Old and Valuable Trees of Wuzhishan, a Tropical City in Hainan, China: Distributional Patterns and Their Drivers

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Research Article

Keywords: Tropical city, Old and valuable tree, Species composition, Geographical distribution pattern, Environmental factor, Driving factor

Posted Date: March 17th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1449578/v1

Abstract

Old, valuable trees (OVT) comprise an important urban ecological and cultural resource. Understanding their innate traits and driving factors can facilitate management, conservation and ecotourism development. This study assessed relationship between the species diversity composition, distribution, growth status, and tree-habitat of OVT in Wuzhishan City in Hainan Province, south China. We acquired tree and site data by field surveys, literature mining, interviews and laboratory tree-age determination. The results show that there are 216 OVT in Wuzhishan City, belonging to eight families and 13 genera and 21 species. Sapindaceae was the family with the largest number of species (79). Lychee was the predominant genus represented by *Litchi chinensis*. The overall age structure of OVT in Wuzhishan City is pyramidal, mainly concentrated in the range of 100-299a (average 163a). According to the grading norms of Chinese OVT, there are three Grade 1, 21 Grade 2 and 192 Grade 3 OVT. Tree height, trunk girth and crown width were normally distributed, mainly concentrated at ten-19 m (mean 32.1 m), 300-499 cm (mean 423 cm) and ten-20 m (mean 17 m), respectively. The overall number of individuals of OVT in Wuzhishan City was evenly distributed. The results of General Linear Model (GLM) analysis showed that the tree height of OVT in Wuzhishan City was highly significantly correlated with precipitation of wettest month (P=8.69E-04), trunk girth was highly correlated with annual mean temperature (P=9.30E-04) and precipitation of coldest quarter (P=3.06E-04), crown width was significantly correlated with mean temperature of warmest quarter (P=8.28E-03). The number of OVT in Wuzhishan City was significantly or highly significantly correlated with most environmental factors. In conclusion, Wuzhishan City has a rich variety of OVT with a uniform distribution; environmental factors have a greater impact on OVT, and it is recommended that targeted protection measures for OVT be developed in conjunction with the actual situation of the city.

1. Introduction

Old trees refer to those over 100 years old. Old and valuable trees (OVT) refer to those that are old or of important historical, scientific or cultural value and have been preserved by design or default in the course of human history. OVT constitute an important part of the cultural heritage and often key ecological entities of human settlements (Lindenmayer et al., 2012; Rudl et al., 2019), serving various socio-cultural and ecological functions (Jim and Zhang, 2013; Zapponi et al., 2017; Zhang et al., 2017).

The sociocultural value indicates a strong connection between human and nature (Jim and Zhang, 2013; Rudl et al., 2019), divided into tangible and cultural aspects (Singh et al., 2011; Blicharska and Mikusiński, 2014). Tangible value refers to the specific uses, including timber, food, medicine and other natural non-wood products (Blicharska and Mikusiński, 2013). Cultural values include the spiritual connection to OVT. These include religious practices (Haberman, 2017), traditional taboo cultures (Blicharska and Mikusiński, 2014), worship of nature, and maintaining ancestral ties (Coggins and Minor, 2018).

OVT also play key roles in ecosystem services. They have thicker trunks and denser branches than common trees and can provide better shelter and more diverse microhabitats for ammensal, commensal and symbiotic plants and animals (Lindenmayer, 2017; Van der Hoek et al., 2017). They can also improve microclimates through strong shading and evaporative cooling effects. They furnish a key source of propagules for ecological restoration (Wenk and Falster, 2015). In addition, they are mainly native species, which can maintain and enhance native plant and non-plant biodiversity (Amici et al., 2015; Zhang et al., 2017; Lai et al., 2019).

OVT reflect social development and natural changes, and are precious genetic, tourism and cultural resources. They can provide important information to study natural ecological changes in specific regions, flora and their evolution, and historical trends in geography and climate. Investigating OVT characteristics can provide data and the theoretical basis to protect landscape and floristic resources, improve awareness of multiple values, promote conservation, and facilitate ecotourism development.

Wuzhishan City in Hainan Province of south China is endowed with urban plant diversity. The climatic conditions and limited urbanization impacts are especially suitable for plant growth and continued survival in the humanized landscape. Despite a relatively small land area, the city has preserved or inherited a rich OVT resources. However, there are few systematic evaluation studies of OVT resources in small cities, especially in the tropical zone. To gain an in-depth understanding of the current status of the diversity of OVTs in Wuzhishan City on a large spatial scale and the environmental factors affecting their distribution patterns. We analyzed the species composition and geographic distribution patterns of Wuzhishan City's OVTs based on historical literature and field surveys, and studied the correlation between the number, tree height, trunk girth and crown width of OVTs and environmental factors. The study of OVTs can better lead to their conservation, and thus to the preservation of the historical record they hold, as well as enabling them to continue to record history. This study is expected to provide reference information for the development of protection measures for OVTs in Wuzhishan City and even in the tropical region.

2. Study Area And Methods

2.1. Study area

Wuzhishan City is a county-level city under the jurisdiction of the Hainan Province in south China. Located in the south-central part of Hainan Island, Wuzhishan City is an inland city as well as a major city and transportation hub on Hainan Island (Fig. 1.). Central Hainan is the traditional home of the ethnic minorities. The geographical coordinates are 109°19 ' E and 18°38 ' N, covering an area of about 1144 km^2. According to the latest census held in 2020 (The seventh census,in China), the permanent population of Wuzhishan City was 112,269, with a population density of 98 persons/km^2. In 2020, the city achieved a GDP of 3.41 million Yuan, with a per capita GDP of 25,595 Yuan (in June 15, 2020, the exchange rate was US$1.00 = Chinese currency Renminbi 7.0902 Yuan).

Wuzhishan City is a famous "jade mountain city", named after the namesake Wuzhishan Mountain, the highest peak on Hainan Island. There are scenic spots such as the Wuzhishan Tropical Rainforest, Hainan Ethnic Museum, tropical Botanical Garden and other scenic spots serving as tourist attractions. Wuzhishan City has a mild tropical monsoon climate characteristic of the mountain and island geography (Duan, 2018). By monthly average temperature, January is the coolest at 18.4 ºC and July is the warmest at 26.2 ºC. The winter is not too cold and the summer is not too hot. On an annual average basis, the temperature is 22.4 ºC, the rainfall is 1690 mm, and the relative humidity is 84%. It is seldom affected by cold waves and occasionally by typhoons.

