

Comparative Study of Flora between the Central Mountainous and Eastern Coastal Regions of Hainan (Postprint)

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Abstract

Hainan Island has a topography that is high in the center and low around the periphery. From the central mountainous region to the eastern coastal plain, the composition of the flora has undergone certain changes due to differences in natural conditions and the degree of historical human disturbance. This study employed quadrat and transect survey methods to conduct species surveys in the Huishan Protected Area in the east-central part of Hainan Island, and combined these with data from the team's previous surveys of the Wuzhishan Original Nature Reserve (now part of the Tropical Rainforest National Park) in the central region, the non-coastal Baishiling Protected Area in the east, and the coastal Tongguling Nature Reserve in the northeast, to perform a comparative analysis of the floristic composition characteristics of the 4 protected areas, aiming to explore the relationship between changes in floristic composition and factors such as secondary nature, area, and altitude of the protected areas. The research results indicate: (1) The Wuzhishan, Huishan, Baishiling, and Tongguling protected areas harbor 1 893, 1 415, 634, and 913 species of wild seed plants, respectively, with the 2 central protected areas having significantly higher plant species richness than the other 2 protected areas. (2) Species similarity between protected areas is significantly negatively correlated with differences in altitude and area ($P < 0.05$). (3) All 4 protected areas are dominated by tropical elements; however, at the genus level, Wuzhishan has the highest proportion of tropical Asian distribution, while the other 3 protected areas have the highest proportion of pantropical distribution; at the species level, all have tropical Asian distribution as the most abundant, with Tongguling having the largest proportion. In summary, from the central mountainous region to the eastern coastal plain, it is demonstrated that as secondary nature increases, altitude decreases, habitat types become fewer, and plant species richness decreases;

simultaneously, at both the genus and species levels, there is a pattern of increasing tropical elements and decreasing temperate elements, Chinese endemic distributions, and relict genera and species.

Full Text

A Comparative Study of Floristic Elements from Central Mountainous Area to Eastern Coastal Area of Hainan

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Abstract

Hainan Island features a topography that is high in the center and low around the periphery. From the central mountainous region to the eastern coastal plains, the composition of flora has undergone considerable changes due to variations in natural conditions and historical human disturbance. This study employed quadrat and line transect surveys to investigate species composition in Huishan Nature Reserve (located in the central-eastern part of Hainan Island). Combined with existing survey data from our research team on Wuzhishan Nature Reserve in the central region (now part of the Tropical Rainforest National Park), Baishiling Nature Reserve in the eastern non-coastal area, and Tongguling Nature Reserve in the northeastern coastal region, we conducted a comparative analysis of floristic composition characteristics across these four protected areas to explore the relationship between floristic changes and factors such as secondary succession, area size, and elevation. The results indicate: (1) Wuzhishan, Huishan, Baishiling, and Tongguling reserves harbor 1,893, 1,415, 634, and 913 wild seed plant species, respectively, with the two central reserves showing significantly higher species richness than the other two. (2) Species similarity between reserves is significantly negatively correlated with differences in elevation and area ($P < 0.05$). (3) All four reserves are dominated by tropical elements, but at the genus level, Wuzhishan shows the highest proportion of tropical Asian distribution, while the other three reserves are dominated by pantropical distribution. At the species level, tropical Asian distribution is predominant in all four reserves, with the largest proportion found in Tongguling. In conclusion, moving from the central mountains to the eastern coastal plains, increased secondary succession, lower elevation, and fewer habitat types correspond to decreased plant species richness. Simultaneously, at both genus and species levels, there is an increasing trend in tropical elements alongside decreasing temperate elements, Chinese endemic distribution, and relict genera and species.

