Research paper

# Species Composition, Size-Class Structure, and Diversity of the Lienhuachih Forest Dynamics Plot in a Subtropical Evergreen Broad-Leaved Forest in Central Taiwan

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【Summary】

The Lienhuachih Forest Dynamics Plot (FDP), measured 500 m by 500 m square, is located in central Taiwan. The collected data, followed a unified method adopted for the worldwide FDP network, were analyzed for floristic composition, size-class structure, and species diversity. In total, the censused trees and shrubs belonged to 144 species in 88 genera and 46 families. The most dominant families were the Fagaceae, Lauraceae, Rubiaceae, Euphorbiaceae, and Melastomataceae. In total, 153268 (6131 $ha^{-1}$) individuals were recorded, and the total basal area was 34.77 $m^2$ $ha^{-1}$. Of the 144 species, the most abundant were *Randia cochinchinensis* and *Blastus cochinchinensis*. *Pasania nantoensis* had the highest basal area (8.38%), followed by *Engelhardtia roxburghiana* (8.12%) and *Schefflera octophylla* (7.23%). Calculation of the importance value (IV, incorporating relative values of abundance and basal area) showed that *R. cochinchinensis*, *B. cochinchinensis*, *S. octophylla*, *Cryptocarya chinensis*, and *E. roxburghiana* were the most dominant species with the highest IV values in the plot. The sum of the 30 top species' IV reached 83.06% of the whole. Although the 1st 2 species were understory and very dominant due to the large number of individuals, certain numbers of rare species however increased the floristic diversity in the plot. Based on the species composition, the forest is characteristic of the *Machilus-Castanopsis* forest

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zone of Taiwan, with certain dominant understory species and possessing 2 pioneer species in the major canopy composition.

For the size-class structure, 102 (each with total stems ≥ 25) species showed 4 patterns of size-class distribution: L-shaped, inverse J-shaped, fluctuating, and bell-shaped. The former 3 patterns in a total of 98 species, including a great number of small-sized individuals, imply that most current species in this study site can display good recruitment with rich resources of saplings. The woody plant richness of the Lienhuachih FDP is the highest among low-elevation FDPs in Taiwan. Compared to other Center of Ttropical Forest Science forest dynamics plots on islands, Fisher's alpha diversity ($ha^{-1}$) index of the subtropical Lienhuachih FDP was similar to that of the Luquillo FDP in Puerto Rico but much lower than that of other FDPs in the tropics.

**Key words:** species composition, size class structure, diversity, subtropical evergreen broad-leaved forest, Lienhuachih Forest Dynamics Plot.

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研究報告

# 蓮華池常綠闊葉林動態樣區之物種組成、徑級結構與多樣性研究

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## 摘　要

依據CTFS長期進行永久樣區研究所發展而成之作業模式，進行木本植物普查，於蓮華池天然林內設置一處25公頃(500 m×500 m)之森林動態學研究永久樣區。調查項目包含每一棵樹的物種名稱、胸高直徑(DBH)與每一棵樹木的位置，調查結果區域內共計有144種木本植物，分屬於46科，88屬；其中DBH在1 cm以上的木本植物株數共計153,268株(6131株/公頃)。

以全樣區各科重要值指數而言，以樟科、殼斗科、茜草科最為優勢。統計數量最多的種類者為茜草樹，次多者為柏拉木。全樣區平均每公頃底面積為34.77 $m^2$。南投石櫟底面積最大，佔全部底面積的8.38%，黃杞及鵝掌柴分別位居第二8.12%及第三7.23%。以重要值IV(相對密度及相對底面積加總)而言，樣區內最優勢的種類分別為茜草樹8.34%及柏拉木5.50%，其次為鵝掌柴5.41%，前30名物種累計可達83.06%。總體而言，優勢組成的集中於少數物種，而株數稀少之種類增加樣區物種的多樣性。

各種類徑級分佈呈現4型，分別為L型，倒J型、波動型及鐘型。前3型共98種，表此森林大部份的物種有足夠的幼苗，更新良好。以生物多樣性而言，與台灣其他低海拔動態樣區比較，蓮華池動態樣區為最為豐富；另與世界上島嶼動態樣區比較，其多樣性值低於其它熱帶的樣區，卻和波多黎各動態樣區相當。

**關鍵詞：**物種組成、徑級結構、多樣性、亞熱帶常綠闊葉林、蓮華池動態樣區。

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## INTRODUCTION

In order to study spatial and temporal patterns of tree and shrub populations, recent studies of forest plots frequently adopted a large plot area. These large datasets that might encompass environmental variations can be used to examine the mechanisms that maintain species diversity, study the consequences of rarity of local species survival, and monitor long-term changes to detect effects of climate change (Hubbell and Foster 1983, Masaki et al. 1992, Tanouchi and Yamamoto 1995, Yamakura et al. 1995, Yamamoto et al. 1995, Condit et al. 1996, Condit 1998, Sato et al. 1999, Manabe et al. 2000). Forest Dynamics Plots (FDPs) were established and used a standardized sampling methodology which allowed researchers to compare directly data collected at different sites (Losos and Leigh 2004).

