Woody plant communities in the Philippine teak forest landscape along Verde Island Passage, Batangas, Luzon, Philippines

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Abstract. Caringal AM, Buot IE Jr, Villanueva ELC. 2019. Woody plant communities in the Philippine teak forest landscape along Verde Island Passage, Batangas, Luzon, Philippines. Biodiversitas 20: 3189-3198. The study described the communities of woody plants in a semi-evergreen tropical forest dominated by endemic Philippine teak (Tectona philippinensis Benth. & Hook. f, Lamiaceae) and determined the local environmental factors affecting the distribution of dominant woody species across the Philippine teak forest (PTF) landscape. The Philippine teak is a Critically Endangered species according to the International Union for the Conservation of Nature (IUCN). Quantitative dominance analysis of arboreal vegetation data (basal area and relative dominance) from 24 (20 m x 20m) sampling plots generated the cluster dendrogram, while Canonical Correspondence Analysis (CCA) was performed for 47 woody species and habitat-environment variables. As a result, four vegetation zones were named: (I) pure stand of Tectona philippinensis, (II) mixed T. philippinensis-Garuga floribunda-Terminalia polyantha, (III) mixed Celtis latifolia-T. philippinensis and (IV) mixed Tamarindus indica-Xylocarpus rumphii. These zones were governed more by physiographic (altitude ) and edaphic influences of predominantly agro-coastal landscapes. The environmental variables were essential in verifying not only the association of dominant tree flora in the local landscape but also provide insight for forest management zoning and the ecological requirements of the tree species for in-situ and ex-situ biodiversity conservation.

Keywords: Endemic species, Philippine teak, Tectona philippinensis, Verde Island Passage

INTRODUCTION

The tropical forests of Southeast Asia is distinct in terms of floristic composition and diversity due to complex biogeography and environmental heterogeneity (Whitmore 1975, 1988; Newbery et al. 1992; Buot and Okitsu 1998; Newbery et al. 1999; Belonias and Aguilar 2004; Buot and Osumi 2011; Heng et al. 2017). Forest vegetation has a subtle response to environmental influences, resulting in variation in species composition and structure, and serve as bio-indicators of landscape productivity and human disturbances (Buot 2007; 2008; Sopsop and Buot 2013; Nguyen et al. 2015; Van and Cochard 2017). Thus, it was always of interest and value to investigate the plant communities in this landscape (Whittaker 1960, 1965; Mueller-Dombois and Ellenberg 1974; Aragones 1991; Villanueva and Buot 2018).

In the Philippines, there is the existence of diverse natural forests known as ecotypes or formation characterized by distinct species composition and structure, which were classified based on the dominant tree elements (Department of Environment and Natural Resources-United Nations Environment Programme, 1997; Baguionon 2000; Malayang 2001; Pullin 2002). These formations ranged from sea level up to 2,954 m altitudes and were the focus of ecological classification since the 1900s (Whitford 1909, 1911; Whitmore 1984; Cadiz 1986; Fernando 1988; Tan and Rojo 1988; Madulid 1994; Fernando et al. 2008). The Philippine teak forest (PTF), however, has not yet been widely studied among the unique ecotypes in the Philippines. In Batangas Province along the Verde Island Passage, the forest with Philippine teak (Tectona philippinensis Benth. & Hook. f, Lamiaceae) occurs as fragments across the agro-coastal landscape at low altitudes (05-200 m asl. particularly in the municipalities of Lobo, San Juan, and Taysan and Batangas City where the natural tree populations show spectacular flowering episodes preceding a long summer (Agoo and Oyong 2008; Caringal et al. 2015). Tectona philippinensis was first described by British botanists George Bentham and Joseph D. Hooker (1876) based on the specimens deposited at London’s Kew Herbarium which was collected by English naturalist Hugh Cuming (1432) from the shores of Batangas, Luzon. Because of its limited and fragmented distribution, the species is of special interest to phytogeographers in the Malesian Region (Madulid and Agoo 1990). Based on the assessment criteria of the International Union for the Conservation of Nature (IUCN), T. philippinensis has been classified as Critically Endangered (Madulid et al. 2008).