Keywords: geographical element, Hainan, flora, species diversity, seed plant

1.1 Study Area Overview

Hainan Island, China's second largest island, covers an area of $3.39 \times 10^4 \text{ km}^2$ and features a central-high, peripheral-low topography. The island can be divided into two geomorphic regions and fourteen sub-regions, with Wuzhishan and Yinggeling mountains forming the uplifted core. The terrain descends step-wise from the center outward, forming a circular layered structure of mountains, hills, terraces, and plains. The geological basement is primarily granite, with basalt, shale, sandstone, and limestone present in some areas. The four nature reserves examined in this study vary in their basic characteristics (Table 1).

Table 1. Basic overview of each nature conservation area

Conservation Area	Area Location (km ²)	Natural Vegetation Preservation Rate (%)	Maximum Elevation (m)	Typical Vegetation Type
Wuzhishan	109°39' 300	92.56	1,867	Alpine shrub, alpine mist forest, mountain rainforest, lowland rainforest, secondary lowland rainforest
Huishan	110°05' 126	45.00	549	Mountain rainforest, lowland rainforest, secondary lowland rainforest
Baishiling	110°22' 12.47	10.05	328	Secondary lowland rainforest

Conservation Area	Area Location	Area (km ²)	Natural Vegetation Preservation Rate (%)	Maximum Elevation (m)	Typical Vegetation Type
Tongguling	110°00' E, 19°37' N	44.45	35.00	338	Lowland rainforest, coastal marsh, mangrove, coastal sandy vegetation

1.2 Research Methods

We conducted route and quadrat surveys in Huishan Nature Reserve to document vegetation types and seed plant species across different slopes and elevations. The sampling design included twenty 20 m × 20 m quadrats and four 10 m × 10 m tree quadrats, within which we established 5 m × 5 m shrub quadrats and 1 m × 1 m herb quadrats, totaling 8,400 m² of surveyed area (Fig. 1). All trees and shrubs with diameter at breast height ≥ 1 cm were measured and identified, with detailed records of height, diameter, elevation, slope, aspect, and position. ≥ 10 m long, ≥ 10 m wide) were also conducted around quadrat location to record seed plant species. Data for Wuzhishan Nature Reserve were collected respectively.

Plant identification followed *Flora Reipublicae Popularis Sinicae* (Editorial Committee of Flora Reipublicae Popularis Sinicae, 1959–2004), *Flora of Guangdong* (South China Botanical Garden, Chinese Academy of Sciences, 1987–2011), and *Checklist of Plant Species in Hainan* (Yang, 2016). Chinese endemic species were determined according to *Diversity and Geographical Distribution of Chinese Endemic Seed Plants* (Huang et al., 2014), and Hainan endemic species were identified based on *Checklist of Plant Species in Hainan* (Yang, 2016). Relict genera were identified following Liao et al. (2014) and Tang et al. (2018). Distribution types of seed plant genera and species were classified according to Wu et al. (1993, 2006).

We used the Jaccard similarity coefficient (Cj) to measure species composition similarity between regions (Jiang, 2010) and SPSS 25 for correlation analysis. The formula is:

$$C_j = c / (a + b - c)$$

where c is the number of shared species between regions A and B, a is the total number of species in region A, and b is the total number of species in region B.

2.1 Plant Composition

As shown in Tables 2 and 3, Wuzhishan Reserve hosts 1,893 wild seed plant species belonging to 775 genera and 157 families; Huishan has 1,415 species in 718 genera and 150 families; Baishiling has 634 species in 404 genera and 117 families; and Tongguling has 913 species in 563 genera and 139 families. These represent 34.29%, 25.63%, 11.49%, and 16.54% of Hainan's total seed plant flora, respectively. While species numbers differ substantially among the four reserves, the family-level composition shows a consistent pattern: families with few species (1-10 species) dominate, while those with ≥ 51 species are relatively rare. Wuzhishan has the most species-rich families, including seven with ≥ 51 species: Compositae (59 species), Lauraceae (73), Papilionaceae (77), Euphorbiaceae (79), Rubiaceae (97), Orchidaceae (113), and Poaceae (104). Baishiling has only one such family, Euphorbiaceae (54 species). Similarly, at the genus level, genera with 1-5 species are more numerous than those with ≥ 6 species, with Wuzhishan having the most genera (69) containing ≥ 6 species, accounting for 8.90% of its total genera.

