because secondary forests below 1200 m ASL were apparently regenerating in areas where shifting cultivation had taken place (Fujikawa et al., 2012; Aung et al., 2015). During the field survey, we also found that lower-elevation forests located near the park's edges were more likely to have experienced selective logging. In contrast, access to the forests at higher elevation had been constrained by steep slopes and law enforcement by the park authorities. Greater number of stems smaller than 30 cm DBH and variations in AGB in the lower elevation sites may reflect that there were differences in past human disturbance and recovery rates. Chan & Takeda (2016) demonstrated that there were variations in the abandonment of slash and burn agriculture practices and they found that above ground biomass accumulation generally increased with fallow ages (varied from 4.24 to 38.65 Mg/ha) in the southern Chin Hills of Myanmar. This study also confirmed a small amount of AGB in the secondary forests at a lower elevation of the study area.

However, stumps could also be found around the edges and even inside the national park (until 2224 m) during our field survey. The collection of fuelwoods may be locally significant pressure on the forests in the study area. Local people have few alternative energy

sources for local household consumption. Makino et al. (2013) indicated that people are cutting for fuelwood even inside the national park. These findings call for effective conservation so that forests in high elevations not to be under threats in the future.

4.2 Changes in species assemblages with altitudes

Forest communities found in this study can be generally grouped into five categories as secondary, pine, laurel and oak, hill evergreen, and oak and *rhohodendron* communities. The characteristic species of each forest category found in this study are in agreement with other regional studies in Asia. *Pinus kesiya* forests were found in tropical dry sunny fire-prone slopes at altitudes of lower montane forests (Ashton & Zhu, 2020). The upper montane forest is dominated by *Eurya*, *Symplocos*, *Myrsine*, whereas the lower montane forests were characterized by the presence of Lauraceae and Fagaceae species. The greatest diversity of *Rhododendron* species is found from the mountainous regions of southern Himalayas to south-western China (Shrestha et al., 2018). Tropical upper montane forests are replaced by high altitudinal oak forests dominated by *Quercus semecarpifolia* approximately at 2300-3000m (Ohsawa, 1993).

4.3 Relationships between forest structure, composition, and environmental factors

According to the results of the NMDS analysis, the associations between forest characteristics and environmental factors indicate that community assemblages (pine communities, hill evergreen, and oak rhododendron) shift from one community to another while laurel and oak forests were sharing species at similar elevations. The disturbance was a major factor at a lower elevation as forests at low elevations were recovering from shifting cultivation and other human disturbance as discussed earlier. AGB stocks were positively correlated with hill evergreen communities where the bigger trees are abundant and increased with an altitudinal gradient.

4.4 Limitations of this study

Although forest structure and associated altitudinal trends were influenced by soil types and soil properties (Fisher et al., 2013), soil data were not included in this study. Furthermore, the author knew very little about the history and impact of local disturbance regimes for each of the sample plots. Further studies with complete sets of environmental factors are desirable to achieve a more comprehensive understanding. Chave et al. (2005) suggested that forest type-dependent models should be used in tropical forest studies because the situation of tropical forest is more complex than the temperate forests where single species regression models can be applied. Additionally, investigations on seed dispersal capacity may also advance the knowledge of vegetation distribution and species range dynamics.

5. Conclusion

This study is the first attempt to provide information on forest structures and their relationships with AGB distributions along the elevational gradient in a tropical montane forest of Myanmar. Past human disturbances, forest structures, composition, and live AGB changed with elevation. The results also confirmed that the establishment of the protected area helps in conserving forest structures (DBH, basal area, height, AGB). Findings from this study suggest that the tropical montane forests store large amount of live biomass if they are well-preserved. In addition, tropical montane elevational transect can provide front-line observations necessary for monitoring the pace of forest responses to climate change and for designing appropriate adaptation options.

6. Acknowledgment

First of all, I would like to express my very great appreciation to my supervisors, Dr. Kaoru Kitajima, Dr. Yusuke Onoda, and Dr. Mamoru Kanzaki, Division of Forest and Biomaterials Science, for their supervision, guidance, and kind support during my study period in Kyoto University, Japan. In addition, my special thanks are extended to Mrs. Masayo Makijima and all the laboratory members for their kind assistance during my two-year-study in the laboratory of Tropical Forest Resources and Environments, Graduate School of Agriculture, Kyoto University

My sincere thanks go Dr. Nyi Nyi Kyaw, Director General of Forest Department, Ministry of Natural Resources and Environmental Conservation, Myanmar, for granting to conduct this study in Natma Taung National Park (NTNP) and the warmest thanks go to all the staffs from NTNP. I would like to offer my special thanks to U Tin Mya Soe, Ma Ling Shein Man, U Law Shein, and U Naing Linn Oo and those who participated in my fieldwork. I also extend my deep appreciation to local people in Chin State who helped us during our stay.

My deep gratitude is extended to Dr. Myat Su Mon, Deputy Director, Remote Sensing, and Geographic Information System (RS&GIS) Section, Forest Department for her valuable suggestions and kind assistance during my study period in Kyoto University. I also appreciate advice from Dr. Kazumi Fujikawa of the Makino Botanical Garden and Dr. Mu Mu Aung (Forest Research Institute) for their valuable advice toward my botanical survey.

This work would not have been possible without the financial supports of the Asian Development Bank -Japan Scholarship, for which I am very grateful.

Finally, I would like to express my heartfelt gratitude to my parents for their patience, support, and encouragement throughout my study. Without their support, this work never would have been accomplished.

7. References

Aiba, S.-I. (1999). Tree Communities on Mount Kinabalu, Borneo Structure, matrix tree communities in an altitude-substrate. *Plant Ecology*, *140*(2), 139–157.

Aiba, S. I., Kitayama, K., & Takyu, M. (2004). Habitat associations with topography and canopy structure of tree species in a tropical montane forest on Mount Kinabalu, Borneo. Plant Ecology, 174(1), 147-161.

Alves, L. F., Vieira, S. A., Scaranello, M. A., Camargo, P. B., Santos, F. A. M., Joly, C. A., & Martinelli, L. A. (2010). Forest structure and live aboveground biomass variation along an elevational gradient of tropical Atlantic moist forest (Brazil). *Forest Ecology and Management*, *260*(5), 679–691. https://doi.org/10.1016/j.foreco.2010.05.023

Anderson, J., Keppel, G., Thomson, S. M., Randell, A., Raituva, J., Koroi, I., … Kleindorfer, S. (2018). Changes in climate and vegetation with altitude on Mount Batilamu, Viti Levu, Fiji. *Journal of Tropical Ecology*, *34*(5), 316–325. https://doi.org/10.1017/S0266467418000299

Angiosperm Phylogeny Group. (2009). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society, 161(2), 105-121.

Ashton, P., & Zhu, H. (2020). The tropical-subtropical evergreen forest transition in East Asia: An exploration. *Plant Diversity*, (xxxx). https://doi.org/10.1016/j.pld.2020.04.001

Aung, P. S., Adam, Y. O., Pretzsch, J., & Peters, R. (2015). Distribution of forest income among rural households: A case study from Natma Taung national park, Myanmar. *Forests Trees and Livelihoods*, *24*(3), 190–201. https://doi.org/10.1080/14728028.2014.976597

Austin, M. P. (1980). Searching for a model for use in vegetation analysis. *Vegetatio*, *42*(1–3), 11–21. https://doi.org/10.1007/BF00048865

Becker, A., Körner, C., Brun, J. J., Guisan, A., & Tappeiner, U. (2007). Ecological and land use studies along elevational gradients. *Mountain Research and Development*, *27*(1), 58–65. https://doi.org/10.1659/0276-4741(2007)27[58:EALUSA]2.0.CO;2

Bruijnzeel, L. A., Mulligan, M., & Scatena, F. N. (2011). Hydrometeorology of tropical montane cloud forests: Emerging patterns. *Hydrological Processes*, 25. https://doi.org/ 10.1002/ hyp. 7974

Bubb, P., Ian, M., Lera, M., & Jeff, S. (2004). Cloud Forest Agenda. In *UNEP World Conservation Monitoring Centre*.

Carpenter, C. (2005). The environmental control of plant species density on a Himalayan elevation gradient. Journal of Biogeography, 32(6), 999-1018.