Given the narrow distribution and current conservation status of Tectona philippinensis, it is therefore important to study the ecological aspect of the PTF to provide in-depth and significant information about this unique ecotype in the...
Philippines. As there were fewer local landscape-level studies about the Philippine teak, this study was undertaken to reveal the dominant floristic elements according to plant community patterns of the Philippine teak forest. Using the data gathered from the vegetation surveys in the Philippine teak forest, the researchers used classification analysis (Cluster Analysis) in identifying the plant communities in the study area. Moreover, ordination analysis (Canonical Corresponding Analysis) was also utilized in investigating the influence of the environment and anthropogenic factors on the species distribution in the Philippine teak forests. The results can be used in forest management zoning particularly in locally and nationally important ridge-to-reef biodiversity conservation corridors of Verde Island Passage.

MATERIALS AND METHODS

Study area

The vegetation survey was conducted along Batangas Province, particularly in the areas of Batangas City, municipality of Lobo, and Isla Verde (08-321 m asl, 13°30'-13°40' North latitudes and 121°05'-121°15'East longitudes) in southwestern Luzon, Philippines (Figure 1). Twenty-four (24) 20m x 20m vegetation plots were taken from Isla Verde to the mainland (56.48 km connectivity), which have gentle to undulating, rolling to moderately steep slopes (0.10 to 51.99%). The plots were located for some distances (58.5m to 6225.28m) along the coastal cliff towards inland ridges and narrow valley facing the sea of Verde Island Passage (Figure 1). The landscape consists of volcanic agglomerates from various ages such as Talahib Andesite (Upper Oligocene-Miocene), Lobo agglomerate (Pleiocene-Pleistocene) and San Juan Quartz Diorite (Lower Miocene) where the underlying geography is shallow, soft and porous reef limestone (Pleistocene) including bushes of corals, shells, algae structure and recently alluvium formation (Bureau of Soils 1987; Bureau of Mines and Geo-Sciences-Mindoro Resources Limited Gold Philippines Inc 1981; Caringal 2007; Comprehensive Land Use Plan of Lobo, Batangas 2012; Cox 2010; Mindoro Resources Limited 2004). The mean annual precipitation (1980-2016) is 151.89 mm in Batangas Province (Figure 2). The precipitation in the province reaches is at its highest records in July (331mm). Low rainfall (27-32mm) was experienced during summer, January to April. Annual mean temperature (AMT) was 27.36°C ranging from 26°C-29°C (Figure 2).

Procedures

Forest vegetation survey

Fieldworks were conducted from October 2016-February 2017 and resulted in a total of 24 (20m x 20m) vegetation plots (=0.96ha). The sampling locations were identified before successive field surveys of the Tectona philippinensis forests. The plots were purposively selected based on (i) the quality of trees and associated plants and (ii) the presence of human-related disturbances or expansion activities that may affect the forest structure. Six vegetation plots were located in the coastal zone (including 1 island coast), three plots in a narrow inland valley, and 15 plots in inland ridges-all lying apart west to east from north to south directions (Figure 1). Vegetation assessment was done following the techniques of Mueller-Dombois and Ellenberg (1974).

Figure 1. The Philippine teak forest landscape along the Verde Island Passage, Batangas Luzon, Philippines. The study plots were shown as small 1-24 black squares from an island to coastal-mainland of Batangas Province, Philippines.
In each plot, the diameter at breast height (DBH) of trees (at least ≥10 cm) was measured with a diameter tape at 1.3 m from the ground while heights were estimated visually following Erenso et al. (2014). Crown dimensions were measured by a meter tape following Almazol and Quintana (2009). Altitudes and coordinates of all study plots were taken using a Garmin 76Csx Global Positioning System (GPS) receiver.

Woody plants were identified with the help of local botanists and verified with photographs of plants from the field and herbarium vouchers lodged at the Batangas State University Herbarium (BatStateU-H) and Plant Biology Division Herbarium of the Institute of Biological Sciences, University of the Philippines at Los Baños (UPLB). Species nomenclature followed the Revised Lexicon of Philippine Trees (Rojo 1999), An Enumeration of Philippine Flowering Plants (Merrill 1923-1926), Flowering Plants and Ferns of Mt. Makiling (Fernando et al. 2004) and Dictionary of Philippine Plant Names (Madulid 2001).