Taiwan is a mountainous island with the rich ecological resources. To understand forest dynamic changes, several FDPs have been successively established since 1990 (Yang et al. 2008), but large intact FDPs of > 5 ha in area in the low-elevation zone included only the Fushan FDP in northern and the Kenting FDP in southern Taiwan. Both are surrounded by intact conserved forests: the Hapen Natural Conservation area (Su et al. 2007) and Kenting National Park (Wang et al. 2004), respectively. Due to the early and sustained development in central Taiwan, it is difficult to find an intact large forest with no artificial disturbances. However, to monitor forest ecological changes and succession for all of Taiwan, the Lienhuachih forest is the largest one remaining at low elevations in centra Taiwan.

The Lienhuachih forest was an aboriginal hunting ground so it was conserved intact with few disturbances. More than half of the species of the Lauraceae and Fagaceae were concentrated in this area, and many rare endemic species existed in this unique habitat (Lu et al. 2001). Lienhuachih was a conserved natural broad-leaved forest representative of central Taiwan. Therefore, establishing an FDP at Lienhuachih can conserve the natural vegetation of central Taiwan, and also allow the monitoring and study of broad-leaved forest dynamics to accumulate knowledge of northern, central, and southern forests throughout all lowlands of Taiwan.

This study includes the species composition, size-class structure, and diversity of the forest of the Lienhuachih FDP. It can serve as a foundation for cross-site comparisons with other FDPs and ecosystems in Taiwan.

## MATERIALS AND METHODS

### Study site

In July 2008, a 25-ha (500 m×500 m) FDP (23º54’49”N, 120º52’43”E) was established within the evergreen, broad-leaved forest in the Lienhuachih Experimental Forest (LEF), Nantou County, central Taiwan (Fig. 1), as part of the Taiwan Forest Dynamics Monitoring Network. The study was conducted in a 25-ha (500 m×500 m) FDP (23º54’49”N, 120º52’43”E) in a natural forest of the LEF, Nantou County, central Taiwan (Fig. 1). The substrate consisted of alternating argillaceous sandstone and shale. The dominant soils could be classified into 2 types, Typical Dystrochrept and Typical Hapleudults red soils (King 1986). The mean annual temperature was 20.8℃. The hottest month of the year was July with a mean temperature of 25.2℃, and the coldest was January with a mean temperature of 14.8℃. The annual precipitation was 2285.0 mm with seasonal variation throughout the year. More than half of the annual rainfall occurred between May

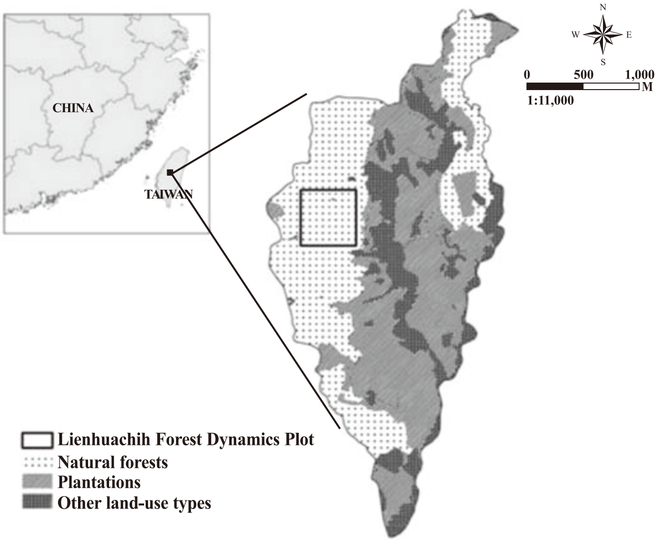


**Fig. 1. Location of the 25-ha Lienhuachih Forest Dynamics Plot in the Lienhuachih Experimental Forest, Nantou County, central Taiwan.**

and September, while the dry season usually began in October and lasted through February with 5 consecutive months averaging <100 mm precipitation a month. The mean relative humidity was 87.1% (Fig. 2) (Lu et al. 2008). Typhoons, a common occurrence in the LEF, swept through the area with violent winds and extremely heavy rainfall, and often caused severe damage (Lee et al. 2008). Landslides also took place, mainly caused by heavy rainfall events and the reshaping of stream channels (Lee et al. 2008).