Chan, N., & Takeda, S. (2016). The Transition Away From Swidden Agriculture and Trends in Biomass Accumulation in Fallow Forests: Case Studies in the Southern Chin Hills of Myanmar. *Mountain Research and Development*, *36*(3), 320–331. https://doi.org/10.1659/ mrd-journal-d-14-00083.1

Chase, M. W., Christenhusz, M. J. M., Fay, M. F., Byng, J. W., Judd, W. S., Soltis, D. E., … Weber, A. (2016). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Botanical Journal of the Linnean Society*, *181*(1), 1–20. https://doi.org/10.1111/boj.12385

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., … Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*(1), 87–99. https://doi.org/10.1007/s00442-005-0100-x

Chave, Jerome, Coomes, D., Jansen, S., Lewis, S. L., Swenson, N. G., & Zanne, A. E. (2009). Towards a worldwide wood economics spectrum. *Ecology Letters*, *12*(4), 351–366. https://doi.org/10.1111/j.1461-0248.2009.01285.x

Chi, C. H., McEwan, R. W., Chang, C. Te, Zheng, C., Yang, Z., Chiang, J. M., & Lin, T. C. (2015). Typhoon disturbance mediates elevational patterns of forest structure, but not species diversity, in Humid Monsoon Asia. *Ecosystems*, *18*(8), 1410–1423. https://doi.org/10.1007 /s10021-015-9908-3

Culmsee, H., Leuschner, C., Moser, G., & Pitopang, R. (2010). Forest aboveground biomass along an elevational transect in Sulawesi, Indonesia, and the role of Fagaceae in tropical montane rain forests. *Journal of Biogeography*, *37*(5), 960–974. https://doi.org/10.1111/j.1365-2699.2009.02269.x

Damgaard, C., & Weiner, J. (2000). Describing inequality in plant size or fecundity. *Ecology*, *81*(4), 1139–1142. https://doi.org/10.1890/0012-9658(2000)081[1139:DIIPSO]2.0.CO;2

Dao, T. H. H., Saborowski, J., & Hölscher, D. (2016). Patterns of tree community differences in the core and buffer zones of a nature reserve in north-western Vietnam. *Global Ecology and Conservation*, *8*, 220–229. https://doi.org/10.1016/j.gecco.2016.09.011

Ding, H. B., Yang, B., Zhou, S. S., Maw, M. B., Maung, K. W., & Tan, Y. H. (2019). New contributions to the flora of Myanmar Ⅰ. Plant diversity, 41(3), 135-152.

Fisher, J. B., Malhi, Y., Torres, I. C., Metcalfe, D. B., van de Weg, M. J., Meir, P., … Huasco, W. H. (2013). Nutrient limitation in rainforests and cloud forests along a 3,000-m

elevation gradient in the Peruvian Andes. *Oecologia*, *172*(3), 889–902. https://doi.org/10.1007/s00442-012-2522-6

Forest Department. (2017). Natmataung (Khaw Num Cung) National Park Management Plan (2018-2019 to 2022-2023).

Fujikawa, K., Motohiro, H., Nobuko, Y., IKEDA, H., Srisanga, P., & Soe, T. M. (2012). Botanical expedition to Natma Taung (Mt. Victoria) National Park, Chin State, west-central Myanmar in 2012. *Newsletter of Himalayan Botany*, *46*(46), 1–12. Retrieved from http://www.qsbg. org/Database/Article/Art_Files/himalayan_botany.pdf

Fujikawa, K., Srisanga, S., Watthana, S., Soe, T. M., Ling, S. M., Law, S., & Ngai, S. G. (2015). 100 Wild Flowers Of Natma Taung: Natma Taung National Park, Chin State, Myanmar. *The Kochi Prefecture Makino Botanical Garden, Kochi* (p. 76 pp). p. 76 pp.

Gebeyehu, G., Soromessa, T., Bekele, T., & Teketay, D. (2019). Species composition, stand structure, and regeneration status of tree species in dry Afromontane forests of Awi Zone, northwestern Ethiopia. *Ecosystem Health and Sustainability*, *5*(1), 199–215. https://doi.org/ 10.1080/20964129.2019.1664938

Girardin, C. A. J., Malhi, Y., Aragão, L. E. O. C., Mamani, M., Huaraca Huasco, W., Durand, L., … Whittaker, R. J. (2010). Net primary productivity allocation and cycling of carbon along a tropical forest elevational transect in the Peruvian Andes. *Global Change Biology*, *16*(12), 3176–3192. https://doi.org/10.1111/j.1365-2486.2010.02235.x

Halbritter, A. H., Alexander, J. M., Edwards, P. J., & Billeter, R. (2013). How comparable are species distributions along elevational and latitudinal climate gradients? *Global Ecology and Biogeography*, *22*(11), 1228–1237. https://doi.org/10.1111/geb.12066

Hernández, L., Dezzeo, N., Sanoja, E., Salazar, L., & Castellanos, H. (2012). Changes in structure and composition of evergreen forests on an altitudinal gradient in the Venezuelan Guayana Shield. Revista de Biología Tropical, 60(1), 11-33.

Hertel, D., Leuschner, C., & Hölscher, D. (2003). Size and structure of fine root systems in old-growth and secondary Tropical Montane Forests (Costa Rica). *Biotropica*, *35*(2), 143–153. https://doi.org/10.1111/j.1744-7429.2003.tb00274.x

Homeier, J., Breckle, S. W., Günter, S., Rollenbeck, R. T., & Leuschner, C. (2010). Tree diversity, forest structure and productivity along altitudinal and topographical gradients in a species-rich Ecuadorian montane rain forest. *Biotropica*, *42*(2), 140–148. https://doi.org/10.1111/ j.1744-7429.2009.00547.x

Istituto Oikos & BANCA. (2011). Myanmar Protected Areas; Context, Current Status and Challenges.

Jin, X. M., Zhang, Y.-K., Schaepman, M. E., Clevers, J. G. P. W., & Su, Z. (2008). Impact of elevation and aspect on the spatial distribution of vegetation in the Qilian Mountain area with remote sensing data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *37*, 1385–1390.

Kine, P. K. (2018). Biogeographical transect studies in the high elevation mountain areas of Myanmar. Philipps-Universität Marburg.

Kitayama, K., & Aiba, S. I. (2002). Ecosystem structure and productivity of tropical rain forests along altitudinal gradients with contrasting soil phosphorus pools on Mount Kinabalu, Borneo. *Journal of Ecology*, *90*(1), 37–51. https://doi.org/10.1046/j.0022-0477.2001.00634.x

Kress, W. J., DeFilipps, R. A., Farr, E., & Kyi, D. Y. Y. (2003). A checklist of the trees, shrubs, herbs, and climbers of Myanmar. A checklist of the trees, shrubs, herbs, and climbers of Myanmar.

Leuschner, C., Moser, G., Bertsch, C., Röderstein, M., & Hertel, D. (2007). Large altitudinal increase in tree root/shoot ratio in tropical mountain forests of Ecuador. *Basic and Applied Ecology*, *8*(3), 219–230. https://doi.org/10.1016/j.baae.2006.02.004

Lovett, J. C., Marshall, A. R., & Carr, J. (2006). Changes in tropical forest vegetation along an altitudinal gradient in the Udzungwa Mountains National Park, Tanzania. African Journal of Ecology, 44(4), 478-490.

Makino, M. F., & JICA. (2013). Education and training of Myanmar personnel for the realization of phyto-diversity conservation and sustainable use of plant resources to improve economy of the rural population. https://doi.org/10.16309/j.cnki.issn.1007-1776.2003.03.004

Miyamoto, K., Sato, T., Alexs, E., Olivos, A., Orellana, G. C., Marcel, C., & Stornaiuolo, R. (2018). Variation in tree community composition and carbon stock under natural and human disturbances in Andean Forests , Peru. 1–15. https://doi.org/10.3390 /f9070390

Mokarram, M., & Sathyamoorthy, D. (2015). Modeling the relationship between elevation, aspect and spatial distribution of vegetation in the Darab Mountain, Iran using remote sensing data. *Modeling Earth Systems and Environment*, *1*(4), 1–6. https://doi.org/10.1007/s40808-015-0038-x

Myat, A. M. (2016). Vegetation Analysis of Semi-Evergreen Montane Forest in Natma Taung National Park (Mt. Victoria), Chin State, Myanmar. Master thesis. George-August University of Goettingen.

Ohsawa, M. (1993). Latitudinal pattern of mountain vegetation zonation in southern and

eastern Asia. *Journal of Vegetation Science*, *4*(1), 13–18. https://doi.org/10.2307/ 3235728

Pandey, A., Rai, S., & Kumar, D. (2018). Changes in vegetation attributes along an elevation gradient towards timberline in Khangchendzonga national park, Sikkim. *Tropical Ecology*, *59*(2), 259–271.

Paudel, P., & Mandal, R. (2019). Comparing growing stock using circular, square and rectangular plots shape in inventory (A study from community forests in Chitwan District, Nepal). *Canadian Journal of Soil Science*, *4*(November), 448–454. https://doi.org/10.32474/ OAJESS.2019.04.000177

Phyu Lwin, P., & Kanzaki, M. (2017). Species composition, diversity, and stand structure of tropical lower montane forests resulting from various human impacts on the Shan Plateau, eastern Myanmar. *Tropics*, *26*(3), 71–82. https://doi.org/10.3759/ tropics.ms17-03

Poorter, L., van der Sande, M. T., Thompson, J., Arets, E. J. M. M., Alarcón, A., Álvarez-Sánchez, J., … Peña-Claros, M. (2015). Diversity enhances carbon storage in tropical forests. *Global Ecology and Biogeography*, *24*(11), 1314–1328. https://doi.org/10.1111/geb.12364

R Core Team. (2016). R: A Language and Environment for Statistical Computing. Vienna, Austria. Retrieved from https://www.R-project.org/

Sang, W. (2009). Plant diversity patterns and their relationships with soil and climatic factors along an altitudinal gradient in the middle Tianshan Mountain area, Xinjiang, China. *Ecological Research*, *24*(2), 303–314. https://doi.org/10.1007/s11284-008-0507-z

Sein, M. M. Z., Ogwang, B. A., Ongoma, V., Ogou, F. K., & Batebana, K. (2015). Inter-annual variability of summer monsoon rainfall over Myanmar in relation to IOD and ENSO. *Journal of Environmental and Agricultural Sciences*, *4*(February 2018), 2313–8629. Retrieved from http://www.researchgate.net/publication/278465029

Shrestha, N., Wang, Z., Su, X., Xu, X., Lyu, L., Liu, Y., … Feng, X. (2018). Global patterns of Rhododendron diversity: The role of evolutionary time and diversification rates. *Global Ecology and Biogeography*, *27*(8), 913–924. https://doi.org/10.1111/geb.12750

Sinha, S., Badola, H. K., Chhetri, B., Gaira, K. S., Lepcha, J., & Dhyani, P. P. (2018). Effect of altitude and climate in shaping the forest compositions of Singalila National Park in Khangchendzonga Landscape, Eastern Himalaya, India. Journal of Asia-Pacific Biodiversity, 11(2), 267-275.

