

Article

# Variation in Mountain Vegetation Composition between the East and the West Sides of Southern Taiwan

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**Abstract:** In this study, we classified twenty associations, 179 families, 810 genera, 1897 species, and identified 291 rare species. The vegetation units were named following floristic-sociological approach. A cocktail determination key was used to classify the following vegetation units of association. More of the west side than the east side of the study area was at a higher altitude, and the vegetation experienced significant compression. Follow the result of detrended correspondence analysis (DCA), winter rainfall and average January temperature were the main environmental factors affecting variation in vegetation distribution by elevation gradient in this area. The particular association type on the eastern side of the study area is attributable to the northeast monsoon experienced year-round in this area, which causes relatively low temperature and humidity and wind rush, as well as the compression of the elevation range in each forest. The monsoon deciduous vegetation area exists only on the west of the low altitude mountains.

**Keywords:** Southern Taiwan; vegetation; DCA; Braun–Blanquet system; cocktail determination key

## 1. Introduction

Situated on the Tropic of Cancer, Taiwan is a subtropical island that is rich in natural forests. Its mountainous topography (highest peak: 3952 m a.s.l.) forms distinct altitudinal vegetation zones, with vegetation corresponding to several latitudinal zones from subarctic to tropical [1] and different geographic areas that vary by precipitation and temperature. Based on climatic data, Taiwan has been classified into seven ecoregions [2]. Our study area involved the west and east sides of Southern Taiwan. Although the west and east sides are close, the types and distribution of vegetation in these areas differ according to the climate [2]. The weather on the west side is moist in summer and dry in winter. By contrast, the weather on the east side is moist the entire year. Several studies have evaluated the types and distribution of vegetation in these areas [3–11]. However, synthetic comparative studies that investigate vegetation types across Southern Taiwan on the basis of floristic composition are lacking, except for studies on *Chamaecyparis montane* cloud forests [12], high-mountain coniferous forests [13], and beech forests [14] in other areas. Formalized vegetation classification can comprise repeatable classification sometimes accompanied by unequivocally described rules for assigning individual vegetation stands to classification units [15]. To classify vegetation types formally, unsupervised numerical classification methods such as cluster analysis [16] or TWINSpan [17], which consistently apply selected classification criteria to the whole data set, can be used. To describe and parameterize recognized vegetation types, formalization can be achieved using supervised classification methods that create unequivocal rules and criteria for determining vegetation types. An example is the cocktail

determination key [18–21], which describes each vegetation type using a logical formula that combines statements concerning the presence or absence of typical or dominant species [1]. The cocktail determination key was developed by combining the presence or absence of specific ecologically meaningful species groups [18] that provide unequivocal rules for assigning relevés to vegetation types [20–23]. We used the vegetation dataset from the National Vegetation Database of Taiwan and used the cocktail determination key to defining unequivocal assignment rules for each vegetation type in this study. We established vegetation types (associations) and sampled environment factors in the study area. In the present study, we describe the most crucial determinants of floristic composition and ecologically essential vegetation types by sampled relevés and environment factors. Furthermore, understanding relationships between vegetation types and environmental factors in Southern Taiwan can facilitate understanding diversity patterns across all of the Taiwan and vegetation change.

## 2. Materials and Methods

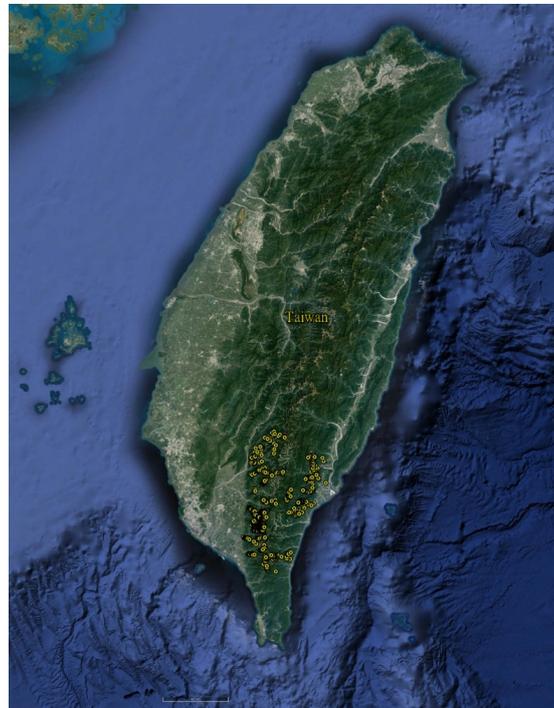
### 2.1. Study Area

Southern Taiwan is a mountainous area located on the Tropic of Cancer. Its area is more than 12,000 km<sup>2</sup>, and the Central Ridge contains more than 50 peaks that are 3000 m asl. Metamorphic rocks are the main bedrock, except in the lowland sedimentary plains. Steep and fragile slopes are common, and landslides frequently occur following heavy rains, road construction, or earthquakes. Temperature mostly corresponds with altitude, with a mean altitudinal lapse rate of 0.55 °C per 100 m, whereas differences in precipitation are caused primarily by monsoon exposure, particularly the northeastern monsoon in winter [1]. In summer, the warm southwestern monsoons and typhoons lead to abundant precipitation across the entire island. In winter, the cool northeastern monsoon leads to moderate precipitation on only the windward slopes. The area not influenced by the winter monsoon experiences a dry period of 2 to 6 months [12]. Because of the northeastern monsoon in winter, southwestern Taiwan experiences a dry season of 6 months from late October to early April; however, southeastern Taiwan does not experience a dry season. More than two typhoons typically hit Taiwan each year in the period from June to September [24]. According to a 2005 inventory made by the Taiwan Forestry Bureau, forests cover 58% of Taiwan. Natural forests, including successional forests after natural disturbances, are concentrated on poorly accessible steep slopes, in remote mountain areas, and in areas without drinking water, soil resources, or seeds from timber species. Of the remaining natural forests, 53% are broadleaf forests, and the remaining are mixed or coniferous forests. Several original broadleaf evergreen forests below 500 m a.s.l. have been converted into buildings or agricultural lands, including bamboo plantations [25]. Su [26] evaluated overall vegetation patterns and proposed six altitudinal vegetation zones by some dominant species in Taiwan that include *Abies*, *Tsuga*, *Quercus* (upper), *Quercus* (lower), *Machilus–Castanopsis*, and *Ficus–Machilus* zones, but drier habitats were more suitable for deciduous or coniferous trees than for broad-leaved evergreens. This scheme was commonly accepted by Taiwanese foresters and vegetation ecologists and widely applied in nature resource management.

