

Endemic Philippine teak (*Tectona philippinensis* Benth. & Hook. f.) and associated flora in the coastal landscapes of Verde Island Passage, Luzon Island, Philippines

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The Philippine teak forest (PTF) is a formation with the Endangered *Tectona philippinensis* Benth. & Hook. f., Lamiaceae – an endemic tree flora in the Batangas Province along the Verde Island Passage, Luzon Island, Philippines. In this study, we determine the general floristic composition of PTF. Vegetation analysis across coastal to inland continuum generated the data for general floristic richness, growth structure and diversity indices. A total of 128 species under 111 genera in 48 families was recorded with overall plant diversity of very low to moderate (Shannon–Wiener: 0.8675–2.681). Plant life based on morpho-species was composed of dominant trees (68 species), shrubs (5) and subshrubs (9), bush palm (1) and palm-like tree (1), lianas (7), epiphytic tree (1), semi-woody climbers (3), epiphytic and geophytic orchids (4), epiphytic and terrestrial ferns (5), annuals to erect succulent perennial herbs (9), herbaceous climbers and creepers (6), geophytic herbs and climber (1), low and tall grasses, including bamboo (5) and sedges (2). Such structural diversity is comprised of some of the unique botanical ensembles associated with endemic *T. philippinensis* in the coastal landscape.

Keywords: Coastal landscape, epiphytes, *Tectona philippinensis*, teak forest.

THE tropical forests of Southeast Asia differ in floristic composition, diversity and structural ensembles due to biogeography and environmental heterogeneity^{1–9}. Across the Philippines, diverse natural forests exist with distinct species composition and structure^{10–12}. These ecotypes or formations ranging from sea level to over 2954 m altitudes (i.e. mangroves, beaches, freshwater peat swamps, forests over ultramafic soils and limestone karst, semi-

deciduous forests, pines, lower and upper montane forests and sub-alpine) based on the dominant floristic elements have been the focus of ecological classification since 1900s (refs 13–16). The Philippine teak forest (PTF), however, has not yet been included in these national classifications.

The forest with endemic *Tectona philippinensis* Benth. & Hook. f., (APG: Lamiaceae) has long been considered as one of the most important areas of floristic richness^{10,17,18}. Until the present study, however, PTF remains to be classified among the major forest ecotypes in the Philippines. Ecological studies for PTF have specially focused on phenological synchrony^{19,20}, xerophytic adaptation²¹, genetic diversity²², and a pioneering conservation assessment for the International Union for the Conservation of Nature (IUCN)²³. However, there is less information on landscape-level details about the floristic elements and structure across the Verde Island Passage Marine Corridor (VIPMC), an area of conservation importance within the Southern Luzon Biogeographic Region of the Philippines^{24,25}.

T. philippinensis was first described by British botanists George Bentham and Joseph D. Hooker (1876) based on the specimens deposited at London’s Kew Herbarium. The species was collected by the English naturalist Hugh Cuming (1432) from the shores of Batangas, Luzon, Philippines¹⁷. Since then, the Philippine teak is of special interest to phytogeographers in the Malesian region.

The Batangas Province has one of the fastest rates of land-use conversion in the Philippines²⁶. Massive development of road networks and lateral expansion of urban settlements to outlying rural districts have been ongoing in Batangas during the last 30 years²⁶. Madulid *et al.*²³ reported for the Species Survival Commission of the IUCN that these developments have threatened the natural population of *T. philippinensis* in the Province. Hence,