Spracklen, D. V., & Righelato, R. (2014). Tropical montane forests are a larger than expected

global carbon store. *Biogeosciences*, *11*(10), 2741–2754. https://doi.org/10.5194/bg-11-2741-2014

Staudhammer, C. L., & LeMay, V. M. (2001). Introduction and evaluation of possible indices of stand structural diversity. *Canadian Journal of Forest Research*, *31*(7), 1105–1115. https://doi.org/10.1139/cjfr-31-7-1105

Takyu, M., Aiba, S.-I., & Kitayama, K. (2002). Effects of topography on tropical lower montane on Mount Kinabulu, Borneo. *Plant Ecology*, *159*(1), 35–49. https://doi.org/10.1023/ A:1015512400074

Tanaka, N. (2005). Plant Inventory Research : Contributions to the Flora of Myanmar. *APG : Acta Phytotaxonomica et Geobotanica*, *56*(1), 21–26. https://doi.org/ 10.18942/ apg.KJ0000462 2909

Thang, T. H., Thu, A. M., & Chen, J. (2020). Tree species of tropical and temperate lineages in a tropical Asian montane forest show different range dynamics in response to climate change. *Global Ecology and Conservation*, *22*, e00973. https://doi.org/10.1016/j.gecco.2020.e00973

Tran, D. Van, Osawa, A., & Nguyen, T. T. (2011). Recovery of vegetation structure and species diversity after shifting cultivation in Northwestern Vietnam, with special reference to commercially valuable tree species. *ISRN Ecology*, *2011*, 1–12. https://doi.org/10.5402/ 2011/751472

Valbuena, R., Packalén, P., Martı, S., & Maltamo, M. (2012). Diversity and equitability ordering profiles applied to study forest structure. Forest Ecology and Management, 276, 185-195.

Wade, C. M., Austin, K. G., Cajka, J., Lapidus, D., Everett, K. H., Galperin, D., … Sobel, A. (2020). What is threatening forests in protected areas? A global assessment of deforestation in protected areas, 2001-2018. *Forests*, 11(5). https://doi.org/10.3390/F11050539

Wang, J., Ye, B., Liu, F., Li, J., & Yang, G. (2011). Variations of NDVI over elevational zones during the past two decades and climatic controls in the qilian mountains, Northwestern China. *Arctic, Antarctic, and Alpine Research*, *43*(1), 127–136. https://doi.org/10.1657/1938-4246-43.1.127

Weiner, J., & Solbrig, O. T. (1984). The meaning and measurement of size hierarchies in plant populations. *Oecologia*, *61*(3), 334–336. https://doi.org/10.1007/BF00379630

8. Appendix

Table 1. List of the 24 study plots in Natma Taung National Park in western Myanmar

Inside or outside of the park boundary	Pre-classified forest type	Plot ID	Latitude (°N)	Longitude (°E)	Elevation (m ASL)	Slope aspect	Total no. of stems (ha^{-1})	Basal area (m^2 ha^{-1})	Maximum DBH (cm)	Maximum tree height (m)	Total AGB (Mg ha^{-1})
Inside	Oak rhododendron	P18	21.2338	93.9046	3049	E	2390	75.18	90.8	20.4	395.68
Inside	Laurel oak	P16	21.2294	93.9103	2959	E	2175	84.28	106	19.2	441.63
Inside	Oak rhododendron	P17	21.2198	93.9352	2784	SE	1440	53.58	92.8	14.9	269.44
Inside	Oak rhododendron	P19	21.2242	93.9555	2723	SE	3575	40.59	74.4	24.6	240.04
Inside	Oak rhododendron	P06	21.2212	93.9559	2635	SE	1460	57.19	115.1	22.3	390.55
Inside	Pine	P22	21.2403	93.9367	2631	E	375	29.74	78.9	23	141.20
Inside	Hill evergreen	P04	21.2219	93.9751	2456	NE	4205	45.91	101.5	29.2	386.15
Inside	Laurel oak	P10	21.2503	93.9441	2451	NW	2935	61.91	99	40.3	616.74
Inside	Hill evergreen	P05	21.2117	93.9946	2416	SE	1220	55.99	98	29.2	346.71
Inside	Hill evergreen	P11	21.2504	93.9405	2367	SW	1900	90.36	173.6	40	801.46
Inside	Oak rhododendron	P02	21.2121	94.0157	2350	SE	540	31.14	65.61	34.9	197.41
Inside	Laurel oak	P01	21.2122	94.0165	2334	NE	4120	53.51	118.47	31.2	336.84
Inside	Hill evergreen	P09	21.2890	93.9505	2224	W	1165	25.39	58.7	25.3	178.33
Inside	Hill evergreen	P08	21.2967	93.9548	2186	NW	575	23.87	63.7	38.5	151.98
Inside	Hill evergreen	P07	21.2991	93.9493	2137	W	3280	45.73	135.7	20.3	224.19
Inside	Pine	P03	21.2068	94.0268	2070	E	2595	25.44	57.36	26.9	118.89
Inside	Laurel oak	P13	21.3187	93.9553	1961	NE	1965	34.93	115	22.2	199.75
Outside	Laurel oak	P14	21.3283	93.9509	1706	N	1605	29.14	55.8	18.3	124.91
Outside	Pine	P20	21.3325	93.9506	1594	NW	3135	29.27	73.2	20	129.29
Outside	Hill evergreen	P15	21.3286	93.9372	1396	W	2390	36.82	93.3	38.4	324.55
Outside	Secondary	P12	21.34686	93.94502	1176	N	3545	18.47	24.3	19.8	65.50
Outside	Secondary	P24	21.1744	94.10069	913	SE	1915	13.12	35	18.6	55.15
Outside	Secondary	P21	21.3571	93.9386	816	SE	2280	9.11	23.4	11.3	23.96
Outside	Secondary	P23	21.1589	94.1159	510	W	475	15.42	47.3	19.7	91.21

Table 2. Number of tree taxa identified at species, genus and family levels in each plot. For the number of species, the number of identified species is shown with the number of additional morpho species distinguished in the parenthesis. Each plot consists of three circles in which individuals with DBH 1-5cm were identified in small circle (0.01ha), DBH 5-18 cm were identified in medium circle (0.04ha) and DBH >18 cm was identified in largest circle (0.1ha).

Location	Plot	Elevation (m ASL)	Number of stems	No. of species	No. of genus	No. of family	% of stems identified at species level	% of stems identified at genus level	% of stems identified at family level
Inside	P01	2334	88	12 (6)	12	11	76.1	93.2	93.2
Inside	P02	2350	42	6 (0)	6	4	100.0	100.0	100.0
Inside	P03	2070	66	5 (3)	6	6	89.4	97.0	97.0
Inside	P04	2456	74	10 (4)	11	9	93.2	94.6	94.6
Inside	P05	2416	62	16 (4)	18	15	83.9	95.2	96.8
Inside	P06	2635	47	9 (4)	9	7	100.0	100.0	100.0
Inside	P07	2137	88	8 (26)	9	7	40.9	54.5	55.7
Inside	P08	2186	32	9 (12)	13	10	50.0	78.1	78.1
Inside	P09	2224	43	8 (11)	9	7	67.4	74.4	76.7
Inside	P10	2451	70	17 (5)	16	14	90.0	95.7	97.1
Inside	P11	2367	64	6 (10)	9	7	48.4	82.8	89.1
Outside	P12	1176	92	7 (23)	7	7	23.9	23.9	23.9
Inside	P13	1961	60	3 (9)	7	5	25.0	91.7	91.7
Outside	P14	1706	54	7 (8)	9	8	81.5	88.9	92.6
Outside	P15	1396	65	9 (21)	14	11	35.4	70.8	78.5
Inside	P16	2959	90	6 (4)	7	6	66.7	97.8	97.8
Inside	P17	2784	39	9 (2)	11	8	79.5	100.0	100.0
Inside	P18	3049	89	5 (3)	6	5	84.3	97.8	97.8
Inside	P19	2723	68	9 (3)	11	10	80.9	97.1	97.1
Outside	P20	1594	69	9 (2)	10	8	84.1	98.6	98.6
Outside	P21	816	66	11 (18)	13	10	37.9	51.5	51.5
Inside	P22	2631	30	3(0)	3	3	100.0	100.0	100.0
Outside	P23	510	34	11 (6)	13	9	73.5	82.4	91.2
Outside	P24	913	61	6 (2)	7	6	73.8	98.4	98.4

Table 3. Correlation of NMDS axis with environmental variables of the study plots. Variables are also indicated as vector arrows in the NMDS plot shown in Figure 12. Disturbance was coded 1 for with sign of disturbance, 0 for no sign of disturbance.