### 2.2. Vegetation Data and Environmental Variables

There were 891 relevés in the study area (Figure 1) that were used classification. The vegetation relevés were taken from the National Vegetation Database of Taiwan (AS-TW-001) and from a field survey. The National Vegetation Database of Taiwan (AS-TW-001) comprises data from 2003 to the end of 2011. It includes 3564 relevés that were sampled in 2003 to 2007 as a part of a vegetation mapping project organized by the Taiwan Forestry Bureau [27]. Other relevés were taken from a field survey conducted in 2010 to 2014. The standardized relevé size was 20 × 20 m<sup>2</sup>, the floristic data included trees and shrubs taller than 1.5 m. The diameter at breast height (DBH) of all individuals in this layer was measured and DBH data were used to calculate the importance value index (IVI: relative dominance, represented by the basal area + relative density, represented by the number of individuals).

All the vascular plant species including trees, shrubs, herbs, lianas, and epiphytes were recorded in these relevés. The percentage cover of lianas, epiphytes, and herbs was estimated and used as a measure of abundance and richness. Information about life forms of all the species, endemic rate, invasive rate and leaf types (coniferous, deciduous broad-leaved or evergreen broad-leaved) of tree species were compiled from the Flora of Taiwan [28].



**Figure 1.** Vegetation relevés in study area (Resource: <https://www.google.com/maps>).

In total, the following eight environmental variables were evaluated: altitude, canopy cover, slope inclination, rock cover, rockiness, ratio of winter precipitation (WP), temperature in January (T1), and topography. Environmental factors such as altitude, slope inclination, aspect, and geographic coordinates of relevés were measured in the field, and rock cover and rockiness were estimated in each relevés. Topography was recorded on a 1 to 6 ordinal scale (1 (ridge), 2 (upper slope), 3 (middle slope), 4 (lower slope), 5 (valley), and 6 (plain)) and was used as a surrogate for soil water availability. Rock cover was estimated as the percentage of area covered by stones larger than 10 cm inside the relevés, and rockiness was estimated as the percentage content of stones with sizes 1~10 cm in the soil. Canopy cover and height were estimated in the field, and the canopy cover was used as a surrogate for light conditions in the understory. Temperature in January was calculated from the monthly mean temperatures computed from satellite images with a resolution of 1 km × 1 km. Temperature data derived from satellite images were more sensitive to topography than the temperature data calculated from the regression model of weather stations [1]. Winter precipitation (the ratio of the sum of precipitation of December, January and February divided by the annual precipitation) was taken as interpolated values from the WorldClim database [29].

### 2.3. Classification of Vegetation Types

In this study, association was a community unit with homogeneous floristic composition and similar habitat conditions among relevés [30] that was the basic vegetation unit in the Braun–Blanquet system and named by the floristic-sociological approach [31]. In this study, we define association as a community unit with homogeneous floristic composition and similar habitat requirements among plots and classified associations by the cocktail determination key, which provided information on

the environment and species composition, which evaluates the composition of different habitats and species. The cocktail determination key is a crucial basis for establishing different species groups. The species group comprises different species that have a similar geographical area and habitat [23,32]. The species groups were based on the species established, and selected from the National Vegetation Database of Taiwan (AS-TW-001) by fidelity (phi coefficient). There were three crucial elements in the cocktail determination key: species groups, logical operators (AND, OR, WITH, WITHOUT, and NOT), and numbers as defining criteria for specifying how many species from a species group must occur in a relevés for the group to be considered present in the relevés. For the species groups, the cover of each species was added to more clearly define them; alternatively, only their presence or absence was considered. Twenty associations were established using cocktail determination key in this study. The cocktail determination key can accurately divide species into different vegetation types; however, when the database search for that vegetation type fails to retrieve a complete identity for that unit of vegetation from the retrieval table, a sample area may be unclassifiable; in such cases researchers should determine new methods for retrieving vegetation type definitions to facilitate gradually establishing a complete database of vegetation units. If the sample could not be defined as a new vegetation unit, then the sample the similarity of species composition with other associations was calculated to determine the most approach association. Therefore, classifying a vegetation unit through the vegetation type may indicate a richness of environmental information. However, retrieving species group changes can be impossible when searching for the association if the sample of the repository has increased or is inconsistent with the status of the classification results. Nonetheless, we followed the discussed steps to determine changes in species groups. We divided the study area into east and west sides by relevés and different zones (*Abies*, *Tsuga*, *Quercus* (upper), *Quercus* (lower), *Machilus–Castanopsis*, and *Ficus–Machilus* zones) by some dominant species, the distribution of altitudes was evaluated in this study follow even warn of its effects on vegetation.