2.2 Species Similarity Coefficients

The number of shared species and Jaccard similarity coefficients between reserves are presented in Table 4. Wuzhishan and Huishan show the highest similarity, sharing 142 families, 570 genera, and 1,001 seed plant species. The lowest similarity occurs between Wuzhishan and Tongguling, sharing only 105 families, 321 genera, and 456 species. Notably, similarity between Tongguling and Baishiling is higher than that between other reserve pairs.

Correlation analysis between similarity coefficients (C_j) and reserve characteristics revealed significant relationships: $r_A = -0.943^{**}$, $r_{RA} = -0.429$, $r_H = -0.829^*$, $r_D = -0.600$, $r_V = -0.265$, where A, RA, H, D, and V represent area ratio, natural vegetation preservation rate ratio, maximum elevation ratio, distance between reserves, and natural vegetation type number ratio, respectively. C_j showed a highly significant negative correlation with area difference ($P < 0.01$) and a significant negative correlation with maximum elevation difference ($P < 0.05$), with non-significant negative correlations for other parameters.

2.3.1 Genus-Level Floristic Composition

Following Wu et al. (2003), we classified the distribution types of plant genera in the four reserves. All reserves contain 14 distribution types (Table 5), with tropical elements dominating. Tropical components account for 86.35%, 89.23%, 93.83%, and 91.90% of non-cosmopolitan genera in Wuzhishan, Huishan, Baishiling, and Tongguling, respectively. Among tropical elements, Wuzhishan has the highest proportion of tropical Asian distribution (26.24%), followed by pantropical distribution (23.96%). In contrast, Huishan, Baishiling, and Tongguling are dominated by pantropical distribution, comprising 37.07%, 31.10%, and 35.78% of their non-cosmopolitan genera, respectively. Tongguling

shows the highest proportion of pantropical elements, followed by Baishiling and Huishan. Tropical Asian distribution in Tongguling accounts for only 18.10%. Notably, Dipterocarpaceae, a characteristic family of Asian tropical rainforests, is absent from Tongguling but present in Wuzhishan (*Hopea hainanensis*, *Vatica mangachapoi*), Huishan (*Vatica mangachapoi*), and Baishiling (*Vatica mangachapoi*). Temperate elements are relatively low across all reserves, with Wuzhishan containing the most and Baishiling the least.

Chinese endemic elements are also present. Wuzhishan hosts 14 endemic genera (1.87%), including five Hainan endemics: *Cathayanthus*, *Setiopsis*, *Metapetrocosmea*, *Pyrenocarpa*, and *Chunia*. Huishan contains four Chinese endemic genera (0.58%), including the Hainan endemic *Metapetrocosmea*. Baishiling has two Chinese endemic genera, *Chieniodendron* and *Oligostachyum* (0.5% of non-cosmopolitan genera). Tongguling contains only *Oligostachyum*. Neither Baishiling nor Tongguling harbor any Hainan endemic genera.

2.3.2 Species Analysis

2.3.2.1 Species Distribution Types Following Wu (1993, 2006) and references on Chinese endemic seed plants (Huang et al., 2014; Yang, 2016), we classified seed plants into 12 distribution types and six variants (Table 6). Tropical distribution dominates at the species level, with 1,319 (Wuzhishan), 1,026 (Huishan), 429 (Baishiling), and 739 (Tongguling) tropical species. Unlike the genus-level pattern, all four reserves are dominated by tropical Asian elements at the species level, accounting for 58.24% (Wuzhishan), 59.58% (Huishan), 59.68% (Baishiling), and 60.39% (Tongguling) of their respective floras. The variant “Indochina to South/Southwest China” is particularly well-represented. Similar to the genus level, Tongguling has the highest proportion of pantropical species, followed by Baishiling, Huishan, and Wuzhishan (3.35%).