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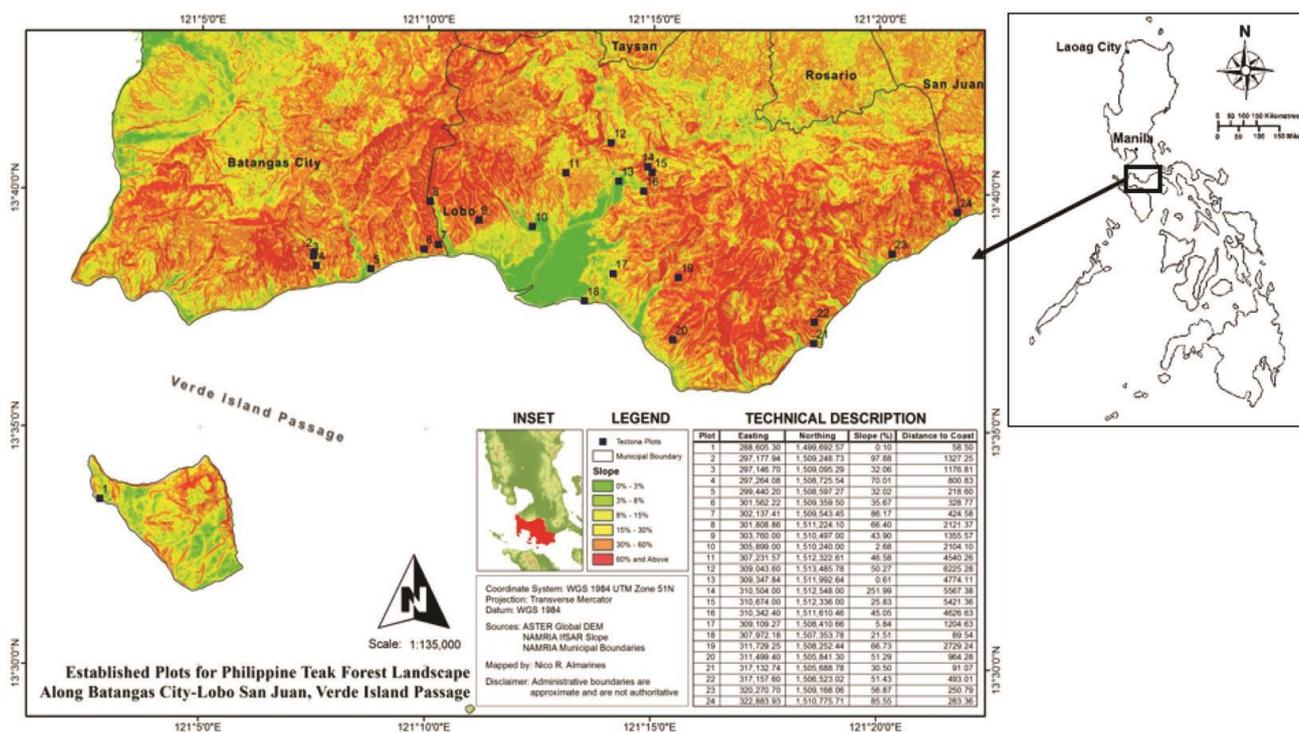


Figure 1. Study area showing the coastal landscapes of island–mainland municipalities of Batangas City, Lobo, and San Juan, Batangas province, Philippines, where Philippine teak forest (PTF) was sampled. Sampling plots are marked as black squares.



Figure 2. PTF in the *satoyama* landscape at Lobo, Batangas.

this study reveals the species composition and structure of PTF which can be lost or degraded in the course of these anthropogenic expansions. The results can be used as an input in designing and implementing native forest restoration projects, particularly in the locally important biodiversity conservation corridor.

As there are fewer accurate reports on the floristic composition and structure about PTF, this study aims to describe the species composition and vegetation structure of the PTF.

Materials and methods

Study area

The study was conducted along Isla Verde–Batangas City–Lobo–San Juan coastal landscapes in Batangas Province (8–321 m asl, 13°30′–13°40′N and 121°05′–121°15′E), southwestern Luzon, Philippines (Figures 1 and 2). The 24 study plots (marked as black squares in the map) from Isla Verde to the mainland (56.48 km connectivity) have gentle to undulating, rolling to moderately steep slopes (0.10–51.99%), located for some distance (58.5–6225.28 m) along the coastal cliff towards inland ridges and narrow valley facing the sea of Verde Island Passage. The landscape consists of volcanic agglomerates from various ages such as Talahib Andesite (Upper Oligocene–Miocene), Lobo agglomerate (Pleistocene–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 recent alluvium formation^{27–29}.

The mean annual precipitation for 1980–2016 was 151.89 mm in Batangas Province. Highest precipitation (113–331 mm) was observed during the southwest monsoon season, viz. May to July, which decreased (292–101 mm) from August to December. Low rainfall (27–32 mm) was experienced during summer, viz. January to April. The

annual mean temperature for the same period at the weather station was 27.36°C, ranging from 26°C to 29°C.