#### 2.4. Ordination, Synoptic Table and Software

Ordination by detrended correspondence analysis (DCA) was used to visualize major gradients. A square-root transformation was applied to IVI data of trees and shrubs prior to the analysis. The synoptic table was summarized by species composition of the resulting vegetation types, in which diagnostic species were identified using a fidelity calculation. Fidelity was measured us as the Phi coefficient of association ( $\Phi$ ). Environmental factors were associated with the first two DCA axes using multiple regression [33]. Species data and a synoptic table were prepared using JUICE Version 7.0.84 software [34]. The ordination diagram and related analysis were computed using the R Version 3.0.1 statistical package [35] and the vegan library package [36].

### 3. Results

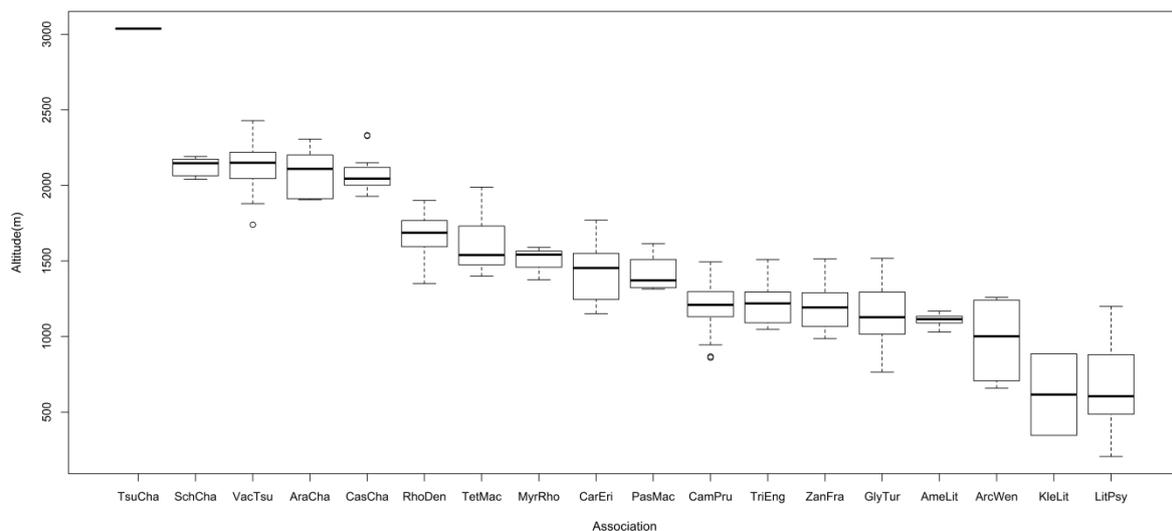
#### 3.1. Vascular Plants and Rare Plant Species

Our data include 179 families, 810 genera, and 1897 species (Supplementary Table S1). The endemic rate and invasive rate in the study area were 24.4%. The staseff included 375 pteridophytes, 23 gymnosperms, 1141 dicotyledons, and 358 monocotyledons. The dicotyledons comprised 70 Fabaceae, 63 Asteraceae, 46 Euphorbiaceae, 46 Lauraceae, 45 Rubiaceae, and 39 Rosaceae species. The monocotyledons comprised 78 Poaceae, 130 Orchidaceae, 32 Cyperaceae, 19 Smilacaceae, and 20 Liliaceae species. A rare species assessment based on the preliminary red list of Taiwanese vascular plants [7] identified 291 rare species, including 10 critically endangered, 32 endangered, 91 vulnerable, 119 near-threatened, and 39 data-deficient species (Supplementary Table S1).

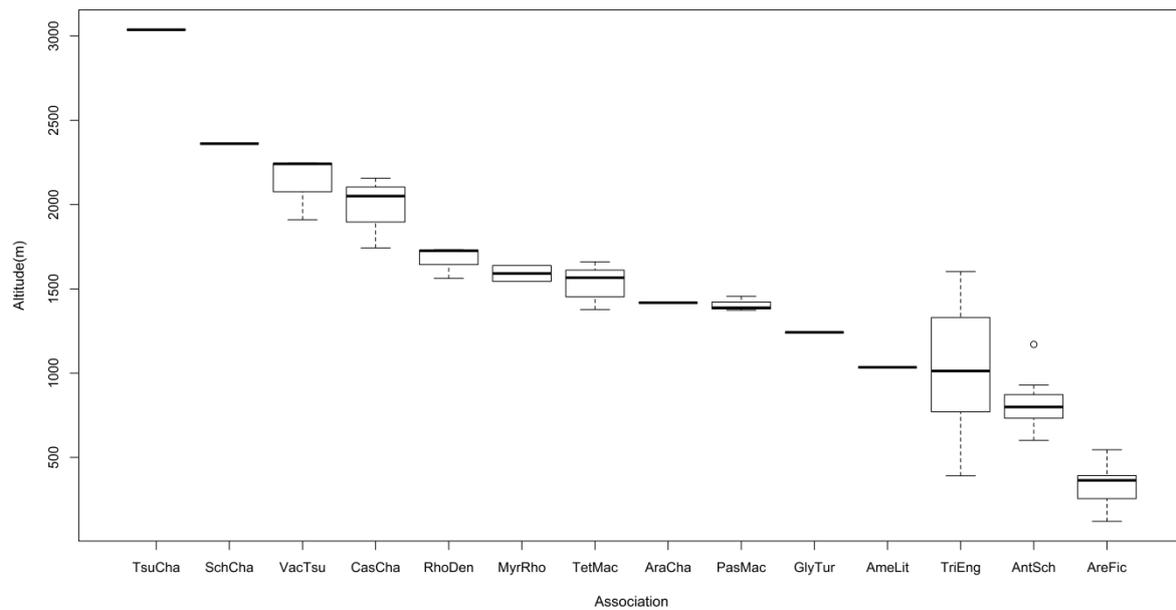
#### 3.2. Vegetation Types

A cocktail determination key was used to classify the following associations (Supplementary Table S2): *Tsugo formosanae–Chamaecyparidetum formosanae* Ching-Yu Liou ex Ching-Feng Li et al.