2.3.2.2 Endemic and Relict Plants Wuzhishan contains the most endemic species (459 species in 97 families and 291 genera), representing 3.04% of China’s total endemic seed plants. Huishan ranks second, while Baishiling has the fewest endemics (91 species in 41 families and 75 genera, 0.424% of China’s total). Wuzhishan also hosts the most Hainan endemics (196 species, 40.58% of Hainan’s total endemics). Based on concepts and identification principles for relict species and genera (Liao et al., 2014; Tang et al., 2018), we identified 55 relict genera and 77 relict species across all reserves, predominantly tropical (40 genera), with tropical Asian elements being most common (22 genera, 40.00% of relict genera). Wuzhishan contains 52 relict genera and 74 relict species; Huishan has 30 genera and 38 species; Baishiling has 12 genera and 14 species; and Tongguling has 10 genera and 10 species. Most relict plants are paleoendemic, though some show biogeographic disjunction. Wuzhishan contains the most disjunct genera, such as *Illicium*, *Saururus*, *Lyonia*, and *Disporum* (East Asia–North America disjunction).

2.3.2.3 Alien Plants Following Yan et al. (2014), we identified and categorized invasive alien plants in the four reserves. Wuzhishan, Huishan, Baishiling, and Tongguling contain 29, 39, 52, and 49 alien invasive species, representing 1.53%, 2.76%, 8.20%, and 5.34% of their total floras, respectively. Wuzhishan has the fewest severely invasive species (six), including *Amaranthus spinosus*, *Ageratum conyzoides*, *Bidens bipinnata*, *Lantana camara*, *Eupatorium odoratum*, and *Mimosa sepiaria*. Huishan has nine, Tongguling has ten, and Baishiling has the most (16), including additional species such as *Alternanthera philoxeroides*, *Eichhornia crassipes*, *Pistia stratiotes*, and *Cenchrus echinatus*. Tongguling has the most severely invasive plants (22 species), followed by Baishiling (15). All reserves are dominated by native plants, but Baishiling and Tongguling harbor more invasive species than Wuzhishan and Huishan.

3.1 Differences in Plant Composition

Generally, larger areas support more habitat types, particularly in low-latitude regions (Kerr et al., 1997), and species diversity depends on habitat heterogeneity—higher habitat diversity yields greater species richness (Fang et al., 2009; Peng et al., 2014). Due to long-term logging and agricultural expansion for rubber and betel nut cultivation, Hainan's natural vegetation has diminished substantially. Consequently, most protected areas in coastal and hilly regions consist of secondary forests with certain characteristics, while better-preserved primary forests remain in the less accessible central mountainous areas (Peng et al., 2008). Among our four study reserves, Wuzhishan has the largest area, highest natural vegetation preservation rate (92.56%), lowest degree of secondary succession, and most diverse habitats, resulting in the highest species richness. Although partially developed, Huishan retains mountain and lowland rainforests, maintaining relatively high species diversity. Baishiling, located at the edge of the central mountains in the coastal plain zone, has experienced extensive agricultural activity, leaving only 10.05% natural vegetation, all secondary (Song, 2019), and consequently the lowest species richness. Tongguling, near the coast with strong secondary succession, supports more species than Baishiling due to its coastal sandy vegetation, mangroves, and other littoral plant communities (Tao et al., 2014).

Correlation analysis reveals that species similarity coefficients decrease as differences in area and maximum elevation increase, explaining the highest similarity between Wuzhishan and Huishan. Additionally, all 38 relict species in Huishan are shared with Wuzhishan, indicating clear systematic and floristic similarity. The lowest similarity between Wuzhishan and Tongguling relates not only to area and elevation differences but also to geomorphology, as these reserves belong to different geomorphic regions with distinct habitats and fewer shared species.