Variables	NMDS1	NMDS2	r^2	p value
Altitude	0.915	0.404	0.898	0.001
Disturbance	-0.776	-0.630	0.596	0.002
AGB	0.315	0.949	0.761	0.001
BA	0.541	0.841	0.773	0.001

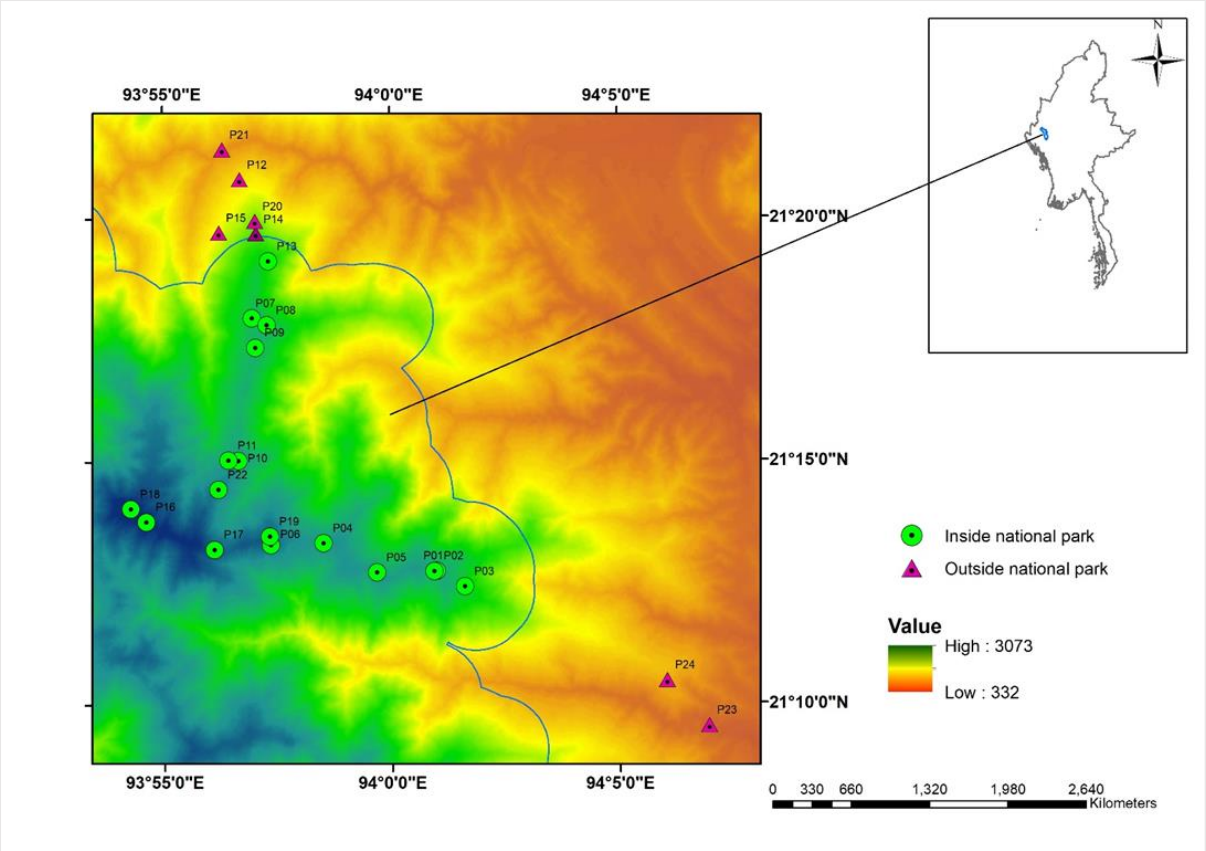


Figure 1. Location Natma Taung National Park (NTNP) in Myanmar (upper right) and the digital elevation map of the map grid including the 24 study plots (elevation ranging from 332 to 3073 m ASL). Green circles indicate plots inside NTNP and purple triangles are plots outside NTNP. Boundary of the national park is shown by thin green lines.

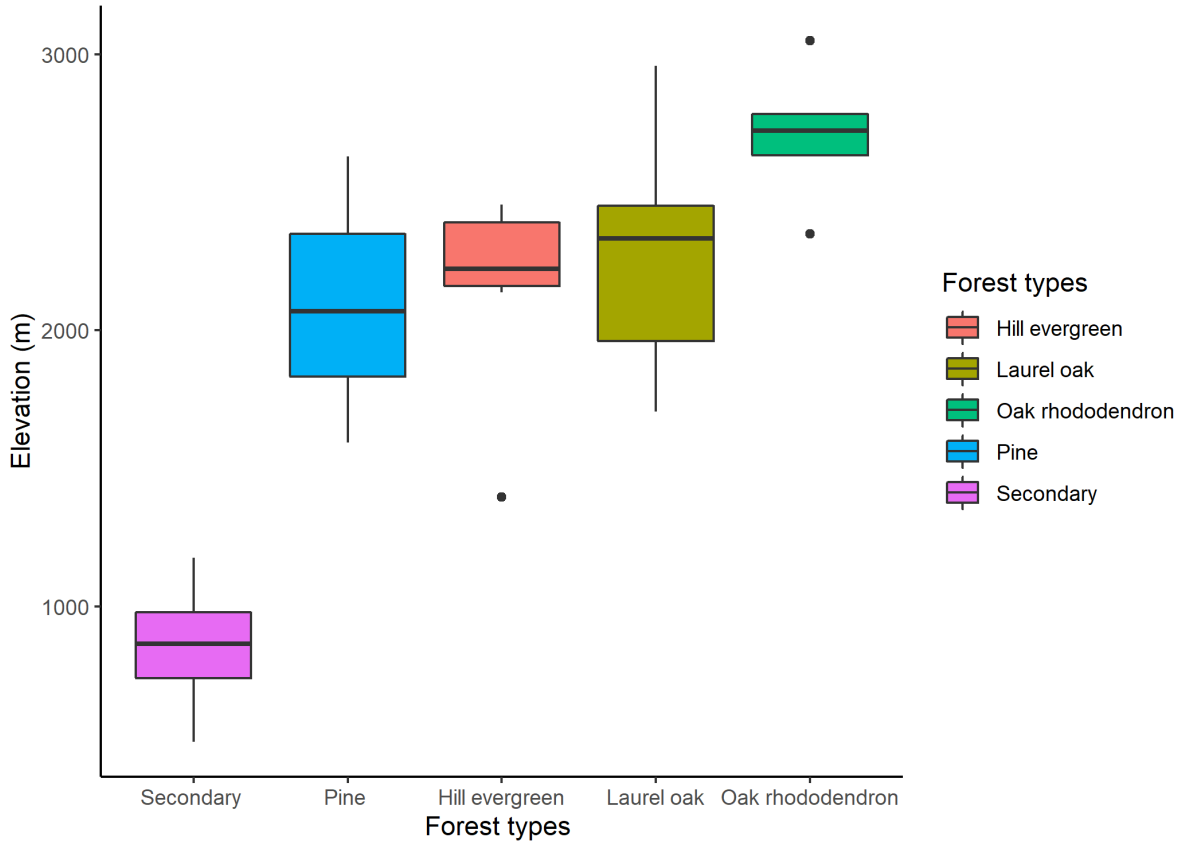
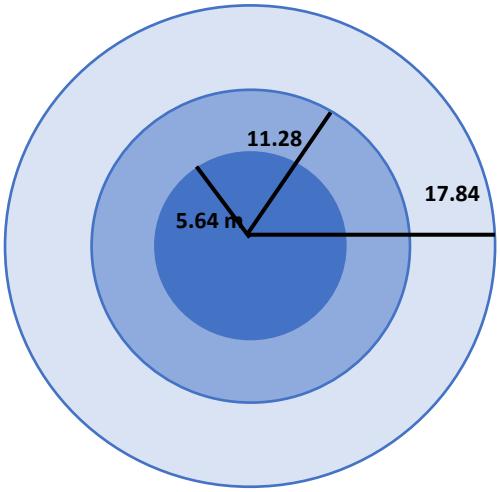