The city's solid geology is mainly composed of medium and acidic extrusive volcanic rocks. The continual deposition and decomposition of organic litter have built up the humus content to render the soil relatively fertile and suitable for tropical and subtropical plant growth (Liu and Wang,2016). The city's main vegetation was originally mountainous evergreen broad-leaved forest dominated by tropical and subtropical families, mainly Lauraceae, Hamamelidaceae and others (Meng and Du,2016). A small number of temperate families and genera could be found mainly at high altitudes. For example, *Carpinus turczaninowii* from Betulaceae, *Acer laurinum* from Sapindaceae, and Rhododendron from Ericaceae.

2.2. Data gleaned from the literature

The basic properties OVTs were acquired from the pertinent references. We searched the literature written in English, and in Chinese in national journals, reports and government documents. Some data were captured from the *Technical regulation for surveying of old and notable trees* (State Forestry Administration of China, 2016), which helped to grading by OVT age and assessing growth potential.

2.3. Field methods

The OVTs and site data were mainly collected by field investigations from June to October 2021. The morphological characteristics of OVTs were used to determine their species classification against the Flora of China. The data comprised the species identity, quantity, tree locations with coordinates, growth potential, tree age, tree height, trunk girth, crown width and tree management department.

OVT structural characteristics comprise tree height, trunk girth and crown width. We measured tree height using a laser rangefinder (Contour XLR, Lasercraft Inc., Norcross, GA, USA) aimed at the base and tallest point on crown of the tree, respectively, at a distance of no less than 10 m from the target tree. We measured the trunk girth at 1.3 m above the ground using a breast size ruler (to an accuracy of 1 mm). We used the projection method and then measured crown width in the east-west and north-south directions with a tape measure (1 cm accuracy) and calculated the average value.

The growth potential of OVT comprised normal, weak, endangered and dead. We assessed the growth potential of the OVTs with the help of the classification scheme in the *technical regulation for surveying of old and notable trees* (State Forestry Administration of China, 2016). Tree assessments were conducted during the active growing season from March to September using a set of standard visual criteria, and it assigned to four classes: (1) Normal: Attaining the normal growth of the species, leaf retention rate above 90%, no or a small number of dead shoots, trunk and main branches free from pests and diseases, and overall indication of normal growth. (2) Weak: Leaf retention rate below 90%, some dead shoot, trunk and main branches infected slightly by pests and diseases, and indicators of weak growth. (3) Endangered: Growth of new shoots not obvious, normal leaf retention rate below 50%, many dead shoots, trunk and main branches with obvious diseases and insect pests, and the growth is seriously dampened. (4) Dead: Foliage extensively yellow, wilted, or dropped, dead trunk main branches, and tree showing no living signs (dead tree).

We extracted an incremental wood core of 0.6 cm in diameter from a 1.3 m high trunk and determined the age of the tree via wood cores. The core samples were analyzed using the LINTAB Series 6 Professional Pack linear tree-ring measuring stage (Rinntech, Heidelberg, Germany). The tree age measurements were supplemented by field visits to conduct interviews with local elderly people to collect corroborative oral-history evidence.

Data on GPS positioning of the OVTs were acquired by the latest GNSS system double star positioning technology (Yang and Kang, 2017). Professional equipment Pro XRT (Trimble Pro XRT, Trimble, Sunnyvale, California, USA) was selected for the reference station to collect precise geographical coordinate data, which were uploaded to the local network to provide accurate differential correction data information. In the field, the coordinates with a precision of 50 cm could be obtained by connecting to the network for real-time determination. If the GPS signal was seriously blocked by buildings and other factors, the mobile station Pro XRT2(Trimble Pro XRT2, Trimble, Sunnyvale, California, USA) was used to collect location data to significantly improve the positioning speed.

2.4. Data analysis

We adopted the criteria used in the *technical regulation for surveying of old and notable trees* (State Forestry Administration of China, 2016) to divide the OVTs into three age grades (Grade 1 over 500 years, Grade 2 300–499 years, and Grade 3 100–299 years). The relative dominance of each tree species was determined by a species' tree frequency in relation to the total OVTs frequency. MS Excel 2010 was used to conduct some of the data analyses and computations.

The dominance index is a measure of the distribution of individuals among species in a community. It can be used in the study of OVT resources to determine the dominant species of OVT, and the formula is (Jiang, 2021):

$$Y=\frac{n_i}{N}f_i \ , \quad (1)$$

In the formula (1): N represents the total number of individuals of all species in seven townships in Wuzhishan city, n_i represents the total number of individuals of species i, and f_i represents the frequency of occurrence of this species at each township. When $Y > 0.02$, the species was the dominant species in the community.

From the perspective of data morphology, OVTs belong to point-like elements. Usually, the spatial distribution types of point-like elements are uniform distribution, random distribution and aggregated distribution, which can be discriminated by the Morisita index in ecology. The Morisita index indicates the spatial distribution characteristics of individuals, i.e., the degree of concentration of individuals within a group (distribution mode), and its formula is (Jiang, 2021):

$$I=N\left[\sum_{i=1}^{N}n_i(n_i-1)/x(x-1)\right] \ , \quad (2)$$

In the formula (2): N is the number of townships in Wuzhishan City, x is the total number of individuals of this species of OVTs, n_i is the number of individuals of this species of OVTs in the ith township. $I < 1$ indicates a uniform distribution, $I = 1$ indicates a random distribution, and $I > 1$ indicates an aggregation distribution.

We downloaded the WorldClim version two (Fick et al., 2017) from its website. It contains the standard (19) WorldClim bioclimatic variables from WorldClim version two, as well as solar radiation, wind speed and water vapor pressure.. The elevation data of WorldClim 2.1 had a resolution of 30 seconds. Using ArcGIS 10.8 (ESRI, Redlands, CA, USA), the Wuzhishan City was divided into a grid of 5 km*5 km, and the OVT locations were recorded as points by latitude and longitude (Fig. 1). The OVT frequency in each grid by Grades 1, 2 and 3 were enumerated. The average tree height, trunk girth, and crown width of OVT in each grid were also calculated. We extracted WorldClim data from each grid and calculated Z-cores to normalize their values. Using R 4.1.1, General Linear Model (GLM) analysis was computed to explore the relationships between OVT frequency, average tree height, trunk girth, and crown width in each grid and the standardized natural factors. The GLM model fitness was tested by the Akaike Information Criterion (AIC) to identify the optimal model with the minimum AIC value. The correlations between OVT frequency, average tree height, trunk girth, and crown width and natural factors were evaluated.