The LEF covered a total area of 461 ha with elevations ranging 576~925 m. About half of the LEF was composed of natural forests, while the other half was made up of various artificial plantations. In total, 879 vascular plant species, belonging to 177 families and 561 genera, had been recorded within the entire LEF (Hwong et al. 2002). The dominant vegetation type in the LEF was considered to be a Lauro-Fagaceous forest (Su 1984). Most of the trees were *Castanopsis* spp., *Cyclobalanopsis* spp., *Machilus* spp., and *Schima superba* (Hwong et al. 2002). Other human

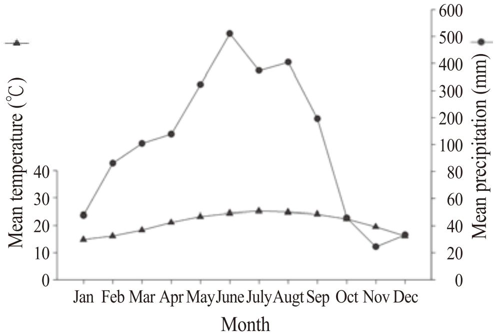


**Fig. 2. Climate diagram for the Lienhuachih Experimental Forest.**

activities in small, widely spaced villages, with agricultural fields and small plantations, occurred within and around the LEF. Natural vegetation in the area was fragmented, degraded, and isolated (Lee et al. 2008).

**Field inventory**

Electronic total-station thedolites were used for precise topographic measurements. The field teams measured all horizontal points at 20-m intervals within the 25-ha plot. The plot was divided into 625 quadrats of 20 m

×20 m, each with other subsidiary points at 10-m intervals. Each 20 m×20 m quadrat was further divided into 16 subquadrats of 5 m×5 m.

All freestanding trees ≥ 1 cm in diameter at breast height (DBH) were mapped, measured, identified, and tagged. The botanical nomenclature, life-form, and endemism of all species, following the Flora of Taiwan (Huang 1993-2000), were determined. Species rareness of fewer than 25 total individuals (< 1 individual $ha^{-1}$) was considered a rare species in the plot (Hubbell and Foster 1986).

**Statistical analysis**

Three parameters, stem density, basal area, and the importance value [IV, which is (relative density + relative basal area)/2], were used to describe the population structure of tree species. The relative dominance of each family and species was determined based on its IV. The main stems of plants with multiple branches at breast height were counted as 1 individual for the density calculation. However, the sum of the basal areas of all stems was used for the basal area.

For the size-class analysis, species with >25 individuals in the plot were analyzed, and each species was carried out by constructing a bar chart with DBH size classes against the numbers of individuals (Hough 1932, Tubbs 1977, McCarthy et al. 1987, Fan et al. 2005). Due to the varied growth rates, limitations of DBH sizes for different species, and non-unified size structures among species, the determination of wide-ranging size class scales followed the modified Sturges's equation instead of using a log-normal equation.

Modified Sturges' equation: $M = 6 \times \log n_i$; where $n_i$ is the number of individuals of species *i*. The class interval of each species = (DBHmax - DBHmin) / M.

For floristic diversity, the species richness, evenness, the Shannon-Wiener diversity index, and Fisher's alpha were used (Hurlbert 1971). Fisher's alpha is a mathematical calculation for determining the diversity within a population, which is usually expressed as the species richness of an area (Fisher et al. 1943, Rosenzweig 1995). It is independent of the sample size and is used to extrapolate species richness to large areas (Losos and Leigh 2004).

Richness is the number of species.

Evenness is H' / ln (Richness).

The Shannon-Wiener diversity index (H') is -sum [Pi×ln (Pi)]; where Pi is the ni/N; ni is the number of individuals in species i; the abundance of species i; and N is the total number of all individuals.

Fisher's alpha: $S = \alpha \ln (1 + n / \alpha)$; where S is the number of species; and n is the number of individuals.

## RESULTS

**Topographic features**

The elevation of the plot ranged from 667 m to 845 m above the sea level. The average slope of the plots was about 35.3°, so the land was very steep. The topography of the plot was characterized by hills with valleys, steep slopes, and ridges. The ridge lies between 2 slopes, a steep slope facing north and gentler slope facing south. Seepage ways, spurs, small hillocks, and several seasonal streamlets cut through these slopes (Fig. 3). Small streams seasonally appeared to carry water in wet seasons. When typhoons with heavy rains passed nearby, instant large amounts of rainfall particularly caused landslides and the collapse of steep slopes and stream banks. In the dry season, small streams usually showed an anhydrous state. The topographic features displayed high spatial heterogeneity within the Lienhuachih FDP (Fig. 3).