Data analysis
Cluster analysis
To identify the plant communities in the forest landscape, the basal area (BA) values of the woody species were subjected to cluster analysis using the unweighted pair group method with arithmetic mean (UPGMA) algorithm and Euclidean distance as the index of similarity among the plots. The PAleontological STatistical (PAST) software (Hammer et al. 2010) was used to run the analysis and generate the cluster dendrogram of the plots. The diagram was used to visualize the representation of the clusters of the vegetation plots as plant communities in the landscape.

Dominance analysis
The dominant species were identified to further describe each of the plant community that was identified from the cluster analysis. In this study, the relative basal area (RBA) of the woody species was used as a measure of dominance. These were quantitatively identified using the of Ohsawa (1984):

\[
d = \frac{1}{N} \left\{ \sum_{i=1}^{T} (x_i - \bar{x})^2 + \sum_{j \neq i} x_j^2 \right\}
\]

Where:
- \(d\) : The deviation
- \(x_i\) : The actual percent share [in this case, the RBA] of the top species (T), i.e. the top dominant in the one-dominant model, or the two top dominants in the two-dominant model and so on
- \(x\) : The ideal percent share based on the aforementioned model
- \(x_i\) : The percent share of the remaining species (U)
- \(N\) : The total number of species.

Consequently, each plant community (cluster) was named after the dominant and co-dominant tree flora, i.e. species with the highest RBA values. The number of the dominant species that represent the plant communities was based on the formula above.

Proximity analysis for physiographic and anthropogenic factors
Proximity analysis of the Philippine teak plots to the various physiographic regime such as altitude (m asl.) and distances (m) to or from the streams, coast or shoreline and anthropogenic disturbances (e.g. roads, built-up areas, settlements, farms) was undertaken by an ArcGIS specialist. This computed the approximate straight line distance (measured in meters) between a plot and any spatial object, given a UTM 51N projected coordinate system and a WGS 1984 geographic projection. The stream network used for the analysis was topographically derived from NAMRIA’s 5m spatial resolution IfSAR DEM, provided that first-order streams have a minimum catchment area of 20,000m². The road network is from Open Street Maps, and built-up areas were isolated from the latest available land cover map of NAMRIA. The results of the GIS-based approximate analysis, however, was in some aspects validated with the actual observation in the studied plots, hence there were some data fine-tunings.

Edaphic environment analysis
These are the results of laboratory analysis done on basic soil chemical properties such as acidity (pH), moisture content (%MO), organic matter (% OM) and organic carbon (% OC), nitrogen (% N), phosphorus (P ppm), and potassium (K ppm). Soil samples in each plot were collected uniformly following the procedures formulated by PCARR (1980). Soil sampling point (25 cm x 25 cm x 30 cm pit) was dug using an auger and spade.
from four corners of each plot and 1 from the middle. At least 1kg soil slices from these 5 points were mixed thoroughly and cleared with stones, grasses, weeds or other plant debris. Each 1kg soil sample was sealed in a plastic bag, labeled and were analyzed at the Regional Soils Testing Laboratory of the Philippine’s Department of Agriculture (DA) in Lipa City, Batangas. These quantitative values were identified and used in analyzing the influence of the environment variables (including soil data) on the formation of the plant communities in the landscape.

Canonical correspondence analysis
To explain the relationship of dominant tree flora in the Philippine teak forest with the habitat environment factors, Canonical Correspondence Analysis (CCA) of Ter Braak (1986) was performed using the statistical software R version 3.4.2 (R Core Team, 2013) with the vegan package (Oksanen et al. 2007). Environmental factors including soil data, altitude, slope and proximity to anthropogenic disturbances were tested (Table 1). These environmental gradients are the basis for visualizing (modelling) and describing the differential habitat preferences ( niches) of taxa through an ordination diagram.

RESULTS AND DISCUSSION

Plant communities of the woody plants in the Philippine teak forest landscape
The dendrogram generated from cluster analysis of woody species basal area (BA) revealed four plant communities (Table 2, Figure 3) named according to their dominant species: (I) pure Tectona philippinensis (33-213 m asl.), (II) mixed Tectona-Garuga-Terminalia (37-321 m asl.), (III) mixed Celtis-Tectona (53 m asl.) and (IV) mixed Tamarindus-Xylocarpus (8-209 m asl.) (Figure 4).

