Species composition, diversity, and stand structure of tropical lower montane forests resulting from various human impacts on the Shan Plateau, eastern Myanmar

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ABSTRACT
We observed species composition, diversity, and stand structure in the tropical lower montane forests of a hilly region in eastern Myanmar and examined the impacts of anthropogenic disturbances on the forest stands. From our survey of 58 sample plots (30 m x 30 m), we categorized four stand types using nonmetric multi-dimensional scaling (NMS) ordination. The four stand types exhibited significant contributions of various anthropogenic impacts, reflecting differences in local livelihoods within different varying landscapes. Anthropogenic disturbances, especially the extraction of firewood, can significantly affect the stand structure of forests and, in turn, the species composition and tree diversity. Some early successional species such as Phyllanthus albizzioides and Albizia odoratissima became indicator species of highly disturbed forests. As firewood is mainly extracted from privately owned forests rather than communal forests, land tenure was also an important factor governing the intensity of anthropogenic disturbances. Species richness and diversity values decreased in stand types exposed to more severe anthropogenic disturbances. Stem density was significantly higher in highly disturbed forests. This was a result of higher numbers of multi-stemmed individuals, which revealed the effect of cutting larger stems for firewood extraction. In old secondary forests, the lack of young trees under the canopy may threaten future forest regeneration. Depending on varying forest conditions and the local population’s input, different forest management activities should be applied to forests to optimize production and protection for the local community.

Key words: Anthropogenic disturbances, cluster analysis, land tenure, nonmetric multi-dimensional scaling

INTRODUCTION
Upland areas of eastern Myanmar belong to the montane mainland of Southeast Asia (MMSEA), which constitutes approximately half of the land area of Cambodia, Laos, Myanmar, Thailand, Vietnam, and Yunnan Province of China (Fox et al. 2012, Jianchu et al. 2006, Rerkasem et al. 2009). This region possesses unique characteristics in terms of conservation and cultural values as it is home to both a rich heritage of indigenous cultures and the headwaters of many major river systems in mainland Southeast Asia (Fox and Vogler 2005). Shifting cultivation (rotational farming characterized by active cultivation fields and differently aged fallow forests) has been the dominant farming system in the MMSEA. It has been practiced for at least a millennium and has greatly influenced land cover throughout the region (Fox et al. 2012). However, at many forest-agriculture frontiers in the tropics, shifting cultivation landscapes are rapidly being transformed to other land-use types (Liao et al. 2015). Furthermore, in mountainous regions of Myanmar, ethnic minorities used to practice shifting cultivation as their major livelihood, including in the Shan Plateau of eastern Myanmar (Maung Maung Than 2015).

As a whole, the Shan Plateau has been ethnically fragmented and topographically diverse. The area includes flat lands and undulating terrains while featuring a number of different land-use paradigms (Baver et al. 2013). In areas where shifting cultivation had been practiced and subsequently abandoned, secondary forests developed naturally, though local people transformed some areas for permanent agriculture. Species composition, diversity, and stand structure at different succession stages of secondary forests differed with those of similar old-growth forests (Van Do et al. 2010). In addition, disturbances to forest ecosystems are one of the driving forces that alter species
composition and diversity (Burslem and Whitmore 1999). Repeated resource extraction, which is a major type of anthropogenic disturbance as relates to forest conditions, can cause significant changes in forest structure, composition, and diversity (Thapa and Chapman 2010). Therefore, species composition and diversity are important indicators used for evaluating the stability and sustainability of forest communities (Sarkar and Devi 2014).

Tropical montane forests play an important role with respect to the conservation of upland watershed areas, the slope stability of mountains, and the local livelihoods of the inhabitants (Hertel et al. 2003). Accordingly, montane forest ecosystems should be given priority when it comes to conservation initiatives. Understanding species composition, diversity, and stand structure along with the impacts of anthropogenic disturbances on these forests is indispensable for developing future land management plans to ensure the sustainability of montane forest ecosystems and the security of livelihoods for local people.