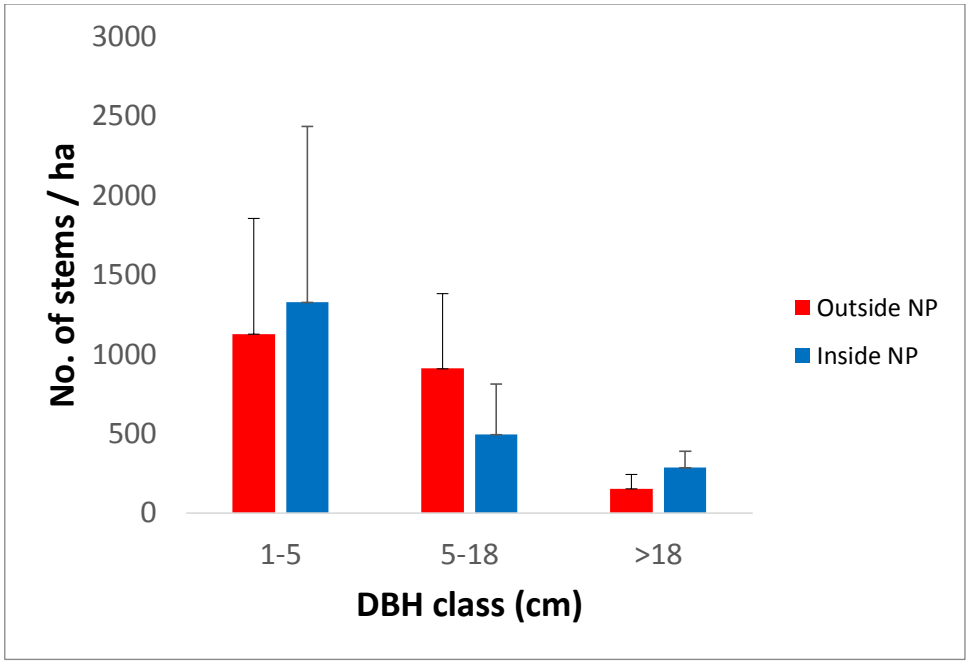
Figure 2. Box plot showing the elevation distribution of study plots classified to different vegetation types (4 in Secondary, 3 in Pine, 7 in Hill evergreen, 5 in Laurel oak and 5 in Oak rhododendron forests).



Radius (m)	Area (m^2)	Trees
5.64	100	DBH ≥ 1 cm
11.28	400	DBH ≥ 5 cm
17.84	1000	DBH ≥ 18 cm

Figure 3. Concentric plot design for the tree survey. Trees greater than 1 cm DBH were measured in the innermost circle, those with DBH ≥ 5 cm were measured in the middle, and those with DBH ≥ 18 cm were measured in the largest circle, as summarized in the table.

(A)



(B)

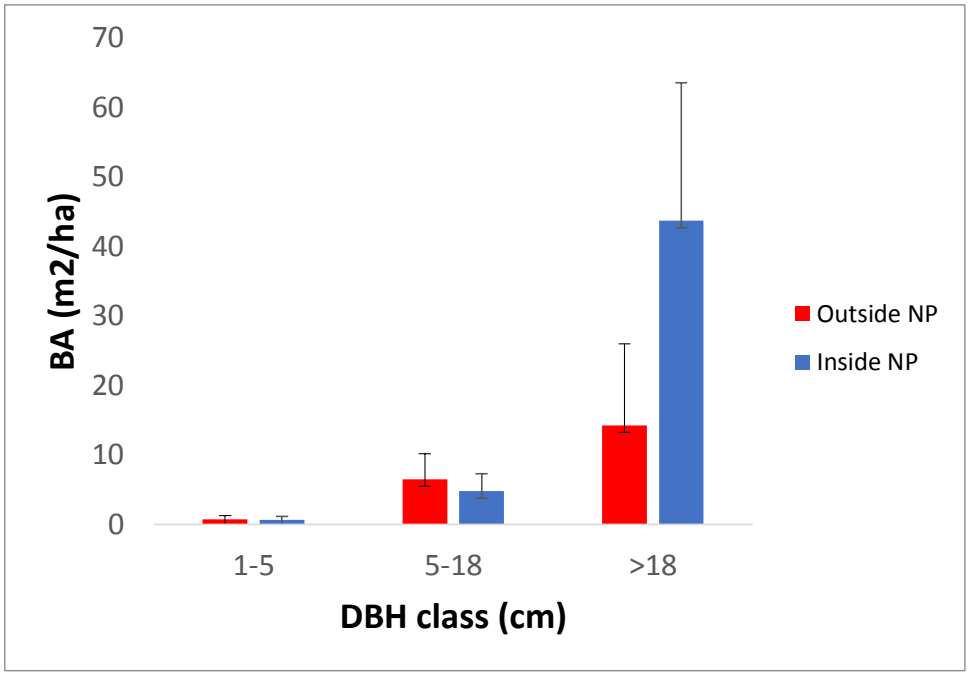


Figure 4. (A) Mean number of stems per ha, and (B) mean basal area for plots inside vs. outside of the NTNP at different diameter classes (cm)

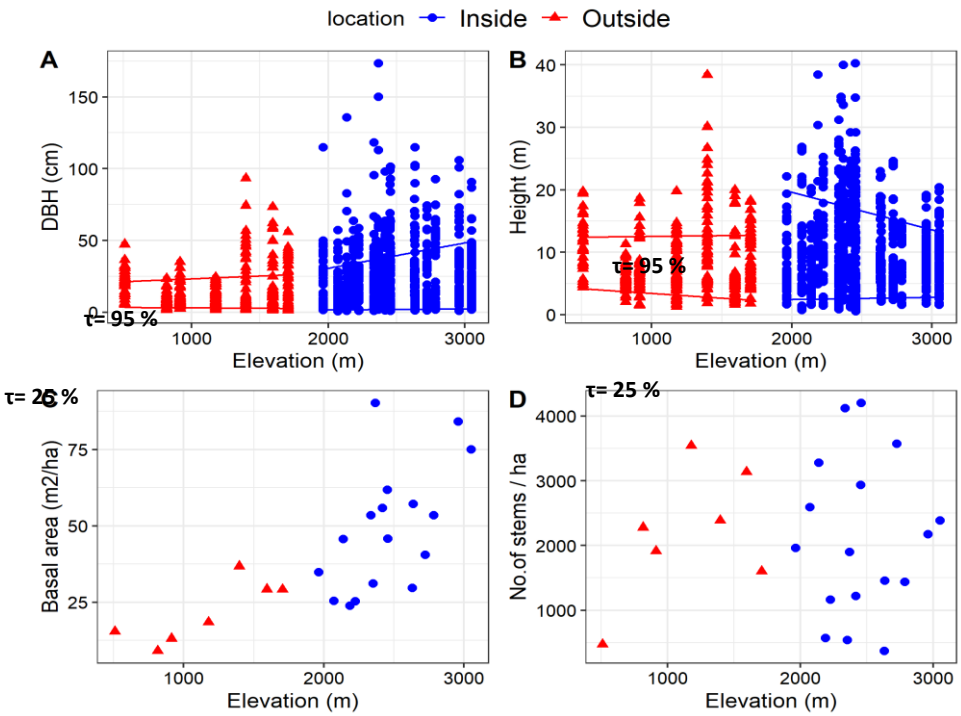


Figure 5. Relationship of forest structure variables per site were plotted against elevation (m). Red triangles are plots outside the national park and blue circles are inside national park. (A) Diameter at breast height (cm) with 25 % lower and 95 % upper quantile regression lines; (B) Tree height (m) with 25 % and 95 % quantile regression lines; (C) Basal area (m^2/ha); (D) Number of stems per ha.

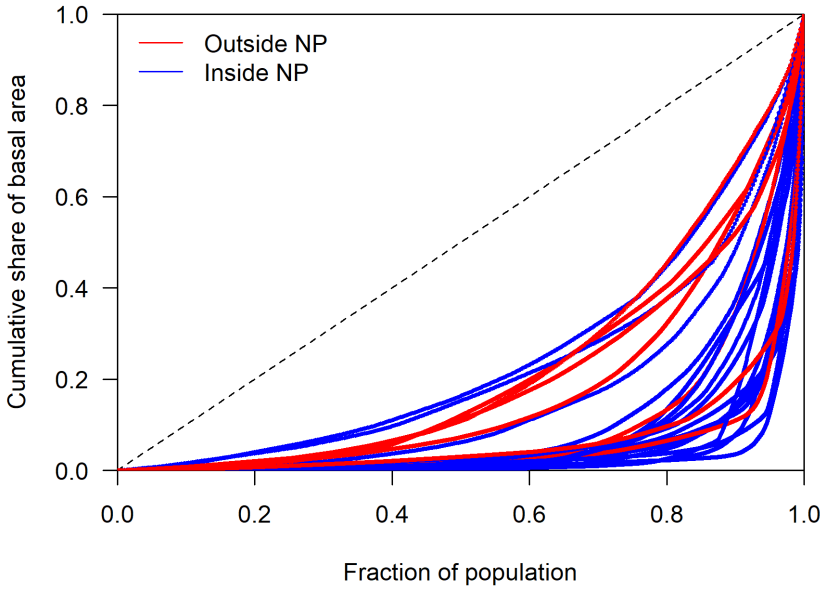


Figure 6. Cumulative basal area (in relative value) from small to large trees for each plot (Lorenz curve), which was used to calculate Gini coefficient. The proportion of the area between each curve and the line of equality (dashed line) is the Gini coefficient. Red solid lines are plots outside the national park (7 plots) and blue solid lines (17 plots) are inside national park. The horizontal axis is the cumulative percentage of individuals, summed from the smallest to the largest.