Table 1. Environmental variables used in Canonical Correspondence Analysis (CCA)

<table>
<thead>
<tr>
<th>Environmental variable</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Physiographic</td>
<td></td>
</tr>
<tr>
<td>Percent slope</td>
<td>SLP</td>
</tr>
<tr>
<td>Proximity to the sea</td>
<td>SEA</td>
</tr>
<tr>
<td>Proximity to the river</td>
<td>RIV</td>
</tr>
<tr>
<td>Altitude</td>
<td>ALT</td>
</tr>
<tr>
<td>Edaphic</td>
<td></td>
</tr>
<tr>
<td>Soil moisture</td>
<td>MO</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>OC</td>
</tr>
<tr>
<td>Organic matter</td>
<td>OM</td>
</tr>
<tr>
<td>pH</td>
<td>pH</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td></td>
</tr>
<tr>
<td>Proximity to built-up areas/</td>
<td>SETL</td>
</tr>
<tr>
<td>settlement</td>
<td></td>
</tr>
<tr>
<td>Proximity to swidden or farm</td>
<td>FR</td>
</tr>
<tr>
<td>Proximity to road</td>
<td>RD</td>
</tr>
</tbody>
</table>

Cluster I. Pure Tectona forest (33-213m asl.): It was formed from a broadleaved monsoon forest, turning completely deciduous in summer months (January-April) located in inland ridges (Figure 7), narrow valley and coast. This plant community has 25 woody species with many indigenous trees such as Memecylon edule, Terminalia polygonha, Vitex parviflora, Sterculia foetida and Hibiscus tiliaceus. There are many anthropogenic disturbances in almost all the plots (Table 2). The tree height were ranged from 4 to 22 m while DBH ranged from 10 to 77.66 cm. The maximum basal area for the most dominant species, i.e. T. philippinensis was 748.01 m² and with RBA of 72.65%.

Cluster II. Mixed Tectona-Garuga-Terminalia forest (37-321 m asl.): This cluster is a broadleaved semi-deciduous forest from inland ridges to the coast composed of other co-dominant species such as Vitex parviflora, Gliricidia sepium, Dehassia triandru, Memecylon edule, Wrightia pubescens and Scolopia luzonensis. The plots were also affected by various anthropogenic disturbances (Table 2). This plant community had 36 woody species with DBH range from 4.14-60.48 cm and height of 6-23 m. The combined total basal area for the three dominant species was 1,103.98 m² with T. philippinensis having the highest RBA of 36.43%.

Cluster III. Mixed Celtis-Tectona (53 m asl.): This is a semi-evergreen forest in a coastal cliff (Plot 5) with very few (5) and scanty woody species adjoining uphll swidden patches overlooking the coastal road and dense settlement below. In this zone, Celtis latifolia is the evergreen broadleaved tree associated with deciduous T. philippinensis. Tree DBH ranged from 3.81-57.93 cm while heights were 5-15 m. The combined basal area of the dominants (C. latifolia and T. philippinensis) was 44.54 m². The RBA of C. latifolia was 51.51%, while T. philippinensis was 35.54%.

Cluster IV. Mixed Tamarindus-Xylocarpus (8-209 m asl.): This is an evergreen forest in ridge valley and beach coast composed of 12 woody species having DBH that ranged from 3.81-91.99 cm and heights ranged from 3-20m. In this plant community, T. philippinensis was overshadowed by most dominant species Tamarindus indica with a basal area of 161.42 m² and RBA of 52.79% and, Xylocarpus rumphii with a basal area of 66.74m² and RBA of 21.83%. In this zone, Terminalia catappa, Thespesia populnea, and Guettarda speciosa are co-dominant trees.

Environmental factors influencing the distribution of woody plants
Using Canonical Correspondence Analysis (CCA), the distribution of 24 sampling plots (quadrats) and 47 woody species over environmental gradients were presented in Figure 5 and Figure 6. The eigenvalue of Axis 1 was 0.531 while Axis 2 was 0.408 with 24.67% total inertia (weighted variance) and 42.12% of the variance in the weighted averages and class totals of the species with respect to environmental variables. The CCA biplot showed that habitat environment variables affected the distribution and dominance of species in the forest.
Table 2. Tree communities, distribution of the sample plots and observed human disturbances in the Philippine teak forest landscape