Methods of floristic inventory and diversity analysis

Vegetation data were collected between October 2016 and February 2017 from 24 20 m × 20 m (=0.96 ha) plots, which were randomly established along the 56 km island–mainland agro-ecosystem continuum. Altitudes and coordinates of all study plots were taken using a Garmin 76Csx global positioning system receiver. In each plot, 100% tallying (abundance count) of woody and non-woody species was done. The diameter at breast height of trees (at least ≥10 cm) was measured with a diameter tape at 1.3 m from the ground, while heights were measured using a tree height meter from the base to the topmost part of the crown. The tree heights were estimated visually³⁰. Crown dimensions were measured by a meter tape³¹. Photographs of plant life were taken. Specimens were collected with the aid of climbers and prepared into herbarium vouchers lodged at the Batangas State University Herbarium in Lobo Batangas, Philippines. Duplicate vouchers were deposited at the Plant Biology Division Herbarium (PBDH), Plant Systematics Laboratory, Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines at Los Baños.

At least 85–90% of floristic morpho-species (trees, shrubs, vines, herbs, ferns and epiphytes) were enumerated. Species nomenclature and growth forms classification were done according to the literature^{32–36}. The families of ferns followed the classification by Smith *et al.*³⁷ and that of Pteridophytes Phylogeny Group³⁸, while angiosperms and gymnosperms followed the subsequent classification updates (1997–2016) of the Angiosperm Phylogeny Group (APG)³⁹.

The species richness (SR) and total abundance or number of individuals (*N*) were derived from species enumeration and density tallying count, while the Shannon–Weiner diversity index (*H'*) and other diversity indices were generated using the Microsoft Excel (2007) table data in the BioDiversityPro software⁴⁰ and Paleontological Statistics (PAST, version 2.10)⁴¹.

Results

Floristic composition of the Philippine teak forest

[Supplementary Table 1](#) shows all the observed species (*S*_{obs}) other than trees as suggested by Langenberger⁴², with notes about growth habit, habitats, abundance records, occurrences and as well as geographic affinity. Altogether, four subspecies and four varieties belonging to 128 species under 113 genera in 46 families were recorded from the 24 plots. Following the species abundance

classification of Colwell⁴³, 80 (63%) of the total 128 observed species in this study were considered abundant – each with more than ten individuals, while 29 species (23%) as rare – each with at least three or fewer than ten individuals. Six species (4%) were rare doubletons – with exactly two individuals, while 13 species (10%) were rare singletons – with exactly a single individual.

The most abundant native trees were *Tectona philippinensis* with 6340 individuals, followed by *Hibiscus tiliaceus* L. subsp. *tiliaceus* (611), *Terminalia polyantha* (560), *Memecylon edule* (472), *Murraya paniculata* (147) and *Vitex parviflora* (129). *Leucaena leucocephala* (1992) and *Tamarindus indica* (164) were the most abundant cultivated trees, while shrubs and ruderal undershrubs such as *Lantana camara* (499), *Acalypha amentacea* (454), *Sida rhombifolia* ssp. *rhombifolia* (1182), *Ageratum conyzoides* (1721), *Hyptis suaveolens* (652), *Crossandra infundibuliformis* (506) and *Chromolaena odorata* (435) were also common.

Epiphytic and terrestrial pteridophytes were observed owing to high abundance of *Adiantum caudatum* (3186), *Drynaria quercifolia* (520), *Sellaginella tamariscina* (205) and *Adiantum philippense* (148). The rare doubletons included *Cordia dichotoma*, *Diospyros ferrea*, *Albizia procera*, *Alseodaphne malabonga*, *Streblus ilicifolius* and *Syzygium mindorensis*. The rarest unique singletons were trees such as *Mallotus philippensis*, *Caesalpinia bonduc*, *Prosopis juliflora*, *Bombax ceiba*, *Heretiera sylvatica*, *Ficus* spp., *Guettarda speciosa*, *Morinda citrifolia*, *Trigonachras cuspidata* and an orchid – *Trichoglottis latisejala* ([Supplementary Table 1](#): N/F).