In this study, we examine the species composition, diversity, and stand structure of tropical lower montane forests in the Shan Plateau of eastern Myanmar. We explain the variation of the stand types of the forests as it relates to anthropogenic disturbances by discussing the importance of local livelihoods and land tenure as factors affecting forest conditions.

**MATERIALS AND METHODS**

**Study area**

The study was conducted within the Ywangan Township located in Shan State (the Shan Plateau) of eastern Myanmar. According to differences in elevation, which tended to differ in vegetation types, we excluded areas located at an altitude <1000 m. Therefore, our focused study area extended from 20°52'21" to 21°18’56” N latitude and 96°21’48” to 96°38’19” E longitude, which together constitutes 770 km² in area (Fig. 1). The altitude ranged from 1000 to 2262 m above sea level (a.s.l) while alternating hills and lowlands as terrain reliefs dominate much of the region. Over the course of 11 years (2003–2014) climatic observations recorded in Ywangan City (at 1275 m a.s.l.), the mean monthly temperature ranged from 18 to 25°C with a mean annual temperature of 22.5°C (unpublished data, Department of Agriculture). The mean annual rainfall was 1978 mm, ranging from 1600 to 2600 mm. Of 28 village tracts (a village tract is a fourth-level administrative division in Myanmar, between village and township) in the whole township which comprised 125 villages, 111 villages in 22 village tracts were included in the study area. The population density in 2014 was 27 persons/km², which was not only lower than the average population density of Shan State (37 persons/km²), but was also much lower than Myanmar’s average population density of 76 persons/km² (Department of Population 2015). The major ethnic group of the area is Danu (one ethnic group of 135 national races within Myanmar). Nearly 95% of the total population resides in rural areas in this township and their major livelihood is farming, notably of upland fields, lowland paddy fields, and orchards (unpublished interview data by the authors). According to land-cover classification (2016 Landsat image classification) of this region, the two most dominant land cover types are forests and agricultural lands, which occupy 46.1% and 45.7% of the total land area, respectively (Lwin & Kanzaki, under review).

Across the study area, we selected three different levels of landscapes (Sites 1, 2, and 3) to investigate species composition, diversity, and stand structure as affected by different levels of anthropogenic disturbances (Fig. 1). Site-
Species composition and stand structure of montane forests in Myanmar

According to (1992) and (1992), reserved forests and the Forest Law, Myanmar usually located beyond the territories of settlement areas open access. In our study area, open access forests were forests was tied to the FAO (2002); private, communal, and other forested areas were unclassified forests where local people could not easily access the land because of its topography and location. Local communities usually access forests within their territories under two types of land tenure: private and communal. Forests under communal land tenure have rarely experienced anthropogenic disturbances such as tree cutting, grazing, and transformation to other land-use types because local communities took control of these lands as their common property. Under private land tenure in this area, individual households have exclusive rights to access those customarily designated forests and therefore owners can extract forest resources. This is especially the case for extraction of firewood from privately owned forests.

Forest administration and land tenure system

All of the land and natural resources are property of the national government of Myanmar. The responsibility for the management of forest resources rests with the Forest Department (FD) under the land titles of the Permanent Forest Estate (PFE) and the Protected Area System (PAS) legally secured by The Forest Law, Myanmar (1992) and The Protection of Wildlife and Conservation of Natural Areas Law (1994) (NEPCon 2013). According to The Forest Law, Myanmar (1992), reserved forests and protected public forests fall under PFE categories, whereas totally protected areas such as wildlife sanctuaries and national parks are categorized as PAS. Apart from those legally designated forested areas of PFE and PAS, other forests have been described as unclassified forests and are legally termed “Land at the Disposal of Government.” This signifies that the land does not fall under the purview of any government department or organization, and that no other person has acquired the property rights under any existing laws (The Forest Law, Myanmar 1992).