<table>
<thead>
<tr>
<th>Tree communities</th>
<th>Tree or woody species richness</th>
<th>Altitude (m asl.)</th>
<th>Slope (%)</th>
<th>Dominant trees</th>
<th>$\sum BA$ (m²)</th>
<th>RBA (%)</th>
<th>Observed Anthropogenic Disturbances (ADs)*</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster I (plots: 3, 4, 7, 16, 17, 13, 20, 1, 24, 22, 12)</td>
<td>25</td>
<td>33-213</td>
<td>0.61-86.17</td>
<td>Tectona philippinensis</td>
<td>748.01</td>
<td>72.65</td>
<td>SCP, PGL, AT, FLG, Ro, HS</td>
<td>Inland ridges, valley, coast</td>
</tr>
<tr>
<td>Cluster II (plots: 6, 14, 15, 8, 18, 9, 10, 21, 11, 19)</td>
<td>36</td>
<td>37-321</td>
<td>2.68-251.99</td>
<td>T. philippinensis</td>
<td>521.43</td>
<td>36.43</td>
<td>SCP, PGL, AT, FLG, Ro, HS</td>
<td>Inland ridges, coast</td>
</tr>
<tr>
<td>Cluster III (plot: 5)</td>
<td>5</td>
<td>53</td>
<td>32.02</td>
<td>Celtis latifolia, Terminalia polyanthes, Garuga floribunda</td>
<td>26.36</td>
<td>51.51</td>
<td>SCP, PGL, AT, FLG, Ro, HS</td>
<td>Coastal cliff</td>
</tr>
<tr>
<td>Cluster IV (plots: 2, 23)</td>
<td>12</td>
<td>8-209</td>
<td>56.87-97.88</td>
<td>Xylocarpus rumphii, Tamarindus indica</td>
<td>161.42</td>
<td>52.79</td>
<td>AT, FLG, Ro, HS</td>
<td>Ridge valley and ridge coast</td>
</tr>
</tbody>
</table>

*Notes: Observed Anthropogenic Disturbances (ADs): SCP: Near swidden and crop plantations, e.g. ates, ipil-ipil, mahogany, other cropping (within 5-20 m distance); PGL: Near pasture or grazing land or the study plots with ipil-ipil source of forage (within 5-20m distance); AT: Near access trail within 5-20m distance; FLG: The plots with remnant cuts of fuelwood or lumber gathering; Ro: Near road within 5-100m distance; HS: Near human settlement within 10-100m distance

Figure 3. Dendrogram generated from cluster analysis based on woody species basal area (BA) in the Philippine teak forest landscape using the UPGMA algorithm with cophenetic correlation of 0.88. At a Euclidean distance between 50-60, four clusters were identified with corresponding dominant tree species having the highest relative basal area (RBA).
The result of ordination is complementing the cluster analysis which modelled four plant communities (Figure 3). On the upper portion of the biplot was Cluster II, associated with edaphic factors such as increasing level of potassium (K), soil moisture (MO) and pH. Cluster III (Plot 5 MC) was more sensitive to moisture and pH levels, while Cluster IV (Plots 2 RV and 23 MC) except with phosphorous level was diverged from most of the edaphic vectors and was also influenced by slope gradient (Figure 5, Figure 6). The lower part of the second axis showed that Zone I (valley and ridge plots) was greatly influenced by physiographic factors such as altitude (ALT) and distance from the coast (SEA).

However, considering the holocoenotic nature of the environment, these seemingly isolating influences of certain edaphic or physiographic factors might also be coupled with other influences such as low to moderate effects of slope (SLP), other edaphic attributes such as level of organic matter (OM), organic carbon (OC) and phosphorous (P); anthropogenic disturbances such as roads (RD), farming (FR) and settlement (SETL) or by combination of all these factors. Interestingly, the sites were ordained generally far from riparian influence (RIV), suggesting that PTF is a formation characteristic of the dry woodland environment along Verde Island Passage.

Discussion

The communities of woody plants have their own distinct characteristics species. There was the pure natural stand of *T. philippinensis* in Cluster I while mixed-stand of *T. philippinensis*, *Terminalia polyantha* and *Garuga floribunda* in Cluster II. The forest canopy in these zones become typically deciduous during summer and extended drought. *Garuga floribunda* was a typical tree of the semi-deciduous forest from 0-900 m altitude in Sierra Madre and Palawan, but in Batangas it was a rare co-dominant with endemic *T. philippinensis*. The PTF occurs with beach flora such as *Celtis latifolia* (Cluster III) but overshadowed in terms of dominance by *Xylocarpus rumphii* and *Tamarindus indica* (Cluster IV). Though *T. indica* was encountered on the island and mainland beach coast or coastal cliff, it has a very low affinity with the beach forest’s *X. rumphii* as the former was more frequent in inland valley and ridges.