2014 ass. nova hoc loco; *Tetrastigmo umbellate–Machilietum japonicae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Vaccinio lasiostemonis–Tsugetum formosanae* Ching-Feng Li et al. 2014 ass. nov. hoc loco; *Schefflera taiwaniana–Chamaecyparidetum formosensis* Ching-Long Yeh et Chien-Chun Liao ex Ching-Feng Li et al. 2014 ass. nov. hoc loco; *Castanopsio carlesii–Chamaecyparidetum formosensis* Ching-Feng Li et al. 2014 ass. nov. hoc loco; *Arachniodo rhomboideae–Chamaecyparidetum formosensis* Ching-Feng Li et al. 2014 ass. nov. hoc loco; *Rhododendro formosanae–Dendropanacetum dentigeri* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Antidesmo hiiranense–Schimetum kankaoensis* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Archidendro lucidae–Wendlandietum uvariifoliae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Camellio salicifoliae–Prunetum phaeostictae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Glycosmio citrifoliae–Turpinietum formosanae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Tricalysio dubiae–Engelhardietum roxburghiana* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Amentotaxo formosanae–Litsetum acutivenae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Pasania konishii–Machilietum thunbergii* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Myrico adenophorae–Rhododendretum formosanum* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Arengo tremulae–Ficetum irisanae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Carpino kawakamii–Eriobotryetum deflexa* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Zanthoxylo pistaciiflorum–Fraxinuetum insularis* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; *Litseo akoensis–Psychotrietum rubrae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco; and *Kleinhovio hospita–Litsetum hypophaeae* Yi-Shin Chian et al. 2016 ass. Nov.hoc loco. The distributions of associations in the study area were from 120 to 3000 m and comprised the *Tsuga*, *Quercus*, *Machilus–Castanopsis*, and *Ficus–Machilus* zones [37]. There are 18 associations in southwestern side (Figure 2) and 14 associations in southeastern side (Figure 3).



**Figure 2.** Distribution of associations in western side (TsuCha: *Tsugo formosanae–Chamaecyparidetum formosanae*; SchCha: *Schefflera taiwaniana–Chamaecyparidetum formosanae*; VacTsu: *Vaccinio lasiostemonis–Tsugetum formosanae*; AraCha: *Arachniodo rhomboideae–Chamaecyparidetum formosensis*; CasCha: *Castanopsio carlesii–Chamaecyparidetum formosensis*; RhoDen: *Rhododendro formosanae–Dendropanacetum dentigeri*; TetMac: *Tetrastigmo umbellate–Machilietum japonicae*; MyrRho: *Myrico adenophorae–Rhododendretum formosanum*; CarEri: *Carpino kawakamii–Eriobotryetum deflexa*; PasMac: *Pasania konishii–Machilietum thunbergii*; CamPru: *Camellio salicifoliae–Prunetum phaeostictae*; TriEng: *Tricalysio dubiae–Engelhardietum roxburghiana*; ZanFra: *Zanthoxylo pistaciiflorum–Fraxinuetum insularis*; GlyTur: *Glycosmio citrifoliae–Turpinietum formosanae*; AmeLit: *Amentotaxo formosanae–Litsetum acutivenae*; ArcWen: *Archidendro lucidae–Wendlandietum uvariifoliae*; KleLit: *Kleinhovio hospita–Litsetum hypophaeae*; LitPsy: *Litseo akoensis–Psychotrietum rubrae*).



**Figure 3.** Distribution of associations in eastern side (TsuCha: *Tsugo formosanae*–*Chamaecyparidetum formosanae*; SchCha: *Schefflera taiwaniana*–*Chamaecyparidetum formosensis*; VacTsu: *Vaccinio lasiostemonis*–*Tsugetum formosanae*; CasCha: *Castanopsis carlesii*–*Chamaecyparidetum formosensis*; RhoDen: *Rhododendro formosanae*–*Dendropanacetum dentigeri*; MyrRho: *Myrico adenophorae*–*Rhododendretum formosanum*; TetMac: *Tetrastigmo umbellate*–*Machilietum japonicae*; AraCha: *Arachniodo rhomboideae*–*Chamaecyparidetum formosensis*; PasMac: *Pasanio konishii*–*Machilietum thunbergii*; GlyTur: *Glycosmio citrifoliae*–*Turpinietum formosanae*; AmeLit: *Amentotaxo formosanae*–*Litsetum acutivenae*; TriEng: *Tricalysio dubiae*–*Engelhardietum roxburghiana*; AntSch: *Antidesmo hiiranense*–*Schimetum kankaoensis*; AreFic: *Arengo tremulae*–*Ficetum irisanae*).