There were 108 species of angiosperm dicots and 14 species of monocots, one gymnosperm (*Cycas edentata* de Laubenfels) and five species of pteridophytes. The species rich plant groups were Fabaceae (18 species), Malvaceae (15), Lamiaceae (7), Apocynaceae, Euphorbiaceae and Moraceae (with 6 species each); as well as Asteraceae, Malvaceae, Poaceae and Rubiaceae (with 5 species each). Orchids and sapindaceous flora with four species each were also unique elements of PTF ([Supplementary Table 1](#)).

Many growth forms were disturbance-indicators (38 species in Table 1), such as herbs (*Achyranthes*, *Ageratum*, *Euphorbia*, *Phyllanthus*, etc.), climbers and vines (*Chromolaena*, *Ipomea*, *Caesalpinia*, *Centrosema*), grasses (*Dactyloctenium*, *Leersia*, *Saccharum*), shrubs and subshrubs (*Acacia*, *Capsicum*, *Crossandra*, *Flemingia*, *Lantana*, *Stachytarpetta*) and some trees (*Gliricidia*, *Gmelina*, *Leucaena*, *Psidium*). There were also common pioneer trees of Philippine secondary growth forest ([Supplementary Table 1](#)) represented by five genera (*Bauhinia*, *Macaranga*, *Mallotus*, *Melanolepis* and *Trema*), whereas the ‘foundation species’ of tropical beach forest such as *Guettarda speciosa*, *Prosopis juliflora*, *Thespesia populnea*, *Terminalia catappa* and *Xylocarpus*

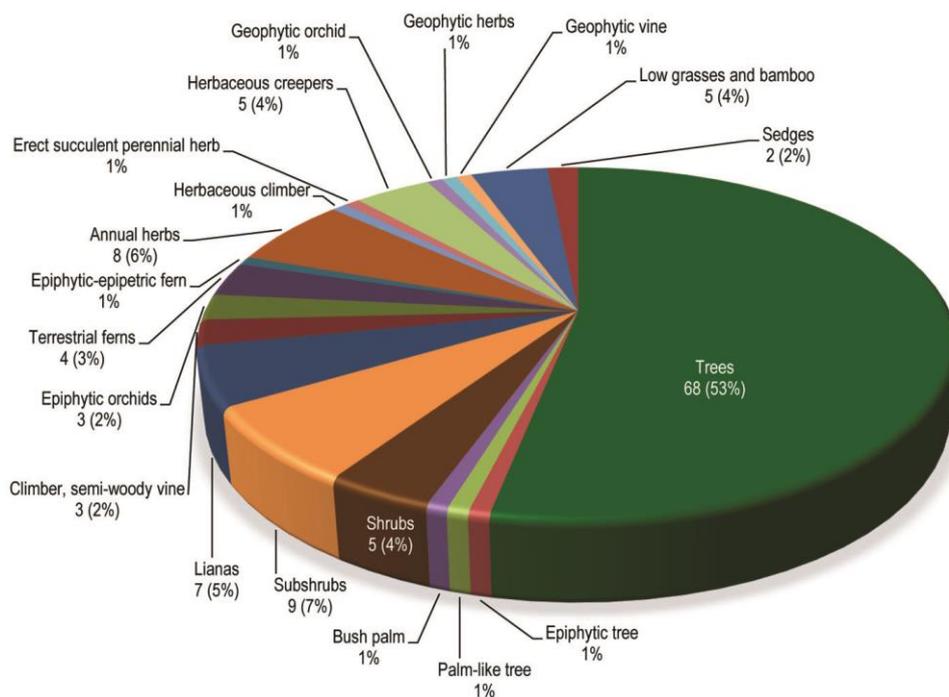


Figure 3. Diversity of plant life structure in PTF.

rumphii were found to be associated with endemic *T. philippinensis*.