3. Results

3.1. Species composition

The study found 216 OVTs in Wuzhishan City, belonging to nine families, 13 genera and 21 species (Table 1). Moraceae was the predominant family the largest number of species (11) and the second highest tree frequency (72 trees, 33.3%). Sapindaceae had only two species but the highest frequency (79 trees 36.6%). Fabaceae and Phyllanthaceae were the third and fourth ranking families, with two and one species and 30 and 25 trees, respectively. The top four families collectively contributing over 95% of the OVTs frequency and 71.4% of the species. The even dominant species, each with over ten trees, included *Litchi chinensis, Tamarindus indica, Bischofia polycarpa, Ficus virens, Ficus benjamina, Ficus altissima* and *Dimocarpus longan* (Fig. 2), accounting for about 85% of OVTs frequency. Eight species, with only a solitary specimen, denoted rare OVTs in the study area: *Ficus carica, Artocarpus nitidus* subsp. *lingnanensis, Artocarpus hypargyreus, Antiaris toxicaria, Falcataria falcata, Alangium salviifolium, Bombax ceiba* and *Terminalia hainanensis.*

Table 1
Tree frequency and notable traits of 21 OVT species in Wuzhishan City.

Family	Species	Common name	Tree frequency (count)	Tree proportion (%)	Native or exotic	Cultivated species	Seasonality	Biological potential height (m)
Moraceae	*Ficus virens*	Big Leaf Fig	24	11.1	Native	Landscape	Deciduous	20
	Ficus benjamina	Weeping Fig	15	6.94	Native	Landscape	Evergreen	20
	Ficus altissima	Lofty Fig	12	5.56	Native	Landscape	Evergreen	30
	Ficus microcarpa	Chinese Banyan	7	3.24	Native	Landscape	Evergreen	25
	Ficus subpisocarpa	Superb Fig	4	1.85	Native	No	Deciduous	7
	Ficus tinctoria subsp. *gibbosa*	Dye Fig	3	1.39	Native	No	Evergreen	20
	Ficus carica	Edible Fig	1	0.46	Exotic	Fruit	Evergreen	10
	Artocarpus heterophyllus	Jackfruit	3	1.39	Exotic	Fruit	Evergreen	20
	Artocarpus nitidus subsp. *lingnanensis*	Big Leaf Rouge	1	0.46	Native	Landscape	Evergreen	20
	Artocarpus hypargyreus	General Wood	1	0.46	Native	Landscape	Evergreen	20
	Antiaris toxicaria	Curare Wood	1	0.46	Native	No	Evergreen	40
	Subtotal		72	33.3				
Sapindaceae	*Litchi chinensis*	Lychee	67	31	Native	Fruit	Evergreen	15
	Dimocarpus longan	Longan	12	5.56	Native	Fruit	Evergreen	40
	Subtotal		79	36.6				
Fabaceae	*Tamarindus indica*	Tamarind	29	13.4	Exotic	Landscape	Evergreen	25
	Falcataria falcata	Albizzia Falcata	1	0.46	Exotic	No	Evergreen	45
	Subtotal		30	13.9				
Phyllanthaceae	*Bischofia polycarpa*	Autumn Maple	25	11.6	Native	Landscape	Deciduous	15
Anacardiaceae	*Mangifera indica*	Mango	4	1.85	Exotic	Fruit	Evergreen	20
Myrtaceae	*Syzygium hainanense*	Jambolan	3	1.39	Native	Landscape	Evergreen	5
Cornaceae	*Alangium salviifolium*	South Chinese Alangium	1	0.46	Native	No	Deciduous	8
Malvaceae	*Bombax ceiba*	Red Kapok	1	0.46	Exotic	Landscape	Deciduous	25
Combretaceae	*Terminalia hainanensis*	Terminalia Nigrevenulosa	1	0.46	Native	No	Deciduous	15
	Total		216	100				

3.2. Structural features

The tree height, trunk girth and crown width of OVTs in Wuzhishan city were positively skewed, that is, the higher the height of the tree, the greater the trunk girth and crown width (Fig. 3). Among 21 species of OVTs (Table 2), *Falcataria falcata* has the highest average tree height of 31 m. The tallest OVT is *Ficus altissima*, reaching 32.1 m. The largest average trunk girth and maximum trunk girth were *Ficus Virens*, 688 cm and 1435 cm respectively. *Falcataria falcata* had the largest average crown width of 32 m. The Maximum crown width was the largest in *Ficus* *virens*, reaching 55 m. *Terminalia Hainanensis* has the lowest mean altitude and maximum altitude of OVT, both 192 m. *Bischofia Polycarpa* has the highest mean altitude and maximum altitude at 559 m and 844 m respectively. In Wuzhishan city, *Litchi Chinensis* has the oldest and the oldest average ages of OVT, which are 203 years and 650 years respectively. Due to the small number of samples of some OVTs, there is only one tree. Therefore, the above data cannot represent the comparison data between species, and they are only used as the realistic data of OVTs in Wuzhishan city for discussion.

Table 2
Key quantitative attributes of the 21 OVT species.

Species	Average tree height (m)	Maximum tree height (m)	Average trunk girth (cm)	Maximum trunk girth (cm)	Average crown spread (m)	Maximum crown spread (m)	Mean altitude (m)	Maximum altitude (m)	Average OVT age (year)	Maximum OVT age (year)
Ficus virens	20.4	29.5	688	1435	23.7	55	528	652	166	366
Ficus benjamina	15.9	22.5	400	670	18.9	28	394	709	135	226
Ficus altissima	22.9	32.1	669	1200	31.8	45	261	630	156	308
Ficus microcarpa	19.6	23.1	492	615	25.0	36	333	601	148	212
Ficus subpisocarpa	17.9	19.7	678	845	20.8	30	384	717	187	266
Ficus tinctoria subsp. *gibbosa*	11.3	14.8	372	392	15.0	18	254	361	109	112
Ficus carica	18.4	18.4	302	302	17.0	17	403	403	108	108
Artocarpus heterophyllus	10.5	12.5	281	315	10.0	12	343	350	148	166
Artocarpus nitidus subsp. *lingnanensis*	14.4	14.4	240	240	11.0	11	315	315	112	112
Artocarpus hypargyreus	18.5	18.5	280	280	17.0	17	559	559	108	108
Antiaris toxicaria	16.8	16.8	425	425	16.0	16	320	320	116	116
Litchi chinensis	15.3	21.5	354	945	13.8	27	478	816	203	650
Dimocarpus longan	13.1	14.8	288	434	13.1	18	318	824	142	316
Tamarindus indica	17.4	24.7	362	605	14.9	22	234	338	129	186
Falcataria falcata	31.0	31.0	465	465	32.0	32	466	466	100	100
Bischofia polycarpa	19.9	28.7	396	721	15.1	23	559	844	149	149
Mangifera indica	18.0	19.5	335	375	12.0	15	196	197	180	180
Syzygium hainanense	21.6	23.7	422	581	13.3	17	352	411	138	206
Alangium salviifolium	10.8	10.8	253	253	11.0	11	333	333	116	116
Bombax ceiba	24.2	24.2	565	565	24.0	24	319	319	100	100
Terminalia hainanensis	23.1	23.1	315	315	23.0	23	192	192	108	108