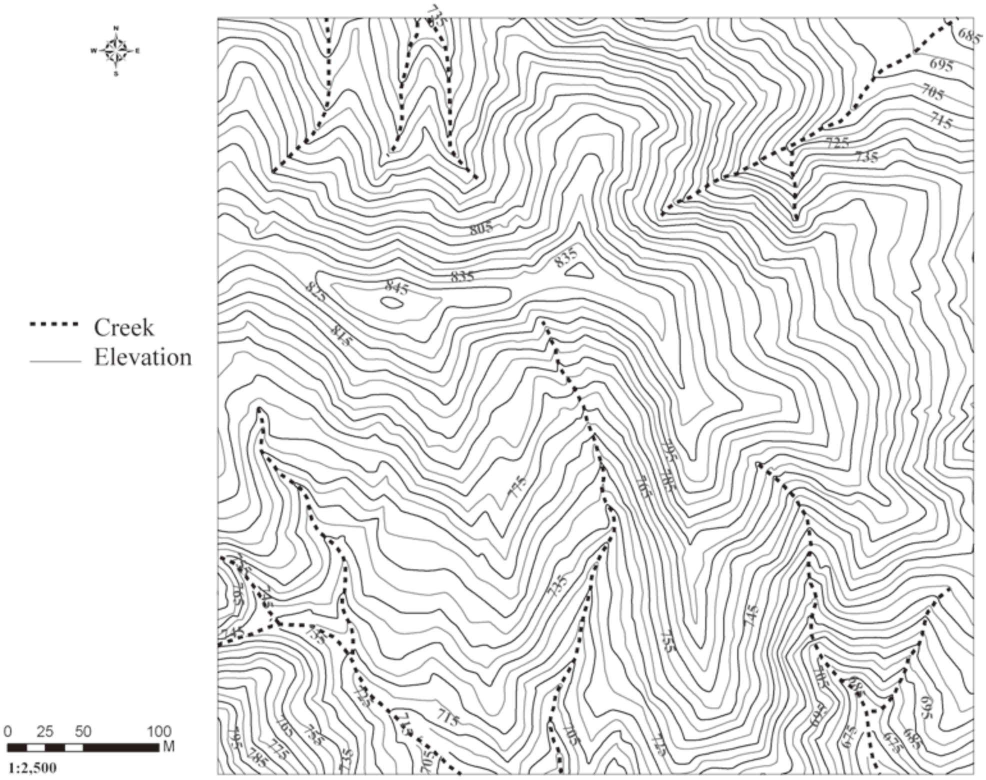


**Fig. 3. Contour map of the Lienhuachih Forest Dynamics Plot with 5-m countour intervals. The dotted lines indicate creeks.**

**Floristic Composition**

The 153,268 (6131 stems $ha^{-1}$) trees surveyed within the 25-ha plot included 144 species in 88 genera and 46 families. The basal area was 869.31 $m^2$ $(25\ ha)^{-1}$ (34.77 $m^2$ $ha^{-1}$). With the exception of 2 gymnosperms (*Podocarpus nakaii*, and *Pinus morrisonicola*) and 1 monocotyledon (*Arecae catechu*), all woody species were dicotyledons. These included of 27 canopy species, 72 sub-canopy species, and 45 shrubs species. Among these, 23 species are endemic in Taiwan.

The 5 most abundant species in descending order were *Randia cochinchinensis* (Rubiaceae), *Blastus cochinchinensis* (Melastomataceae), *Euonymus laxiflorus* (Celastraceae), *Cryptocarya chinensis* (Lauraceae), and *Tricalysia dubia* (Rubiaceae). The first 2 species are small trees or shrubs which are distributed throughout most of the plot. Both accounted for 24.32% of the total abundance, but only 3.53% of the total basal area. Based on the basal area, the dominant species were large-statured, less-abundant trees, including *Pasania nantoensis* (Fagaceae), *Engelhardtia roxburghiana* (Juglandaceae), *Schefflera octophylla* (Euphorbiaceae), *Cryptocarya chinensis* (Lauraceae), and *Schima superba* (Theaceae). Most of them, except *C. chinensis*, are canopy species. The most important species as indicated by the IVs were *R. cochinchinensis*, *B. cochinchinensis*, *S. octophylla*, *C. chinensis*, and *E. roxburghiana*. The top 30 dominant species contributed over 80% to the total IV (Table 1). Among the 20 most dominant species, *Mallotus paniculatus* at

10th and *Sapium discolor* at 20th are pioneer species, and both reached the top 10 major canopy species with the highest IV.

Families with the most number of species in the plot were the Lauraceae, followed by the Rubiaceae, Fagaceae, Theaceae, and Euphorbiaceae. Families with the greatest basal areas were the Fagaceae (26.47% of the total basal area), followed by the Lauraceae, Juglandaceae, Euphorbiaceae, and Araliaceae.