In terms of phytogeographic affinity ([Supplementary Table 1](#)), many of the floristic elements were of Malesian, Asiatic, Australia–Asian to Pantropic distribution. Interestingly, there were seven tree flora reported as Luzon’s endemic encountered in the study sites: *Arenga tremula* (Arecaceae), *Callicarpa erioclana* (Lamiaceae), *Garuga floribunda* (Burseraceae), *Scolopia luzonensis* (Flacourtiaceae), *Tectona philippinensis* (Lamiaceae), *Terminalia polyantha* (Combretaceae) and *Syzygium mindorensis* (Myrtaceae). Many of the enumerated species are indigenous or can be found throughout the Philippines and in the Malesian phytogeographic region.

Vegetation structure

The different growth habits or life-form structures which are the valid primary elements of vegetation type or plant association were observed in different morpho-species in the PTF (Figure 3)^{44–46}. There were trees (68 species), shrubs (5) and subshrubs (9), bush palm (1) and palm-like tree (1), lianas (7), epiphytic tree (1), semi-woody climbers (3), epiphytic and geophytic orchids (4), epiphytic and terrestrial ferns (5), annuals to erect succulent perennial herbs (9), herbaceous climbers and creepers (6), geophytic herbs and climber (1), low and tall grasses, including bamboo (5) and sedges (2). Physiognomically, such structural diversity comprises some of the unique botanical ensembles in the PTF landscape.

Diversity analysis of the flora

Table 1 presents the comparative measures of diversity for the general floristic composition of PTF. The proportion of abundance among species resulted in ‘very low to moderate level of diversity’, as reflected in abundance-dependent Shannon–Wiener index (H'), with values ranging between 0.84 and 2.69 across plots (Figure 4). This can be attributed to the disproportion of abundance among species, but if taken collectively, the PTF consists of highly abundant plant population (N) resulting in high abundance to species richness ratio (N/SR; Table 1).

SR as a direct measure of diversity varied across the 24 sites with 15–42 species and was within Chao-1 estimate of 15–50 species. SR also complements the results of Hill’s diversity numbers. Chao-1 and Chao-2 SR estimators revealed that there was a minimum of 141 species and maximum of 172 species (Table 2). This is an indication of the possible range of SR in PTF as there are species that might not have been recorded during sampling. Even so, both estimates revealed that the total SR (128 species) in the present study accounts for 74.56–90.78% of the potential range of SR. Moreover, the species accumulation curve for the 24 sites shows gradual elevation and has not attained its asymptote (Figure 5), suggesting that if sampling efforts continue, there may be additional species.

Considering both the maximum and mean values, Fischer’s α and Margalef index gave the highest diversity values for PTF, as these two indices were weighted to SR

Table 1. Diversity value indices for the general floristic composition of the Philippine teak forest (PTF) (pooled from 24 quadrats)