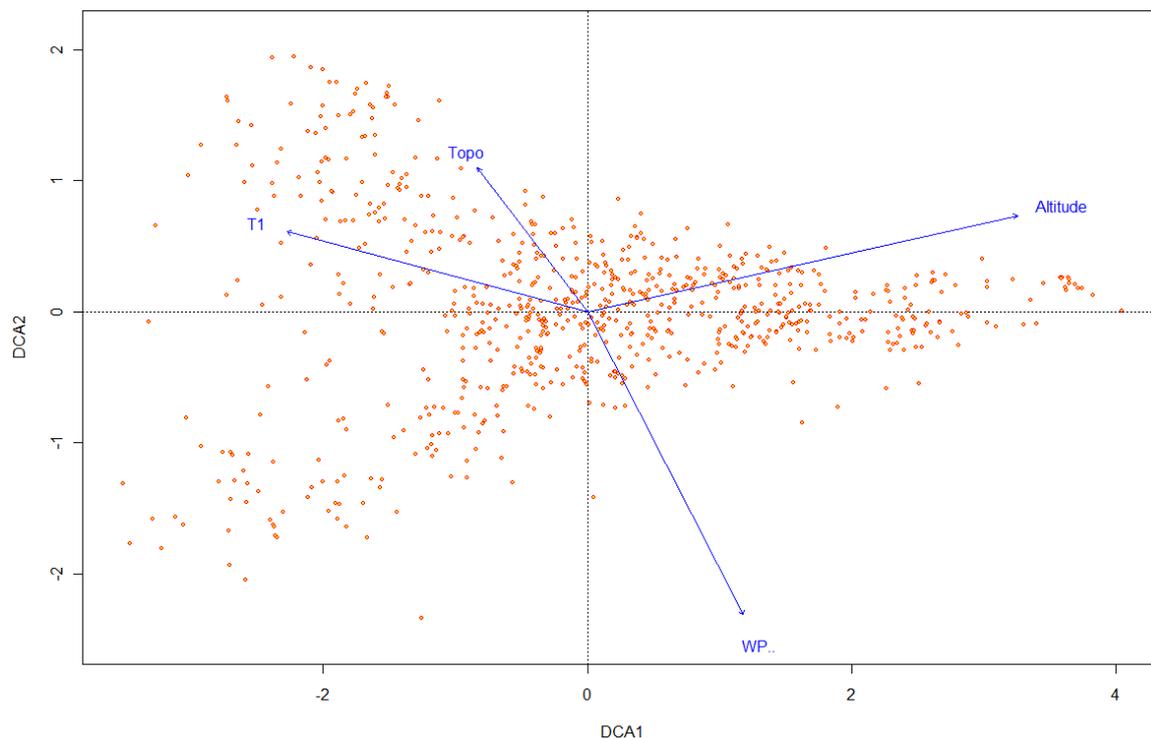
### 3.3. Relationship between Vegetation and Environmental Factors

DCA was based on data from 891 relevés, which included a total of 1504 vascular plant species. The result of DCA shows the length, the eigenvalues (Table 1) and the Correlation value of environment factors (Table 2) with each axis. The distribution of vegetation units in Southern Taiwan is structured strongly by the altitude, January temperature (T1) and winter precipitation (WP) gradient by DCA (Figure 4).

**Table 1.** Results of the length and the eigenvalues with each axis in detrended correspondence analysis (DCA).

|                                  | Axis 1   | Axis 2 | Axis 3 |
|----------------------------------|----------|--------|--------|
| eigenvalue                       | 0.743    | 0.431  | 0.343  |
| length                           | 8.159    | 5.074  | 5.071  |
| Monte Carlo significance testing |          |        |        |
| <i>p</i> value                   | 0.002 ** | 0.062  | 0.086  |

\*\*  $p \leq 0.01$ .



**Figure 4.** Distribution of relevés and environment factors in detrended correspondence analysis (DCA) (T1: temperature of January; WP: precipitation in winter; Topo: topography; Altitude: Altitude).

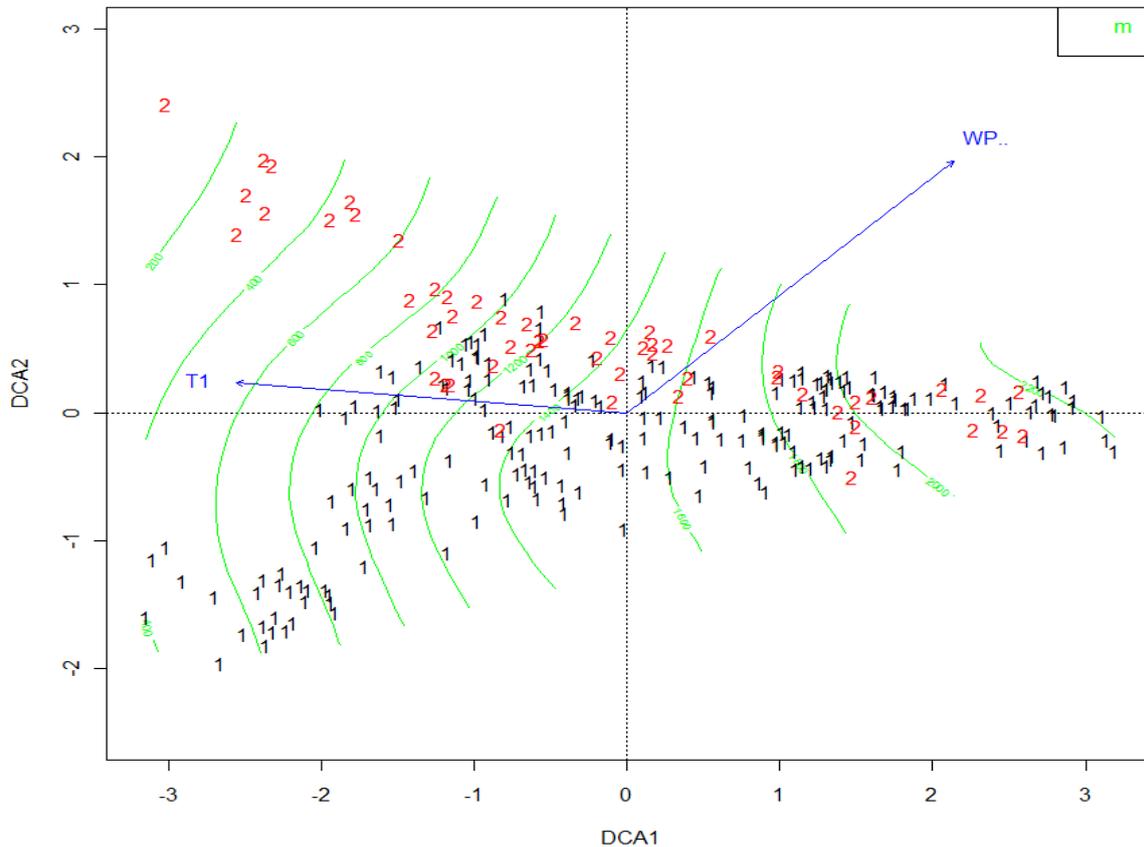
**Table 2.** Correlation value of environment factors and axis in DCA.