All four reserves exhibit strong tropical characteristics at both genus and species levels, consistent with other Hainan regions (Yin et al., 2019; He et al., 2020). At the genus level, all reserves except Wuzhishan are dominated by pantropical

elements, while at the species level, tropical Asian elements prevail, demonstrating strong tropical Asian affinity or Indo-Malaysian relationships (Zhu, 2017). Zhu (2008) found that in Yunnan, tropical element abundance correlates closely with elevation—lower elevations have higher proportions of tropical distribution, likely because high-elevation areas with lower mean annual temperatures can accommodate more temperate species. Consequently, Wuzhishan contains the highest proportion of temperate elements, while Tongguling and Baishiling have relatively low proportions.

Wuzhishan and Huishan contain more endemic species than Baishiling and Tongguling. Research shows that Hainan's endemic species concentrate in the central-southern mountains, accounting for 80.12% of the island's total, while coastal hills and terraces host only 17.81% (Lin, 2016). The formation and differentiation of endemic genera and species are primarily driven by habitat specificity (Zhang et al., 2010; Li et al., 2018). Mountains with complex topography, such as Wuzhishan and Huishan, provide more opportunities for Hainan endemics than hills and terraces. For example, *Michelia shiluensis*, *Alseodaphne rugosa*, and *Lithocarpus chiungchungensis* grow at mid-high elevations in both Wuzhishan and Huishan, while Wuzhishan's complex terrain has fostered local endemics such as *Michelia wuzhishangensis*. In contrast, Baishiling and Tongguling endemics are mostly low-elevation species like *Mallotus anomalus*, *Croton laevigatus*, and *Hedyotis cryptantha*. *Nephelium topengii*, once common across low to mid-elevations in the 1990s and currently found in central mountains and scattered southern and northern locations (Li, 1991; Lin, 2016), is absent from Baishiling and Tongguling, likely due to habitat destruction from agricultural encroachment.

Since the late Tertiary, when the Arctic entered a pre-glacial phase and Asian climates cooled, many plant species migrated southward, gradually enriching Hainan's flora (Jin et al., 2008). Quaternary glaciation created cooler, drier conditions in South China, forcing some plants to retreat to Hainan (Harrison et al., 2001; Ma, 2008). Relict species persist in unstable habitats such as steep slopes, foothills, riverbanks, and valleys—for example, *Cephalotaxus hainanensis* occurs sporadically in ravines and along streams (Chen, 2011). Wuzhishan's large area, well-preserved natural vegetation, and complex habitats, combined with orographic effects on its eastern slopes (Zheng, 1991), have made it a refuge for most relict plants, with Huishan ranking second. Baishiling and Tongguling, with simpler habitats, host fewer relict taxa. The shared relict genera across all reserves are predominantly tropical Asian elements, mostly Tertiary relicts such as *Manglietia*, *Bischofia*, *Homonoia*, *Distylium*, *Alniphyllum*, and *Exbucklandia* (Hemsley, 1880; Mai, 1991; Liao et al., 2014). *Exbucklandia* (four species) has fossil records dating to the Paleocene (Zhang & Lu, 1995; Wu et al., 2009), and *E. tonkinensis* in Wuzhishan is distributed in southern and southwestern China and northern Vietnam. Similarly, *Platycodon grandiflorus* (tropical Asian distribution) occurs in southern Yunnan, Guangxi, Guangdong, and Hainan (Zhu, 2017), suggesting historical connections between Hainan, Vietnam, and Guangxi (Zhu, 2020).

In summary, from central mountainous areas to eastern coastal plains, increased secondary succession, lower elevation, and reduced habitat diversity correspond to decreased plant species richness. Concurrently, at both genus and species levels, tropical elements increase while temperate elements, Chinese endemic distribution, and relict genera and species decrease.

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Note: Figure translations are in progress. See original paper for figures.

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