Only 10.1% of the total land area fell under PFE while other forested areas were unclassified forests where local people have customary rights to access those lands in this study area. Customarily, three different forms of land tenure have been found in this area as regards access to forests. Categorization of customary land tenure on unclassified forests was tied to the FAO (2002); private, communal, and open access. In our study area, open access forests were usually located beyond the territories of settlement areas where local people could not easily access the land because of its topography and location. Local communities usually access forests within their territories under two types of land tenure: private and communal. Forests under communal land tenure have rarely experienced anthropogenic disturbances such as tree cutting, grazing, and transformation to other land-use types because local communities took control of these lands as their common property. Under private land tenure in this area, individual households have exclusive rights to access those customarily designated forests and therefore owners can extract forest resources. This is especially the case for extraction of firewood from privately owned forests.

Forest survey

To collect floral and structural data from the forests at the three sites, we arbitrarily laid out 58 sample plots (30 m × 30 m) across the three study sites. Fourteen plots were sampled in Site-1, 11 plots in Site-2, and 33 plots in Site-3. To reduce the effect of spatial autocorrelation for covering the variation of floral composition, sample plots were separated from each other by at least 500 m. To avoid sampling early stages of regeneration, we selected forests with a minimum canopy height of 12 m. Data were collected from April to December 2015. In each sample plot, we measured the diameter at breast height (DBH) and the height of all trees (with ≥5 cm DBH and ≥2 m in height). We measured tree heights using a Vertex IV hypsometer (Haglöf Sweden AB). For multi-stemmed individuals, we measured each stem with DBH ≥5 cm. Specimens of leaves, shoots, fruits, seeds, flowers, and barks were collected from each species with their local names for the later identification. The specimens were sent to the Herbarium of Forest Research Institute, Myanmar, for taxonomic identification. We followed the nomenclature of Kress et al. (2003) and Gardner et al. (2000). For data collection, we only measured trees, while other plants, such as climbers, shrubs, and herbs, were excluded.

Environmental factors

We recorded seven environmental factors, two topographic factors, and five anthropogenic factors for each plot. The two topographic factors were elevation and slope inclination. We recorded the location (UTM coordinate system) of each sample plot using GPS coordinates (Garmin GPSmap 62s). The terrain variables, elevation (m), and
slope (degrees) were extracted from the digital elevation model (Aster Global DEM) in ArcMAP 10.4.1 using a spatial analysis tool. Aster Global DEM version2 (with 30 m postings and 1 × 1 degree tiles) was obtained from the United States Geological Survey (USGS: https://earthexplorer.usgs.gov/). Anthropogenic variables included distance to the nearest village, time from last cutting, land tenure, intensity of forest resource extraction, and fire occurrence. Distance to the nearest village were determined using ArcMAP 10.4.1. We documented the other anthropogenic variables through interviews with forest owners as well as elder persons and local field guides who had knowledge of the forests. Time from last cutting was defined as the period since the last disturbance (such as shifting cultivation, rotational cutting of trees for firewood) occurred. The responses of forest owners ranged from 7 years up to 100 years, and we used these values directly. Three levels of extraction were defined; no extraction, extraction of non-timber forest products excluding firewood, and extraction of all forest resources including firewood. In the plots sampled, no trees were harvested for timber.

Preparation of data matrices

For numerical analyses, we organized our collected data into two matrices named species matrix and environmental matrix. The 58 plots were put as row headings for both matrices. The total 285 species were put as column headings for the species matrix, while each cell contained the number of stems of each species that occurred in each plot. For the environmental matrix, seven observed variables made up the column headings and the cells contained values for each respective plot. Two binary variables, land tenure (1 = communal, 0 = private) and fire occurrence (1 = yes, 0 = no), were included in the matrix. There was one ordinal variable for intensity of forest resource extraction (no extraction = 0, non-timber forest products = 1, and firewood = 2). The other four variables were continuous variables.