| Variable     | Axis 1    | Axis 2    | Axis 3 |
|--------------|-----------|-----------|--------|
| Altitude     | −0.915 ** | −0.109    | −0.112 |
| Canopy cover | −0.057    | −0.046    | −0.099 |
| Slope        | 0.15      | −0.323    | −0.320 |
| Rock cover   | 0.069     | −0.261    | 0.26   |
| Rockiness    | 0.375     | −0.211    | −0.497 |
| WP           | −0.415 ** | −0.814 ** | −0.006 |
| T1           | 0.402 **  | −0.023    | 0.172  |
| Topography   | 0.343     | 0.368 **  | −0.338 |

\*\*  $p \leq 0.01$ .

Because the length of all three axis were more than four SD, the species composition of relevés are different in two side of axis. The results were compared with the vegetation types. Species were classified after dividing the study area into east and west sides for each vegetation zone (Table 3). High fidelity species in study area of the southwestern side include *Prunus phaeosticta*, *Turpinia formosana*, *Litsea akoensis*, *Polygonum chinense*, *Camellia sinensis* f. *formosensis*, *Ilex asprella*, *Maesa perlaria* var. *formosana*, *Eriobotrya deflexa*, *Strobilanthes cusia*, *Wendlandia uvariifolia* and *Pittosporum illicioides*. High fidelity species in the southeastern side were as *Schima superba* var. *kankaoensis*, *Calamus quiquisetinerviis*, *Turpinia ternata*, *Psychotria serpens*, *Selaginella delicatula*, *Ventilago elegans*, *Syzygium euphlebium*, *Ficus fistulosa*, *Antidesma hiiranense*, *Wendlandia formosana*, *Schefflera octophylla*, *Magnolia kachirachirai*, *Ormosia hengchuniana*, *Vandenboschia auriculata*, *Machilus thunbergii*, *Piper kadsura*, *Arenga tremula*, *Pileostegia viburnoides*, *Alpinia pricei*, *Eria ovata*, *Pothos chinensis*, *Bridelia balansae* and *Callicarpa remotiserrulata*. The result from classification were similar in the two sides. For example, *Antidesma hiiranense*–*Schimetum kankaoensis* and *Arengo tremulae*–*Ficetum irisanae* were found in the study area of the southeastern side only, and habitat of associations was moist. On the southwestern

side, *Archidendro lucidae*–*Wendlandietum wuariifoliae*, *Camellio salicifoliae*–*Prunetum phaeostictae*, *Carpino kawakamii*–*Eriobotryetum deflexa*, *Zanthoxylo pistaciiflorum*–*Fraxinuetum insularis*, *Litseo akoensis*–*Psychotrietum rubrae* and *Kleinhovio hospitae*–*Litsetum hypophaeae* were found in this side only, and habitat of associations was dry in winter and landslide. We divided vegetation types into east and west zones using DCA (Figure 5).



**Figure 5.** Relevés of different area and environment factors in DCA (1: indicates the relevés of western area of Southern Taiwan; 2: indicates the relevés of eastern area of Southern Taiwan; T1: temperature of January; WP: precipitation in winter; contour line: altitude (m)).

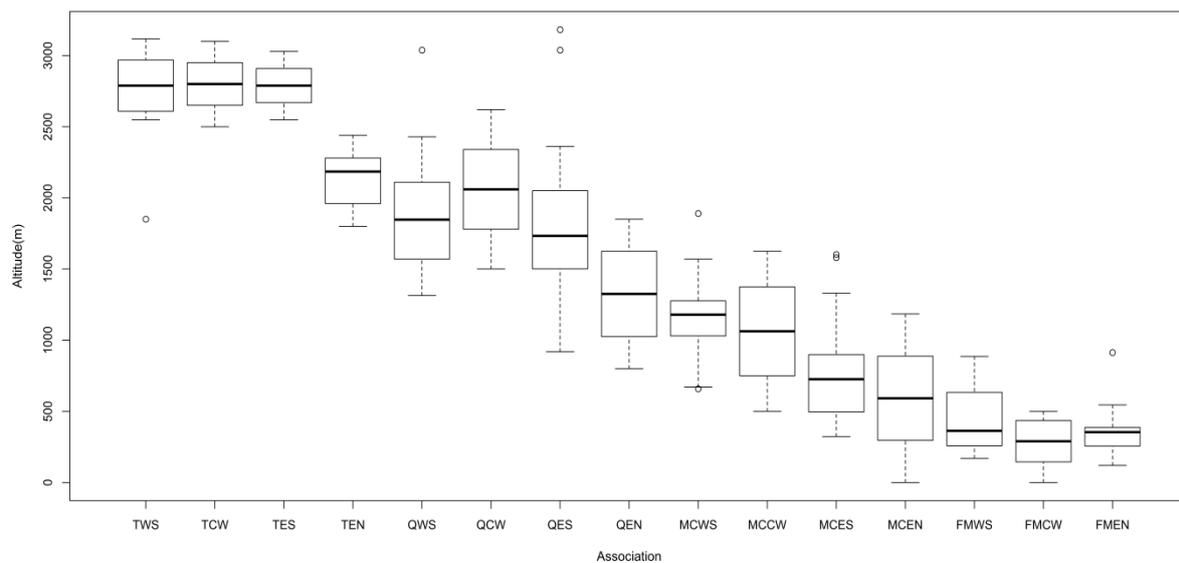
**Table 3.** Diagnostic species of southwestern and southeastern climatic regions. Values are the percentage constancy and species are sorted by decreasing fidelity ( $\Phi$ ).