3.3. Geographical and topographical distribution

In terms of geographical distribution by township, Grade 1 OVTs were all found in Shuiman (Fig. 1 and Table 3). Grade 2 OVTs were mainly concentrated in Changhao and Maodao. Grade 3 OVTs were relatively evenly distributed in the seven townships. The OVT frequencies in individual townships ranged from 38 to 20 (average 31), indicating a relatively even spatial width. Changhao, Shuiman and Maodao had the smallest population size and the lowest population density of 36, 41 and 48 persons/km^2, compared to the citywide average of 95 persons/km^2. Correspondingly, they had high OVT frequency of 38 (the highest), 34 (third highest) and 38, compared to the average of 31. They also had the highest OVT density of 0.26, 0.35 and 0.37 OVTs/km^2, respectively, compared to the average of 0.19 OVTs/km^2. In contrast, the city center Tongza with the largest population size and highest population density of 197 persons/km^2, had the lowest OVT density of merely 0.09/km^2.

Table 3
Distribution of the OVT by three age grades in the seven townships and related urban development data.

Township	Grade 1 OVTs (count)	Grade 2 OVTs (count)	Grade 3 OVTs (count)	Total OVTs (count)	OVT density (OVTs/km^2)	Population (person)	Population density (persons/km^2)	Township total area (km^2)
Changhao	0	9	29	38	0.26	5528	38.49	143.6
Maodao	0	1	37	38	0.37	5432	52.53	103.4
Maoyang	0	2	34	36	0.16	15318	67.54	226.8
Shuiman	3	7	24	34	0.35	4517	45.92	98.4
Tongza	0	2	27	29	0.09	63885	202.62	315.3
Fanyang	0	0	21	21	0.18	9905	87.19	113.6
Nansheng	0	0	20	20	0.14	10445	72.99	143.1
Total	3	21	192	216		1E + 05		1144.2
Average	0.4	3.0	27.4	30.9	0.19		100.53	163.5
Percent	1.39	9.72	88.89	100.00				

The distribution of OVTs in Wuzhishan City varied with altitude (Fig. 4). More OVTs were found at 200—299 m, 300—399 m and 600—699 m, presenting a bimodal pattern. OVT distribution was related to slope aspect and slope gradient (Fig. 4). By slope aspect, more OVTs were found in the west direction. By slope gradient, more OVTs were growing on moderate (20–39°) to steep slopes (40–59°), accounting for about 64.8% of tree frequency.

3.4. Dominant species and distribution type of OVTs in Wuzhishan city

The dominance index formula was used to calculate the species dominance index of 21 OVTs in Wuzhishan city, and the results were shown in Table 4. In Wuzhishan city, the species with species dominance index greater than 0.02 were *Litchi chinensis*, *Tamarindus indica*, *Bischofia polycarpa*, *Ficus virens*, *Ficus benjamina*, *Ficus altissima* and *Dimocarpus longan*, 33.33% species of OVT in the study area accounted for 85.19% of the total. Among them, *Litchi chinensis* is the most abundant tree species, followed by *Tamarindus indica*, *Bischofia polycarpa*, *Ficus virens*, *Ficus benjamina*, *Ficus altissima* and *Dimocarpus longan*. Therefore, seven tree species, *Litchi chinensis*, *Tamarindus indica*, *Bischofia polycarpa*, *Ficus virens*, *Ficus benjamina*, *Ficus altissima* and *Dimocarpus longan*, were the dominant species of OVT in the study area.

Table 4
Dominant species of OVT in Wuzhishan city.

Tree species	Tongza	Nansheng	Maoyang	Fanyang	Changhao	Maodao	Shuiman	Y	I
Ficus virens	5	4	0	0	2	0	13	0.063	2.41
Ficus benjamina	0	2	0	2	3	7	1	0.05	1.73
Ficus altissima	1	1	1	7	1	1	0	0.048	2.23
Ficus microcarpa	0	2	3	0	0	1	1	0.019	-
Ficus subpisocarpa	0	0	0	1	1	2	0	0.008	-
Ficus tinctoria subsp. Gibbosa	0	1	0	2	0	0	0	0.004	-
Ficus carica	1	0	0	0	0	0	0	7E-04	-
Artocarpus heterophyllus	0	0	0	0	0	3	0	0.002	-
Artocarpus nitidus subsp. Lingnanensis	0	0	0	0	1	0	0	7E-04	-
Artocarpus hypargyreus	0	1	0	0	0	0	0	7E-04	-
Antiaris toxicaria	0	1	0	0	0	0	0	7E-04	-
Litchi chinensis	8	3	6	0	18	13	19	0.266	1.42
Dimocarpus longan	1	0	8	0	3	0	0	0.024	3.29
Tamarindus indica	0	0	9	8	2	10	0	0.077	1.90
Falcataria falcata	1	0	0	0	0	0	0	7E-04	-
Bischofia polycarpa	12	4	3	1	5	0	0	0.083	1.98
Mangifera indica	0	0	4	0	0	0	0	0.003	-
Syzygium hainanense	0	0	1	0	2	0	0	0.004	-
Alangium salviifolium	0	0	0	0	0	1	0	7E-04	-
Bombax ceiba	0	1	0	0	0	0	0	7E-04	-
Terminalia hainanensis	0	0	1	0	0	0	0	7E-04	-

The Morisita index formula was used to calculate the individual dispersal index of dominant species in the study area, and the results were as follows: $I_{Litchi\ chinensis}$ = 1.42, $I_{Tamarindus\ indica}$ = 1.90, $I_{Bischofia\ polycarpa}$ = 1.98, $I_{Ficus\ virens}$ = 2.41, $I_{Ficus\ benjamina}$ = 1.73, $I_{Ficus\ altissima}$ = 2.23, $I_{Dimocarpus\ longan}$ = 3.29. The Morisita index of seven dominant species were all greater than one, indicating that all dominant species showed aggregation distribution in the study area. *Litchi chinensis* is mainly distributed in wuzhishan city of Changhao, Maodao, Shuiman of villages and towns, *Tamarindus indica* is mainly distributed in Wuzhishan city of Maoyang, Fanyang, Maodao township, *Bischofia polycarpa is* mainly distributed in Wuzhishan city of Tongza villages and towns, *Ficus virens* is mainly distributed in Wuzhishan city of Shuiman towns, *Ficus benjamina* is mainly distributed in Wuzhishan city of Maodao of villages and towns, *Ficus altissima* is mainly distributed in Wuzhishan city of Fanyang township, *Dimocarpus longan is* mainly distributed in Wuzhishan city of Maoyang township.