Data analyses

By using the species matrix, we performed hierarchical agglomerative cluster analysis with the Bray-Curtis (abundance data) distance measure with its compatible linkage method of Flexible beta (at β value = −0.25) to define different stand types (McCune and Grace 2002). To investigate the statistical significance of the differences among designated stand types, we applied Multi-Response Permutation Procedures (MRPP) based on the Bray-Curtis distance measure (Mielke 1991). The plant community similarities among stand types were analyzed by calculating the Bray-Curtis similarity index. We defined the most dominant species in each stand type by means of each species’ relative stem density (%). For Indicator Species Analysis (Dufrène and Legendre 1997), we identified indicator species for each stand type. In this approach, a species’ relative abundance and its relative frequency of occurrence in the various stand types were considered. The statistical significance of indicator values for each species (P < 0.05) was determined using the Monte Carlo test. The following equation was used to calculate the indicator values of each species (Dufrène and Legendre 1997):

\[ A_j = \frac{N_{individials_j}}{N_{individials}}, \]

\[ B_j = \frac{N_{sites_j}}{N_{sites}}, \]

\[ INDVAL_q = A_j \times B_j \times 100, \]

where \( INDVAL_q \) is the indicator value of species \( i \) in stand type \( j \), \( A_j \) is a measure of specificity, \( N_{individials_j} \) is the mean number of individuals of species \( i \) across plots in stand type \( j \), and \( N_{individuals} \) is the sum of the mean numbers of individuals of species \( i \) over all plots. \( B_j \) is a measure of fidelity, \( N_{sites_j} \) is the number of plots in stand type \( j \) where species \( i \) is present, and \( N_{sites} \) is the total number of plots in that stand type.

We then performed nonmetric multi-dimensional scaling (NMS) ordination. NMS is the method of choice for graphical representation of community relationships (Clarke 1993), and it is well suited for ecological data, as it allows the use of any distance measure (McCune and Grace 2002). Sample plots were first ordinated based on the Bray–Curtis distance measure using the species matrix. The relationship between environmental variables and scores on the NMS ordination axes were examined using nonparametric Kendall rank correlations. Then, strongly correlated environmental factors were overlaid on the ordination graphs. Environmental factors were also compared among stand types using the Kruskal–Wallis test for continuous variables and the chi-square test (\( X^2 \)) for categorical variables.

To analyze floristic diversity, we quantified the alpha diversity of each plot and stand type (Whittaker 1972). To compare species richness, a rarefaction method was used to obtain species richness of the same number of stems for reliable comparisons, and rarefaction curves were developed for each stand type. We ran 100 randomizations
to calculate species richness for 10 stems per plot and for 400 stems per stand type using EstimateS software (Gotelli and Colwell 2001). The β-diversity (Whittaker 1960) of each stand type was calculated as $\beta = \gamma / \alpha$, where $\gamma$ is the total number of species, and $\alpha$ is the mean number of species per plot in each stand type. To determine stand structural characteristics, we calculated the mean DBH (cm), maximum tree height (m), total basal area (m²), stem density, and sprouting ratio (%) (= sprouting stem / total stem × 100) where sprouting stems are the total number of multi-stemmed individuals) for each plot. For comparative analyses of stand structural and species compositional attributes, we first checked normality using the Shapiro–Wilk test (Shapiro and Wilk 1965) and for homogeneity of variance using Levene’s test at the $P<0.05$ significant level (Olkin 1960). As normality and homogeneity were rejected for some of our observed attributes, we applied the nonparametric Kruskal–Wallis test to compare all data attributes among stand types. To clearly determine the impact of disturbance on forest structure, we first classified DBH values of all measured stems into classes at 5-cm intervals. We then compared the stem-diameter distribution among stand types using the Kolmogorov–Smirnov test. Cluster Analysis, MRPP, Indicator Species Analysis, and NMS ordination were performed using PC-ORD software v.5.10 (McCune and Grace 2002), and all other statistical analyses were performed using the statistical software package R. v.3.3.2.