| Scientific Name                              | Ecoclimatic Regions |              |
|--|---------------------|--------------|
|  | Southwestern        | Southeastern |
| <i>Prunus phaeosticta</i>                    | 38.2                |              |
| <i>Litsea akoensis</i>                       | 34.8                |              |
| <i>Turpinia formosana</i>                    | 32.6                |              |
| <i>Camellia sinensis</i> f. <i>formosana</i> | 27.5                |              |
| <i>Ilex asprella</i>                         | 25.2                |              |
| <i>Maesa perlaria</i> v. <i>formosana</i>    | 22.7                |              |
| <i>Pittosporum illicioides</i>               | 21.3                |              |
| <i>Polygonum chinense</i>                    | 21.2                |              |
| <i>Wendlandia wuariifolia</i>                | 20.8                |              |
| <i>Schima superba</i> v. <i>kankaoensis</i>  |                     | 43.2         |
| <i>Psychotria serpens</i>                    |                     | 41.9         |
| <i>Calamus quiquestineroius</i>              |                     | 41.4         |
| <i>Syzygium euphlebium</i>                   |                     | 37.1         |

Table 3. Cont.

| Scientific Name                   | Ecoclimatic Regions |              |
|-----------------------------------|---------------------|--------------|
|                                   | Southwestern        | Southeastern |
| <i>Turpinia ternata</i>           |                     | 36.8         |
| <i>Ventilago elegans</i>          |                     | 36.4         |
| <i>Antidesma hiiranense</i>       |                     | 35.5         |
| <i>Wendlandia formosana</i>       |                     | 34.2         |
| <i>Ficus fistulosa</i>            |                     | 32.9         |
| <i>Selaginella delicatula</i>     |                     | 31.8         |
| <i>Ormosia hengchuniana</i>       |                     | 31.5         |
| <i>Alpinia pricei</i>             |                     | 30.8         |
| <i>Callicarpa remotiserrulata</i> |                     | 30.1         |

On the western side, the *Quercus* zone was located at approximately 1400 m asl, the *Machilus–Castanopsis* zone was located 600 m asl or higher, and only remnants of the *Ficus–Machilus* zone were located in a valley at 400 m or lower. On the eastern side, the *Quercus* zone was located at more than 1000 m asl, the *Machilus–Castanopsis* zone was located 400 m asl or higher, and the *Ficus–Machilus* zone was distributed in a forest area at 400 m or lower (Figure 6).



**Figure 6.** Distribution of different vegetation zones with different climatic regions in Taiwan. (TWS: *Tsuga* zone in southwestern climatic regions; TCW: *Tsuga* zone in central west climatic regions; TES: *Tsuga* zone in southeastern climatic regions; TEN: *Tsuga* zone in northeastern climatic regions; QWS: *Quercus* zone in southwestern climatic regions; QCW: *Quercus* zone in central west climatic regions; QES: *Quercus* zone in southeastern climatic regions; QEN: *Quercus* zone in northeastern climatic regions; MCWS: *Machilus–Castanopsis* zone in southwestern climatic regions; MCCW: *Machilus–Castanopsis* zone in central west climatic regions; MCES: *Machilus–Castanopsis* zone in southeastern climatic regions; MCEN: *Machilus–Castanopsis* zone in northeastern climatic regions; FMWS: *Ficus–Machilus* zone in southwestern climatic regions; FMCW: *Ficus–Machilus* zone in central west climatic regions; FMES: *Ficus–Machilus* zone in southeastern climatic regions).

The results indicated vegetation of the east side was lower than the west side of the study area, with obvious vegetation compression in the forest on the east side. The effect of the altitude distribution on the east and west sides of the *Quercus* zone at more than 1400 m asl was insignificant. The natural elevation drop on the east side of the *Machilus–Castanopsis* zone significantly affected the compression. The DCA results showed that the main environmental factors affecting variation in

vegetation distribution by elevation gradient between the east and west sides were winter rainfall (WP) and the average January temperature (T1).