The vegetation succession or the dynamic of habitat-environment interaction can be initiated by the interplay of the following factors: [i] floristic composition of a given landscape, [ii] ability of a given species to reach the habitat, [iii] eco-physiology and morphology of plant life, [iv] the habitat, and [v] the time that has elapsed following a major disturbance (Mueller-Dombois and Ellenberg 2002). The Philippine teak plant communities can be best seen as a consequence of habitat-environment gradient filtering, as well as habitat specialization, as proposed by Oliveira et al. (2014) for the “restinga” forest in the Brazilian coast, where more abundant species in “restinga” forest has niche overlap with other species in at least one habitat. Closely related species tended to occur in different habitats while neighboring trees tended to belong to more distantly related species (Oliveira et al. 2014). This made the structure of the ecological species groups to be associated with a combination of habitat factors such as elevation, soil pH, vegetation type and management disturbance regime and, thus, good indicators (Quimio et al. 2013).
Figure 5. The results of ordination analysis in the studied area over 13 environmental variables using Canonical Correspondence Analysis (CCA) based on relative basal area (RBA) of 47 woody species. The 13 environmental variables were: physiographic-percent slope (SLP), proximity to the sea (SEA) and river (RIV), and altitude (ALT) above the sea; edaphic-levels of soil moisture (MO), organic carbon (OC), organic matter (OM), pH, phosphorous (P) and potassium (K) and anthropogenic-proximity to built-up areas, settlement (L or SETL), swidden or farm (FR) and road (RD). The objects (plots 1-24, green squares) are representing four vegetation zones across satoyama-satoumi landscape such as mainland ridges (MRs), ridge valleys (RVs), mainland coast (MC) and island coast (IsC). The four clusters of plots are encircled in red.

Figure 6. CCA ordination diagram showing the distribution of the woody species in the biplot (orange dots S1 to Sn…). The figure also indicated the 24 sampling sites (green squares, unlabeled) and 13 environmental variables influencing the distribution patterns of the woody species. The Sn are descriptors of 47 woody species under the following genera: Spondias (S1), Wrightia (S2), Garuga (S3), Bauhinia (S4), Tamarindus (S5), Celtis (S6), Capparis (S7), Crataeva (S8), Salacia (S9), Terminalia catappa (S10), T. polyantha (S11), Cycas (S12), Diospyros (S13), Macaranga (S14), Hibiscus (S15), Melanolepis (S16), Gliricidia (S17), Scolopia (S18), Cratoxylum (S19), Tectona philippinensis (S20), Vitex (S21), Dehassia (S22), Berrya (S23), Bombax (S24), Colona (S25), Grewia (S26), Pterocymbium (S27), Pterospermum (S28), Serculila (S29), Theopsis (S30), Memecylon (S31), Xylocarpus (S32), Acacia (S33), Albizia (S34), Leucaena (S35), Ficus sumatrana (S36), F. ulmifolia (S37), F. variegata (S38), Antidesma (S39), Camthian (S40), Guettarda (S41), Mussuenda (S42), Tarrena (S43), Murraya (S44), Dimocarpus (S45), Dodonaea (S46) and Harpaullia (S47).
Edaphic and physiographic factors displayed influence on the formation of plant communities and species distribution patterns. Available edaphic data analysis further revealed that PTF occurred in slightly acidic to acidic soils (pH 5.73); low in moisture (11.88%) but still has an adequate organic matter (6.08%); medium organic carbon content (3.54%); medium amount of phosphorus (8.37ppm) and extremely high potassium content (360.5ppm). Given such data-based analysis, the PTF can be seen improving soil quality or evolved by sets of the valuable edaphic environment (forest-soil interaction), hence the dominant T. philippinensis can be considered among the edaphic-endemic species of the Philippines. The Philippine teak forests occurred along coastal hills, littoral cliffs and inland limestone ridges with shallow sedimentary rock formation known as Mt. Santiago Limestone developed during the Pliocene and Pleistocene period (Madulid and Agoo 1990; Bureau of Soils 1987; Caringal et al. 2015). Generally, limestone substrate have shallow clayey topsoil consisting mainly of porous calcium carbonate and sands (Cox 2010), low in water and nutrient holding capacity and high permeability, slightly acidic to mildly alkaline and moderate to high fertile soils support the Philippine teak forest (Ecosystems Research and Development Bureau 2003; Hernandez et al. 2016). All these, together with other attributes of limestone substrates, make the PTF landscape a very dry one (Whitford 1911). The arid environment of PTF can be also attributed to anomalous macroclimate turning the forest completely deciduous, creating canopy gaps and exposing the landscape to direct sunlight during summer and periodic prolonged droughts (Madulid and Agoo 1990; Caringal and Makahiya 2000; Caringal et al. 2015; Briones et al. 2018). Under these stressful edaphic-climatic conditions, it was found out that T. philippinensis had already developed special physio-anatomical features related to persistent adaptation in xeric habitat (Hernandez et al. 2016). Edaphic factors such as moisture availability and nutrients directly influence species niche differentiation and spatial distribution of tropical trees at the local-regional scales (Engelbrecht et al. 2007). The assembly of tropical tree communities at plot scales is largely influenced by soils and habitat factors in the landscapes (John et al. 2006).