3.5. Biomass structure and growth potential

The OVT frequency varied greatly between the age grades. The predominant Grade 3 contributed 191 trees (88.9%), compared with 21 in Grade 2 and merely three in Grade 1 (Table 3). The overall age structure was biased towards the relatively younger trees, which constitute a ready supply to join Grade 2 and then Grade 1 in the years to come. The tiny cohort of the oldest Grade 1 trees, considered as particularly precious, call for special protection.

Regarding the quality of the OVT sites, 114 (53%) were rated good, 80 (37%) poor and 21 (10%) very poor. Nearly half of OVT had unsatisfactory growth conditions due to a combination of human and natural impacts. However, OVT growth potential was relatively better with 151 trees (70%) rated as “normal”, 59 trees (27%) as “weakness”; and six trees (3%) as “endangered”. The majority of OVT had normal growth potential, reflecting suitability of climate and soil conditions and adequate protection.

3.6. Relationship between OVT frequency and basic properties and natural factors

The optimal GLM model with the minimum AIC value was chosen to identify the variable pairs with significant statistical relationships (Table 5). The results showed that (1) Grade 1 OVTs has strong significance with wind speed (P = 1.96E-03) and vapor pressure (P = 1.77E-03) in the region. (2) Grade 2 OVTs has strong significance with precipitation of Warmest Quarter (P = 6.72E-03) and slope (P = 2.99E-03). (3) Grade 3 OVTs was significantly correlated with precipitation of driest month (P = 6.63E-04) in the region. (4) Total OVTs has strong significance with mean temperature of warmest quarter (P = 9.38E-03), solar radiation (P = 3.90E-03), precipitation of driest month (P = 1.90E-03), vapor pressure (P = 5.28E-03) and slope (P = 3.30E-03).

Table 5

Results of GLM analysis of the relationship between OVT frequency and standardized natural factors. [a] For significance level, * denotes $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. [b] Using monthly mean values. [c] Using the ratio of Mean Diurnal Temperature Range to Temperature Annual Range and multiply by 100

					OVT frequency[a]			
Natural factor	Parameter	Average tree height	Average trunk girth	Average crown width	Grade 1	Grade 2	Grade 3	Total
Climate & seasonality	Annual Mean Temperature	2.25E-02 *	9.30E-04 ***	1.06E-02 *	-	2.31E-01	-	-
	Mean Diurnal Temperature Range[b]	7.00E-02.	-	8.87E-02.	1.14E-01	1.01E-01	8.13E-03 **	-
	Isothermality[c]	6.56E-02.	1.93E-01	9.06E-02.	1.10E-01	1.07E-01	-	4.96E-02 *
	Temperature Seasonality	1.68E-02 *	7.01E-02.	3.87E-02 *	-	-	-	-
	Max Temperature of Warmest Month	2.07E-01	-	3.72E-02 *	4.19E-02 *	1.14E-01	7.25E-02	5.16E-02
	Min Temperature of Coldest Month	2.07E-01	3.95E-02 *	3.72E-02 *	4.19E-02 *	1.14E-01	7.25E-02	5.16E-02
	Temperature Annual Range	2.07E-01	8.25E-02.	3.72E-02 *	4.19E-02 *	1.14E-01	7.25E-02	5.16E-02
	Mean Temperature of Wettest Quarter	3.62E-03 **	-	1.77E-01	2.02E-01	2.67E-01	1.33E-01	4.57E-02 *
	Mean Temperature of Driest Quarter	3.23E-03 **	2.29E-02	1.24E-01	1.03E-01	6.12E-02	1.49E-01	1.38E-01
	Mean Temperature of Warmest Quarter	7.96E-03 **	1.96E-03 **	8.28E-03 **	1.13E-01	4.42E-02 *	1.45E-02 *	9.38E-03 **
	Mean Temperature of Coldest Quarter	1.16E-01	-	-	-	7.12E-02	2.33E-02 *	1.18E-01
	Solar radiation	1.04E-02 *	6.97E-02.	1.50E-01	1.36E-01	1.94E-01	1.11E-03 **	3.90E-03 **
	Wind speed	1.50E-02 *	2.16E-01	1.07E-02 *	1.96E-03 **	1.19E-01	2.70E-02 *	1.98E-02 *
Water	Annual Precipitation	3.45E-01	1.51E-01	-	-	1.95E-01	1.51E-02 *	5.23E-02.
	Precipitation of Wettest Month	8.69E-04 ***	3.91E-02 *	4.44E-02 *	7.79E-02	-	1.84E-01	-
	Precipitation of Driest Month	3.46E-01	-	1.28E-01	7.79E-02.	7.30E-02	6.63E-04 ***	1.90E-03 **
	Precipitation Seasonality	1.25E-01	-	-	-	-	-	-
	Precipitation of Wettest Quarter	6.70E-03 **	5.18E-02.	1.05E-02 *	-	-	-	-
	Precipitation of Driest Quarter	1.58E-02 *	1.36E-03 **	3.27E-02 *	6.72E-02	8.25E-02	6.54E-02	4.44E-02 *
	Precipitation of Warmest Quarter	4.55E-01	-	-	1.63E-01	6.72E-03 **	8.90E-02	2.46E-02 *
	Precipitation of Coldest Quarter	6.92E-03 **	3.06E-04 ***	-	1.26E-01	1.59E-01	1.55E-01	1.20E-01
	Vapor pressure	1.14E-01	-	2.67E-01	1.77E-03 **	4.40E-02 *	5.42E-03 **	5.28E-03 **
Topography	Slope	5.56E-02.	-	-	2.87E-02 *	2.99E-03 **	1.61E-02 *	3.30E-03 **

					OVT frequency[a]			
	Elevation	9.34E-02.	7.17E-02.	2.84E-01	1.51E-02 *	2.15E-01	1.51E-02 *	2.50E-02 *
Model	AIC	152.78	402.04	187.46	55.435	94.903	165.32	184.7
	p-value	3.06E-12 ***	< 2e-16 ***	5.74E-15 ***	2.55E-01	7.13E-04 ***	9.63E-10 ***	3.58E-09 ***

Similarly, the same GLM analysis was conducted for the average tree height, trunk girth and crown width of OVTs in Wuzhishan city, and the optimal model with minimum AIC value was obtained (Table 5). The results show that (1) Precipitation of wettest month (P = 8.69E-04) is the most important natural factor affecting the average tree height of OVTs. (2) The natural factor that most influences average trunk girth of OVTs is annual mean temperature (P = 9.30E-04), precipitation of coldest quarter (P = 3.06E-04). (3) Mean temperature of warmest quarter (P = 8.28E-03) is the most influential natural factor to average crown width of OVTs.