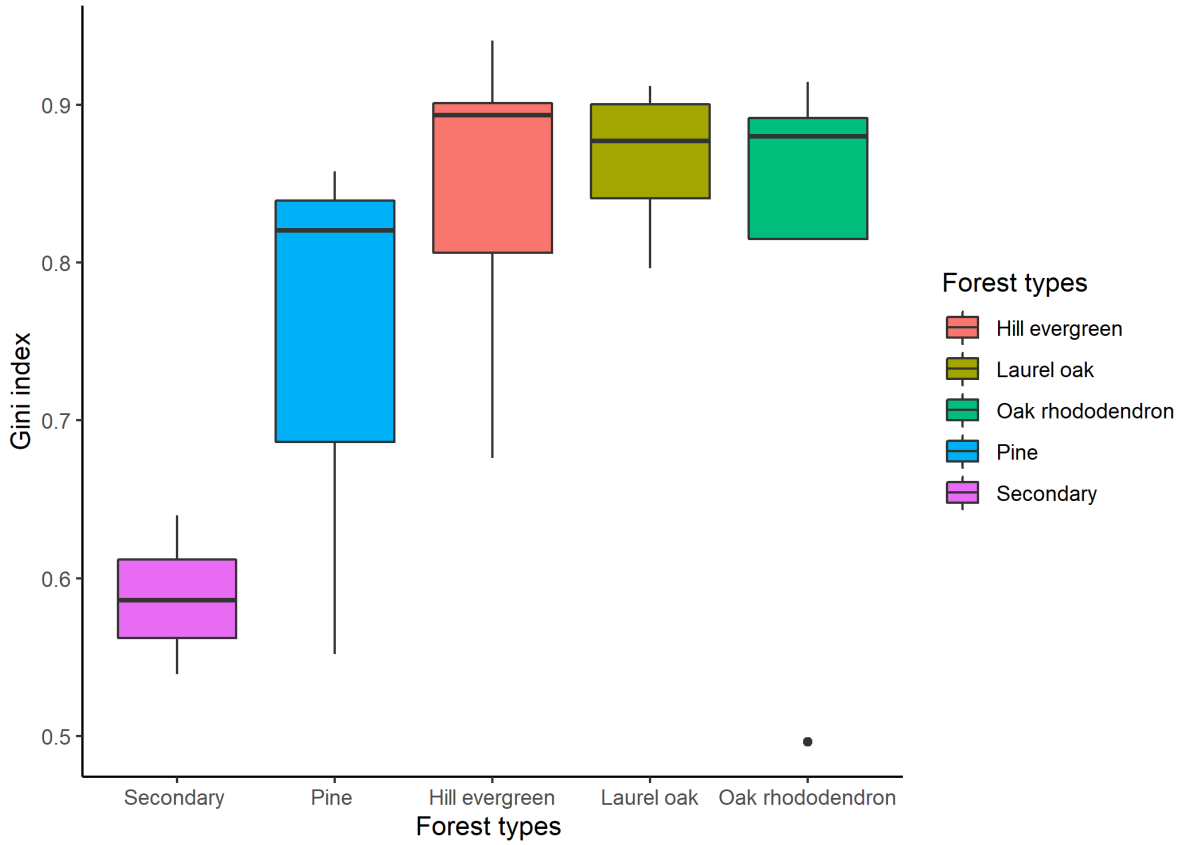


Figure 7. Distribution of study plots in different vegetation types and their Gini index range. For the number of plots in each vegetation type, see the legend for Figure 2.

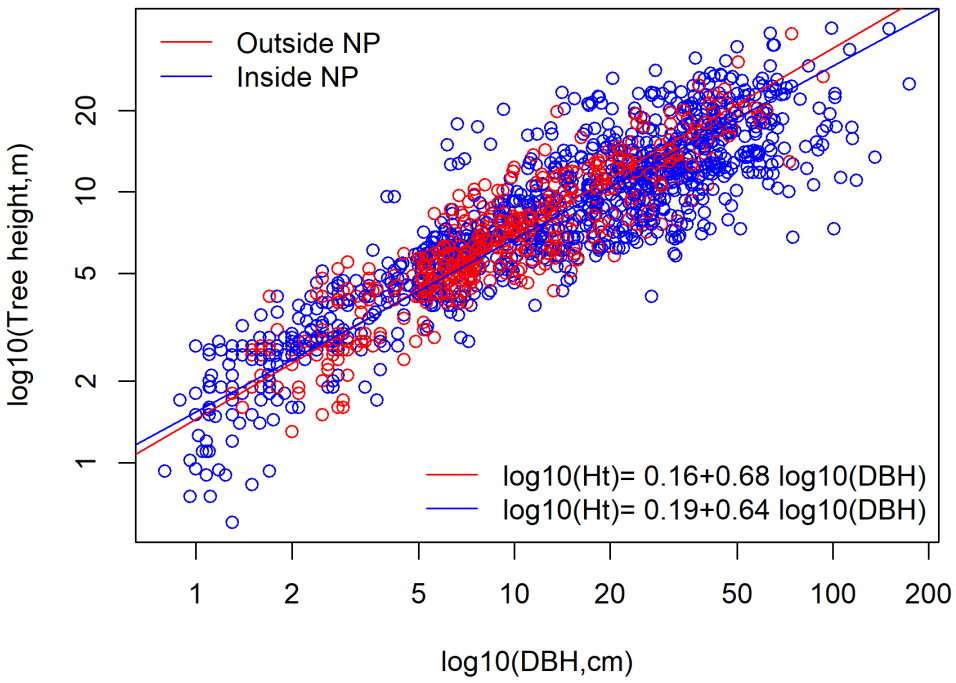


Figure 8. Relationship between tree height (m) and diameter at breast height (cm) of all trees at log-transformed scales measured across the 24 plots in the NTNP. Red circles and blue circles indicate stems outside and inside NTNP, respectively.

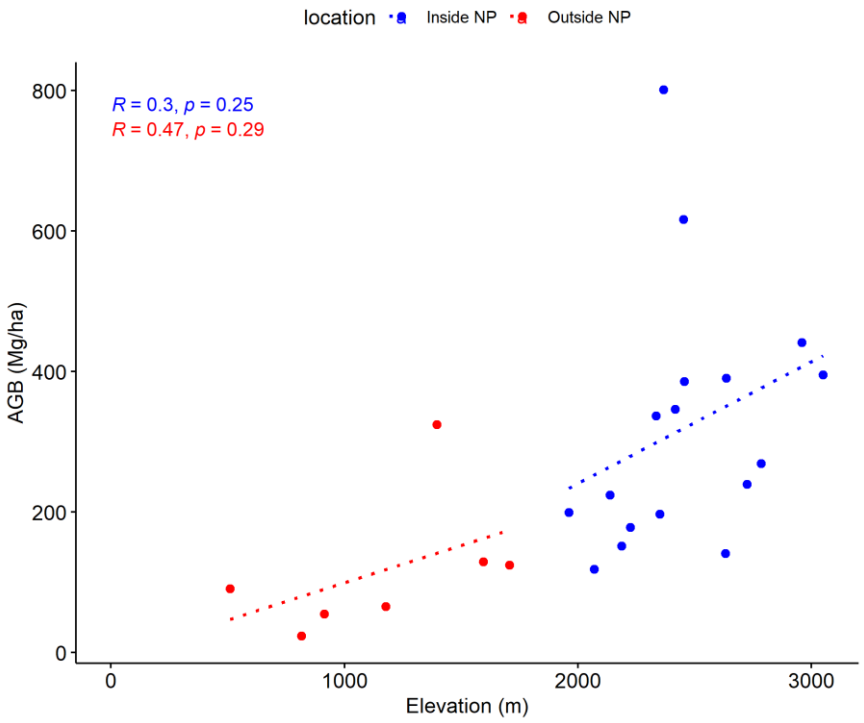


Figure 9. Above Ground Biomass (Mg/ha) vs. elevation (m) for 24 study plots. Red points indicate 7 study plots outside NTNP, and blue circles indicate 17 study plots inside NTNP. Pearson correlation was analyzed, and R and p-values were given.