As a semi-deciduous secondary forest, PTF depends on the dynamic aspect of physiography as it grows on low relief, slightly dissected limestone hills and abyss with slopes ranging from 18 to 50% characterized by moderate hazards (Madulid and Agoo 1990). More specifically, available GIS proximity data analysis showed that on the average, the PTF grows inland at low altitude (142 m asl.) as far as 1.95 km from the coast; along steep ridges or hilly to mountainous areas (52.37% slope) and very far...
(2.038km) from major riparian vegetation. The forest formations in the Philippines were classified according to physiographic conditions from sea level up to the highest mountain (DENR-UNEP 1997; Malayan 2001; Pulhin 2002; Fernando et al. 2008). Richardson et al. (1995) stressed that soils and topographic conditions explained well the patterns of distribution and co-existence among plant species.

Pausas and Austin (2001) suggested that studying multidimensional environmental factors can help understand the plant species composition in the landscape. This generalization was particularly important for the PTF as other factors are affecting this threatened biota. In particular, the forest patches are generally far (1.4 km) from the settlement but near, 129.4m to cultivated hilly lands and affected by road expansion 364 m away. Patches of “kaingin” (swidden), monocrop “ates” plantations as well as grazing extend up from the base of the coastal hills to narrow uplifted valley and inland ridges where there are sparse human settlements and road extensions. In less accessible ridges known by Loboanos as “nasya” (horseback) and “kastilyo” (rocky ridgetop), natural stands of T. philippinensis have straight boles and with medium to large diameter individuals. Here, some rare and singleton species such as Cycas, Diospyros, Marraya, Vandas, geophytes, and epiphytes thrive well. But in more disturbed sites such as frequently grazed valley and coastal hills cleared for farming, settlement, and dissected by road construction, T. philippinensis exhibits slashed and stunted growth, multi-stemmed and intermixed with shrubs and undershrubs of the genus Chromolaena, Hypitis, Lantana, and Sida.

This study identified four plant community types along the Philippine teak forest landscape at Verde Island Passage, Batangas, Philippines. The formation of the plant communities does not only reveal the dominance of T. philippinensis on-site (Clusters I); it also displayed the co-existence and/or co-dominance of other plant species, as in the case of the other clusters identified (II, III and IV) from the cluster and dominance analyses.

The PTF has its ecological niche among the classified Philippine forest formations. Within the broad and yet regionally important tropical forests, environmental factors such as elevation and soil type have determined the corresponding differences in forest structure and dominant species. Though climatic factors like rainfall also helped essentially the unique plant diversity, ‘geodiversity’ (soil type and elevation) was greatly recognized for the existence of different forest formations in the tropics such as the tropical dry forest and semi-evergreen forest (Thomas and Baltzer, 2002).

For future studies, it is also recommended to consider conducting studies on the vegetation of PTF on other areas along the Verde Island Passage, particularly in the areas of Northwest Island and other coastal municipalities (Mabini, Tingloy, and Nasugbu) in Batangas. Moreover, GIS mapping of this forest type will also be helpful for the land-use zoning and development planning, so that the conservation and management efforts for the Philippine teak will be integrated into the local and national government initiatives.

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