**Table 1. Top 30 species with the highest importance values in the Lienhuachih Forest Dynamics Plot**

| Species | Basal area [$m^2$ (25 ha)$^{-1}$] | Relative basal area (%) | Abundance [stems (25 ha)$^{-1}$] | Relative density (%) | Importance Value (%) | Mean DBH (cm) |
|---|---|---|---|---|---|---|
| *Randia cochinchinensis*✚ | 26.95 | 3.10 | 21075 | 13.75 | 8.43 | 2.88 |
| *Blastus cochinchinensis*✱ | 3.77 | 0.43 | 16199 | 10.57 | 5.50 | 1.44 |
| *Schefflera octophylla* | 62.88 | 7.23 | 5490 | 3.58 | 5.41 | 7.34 |
| *Cryptocarya chinensis*✚ | 53.06 | 6.10 | 6936 | 4.53 | 5.31 | 5.16 |
| *Engelhardtia roxburghiana* | 70.55 | 8.12 | 1769 | 1.15 | 4.63 | 12.45 |
| *Pasania nantoensis* | 72.89 | 8.38 | 821 | 0.54 | 4.46 | 11.28 |
| *Cyclobalanopsis pachyloma* | 36.17 | 4.16 | 3875 | 2.53 | 3.34 | 6.80 |
| *Diospyros morrisiana* | 26.82 | 3.09 | 5001 | 3.26 | 3.17 | 5.16 |
| *Cinnamomum subavenium*✚ | 30.64 | 3.52 | 3800 | 2.48 | 3.00 | 5.27 |
| *Mallotus paniculatus* | 30.35 | 3.49 | 3794 | 2.48 | 2.98 | 6.40 |
| Top 10 | 414.08 | 47.63 | 68,760 | 44.86 | 46.25 | |
| *Tricalysia dubia*✚ | 15.62 | 1.80 | 6251 | 4.08 | 2.94 | 4.12 |
| *Schima superba* | 44.86 | 5.16 | 744 | 0.49 | 2.82 | 16.88 |
| *Helicia formosana*✚ | 17.47 | 2.01 | 5241 | 3.42 | 2.71 | 3.81 |
| *Euonymus laxiflorus*✱ | 2.94 | 0.34 | 7767 | 5.07 | 2.70 | 1.83 |
| *Syzygium buxifolium*✚ | 11.82 | 1.36 | 5962 | 3.89 | 2.63 | 3.59 |
| *Castanopsis fargesii* | 31.97 | 3.68 | 1277 | 0.83 | 2.26 | 7.71 |
| *Ormosia formosana* | 11.08 | 1.27 | 4779 | 3.12 | 2.20 | 2.93 |
| *Psychotria rubra*✱ | 5.09 | 0.59 | 5720 | 3.73 | 2.16 | 2.12 |
| *Ardisia quinquegona*✱ | 3.35 | 0.38 | 5693 | 3.71 | 2.05 | 2.08 |
| *Sapium discolor* | 24.32 | 2.80 | 1176 | 0.77 | 1.78 | 10.05 |
| Top 20 | 582.59 | 67.02 | 113,370 | 73.97 | 70.49 | |
| *Helicia rengetiensis*✚ | 8.23 | 0.95 | 3196 | 2.09 | 1.52 | 3.46 |
| *Litsea acuminata*✚ | 1300 | 1.49 | 2183 | 1.42 | 1.46 | 5.06 |
| *Castanopsis kawakamii* | 22.07 | 2.54 | 331 | 0.22 | 1.38 | 8.28 |
| *Neolitsea aciculata*✚ | 3.10 | 0.36 | 3514 | 2.29 | 1.32 | 2.39 |
| *Podocarpus nakaii* | 8.26 | 0.95 | 2494 | 1.63 | 1.29 | 4.69 |
| *Glochidion acuminatum* | 12.47 | 1.43 | 1396 | 0.91 | 1.17 | 7.56 |
| *Castanopsis cuspidata* | 16.58 | 1.91 | 647 | 0.42 | 1.16 | 8.04 |
| *Pasania konishii* | 11.86 | 1.36 | 1320 | 0.86 | 1.11 | 4.26 |
| *Pasania harlandii* | 13.42 | 1.54 | 986 | 0.64 | 1.09 | 7.52 |
| *Machilus zuihoensis* | 15.35 | 1.77 | 544 | 0.35 | 1.06 | 10.46 |
| Top 30 | 706.92 | 81.32 | 129,981 | 84.81 | 83.06 | |

✚ sub-canopy species; ✱ shrub species. No marks indicating canopy species. DBH, diameter at breast hight.

The Rubiaceae had the greatest density, consisting of 20.86% of the total. The top 15 families in terms of IVs are shown in Table 2. The most dominant families were ranked in the order of the Fagaceae, Lauraceae, Rubiaceae, Euphorbiaceae, and then the Melastomataceae.