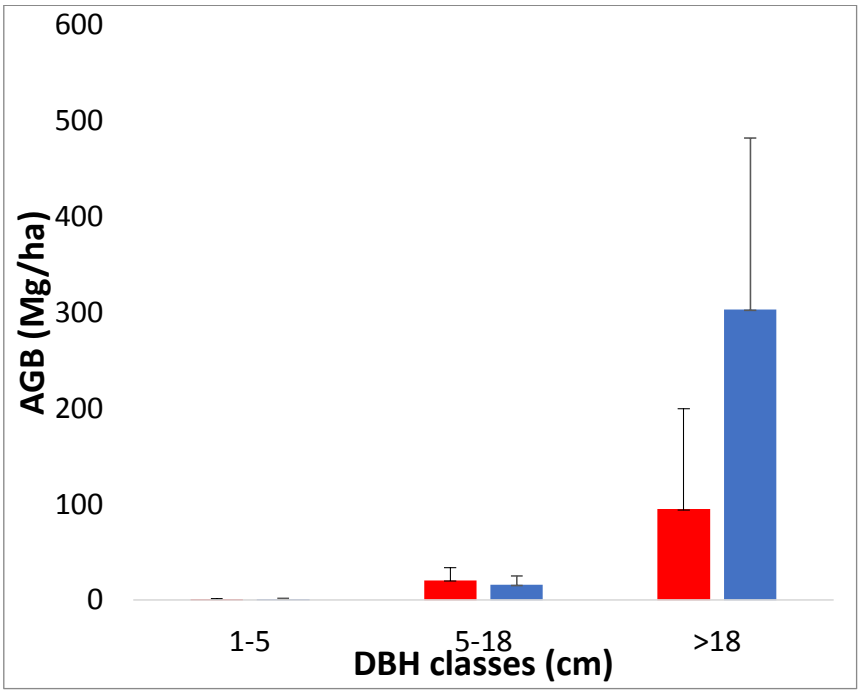


Figure 10. AGB (Mg/ha) explained by different diameter classes (cm) for 7 study plots outside NTNP (red) and 17 study plots inside NTNP (blue).

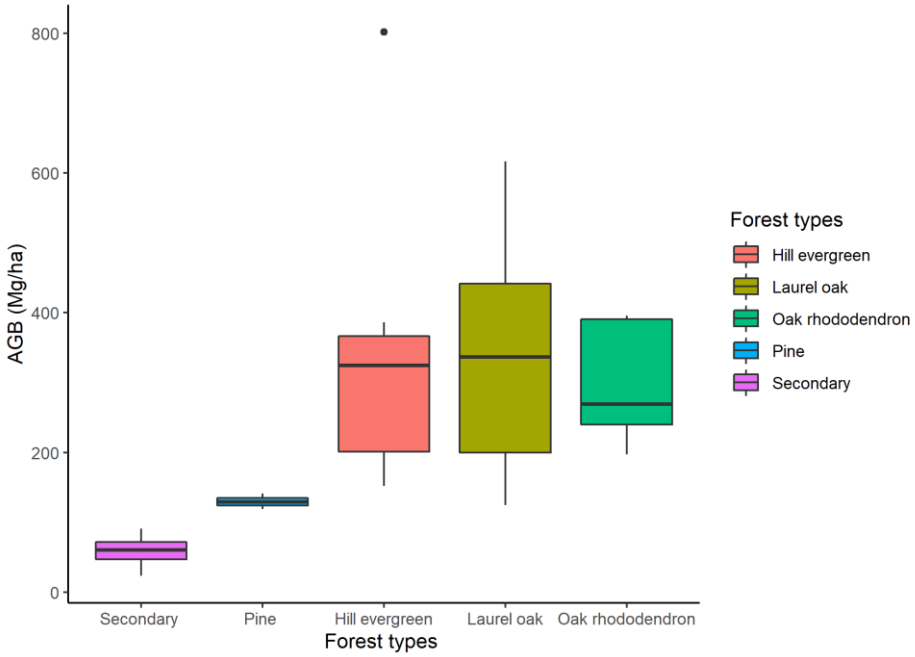


Figure 11. Box plot showing above ground biomass (Mg/ha) for the five vegetation types. For the number of plots in each vegetation type, see the legend for Figure 2.

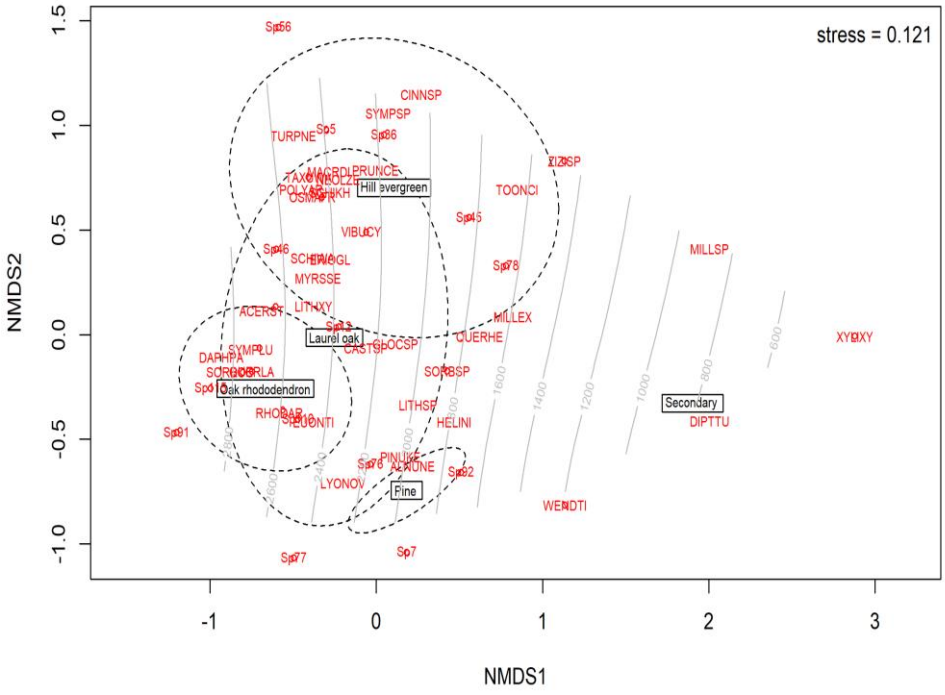


Figure 12. The result of non-metric multidimensional scaling (NMDS) analysis based on species composition (presence / absence) of 21 plots inside and outside of NTNP. Three plots with low levels of species identification (< 42%) were removed from this analysis (See Table 2). Pre-classified forest types (Pine, Hill evergreen, Laurel oak, and Oak Rhododendron communities) were indicated by circles drawn with broken lines. Grey lines represent elevation (m), which overall increases from right to left. Species are indicated by 6 letter codes in red letters. See the appendix 1 for species 6 letter code).

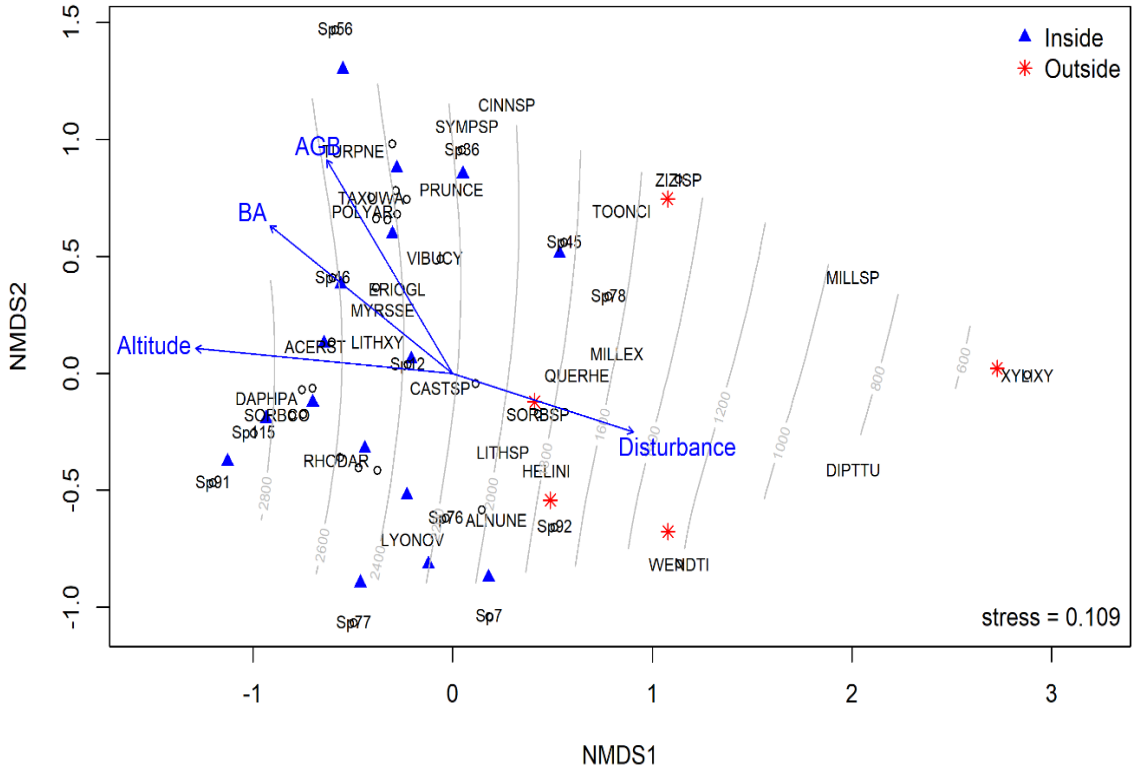


Figure 13. The result of NMDS analysis as in Fig. 12, but with environmental variables significantly associated to species composition ($p \leq 0.05$) as vector arrows. See methods for the explanation of variables.