RESULTS

Identification of different stand types

From our survey of 58 sample plots, we recorded 5003 stems (with DBH ≥5 cm and total height ≥2.0 m) of 285 species, 114 genera, and 56 families. Fagaceae, Lauraceae, Rubiaceae, Theaceae, Euphorbiaceae, Oleaceae, Myrsinaceae, Myrtaceae, and Fabaceae were the most dominant families, each represented by more than 100 stems. Cluster analysis identified four significant stand types (MRPP: $A = 0.49$, $P<0.00001$). Fourteen plots in stand type 1 (ST1) were from agriculture-dominated landscapes (Site-1), whereas only two plots were from the other two landscapes (Site-2 and Site-3). All of the plots (10 plots) that occurred in stand type 2 (ST2) were from transitional landscapes (Site-2). Stand type 3 (ST3) and 4 (ST4) were only present in the forest landscapes (Site-3), with 16 plots in each stand type. ST3 and ST4 showed the highest similarity (Bray-Curtis) at 29.6 %, followed by 18.5 % between ST1 and ST2, and 17.5 % between ST2 and ST4.

Dominant species and indicator species

In ST1, abundance was shared more equally among species, as the most dominant species, *Maesa* sp., occupied only 5.79 % of total stem density. In contrast, the most dominant species in other stand types (ST2, ST3, and ST4) accounted for larger proportions of total stems, ranging from 10.53 % in ST2 to 14.63 % in ST4 (Table 1).

Altogether, 25 tree species were identified as significant indicator species for the designated four stand types (P<0.05 for ST1 and P<0.001 for the other stand types) (Table 2). ST1 and ST2, each had five significant indicator species. A higher number of significant indicator species appeared in ST3 and ST4 (Table 2).

Factors influencing differences in species composition

NMS ordination confirmed the categories of four significant stand types that were a result of cluster analysis (Fig. 2). By separating species composition, three axes explained 64.7 % of the correlations between the distance at the original space and the ordination distance (Table 3). For statistical reliability of the NMS ordination, the final stress value for the three-dimensional solution was 16.9 % which lies within an acceptable range of <20 % (Kruskal 1964) with final instability of 0.001 after 500 iterations. Kendall rank correlations among three NMS axis scores and observations of environmental factors showed that axis-1 alone explained 28.4 % of the floristic variance and was significantly correlated with all factors. Axis-2 showed the strongest negative correlation with elevation and was positively correlated with communal land tenure. All environmental factors except elevation showed significant correlations with Axis-3.

The nonparametric Kruskal–Wallis and the chi-square tests revealed that all environmental variables tested varied significantly among the four stand types. The mean elevation varied from 1222 m to 1559 m, while slope inclination of the plots in the four stand types ranged from 5.2 degrees in ST1 to 15.8 degrees in ST4 (Table 4). ST4 was found farthest away from settlement areas, whereas the other three stands did not differ significantly in terms of their distance from nearby villages. For time from last cutting, ST1 was significantly longer than were ST3 and ST4. Most of the plots from ST1 and ST2 were communal
forests, whereas those of ST3 and ST4 were privately owned forests. As a key indicator of anthropogenic disturbance, the extraction of firewood was found to be highest in ST4. The greatest number of plots that had experienced fire was found in ST4, followed by ST3 and ST2 (Table 4).

**Tree diversity and stand structure**

The stand type-level values for species composition showed that ST1 possessed the highest number of species, genera, and families (Table 5). The rarefied species and rarefaction curves also confirmed that the greatest species richness was found in ST1, and the lowest in ST3, both in samples of 400 stems (Table 5 and Fig. 3). The \( \beta \)-diversity values of four stand types ranged from 8.48 (ST1) to 4.30 (ST3). For stand-level species richness, the nonparametric Kruskal–Wallis test resulted in non-significant differences ranging from 7.30 species/10 stems (ST1) to 6.54 species/10 stems (ST4).

Stand structural attributes differed significantly across the four stand types (\( P \leq 0.001 \)) except for the total basal area (\( P = 0.117 \)) (Table 5). Based on pairwise comparisons, ST1 was significantly different from ST3 and ST4 in its values of mean DBH and stem density whereas ST4 was significantly different from ST1 and ST2 in terms of maximum height and sprouting ratio (Table 5).