The species-area curve shows that the number of species increased rapidly, and the curve inclined to nearly a plateau after an area of 10 ha (Fig. 4). The curve appears to approach an asymptote, and very few species were added to the plot beyond the point.

The species-area curve showed that the number of species increased rapidly until the incline plot area reached 2.43 ha, when about 80% of species had accumulated (Fig. 4). The curve inclined to nearly a plateau after an accumulated total area of 10 ha. Then, the curve appeared to approach an asymptote and very few species were added as the plot size was enlarged.

The species-abundance pattern (Fig. 5) showed that a few species contributed a great proportion to the stem abundance. The sum of ranks 1 and rank 2 was 37,274 individuals as 24.32% of the total. From ranks 3 to 22, the curve exhibited a shallow gradient, and the total of the top 22 species reached 80%

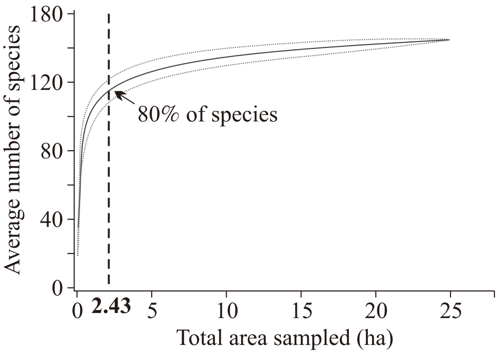


**Fig. 4. Species-area curve for the 25-ha Lienhuachih Forest Dynamics Plot.**

**Table 2. Top 15 families with the highest importance values in the Lienhuachih Forest Dynamics Plot**

| Family | Basal area ($m^2$/25 ha) | Relative basal area (%) | Density (stems/25 ha) | Relative Density (%) | Important Value (%) | Nomber of Species |
|---|---|---|---|---|---|---|
| Fagaceae | 230.15 | 26.47 | 21597 | 10.62 | 18.55 | 11 |
| Lauraceae | 152.41 | 17.53 | 25771 | 12.68 | 15.10 | 17 |
| Rubiaceae | 51.97 | 5.98 | 42417 | 20.86 | 13.42 | 13 |
| Euphorbiaceae | 67.60 | 7.78 | 7166 | 3.52 | 5.65 | 8 |
| Melastomataceae | 3.83 | 0.44 | 21274 | 10.46 | 5.45 | 2 |
| Araliaceae | 62.88 | 7.23 | 6359 | 3.13 | 5.18 | 1 |
| Proteaceae | 26.22 | 3.02 | 14101 | 6.94 | 4.98 | 3 |
| Juglandaceae | 70.55 | 8.12 | 2401 | 1.18 | 4.65 | 1 |
| Theaceae | 58.63 | 6.74 | 3013 | 1.48 | 4.11 | 9 |
| Ebenaceae | 27.66 | 3.18 | 5875 | 2.89 | 3.04 | 2 |
| Myrsinaceae | 8.16 | 0.94 | 8789 | 4.32 | 2.63 | 5 |
| Celastraceae | 2.95 | 0.34 | 9907 | 4.87 | 2.61 | 3 |
| Myrtaceae | 13.88 | 1.60 | 7226 | 3.55 | 2.58 | 2 |
| Leguminosae (Fabaceae) | 11.08 | 1.27 | 5180 | 2.55 | 1.91 | 2 |
| Aquifoliaceae | 6.93 | 0.80 | 5048 | 2.48 | 1.64 | 7 |
| Others | 74.41 | 8.56 | 17191 | 8.46 | 8.51 | 59 |
| Total | 869.31 | 100.00 | 203315 | 100.00 | 100.00 | 144 |

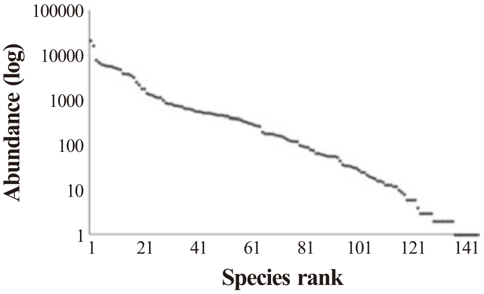


**Fig. 5. Species-abundance curve for the Lienhuachih Forest Dynamic Plot.**

relative abundance. Among 144 species, 43 species (29.86%) had < 25 individuals (< 1 individual $ha^{-1}$, and were considered to be rare species), and 9 of them were represented by a single stem.