Indices/measures of diversity	Minimum–maximum values (24 sites; mean value)	Relevance to the structure and dynamics of PTF
Shannon–Wiener (H')	0.87–2.69 (1.97)	PTF has very low to moderate level of diversity resulting from the dominance of most abundant species. H' value usually lies between 1.5–3.5 and rarely exceeds 4.0 ⁶⁵ .
Species richness (SR)	15–42 (26)	Species-rich forest; heterogeneous at the habitat level ^{47,66–70} .
Hill's diversity numbers	13–42 (25)	Reflect similar information with SR about effective number of (observed) species ^{71,72} .
Chao-1 (SR estimator)	15–50 (30)	More unseen species were detected from the abundance of singleton (1N) species, but SR was within Chao-1 values, where at least 90.78% was the degree of species collection effort.
Species abundance (N)	242–2,707 (1060)	PTF consists of abundant plant population (abundant >10N, rare 3–9N, doubleton 2N and singleton 1N) ⁴³ .
N/SR ratio	11.2–110 (43.38)	There was abundant number of individuals among species in the PTF.
Fischer's α	2.4–9.72 (5.18)	PTF has low to very high diversity attributed to SR regardless of abundance distribution among species ^{47–49} .
Margalef's richness index	1.96–6.23 (3.71)	PTF has very low to very high diversity weighted to the measure of species richness ⁷³ .
Brillouin index	0.85–2.60 (1.91)	Reflects the same information with H' , though values are lower than H' ^{47,49} .
Mackintosh diversity index	0.74–2.55 (1.75)	Very low to moderate diversity; reflects similar trend with H' and Brillouin indices, as the index was weighted towards species dominance ⁶⁶ .
Menhinick diversity index	0.42–1.56 (0.91)	Very low diversity under condition of reduced effect of abundance to species richness.
Simpson's diversity (S 1-D) index	0.35–0.90 (0.73)	Low to moderate diversity (forest with uneven to even species composition). PTF is dominated by few most abundant species attributed to relative abundance of each species, as 1 represents infinite diversity and 0 represents no diversity ⁶⁷ .
Berger–Parker dominance index	0.20–0.80 (0.41)	PTF has low to high species dominance. The species composition is uneven and values are more weighted to the most abundant (dominant) species. An increase in the value accompanies an increase in diversity and a reduction in dominance ^{47,74,75} .
Pielou's evenness index (e^{HS})	0.10–0.54 (0.32)	Very low to mid-range of evenness as E' ranges normally between 0 and 1, where 1 representing a situation in which abundance is equally (evenly) distributed among species in the samples ^{47,76} .
Simpson's concentration of dominance (D)	0.09–0.65 (0.27)	Low diversity as individuals (N) are not equally (or evenly) distributed among species resulting in low evenness (nearly 0), while some species dominated the forest (above mid-value but far from approaching 1). Low evenness indicates high dominance in the presence of a few species ⁷⁷ . Similar tendency with e^{HS} and Berger–Parker index.
Shannon's equitability (J)	0.32–0.82 (0.61)	PTF has low to moderate species equity. It reflects similar information with Pielou's evenness index. When all species are equally abundant, an evenness index would be at a maximum (1.0) and decrease towards zero as the relative abundances of the species diverge away from evenness ⁷² .
Whittaker beta diversity (β_w)	0.83–3.02 (1.96)	Low to moderate diversity; low (<1) to high (≥ 5) but does not have a fixed maximum value. Increasing β_w indicate that there are many species not shared among the sample units ^{50,78} .

Table 2. Chao estimates for species richness in PTF

Characteristics/parameters	Value
Number of pooled samples	24
Total species abundance, stem density (N)	25,435
Total observed, recorded species (S_{obs})	128
Chao 1 ($F = 13$ singletons and 2 doubletons)	141
Chao 2 ($F = 42$ uniques and 18 duplicates)	172
Bootstrap	145.82
Degree or intensity of species collection (%)	74.42–90.78

regardless of abundance^{47–49}. The values obtained for Brillouin, Mackintosh and Menhinick indices showed similar tendency with H' (Table 1).

The other measures of diversity such as dominance (Simpson's $1D$, Berger-Parker, Simpson's D), evenness (Pielou's E) and equity (Shannon's J) all reflect low to moderate diversity (Table 1), as their values diverge away from complete evenness (1) and decreasing towards zero (0). This shows that PTF is dominated by the most abundant species. The increasing values of Whittaker beta diversity (β_w), on the other hand, indicates that there are many species not shared in all the quadrats which can be attributed to rare, doubleton and singleton taxa. Both β_w and the above-mentioned alpha diversity indices together measure the overall diversity or biotic heterogeneity of an area^{50,51}.