4. Discussion

4.1. The relationship between OVTs and humans

In this study, we analyzed the OVTs in Wuzhishan City, Hainan Province. We listed a total of 21 species. The dominant species of OVTs in Wuzhishan City were obvious, and the dominant species with species dominance index greater than 0.02 were, in order, *Litchi chinensis, Tamarindus indica, Bischofia polycarpa, Ficus virens, Ficus benjamina, Ficus altissima* and *Dimocarpus longan* (Table 4), and were clustered in the study area. Among the 216 existing OVTs in Wuzhishan City, *Litchi chinensis* was the dominant tree species with the highest number of 67 trees (Table 1). This is because the *Litchi chinensis* on the growth environment requirements are not harsh, in summer and autumn high temperature and rain, winter and spring low temperature and dry climate conditions are able to grow better. And because the edible use of *Litchi chinensis* is more sustainable compared to destructive uses such as construction materials. People usually eat its as a fruit, so they choose to plant the tree in large quantities and then preserve it well. Therefore, in Wuzhishan City, *Litchi chinensis* are the most abundant OVT. *Bischofia Polycarpa* is mainly used for construction, while *Litchi Chinensis* and *Tamarindus indica* are mainly used for food or medicine. In terms of quantity, there are 25 *Bischofia Polycarpa* trees among OVTs in Wuzhishan city, next only to *Litchi Chinensis* with 67 trees and *Tamarindus Indica* with 29 trees. *Bischofia Polycarpa* is mainly used for furniture and building materials, but it accounts for 11.57% of the total number of OVTs in Wuzhishan city (Table 1). This can be explained by the fact that in order to ensure an adequate supply of wood, people are planting far more than is needed for wood resources. Therefore, *Bischofia Polycarpa* gradually become OVT and are preserved (Huang et al., 2020b). This suggests that in terms of tangible value of OVT, wood is second only to the more sustainable edible medicinal uses as a destructive use (Jin et al., 2020). Tree species that provide tangible value may have a greater impact on human livelihoods (Sandberg and Jakobsson, 2018; Shackleton et al., 2019).

Wuzhishan City's OVTs include the rare national protected species, Artocarpus hypargyreus, of which there is only one. 1992, it was listed as a rare species in the Red Book of Chinese Plants - Rare and Endangered Plants (Book I), and it was classified as a national grade III endangered tree species. It is listed in the IUCN Red List (IUCN) with the protection level of Endangered (EN). They are excellent genetic resources with important conservation significance. In addition, historical international exchange and cooperation, as well as increased human demand for natural products, have promoted the cultivation of some exotic species in cities (Pan et al., 2015; Seebens et al., 2015). For example, Ficus Carica, native to the Mediterranean coast. It has been distributed from Turkey to Afghanistan. It was introduced to China from Persia during the Tang Dynasty and is now cultivated in the north and south as well as in Hainan Province. Their persistence and successful natural regeneration mark a certain competitive advantage (Chen et al., 2018). Their conservation can make a significant contribution to regional biodiversity conservation (Le Roux et al., 2018; Bezemer et al., 2019). However, most of the OVTs in Wuzhishan City are native species. Therefore, in the cultivation of OVTs backup resources in Wuzhishan City, it is recommended to focus on native tree species, which is because native tree species not only have strong resistance and adaptability to local catastrophic weather, climate, and local regional hydrological conditions, but also can adapt to the local standing environment and ecological conditions, and to a certain extent coalesce local history and culture, reflecting the local folk culture and customs (Xie, 2019).

It is worth noting that most of the OVTs involved in this study were left behind after artificial cultivation, indicating that human activities have a greater influence on the distribution of OVTs in Wuzhishan City, mainly in terms of habitat differences, regional differences, and socioeconomic differences caused by human activities (Jim, 2013; Hartel et al., 2018). From the geographical distribution pattern of the number of individuals and species of OVTs in Wuzhishan City (Table 3), there are fewer OVTs distributed in Tongza Town, Nansheng Town, and Fanyang Town. Tongza town is the most populous township in Wuzhishan City, which is both the core area of economic development and the most urbanized area in Wuzhishan City. The survival space of old trees is further compressed, and habitat fragmentation and landscape heterogeneity increase, which is not conducive to the survival of old trees. In summary, human activities are one of the important factors for the low diversity of OVTs in Tongza Town.

4.2. Influence of natural factors on OVT frequency and Basic Attributes

We discuss the results of the GLM analysis of OVT frequencies and natural factors in Wuzhishan City (Table 5). In the analysis results, data marked with "*" indicated that the natural factor was significant for OVT. Since there were only three Grade 1 OVTs in Wuzhishan City and the sample size was too small, the results of Grade 1 OVTs were only for reference and not for discussion. The results showed that only four natural factors, mean temperature of warmest quarter, precipitation of warmest quarter, vapor pressure, and slope, showed significant or highly significant correlations for Grade 2 OVTs. There were ten natural factors, mean diurnal temperature range, mean temperature of warmest quarter, mean temperature of coldest quarter, solar radiation, wind speed, annual precipitation, precipitation of driest month, vapor pressure, slope and elevation showed significant or highly significant correlations for Grade 3 OVTs. Natural factors such as climate, precipitation and topography had the least effect on the number of Grade 2 OVTs and the most effect on the number of Grade 3 OVTs. We hypothesize that Grade 2 OVTs are in their "prime" and are the most vigorous and least influenced by the environment. Grade 3 OVTs are in their "youth" and are susceptible to environmental influences, requiring more appropriate temperature, light, and precipitation. In addition, the younger the OVT, the greater the correlation with most climatic and water factors, indicating that the younger the OVT, the more dependent it is on climate and water, which may indicate that future climate change has an impact on the development of OVT and that OVT need to be watered and insulated according to climate change and the health of the OVT (Liu and Xu. 2013). As OVT grow older, the correlation with wind speed and topography becomes stronger, and the higher the uncovered area, the higher the wind speed, which may mean that extreme weather such as typhoons have a destructive effect on OVT, and we should strengthen the prevention of typhoons. Preventing typhoon damage to OVT (Ye, 2018; Chen and Huang, 2018). The results of the analysis provide guidance for the protection of OVT. We should mainly rejuvenate and restore OVT to minimize their aging rate. For Grade 2 OVTs, which have the highest environmental stability, protection should be based on daily maintenance. The protection of Grade 3 OVTs should be strengthened and given more attention to avoid negative impacts of climate change on their growth.

Through GLM analysis of the basic attributes (average tree height, average trunk girth, and average crown width) and natural factors of OVTs in Wuzhishan City was performed. The results showed that tree height, trunk girth and crown width were closely correlated with most temperature, precipitation and light, except for the limitation of OVT species. The correlation with topographic factors (elevation, slope) was weak. This may imply that extreme climate change will affect the healthy growth of OVT.