**Size-class structure**

One hundred and two (each with total stems ≥ 25) out of 144 species were examined by size class. The charts exhibited 4 patterns: L-shaped, inverse J-shaped, fluctuating, and bell-shaped (Fig. 6). The L-shaped pattern was found in 9 species, such as *Ormosia formosana* and *Psychotria rubra*, and it showed a dramatic drop in the number of individuals in the small size-class. The inverse J-shaped pattern had a smooth, downward curve, which was shown by 60 species; for example, *E. roxburghiana* and *Helicia rengetiensis*. Twenty-nine species showed the fluctuating pattern, having the greatest number of individuals in the smallest size and a varied number of individuals in the other size classes, such as *Mallotus paniculatus* and *E. laxiflorus*. Only 4 species, such as *Antidesma japonicum* and *Rhododendron mariesii*, showed a bell-shaped pattern, and appeared to have quite a few saplings.

**Floristic diversity**

The composition and diversity of the size-classes of all woody individuals in the Lienhuachih FDP showed that trees of the size class ≥ 10-cm dbh included 16,513 stems (10.77%) and made up 710.08 $m^2$ (81.68%) of the total basal area and those in the size class ≥ 30-cm dbh only included 2,267 stems (1.48%) with 370.11 $m^2$ (42.57%) in basal area. The Evenness index for those with dbh ≥ 10 cm of the 25-ha plot was 0.79, which was very high, and 0.86 $ha^{-1}$. The Shannon-Wiener diversity index (H') for those dbh ≥ 10 cm was 3.64 in the 25-ha plot and 3.40 $ha^{-1}$, which was the highest among those ≥ 1-, 10-, 30-, 60-cm dbh ranks. The Evenness index inclined with increases along the diameter of the size class, but Fisher's alpha diversity showed the opposite trend.

A comparison of CTFS FDPs on islands used Fisher's alpha diversity index to evaluate their phytodiversity. Fisher's alpha diversity index for all woody plants with DBH ≥ 1 cm was the highest at the Lienhuachih FDP among those of 4 large lowland FDPs in Taiwan (Table 3). Its highest number of species and the second highest abundance resulted in the richest diversity on the island of Taiwan (Table 3). Compared to other CTFS FDPs on islands, Fisher's alpha diversity ($ha^{-1}$) index of the subtropical Lienhuachih FDP was similar to that of the Luquillo FDP in Puerto Rico but much lower than that of the Palana FDP in the Philippines, Sinhraja FDP in Sri Lanka, or Barro Colorado Island (BCI) FDP in Panama in the tropics. Meanwhile, Lienhuachih FDP was in a status between the Luquillo FDP and other tropical FDPs in terms of diversities of those large trees communities with DBH ≥ 10 cm and ≥ 30 cm. However, for those with a DBH ≥ 60 cm, the canopy diversity of the Lienhuachih FDP was much higher than those of the Fushan FDP in Taiwan, Luquillo FDP in the Philippines, and Sinhraja FDP in Sri Lanka, but was lower than that of the BCI FDP in Panama.