The highest number of stems was found in the smallest diameter class (5–10 cm) in ST2, ST3, and ST4, whereas ST1 possessed the highest stem density in the largest diameter class (DBH > 55 cm) (Fig. 4). A Kolmogorov–Smirnov test indicated that the stem-diameter distribution differed significantly between ST1 and ST2 (\( Z = 5.07, P = 0.000 \)), ST1 and ST3 (\( Z = 6.96, P = 0.000 \)), ST1 and ST4 (\( Z = 8.92, P = 0.000 \)), ST2 and ST4 (\( Z = 4.35, P = 0.000 \)), and ST3 and ST4 (\( Z = 4.84, P = 0.000 \)). Non-significant differences were found only between ST2 and ST3 (\( Z = 1.24, P = 0.093 \)).

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**Table 1. List of the top five dominant species, the values of stem density (number of stems), and their relative stem density (%) in each stand type in the Ywangan Township, eastern Myanmar**

| Stand Type 1 | Scientific name | Family          | Stem density (n) | Relative stem density (%) |
|--------------|-----------------|-----------------|------------------|---------------------------|
| 1            | *Maesa* sp.     | Myrsinaceae     | 26               | 5.79                      |
| 2            | *Lithocarpus* sp.12 | Fagaceae      | 17               | 3.79                      |
| 3            | *Bauhinia acuminata* | Caesalpinaceae | 16               | 3.56                      |
| 4            | *Cinnamomum obtusifolium* | Lauraceae   | 11               | 2.45                      |
| 5            | *Lithocarpus lindleyanus* | Fagaceae      | 11               | 2.45                      |

| Stand Type 2 | Scientific name | Family          | Stem density (n) | Relative stem density (%) |
|--------------|-----------------|-----------------|------------------|---------------------------|
| 1            | *Tarenmoidea wallichii* | Rubiaceae    | 70               | 10.53                     |
| 2            | *Wendlandia tinctoria* | Rubiaceae      | 43               | 6.47                      |
| 3            | *Olea dentata* | Oleaceae       | 41               | 6.17                      |
| 4            | *Wendlandia sp.2* | Rubiaceae      | 40               | 6.02                      |
| 5            | *Mallotus philippinensis* | Euphorbiaceae | 27               | 4.06                      |

| Stand Type 3 | Scientific name | Family          | Stem density (n) | Relative stem density (%) |
|--------------|-----------------|-----------------|------------------|---------------------------|
| 1            | *Litsea cubeba* | Lauraceae       | 230              | 12.02                     |
| 2            | *Wendlandia sp.2* | Rubiaceae    | 126              | 6.58                      |
| 3            | *Quercus sp.3* | Fagaceae       | 123              | 6.43                      |
| 4            | *Ardisia sp.* | Myrsinaceae    | 112              | 5.85                      |
| 5            | *Quercus serrata* | Fagaceae       | 89               | 4.65                      |

| Stand Type 4 | Scientific name | Family          | Stem density (n) | Relative stem density (%) |
|--------------|-----------------|-----------------|------------------|---------------------------|
| 1            | *Litsea sp. 4* | Lauraceae       | 289              | 14.63                     |
| 2            | *Quercus mespilifolia* | Fagaceae      | 191              | 9.67                      |
| 3            | *Wendlandia tinctoria* | Rubiaceae    | 178              | 9.01                      |
| 4            | *Schima wallichii* | Theaceae       | 71               | 3.59                      |
| 5            | *Anneslea sp.3* | Theaceae       | 68               | 3.44                      |
DISCUSSION