5. Conclusion

By analyzing the species and quantity distribution of OVTs in Wuzhishan city, the following conclusions can be drawn: **(1)** *Litchi chinensis*, *Tamarindus indica*, *Bischofia polycarpa*, *Ficus virens*, *Ficus benjamina*, *Ficus altissima* and *Dimocarpus longan* are the dominant species of OVTs in Wuzhishan city. (2) The dominant species were clustered and distributed in the study area, *Litchi chinensis* is mainly distributed in wuzhishan city of Changhao, Maodao, Shuiman of villages and towns, *Tamarindus indica* is mainly distributed in Wuzhishan city of Maoyang, Fanyang, Maodao township, *Bischofia polycarpa is* mainly distributed in Wuzhishan city of Tongza villages and towns, *Ficus virens* is mainly distributed in Wuzhishan city of Shuiman towns, *Ficus benjamina* is mainly distributed in Wuzhishan city of Maodao of villages and towns, *Ficus altissima* is mainly distributed in Wuzhishan city of Fanyang township, *Dimocarpus longan is* mainly distributed in Wuzhishan city of Maoyang township. (3) The age structure of OVTs in Wuzhishan City has a pyramidal distribution, while the structure of tree height, trunk girth and crown width with a normal distribution. (4) *Litchi chinensis* is the most widely distributed, abundant and adaptable tree species in Wuzhishan City. (5) The OVTs in Wuzhishan City have obvious endemism in species composition, superior genetic structure, and adaptability to local growth conditions. (6) Most environmental factors such as temperature, moisture and topography were significantly or highly significantly correlated with the number and basic attributes of Wuzhishan's OVTs. Human activities also have a greater impact on it.

This paper combines field surveys and theoretical studies to systematically analyze the distribution pattern and composition structure of OVT resources in Wuzhishan City, and further analyzes their influencing factors. Based on the current status and distribution characteristics of OVTs in Wuzhishan City, several suggestions are made for the protection and resource investigation of OVT. First, to implement graded protection of OVT, firstly to protect the severely damaged OVT, and then to focus on the dominant tree species in the jurisdiction with the gathering of OVT, as well as the scattered OVT, combining the reasons for differentiated protection, in order to protect the ancient and rare plant species and increase the biodiversity of the urban landscape; secondly, to raise the villagers' awareness of the protection of OVT, so as not to destroy the OVT due to the development of urbanization OVT and make them disappear.

1. Please note that the corresponding author emails address in your manuscript file differ from those entered within the submission system - please correct so they are consistent with each other.

Declarations

Funding: This study was supported by National Natural Science Foundation of China (32160273).

Conflicts of interest/Competing interests: All authors declare no conflicts of interest.

Availability of data and material: All raw data is provided as appendix.

Code availability: No custom code was used.

Ethics approval: Not applicable.

Consent to participate: Not applicable.

Consent for publication: All author agrees to publish present version of manuscript.

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Figures

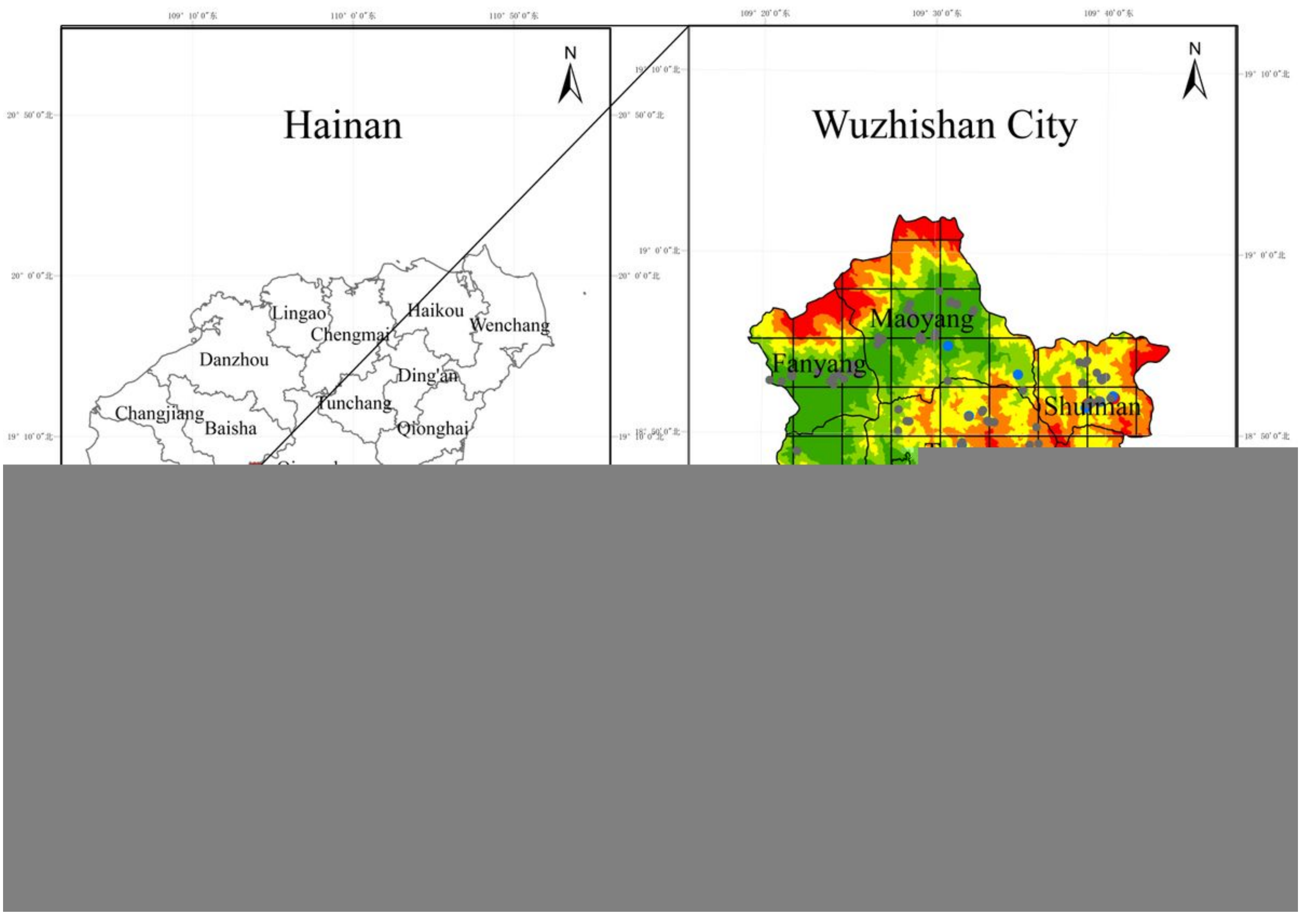

Figure 1

The study area, Wuzhishan City in Hainan Province in south China, and the distribution of OVTs in the seven townships.The (a) Grade 1 OVT (over 500 years) are red, the (b) Grade 2 OVT (300–499 years) are green, and the (c) Grade 3 OVT (100–299 years) are gray.