Appendix

Family	Genus	Species	Code
Sapindaceae	Acer	*Acer sterculiaceum*	ACERST
Rutaceae	Aegle	*Aegle marmelos*	AEGLMA
Ericaceae	Agapetes	*Agapetes moorei*	AGAPMO
Fabaceae	Albizia	*Albizia chinensis*	ALBICH
Betulaceae	Alnus	*Alnus nepalensis*	ALNUNE
Pentaphylacaceae	Anneslea	*Anneslea fragrans*	ANNEFR
Combretaceae	Anogeissus	*Anogeissus acuminata*	ANOGAC
Araliaceae	na	*Araliaceae* sp1	ARALSP
Fabaceae	Archidendron	*Archidendron clypearia*	ARCHCL
Primulaceae	Ardisia	*Ardisia nervosa*	ARDINE
Primulaceae	Ardisia	*Ardisia polycephala*	ARDIPO
Primulaceae	Ardisia	*Ardisia* sp1	ARDISP
Lauraceae	Beilschiedia	*Beilschiedia globularia*	BEILGL
Berberidaceae	Berberis	*Berberis asiatica*	BERBAS
Betulaceae	Betula	*Betula alnoides*	BETUAL
Lamiaceae	Callicarpa	*Callicarpa arborea*	CALLAR
Fagaceae	Castanopsis	*Castanopsis* sp1	CASTS1
Fagaceae	Castanopsis	*Castanopsis* sp2	CASTS2
Fagaceae	Castanopsis	*Castanopsis tribuloides*	CASTTR
Celastraceae	Celastrus	*Celastrus paniculatus*	CELAPA
Taxaceae	Cephalotaxus	*Cephalotaxus mannii*	CEPHMA
Lauraceae	Cinnamomum	*Cinnamomum* sp1	CINNSP
Malvaceae	Colona	*Colona floribunda*	COLOFL
Cornaceae	Cornus	*Cornus obaloga*	CONUOB
Ericaceae	Craibiodendron	*Craibiodendron stellatum*	CRAIST
Fabaceae	Dalbergia	*Dalbergia oliveri*	DALBOL
Fabaceae	Dalbergia	*Dalbergia* sp1	DALBSP
Thymelaeaceae	Daphne	*Daphne papyracea*	DAPHPA
Dipterocarpaceae	Dipterocarpus	*Dipterocarpus tuberculatus*	DIPTTU
Elaeocarpaceae	Elaeocarpus	*Elaeocarpus braceanus*	ELAEBR
Elaeocarpaceae	Elaeocarpus	Elaeocarpus sp1	ELAESP
Juglandaceae	Engelhardtia	*Engelhardtia spicata*	ENGESP
Rosaceae	Eriobotrya	*Eriobotrya glabrescens*	ERIOGL
Celastraceae	Euonymus	*Euonymus tingens*	EUONTI
Euphorbiaceae	Euphorbiaceae	*Euphorbiaceae* sp1	EUPHSP
Pentaphylacaceae	Eurya	*Eurya* sp1	EURYSP
Fabaceae	Fabaceae	*Fabaceae* sp1	FABASP
Fagaceae	Fagaceae	*Fagaceae* sp1	FAGASP
Bignoniaceae	Fernandoa	*Fernandoa adenophylla*	FERNAD
Moraceae	Ficus	*Ficus geniculata*	FICUGE
Burseraceae	Garuga	*Garuga pinnata*	GARUPI
Phyllanthaceae	Glochidion	*Glochidion* sp1	GLOCSP
Anacardiaceae	Gluta	*Gluta usitata*	GLUTUS
Malvaceae	Grewia	*Grewia laevigata*	GREWLA
Proteaceae	Helicia	*Helicia nilagirica*	HELINI

Meliaceae	Heynea	*Heynea trijuga*	HEYNTR
Dipterocarpaceae	Hopea	*Hopea odorata*	HOPEOD
Oleaceae	Jasminum	*Jasminum lanceolaria*	JASMLA
Malvaceae	Kydia	*Kydia calycina*	KYDICA
Lythraceae	Lagerstroemia	*Lagerstroemia venusta*	LAGEVE
Lauraceae	na	*Lauraceae* sp1	LAURSP
Fagaceae	Lithocarpus	*Lithocarpus* sp1	LITHS1
Fagaceae	Lithocarpus	*Lithocarpus* sp2	LITHS2
Fagaceae	Lithocarpus	*Lithocarpus xylocarpus*	LITHXY
Lauraceae	Litsea	*Litsea elongata*	LITSEL
Lauraceae	Litsea	*Litsea* sp1	LITSSP
Ericaceae	Lyonia	*Lyonia ovalifolia*	LYONOV
Euphorbiaceae	Macaranga	*Macaranga peltata*	MACAPE
Lauraceae	Machilus	*Machilus dumicola*	MACHDU
Araliaceae	Macropanax	*Macropanax dispermus*	MACRDI
Fabaceae	Millettia	*Millettia extensa*	MILLEX
Fabaceae	Millettia	*Millettia* sp1	MILLS1
Rubiaceae	Mitragyna	*Mitragyna rotundifolia*	MITRRO
Moraceae	Morus	*Morus* sp1	MORUSP
Rubiaceae	Mussaenda	*Mussaenda* sp1	MUSSSP
Myricaceae	Myrica	*Myrica esculenta*	MYRIES
Primulaceae	Myrsine	*Myrsine semiserrata*	MYRSSE
Lauraceae	Neolitsea	*Neolitsea zeylenica*	NEOLZE
Cornaceae	Nyssa	*Nyssa javanica*	NYSSJA
Oleaceae	Osmanthus	*Osmanthus fragrans*	OSMAFR
Euphorbiaceae	Ostodes	*Ostodes katharinae*	OSTOKA
Lauraceae	Phoebe	*Phoebe* sp1	PHOESP
Rosaceae	Photinia	*Photinia integrifolia*	PHOTIN
Phyllanthaceae	Phyllanthus	*Phyllanthus emblica*	PHYLEM
Pinaceae	Pinus	*Pinus kesiya*	PINUKE
Icacinaceae	Pittosporopsis	*Pittosporopsis kerrii*	PITTKE
Polygalaceae	Polygala	*Polygala arillata*	POLYAR
Rosaceae	Prunus	*Prunus cerasoides*	PRUNCE
Fabaceae	Pterocarpus	*Pterocarpus macrocarpus*	PTERMA
Fagaceae	Quercus	*Quercus griffithii*	QUERGR
Fagaceae	Quercus	*Quercus helferiana*	QUERHE
Fagaceae	Quercus	*Quercus lanata*	QUERLA
Fagaceae	Quercus	*Quercus* sp1	QUERSP
Fagaceae	Quercus	*Quercus semecarpifolia*	QUERSE
Fagaceae	Quercus	*Quercus semiserrata*	QUERSI
Ericaceae	Rhododendron	*Rhododendron arboreum*	RHODAR
Anacardiaceae	Rhus	*Rhus chinensis*	RHUSCH
Rosaceae	na	*Rosaceae* sp	ROSASP
Salicaceae	Salix	*Salix tetrasperma*	SALITE
Araliaceae	Schefflera	*Schefflera* sp1	SCHESP
Theaceae	Schima	*Schima khasiana*	SCHIKH
Theaceae	Schima	*Schima wallichii*	SCHIWA
Sapindaceae	Schleichera	*Schleichera oleosa*	SCHLOL

Dipterocarpaceae	Shorea	*Shorea obtusa*	SHOROB
Dipterocarpaceae	Shorea	*Shorea* sp1	SHORSP
Rosaceae	Sorbus	*Sorbus corymbifera*	SORBCO
Rosaceae	Sorbus	*Sorbus* sp1	SORBSP
Loganiaceae	Strychnos	*Strychnos nux-blanda*	STRYNU
Symplocaceae	Symplocos	*Symplocos lucida*	SYMPLU
Symplocaceae	Symplocos	*Symplocos racemosa*	SYMPRA
Symplocaceae	Symplocos	*Symplocos ramosissima*	SYMPRM
Symplocaceae	Symplocos	*Symplocos* sp1	SYMPSP
Taxaceae	Taxus	*Taxus wallichiana*	TAXUWA
Verbenaceae	Tectona	*Tectona grandis*	TECTGR
Combretaceae	Terminalia	*Terminalia alata*	TERMAL
Meliaceae	Toona	*Toona ciliata*	TOONCI
Cannabaceae	Trema	*Trema orientalis*	TREMOR
Myrtaceae	Tristaniopsis	*Tristaniopsis burmanica*	TRISBU
Staphyleaceae	Turpinia	*Turpinia nepalensis*	TURPNE
Caprifoliaceae	Viburnum	*Viburnum cylindricum*	VIBUCY
Caprifoliaceae	Viburnum	*Viburnum* sp1	VIBUS1
Caprifoliaceae	Viburnum	*Viburnum* sp2	VIBUS2
Lamiaceae	Vitex	*Vitex burmensis*	VITEBU
Rubiaceae	Wendlandia	*Wendlandia tinctoria*	WENDTI
Apocynaceae	Wrightia	*Wrightia arborea*	WRIGAR
Fabaceae	Xylia	*Xylia xylocarpa*	XYLIXY
Rutaceae	Zanthoxylum	*Zanthoxylum acanthopodium*	ZENTAC
Rhamnaceae	Ziziphus	*Ziziphus*_sp1	ZIZISP