Differentiation of stand type and control factors

As the plots of all stand types were located in highland areas (elevation range, about 1200 to 1600 m), the forests can be categorized as hill evergreen forests (Gardner et al. 2000). The strong separation of stand type clusters in NMS ordination and the subsequent significant correlation results highlighted the collective effects of the observed environmental factors (topographic and anthropogenic factors) influencing variations in species composition among sites (Table 3). ST1 and ST2 (forests from Site-1 and Site-2) can be categorized as less-disturbed forests, as they were mostly exempt from firewood extraction (Table 4). Differing species composition between Site-1 (clustered as ST1) and Site-2 (clustered as ST2) was governed by the previous and current livelihood patterns of local people. In agriculture-dominated areas (Site-1), where permanent agricultural practices have been widespread across moderately flat lands for several decades, remnant forests were likely old secondary forests. *Bischofia javanica* and *Cinnamomum obtusifolium*, which usually occur in primary evergreen forests (Maxwell and Elliot 2001), were identified in ST1 as indicator species. However, we cannot ignore the past disturbances in ST1 that might have
eliminated shade tolerant species, such as many Fagaceae species, and allowed the invasion of light demanding species like *Macaranga* and *Vitex*, which were also indicator species of ST1. At Site-2, where undulating terrain is mixed with moderately flat lands, remnant forests were young secondary forests affected by prior shifting cultivation. Recently, little anthropogenic disturbance occurred for collection of firewood. *Tarennoidea wallichii*, which usually occurs in less disturbed forests (Gardner et al. 2000), was the most dominant species as well as an indicator species in ST2. In Site-3, which was mostly made up of undulating hilly regions where extensive agriculture was not economical, the farming patterns of local people differed from those at Site-1 and Site-2, as they previously practiced shifting cultivation, but now grow only tea orchards. ST4 was more strongly affected by extraction of firewood than ST3 was, and the species composition differed between ST3 and ST4, despite both stand types occurring only in Site-3. Early successional species, such as *Phyllanthus albizzioides* and *Albizia odoratissima*, and *Shima wallichii* which was usually abundant in lands abandoned after shifting cultivation in Chiang Mai Province of Northern Thailand and in Son La Province of Northwestern Vietnam (Fukushima et al. 2008; Van Do et al. 2011), were indicator species in ST4, showing the impact of severe anthropogenic disturbance. Even on the same landscape, the location of the forest stands strongly influenced the disturbance intensity, as the most disturbed forests (ST4) were located at quite a distance from the villages (Table 4). Our findings contradict previous studies in other regions of Myanmar as well as in other Asian countries; most previous studies have found that forests were more prone to human disturbance when they were located near settlement areas and accessible roads (Htun et al. 2011, Mon et al. 2012, Thapa and Chapman 2010). On the other hand, Fukushima et al. (2008) and Takeda et al. (2005) reported that the Karen people in Myanmar and Northern Thailand protect the forest surrounding residential areas and use shifting cultivation sites that stretch outside of this protected forest. The observed pattern is similar to the situation in these reports. The contradiction between the current and previous studies may be associated with differences in customary land allocation and past land-use systems of the study sites.

Land tenure also differed based on differences in resource utilization patterns of the local populations at the three sites (Table 4). In forest-dominated landscapes (Site-3), where firewood requirements were higher for the drying of tea leaves, most forested lands were occupied by local people as privately owned forests. Therefore, forest stands categorized as ST3 and ST4 were mostly privately owned forests. In the other two landscapes where firewood demands were not as high, forests were mostly communal, and accordingly, ST1 and ST2 were mostly composed of forest stands under communal land tenure.

**Variations in species richness, diversity, and stand structure**

Although species diversity at plot-level (α-diversity)
Table 3. Variance (%) explained by each NMS axis and Kendall ranked correlations (tau) between NMS axes scores and environmental variables of plots from three regions in the Ywangan Township, Southern Shan State, Myanmar

|                        | Axis 1 | Axis 2 | Axis 3 |
|------------------------|--------|--------|--------|
| % of variance explained | 28.4   | 19.8   | 16.6   |
| Cumulative % of variance explained | 28.4   | 48.2   | 64.7   |
| Elevation (m)           | 0.270**| -0.552**| -0.059 |
| Slope (degree)          | 0.339**| -0.182* | -0.275**|
| Distance to village (m) | 0.354**| 0.048    | -0.479**|
| Time from last cutting (year) | -0.395**| 0.192* | 0.301**|
| Land tenure (Communal)  | -0.285**| 0.322**| 0.444**|
| Extraction of forest products | 0.263* | -0.079 | -0.420**|
| Fire occurrence         | 0.284**| -0.178 | -0.264*|