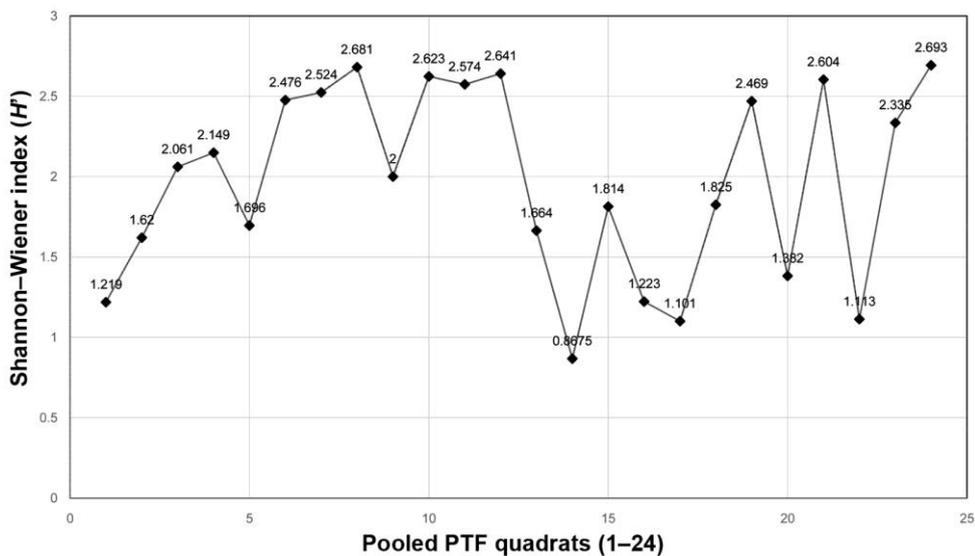


Figure 4. Shannon–Wiener diversity values of PTF across 24 quadrats.

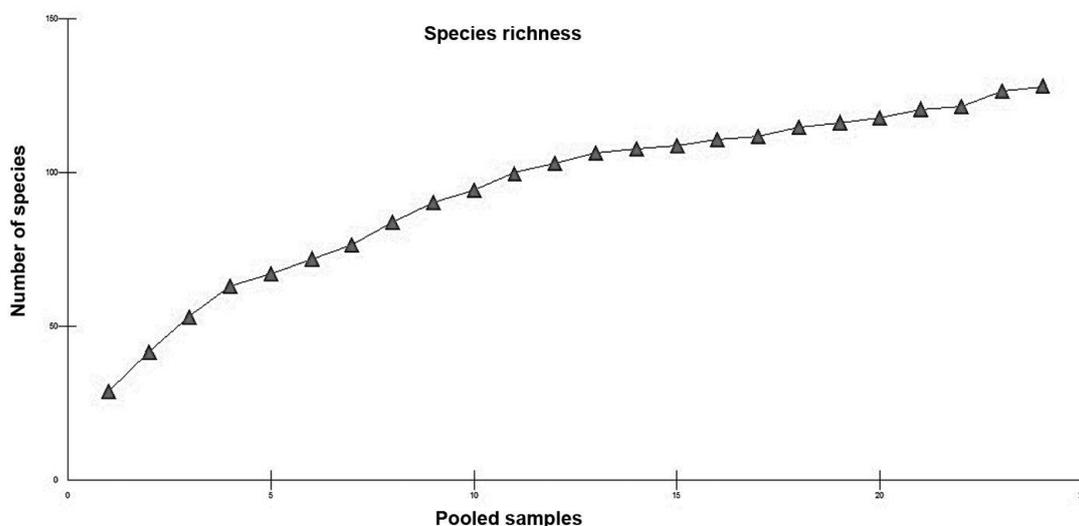


Figure 5. Species richness (y-axis) accumulation curve pooled from 24 quadrats (x-axis) in the PTF landscape using BioDiversityPro software of McAlecece *et al.*⁴⁰.

Discussion

Floristic composition, species diversity and interface with human agroscape

SR (= 128 species) in the present study is higher than the number of species reported from a previous study⁵² for PTF in Batangas, which accounted for 47 species over the range 11–30 species per plot. According to Heck *et al.*⁵³, the recording of at least 50–75% of the total species of a given plant community is sufficient. Apart from trees, the present study has incorporated other possible morpho-species, including ‘unseen’ or rare species (e.g. palm-like *Cycas*, sedges, undershrubs, climbers, ferns, grasses, epi-

phytes and geophytes). It was found that 80 species (63%) were abundant, while 48 (37%) were rare. Rare taxa (rare, doubleton and singleton) are those having low abundance or small ranges⁵⁴, and a combination of biophysical factors could restrict either species abundance or geographical range⁵⁵. The unexpected encounter with the rare *Cycas* suggests that the PTF landscape is of primitive origin. This remnant of Cycadales has flourished since the Cretaceous and Mesozoic era and is one of the most ancient coned plants found to this day in the Indo-Malayan Archipelago⁵⁶.

Fabaceae consisting of vines, shrubs and trees is the most species-rich plant group, indicating that PTF has interfaced with the agroecosystem landuse. This is evident

with the occurrence of locally important cultivated trees such as *Gliricidia sepium* and *Leucaena leucocephala* as well as naturalized stands of *Tamarindus indica*—a commercially valuable fruit tree in southern Batangas. *Gliricidia* and *Leucaena* are used as biofence, fodder and fuelwood, especially in managed hilly farms. The dominance of Fabaceae is an indication that the PTF is within the agro-forest landscape of Lobo Batangas Watershed⁵².