#### 4. Discussion

##### *Relationship between Distribution of Vegetation and Environmental Factors*

The study area included to the west side and east side other of Taiwan Central Mountain Range [38]. Theoretically, different geographies and climate zones have different vegetation types, but the *Quercus* zone had similar associations in the two regions. For example, the variety of types in the high altitudes of the *Quercus* zone was limited, including vegetation such as *Tsugo formosanae*–*Chamaecyparidetum formosanae*, *Vaccinio lasiostemonis*–*Tsugetum formosanae*, and *Schefflera taiwaniana*–*Chamaecyparidetum formosensis*. Although temperature and moisture were similar in these two regions, the average rainfall on the west side was less than the east side of the *Quercus* zone. That was caused by the factor compensation effect (altitude, fog, and temperature) in the west side, which maintains the moisture content of this area at a certain level [39]. The climate of the west and east sides of the *Quercus* zone are different, due to winter rainfall being greater on the east side that is no dry season in southeastern Taiwan. Although rainfall concentrated along east side and Hengchun Peninsula in summer, a phenomenon similar to the wet season persists because of the northeast monsoon. In the west side, the rainfall mainly results from the southwest monsoon on the west side and from typhoons in summer. In addition, heavy rainfall caused by convection of afternoon heat and the temperature was high in the west side. Moreover, the barrier of the Central Mountain Range produces a rain shadow effect, with less precipitation than summer. Several deciduous species, such as *Albizia procera*, *Castanopsis formosana* and *Kleinhovia hospita*, and several deciduous associations, such as *Carpino kawakamii*–*Eriobotryetum deflexa*, *Zanthoxylo pistaciiflorum*–*Fraxinuetum insularis*, *Litseo akoensis*–*Psychotrietum rubrae* and *Kleinhovia hospita*–*Litsetum hypophaeae*, can be found on the west side, corresponding to the seasonal deciduous vegetation [40].

The east side is more humid during the winter due to the northeast monsoon, which is characterized by increased airflow. Moreover, the northeast is not as humid as the southeast. However, the terrain along the southern tip of the Central Mountain Range causes east winds to ascend the slope. The physiognomy of this forest zone is caused primarily by factors such as wind speed and the ridgeline slope. Because of the southwest and northeast monsoons the composition and distribution of species from Beidawushan to Chinshueiyung include tropical cloud vegetation types such as Grammitidaceae and Hymenophyllaceae that are tropical mountain cloud forest species [41]. The area between Dahanshan and Chachayalaishan connects the crucial transition zone between Beidawushan alpine plants and Hengchun Peninsula species [3]. In the west side of the study area, the clouds begin at approximately 1000 m asl [42], whereas in the southwest of the Hengchun Peninsula, the clouds begin at 500 m [43]. We could find some deciduous associations in the west side [44,45] and found vegetation settlement on the east side (Figure 6). Clouds on the mountains of the west side have been gradually moving to the climatic conditions east side that has no dry season [46], but west lowlands were different [44]. Due to its special habitat, the montane cloud band on the east side that includes many rare species in narrow habitats [47]. We found similar results by associations. The east side of the study area comprised associations such as *Antidesmo hiiranense*–*Schimetum kankaoensis*, *Arengo tremulae*–*Ficetum irisanae*, *Amentotaxo formosanae*–*Litsetum acutivenae*, *Pasanio konishii*–*Machiletum thunbergii*, and *Myrico adenophorae*–*Rhododendretum formosanum*. The northeast monsoon, which is experienced year-round in this area, induces this particular environmental habitat with its accompanying wind rush and relatively low temperature and humidity, in addition to compressing the elevation range of each forest. In the low-altitude mountainous terrain of the study area's west side, we observed the deciduous vegetation association of *Kleinhovia hospita*–*Litsetum hypophaeae*, *Carpino kawakamii*–*Eriobotryetum deflexa* and *Zanthoxylo pistaciiflorum*–*Fraxinuetum insularis*; however, these were not observed on the east side. Many species of high altitude occur in Nandawushan and

continue to the southern boundary of the habitat [42], such as *Juniperus formosana*, *Tsuga chinensis* var. *formosana*, *Grammitis nuda*, *Hymenophyllum devolii*, *Swertia changii* and *Sorbus randaiensis*, and they are particularly apparent in the southern section of the Central Mountain Range, from Beidawushan to Chinshueiying.

Montane ecosystems are thought to be at disproportionate risk to climate change due to temperature sensitivity and restricted geographical ranges [48]. Southern Taiwan is a mountainous area located on the Tropic of Cancer that includes different topography (mountain, valley, Landslides, etc.), habitat (moisture, dry, etc.) and rare species that include tropical and subtropical species (Supplementary Table S1) in a small geographic area. There is high diversity by many different species group and associations in the study area. Careful planning is needed to sustain diversity and habitat, particularly for rare associations.

## 5. Conclusions

We identified 179 families, 810 genera, and 1897 species (Supplementary Table S1), including 291 rare species (Supplementary Table S1), in the study area, which comprised 891 plant plots. A classification system that employed vegetation taxa and cocktail determination key identified twenty associations. By comparing the vegetation types and species, we determined the distribution status of each vegetation zone. More of the west side than the east side of the study area was at a higher altitude, and the vegetation experienced significant compression. The natural elevation drop on the east side of the *Machilus–Castanopsis* zone significantly affected the compression. Winter rainfall and the average January temperature were the main environmental factors affecting variation in vegetation distribution by elevation gradient in the study area. The particular association types on the eastern side of the study area are attributable to the northeast monsoon experienced year-round in this area, which causes relatively low temperature and humidity and wind rush, as well as the compression of the elevation range in each forest. The deciduous vegetation exists only on the western of the mountains.

**Supplementary Materials:** The following are available online at [www.mdpi.com/1999-4907/7/8/179/s1](http://www.mdpi.com/1999-4907/7/8/179/s1), Table S1: Plant list in study area, Table S2: Synoptic table of associations.

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**Author Contributions:** Yi-Shin Chian conceived and designed the study, carried out fieldwork, analyzed data and prepared the manuscript. Ching-Long Yeh and Chih-Chiang Wang supervised the study, analyzed data, and reviewed and edited the work.

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