Correlation is significant at **P<0.01, *P<0.05

Table 4. Characteristics of different stand types in the Ywangan Township, Shan State, Myanmar. Those within a row not followed by the same letter are not significantly different by pairwise comparison of the Kruskal-Wallis test. Mean (± SD) values are shown for continuous variables while numbers of plots (%) are described for categorical variables (H = Kruskal-wallis test statistics; X² = Chi-square test statistics).

| ST1 | ST2 | ST3 | ST4 | H/X² | P |
|-----|-----|-----|-----|------|---|
| Elevation (m) | 1222 (75)a | 1464 (42)b | 1559 (70)b | 1368 (65)c | 46.334 | <0.001 |
| Slope (Degree) | 5.2 (4.8)a | 12.8 (3.6)b | 12.6 (5.4)b | 15.8 (8.0)b | 23.279 | <0.001 |
| Distance to village (m) | 871 (234)a | 790 (296)a | 1232 (757)a | 3120 (817)b | 33.704 | <0.001 |
| Time from last cutting (year) | 88 (24)a | 60 (18)b | 53 (29)c | 30 (15)f | 26.285 | <0.001 |
| Land tenure (%) | 93.75 | 100 | 37.5 | 31.25 | 23.489 | <0.001 |
| Exhibition of forest products (%) | 6.25 | 0 | 62.5 | 68.75 | 30.086 | <0.001 |
| Private Tenure | 31.25 | 40 | 31.25 | 6.25 | 6.25 |
| Communal tenure | 62.5 | 60 | 12.5 | 12.5 | 12.5 |
| Extraction of forest products (%) | 6.25 | 0 | 56.25 | 81.25 | 81.25 |
| Fire occurrence (%) | 37.5 | 70 | 75 | 93.8 | 12.271 | 0.007 |

did not significantly differ among stand types, ST1 possessed the highest values in β-diversity and γ-diversity values (Table 5). These results indicate that the highest γ-diversity in ST1 resulted from the highest species turnover among plots within ST1. In agreement with the findings of previous studies (e.g., Bhuyan et al. 2003; Sagar et al. 2003; Thapa and Chapman 2010), our study demonstrated that disturbance to forests from resource extraction can significantly affect stand structure, and thereby affect species diversity. Repeated cutting of larger stems induced coppice regrowth. Forest owners used selective cutting of one-third of stems with a rotation of 5–10 years when cutting larger stems for firewood. As suggested by McLaren and McDonald (2003), differing abilities of species to produce coppice shoots will likely affect long-term species diversity. In this study, the contribution of a large number of multi-stemmed individuals of some species in highly disturbed stand types (especially ST4) could lead to dominance of these species in forests, which may alter species composition and decrease species richness. This result was confirmed by the diameter class distribution across four stand types, as two stand types (ST3 and ST4) possessed greater numbers of stems, especially in smaller-diameter classes. On the other hand, ST1 had fewer stems in the smaller diameter classes.

Based on our results, we can conclude that the species composition, diversity, and stand structure of tropical lower montane forests differed in relation to heavier anthropogenic disturbances resulting from varying local livelihoods in different landscapes. The results indicate that anthropogenic disturbances were associated with higher elevation, steeper slope, and private land tenure. In forests where
resource extraction was intense, species composition changed, and species richness was diminished. On the other hand, old secondary forests with long periods free from anthropogenic disturbance seemed over-mature because these forests lacked young trees under the canopy, which may threaten their future regeneration.

In this study, we found two different customary types of forests: young secondary forests for production purposes and old secondary forests mainly focused on protection. Therefore, introducing particular forest management activities to the different stand types in the study area would be impractical. In the case of forests utilized by local people for collection of firewood, management for the sustainable production of forest resources is essential to support local livelihoods while also promoting conservation of native tree species in lower montane forests. For old secondary forests that are over-mature and lack regeneration of young trees, dense tree canopies might impede the growth of young trees for sustainable forest regeneration. In this case, silvicultural treatments such as thinning, pruning, and artificial or assisted natural regeneration activities should be considered.
Species composition and stand structure of montane forests in Myanmar

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