The species composition of PTF is a representation from ridge to coast having very low to moderate species diversity, some less disturbed while other sites are more altered by human presence. Disturbance-indicator genera are *Annona*, *Chromolaena*, *Lantana*, *Leucaena*, *Mimosa*, *Gliricidia*, *Gmelina*, *Psidium* and *Saccharum*. Since 1970s, commercial fruit-bearing *Annona squamosa* and introduced fodder–fuelwood *Leucaena leucocephala* have been components of the agroecosystem landscape in southern Batangas^{57,58}, where the centre distribution of the Philippine teak population was first assessed¹⁷. Moreover, many weed trees and shrubs of an ‘open area phenomenon’ such as *Acacia*, *Antidesma*, *Bauhinia*, *Gliricidia*, *Macaranga*, *Mallotus*, *Melanolepis*, *Mimosa* and *Tamarindus* are found in the PTF landscape. These genera, if not outright disturbances, are bio-indicators of anthropogenic coexistence with the PTF. Elsewhere in tropical Asia, many of the aforementioned floristic elements are typical in savannah, abandoned farms, forest edges and disturbed woodlands^{59–61}.

SR is a clear biological measure of alpha (α) diversity and is expressed simply as the number of recorded species in the sampled habitat⁵⁰. Generally, the results imply that SR and abundance can be used as helpful diversity measures of regenerative potential of PTF. This forest superficially allows regeneration or turnover of many other species, as evident from the low to very high number of individuals. Hence, it can be considered as not anti-succession, which means that regeneration of future floristic composition can be sustained naturally.

Regardless of growth forms, dominance in the plant communities of the PTF landscape is expected among individual taxa with greater or high abundance (N), resulting in low mean evenness (0.32) to moderate equity (0.61). Human-propelled landscape alterations such as farming, deforestation for exotic plantation establishment and influx of settlement have all contributed to fragmentation of native tropical forests. They create gaps among fragments, isolating the native plant populations and spreading the alien species over the forest gaps and edges resulting in a deleterious, eliminating impact on native plant diversity^{62,63}. This could be the reason for the low to moderate species heterogeneity (H') in the PTF, resulting not only from the shares of native plant population where *T. philippinensis* was among the most abundant tree element, but by the contribution of abundant generalist,

non-native ruderal flora with Asiatic or pantropic distributions.

Conclusion

The PTF is composed of a large number of non-woody and woody species. High SR, diverse morpho-species and very low to moderate level of heterogeneity characterize the PTF in the predominantly agro-ecosystem landscape. High abundance is shared by both endemic–indigenous and disturbance–indicator species, while low abundance has been recorded in rare, doubleton and singleton taxa collectively resulting in low evenness and equity. The proportion of trees is higher than other floristic growths.

The presence of PTF in a provincial scale suggests the narrow distribution of the Philippine teak resulting in endemism. This is typical of many tropical forests which have been reduced to small, island-like regions called ‘refugia’ following significant climatic changes during the Pleistocene, which involved decreased precipitation and changes in sea level. These tropical forests often show particularly moderate to high levels of plant diversity and endemism⁶⁴. Overall, the floristics of the PTF is comparable with other Philippine ecotypes as classified according to dominant flora, altitude and local geographic distribution. The PTF along the coastal landscape of Verde Island Passage needs to be added to the list of forest formations of the Philippines on account of its uniqueness with abundance of an endangered, endemic *T. philippinensis*.

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ACKNOWLEDGEMENTS. This study was made possible with funding support from the Department of Science and Technology–Accelerated Science and Technology Human Resource Development Programme (DOST-ASTHRDP) through the Graduate School and School of Environmental Science and Management, University of the Philippines Los Baños, Philippines (GS/SESAM, UPLB). The botanical herbarium collections in Lobo, Batangas was also partially funded by the Batangas State University under its research fund.

Received 18 November 2019; accepted 11 December 2020

doi: 10.18520/cs/v120/i6/1057-1065