Figure 2

Images of some typical specimens of OVTs in Wuzhishan City. Photo A denotes *Ficus subpisocarpa*; Photo B *Bischofia polycarpa*; Photo C *Litchi chinensis*; Photo D *Tamarindus indica*; Photo E *Ficus benjamina*; Photo F *Mangifera indica*; Photo G *Dimocarpus longan*; Photo H *Ficus virens*; Photo I *Ficus microcarpa*; Photo J *Ficus altissima.*

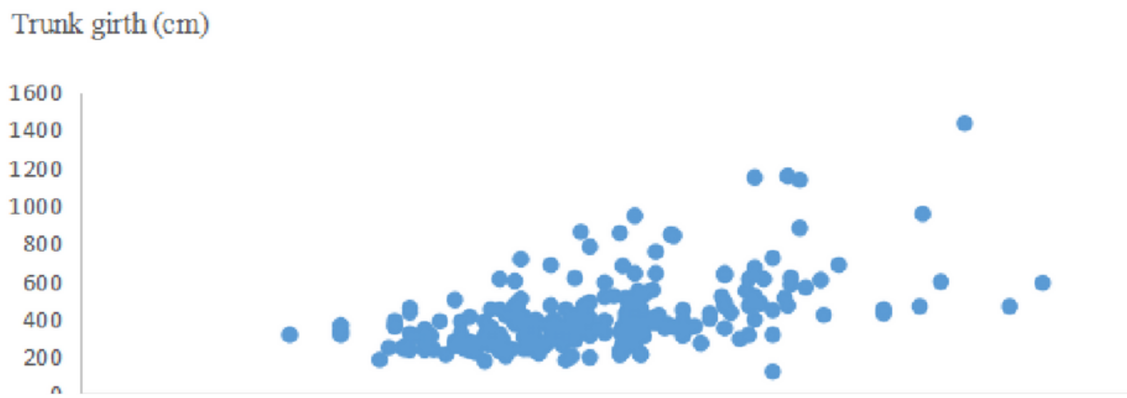

Figure 3

(a) Scattered distribution of OVT tree height and trunk girth in Wuzhishan City

(b) Scattered distribution of OVT tree height and crown width in Wuzhishan City

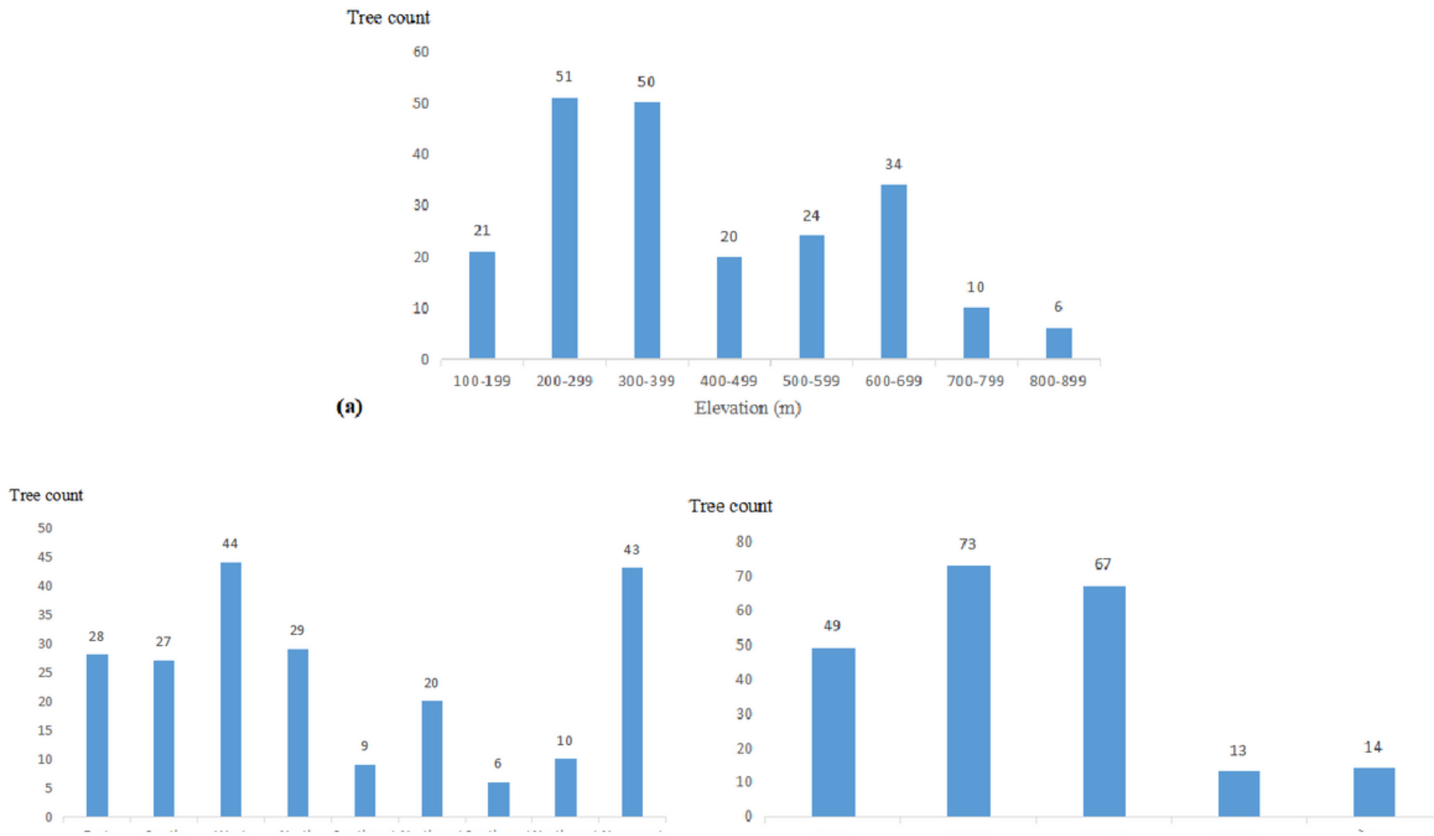

Figure 4

(a) Distribution of OVTs by altitudinal zones in Wuzhishan City.

(b) Distribution of OVTs by slope aspect in Wuzhishan City.

(c) Distribution of OVTs by slope gradient in Wuzhishan City.

Supplementary Files

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- Appendix.xlsx