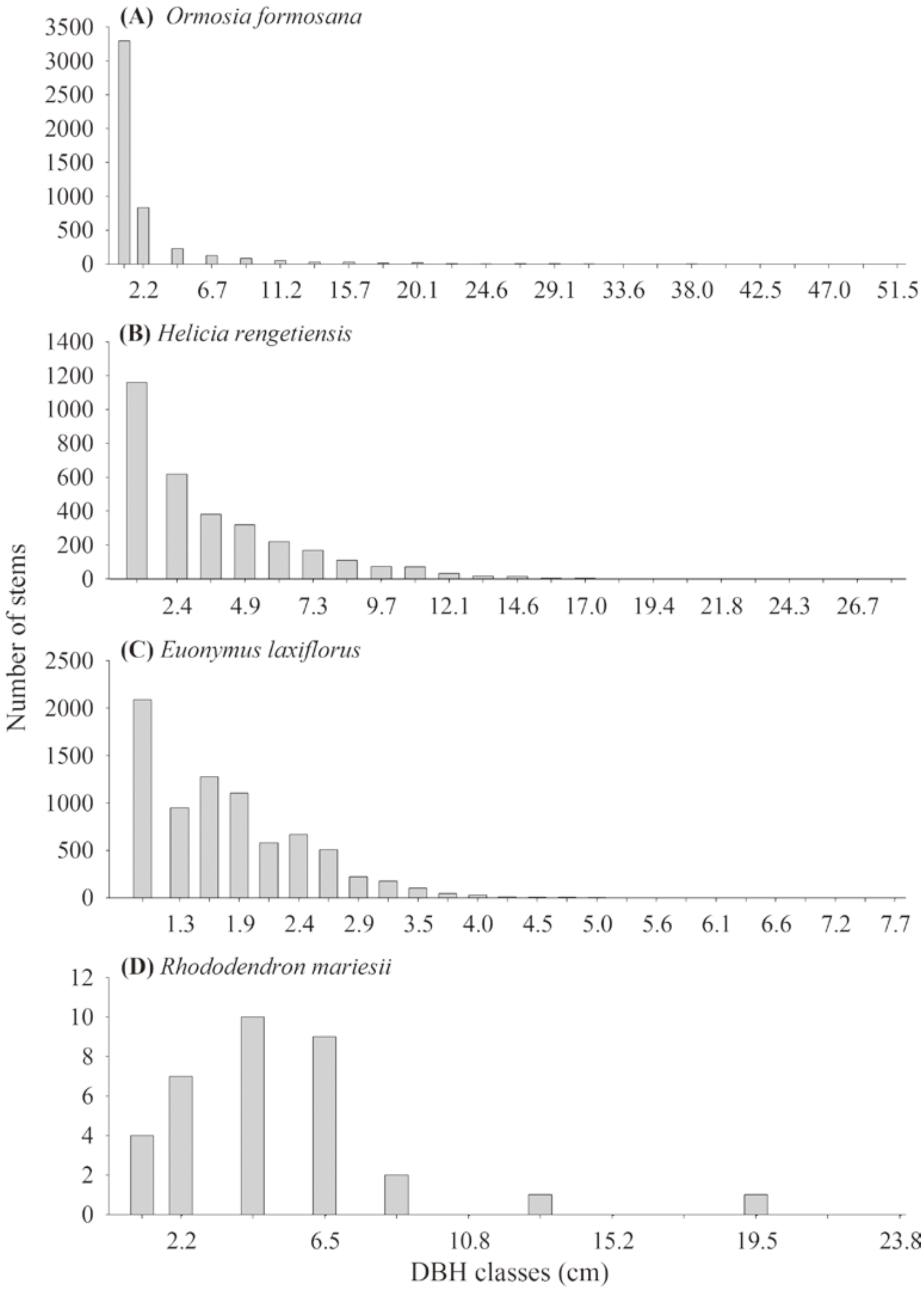


**Fig. 6. Size-class structure of 4 representative species. A, L-shaped size-class pattern, representative species: *Ormosia formosana*; B, inverse J-shaped size-class pattern, representative species: *Helicia rengetiensis*; C, fluctuating size-class pattern, representative species: *Euonymus laxiflorus*; D, bell-shaped size-class pattern, representative species: *Rhododendron mariesii*.**

**Table 3. Lowland forest dynamics plots of Taiwan**

| Location | Elevation (m) | Location | Area (ha) | Number of species | Basal area ($m^2$ $ha^{-1}$) | Abundance (individual $ha^{-1}$) | Fisher's alpha |
|---|---|---|---|---|---|---|---|
| Fushan* | 600~733 | North | 25 | 110 | 41.40 | 4580 | 12.0 |
| Lienhuachih | 667~845 | Central | 25 | 144 | 34.77 | 6631 | 15.8 |
| Nanjenshan+ | 300~340 | South | 3 | 118 | 36.30 | 12209 | 15.2 |
| Kenting | 280~300 | South | 10 | 110 | 45.12 | 4785 | 13.5 |

* Data of Fushan adopted from Su et al. 2007.

+ Data of others than Lienhuachih and Fushan adopted from Losos and Leigh 2004.

## DISCUSSION

### Floristic composition and size-class structure

The vegetation of the Lienhuachih FDP is dominated by the families Fagaceae, Lauraceae, Rubiaceae, Euphorbiaceae, and Melastomataceae. These dominant families of forests are found widely in humid areas of low elevations in the Northern Hemisphere (Kira 1991, Tagawa 1995). Although our studied dominant canopy species were characterized by *P. nantoensis*, *E. roxburghiana*, *S. octophylla*, and *Cryptocarya chinensis*, the top 30 dominant canopy species also including *Castanopsis fargesii*, *Cast. kawakamii*, *Cast. Cuspidate*, and *Machilus zuihoensis* were similar to species in the *Machilus-Castanopsis* forest zone (Su 1984). Even the sub-canopy and shrub species such as *Cryptocarya chinensis* and *B. cochinchinensis* are also common species found in this zone. These 2 species are very dominant due to the large number of individuals. Characteristics of the vegetation might be defined by the dominant families, genera or species but nearly never by non-canopy species. Prior to further analysis, the Lienhuachih FDP can be roughly recognized as a *Pasania-Engelhardtia-Schefflera* forest with dominant under-canopy of *R. cochinchinenesis*, *Cryptocarya chinensis* and *B. cochinchinensis*, which refer to the vegetation zone of Lauro-Fagaceous forests as well as *Machilus-Castanopsis* forests.

Most mature forests do not consist of pioneer species, except in areas of frequent disturbances or large gaps. Among the 20 most dominant species, 2 pioneer and canopy species, *Mallotus paniculatus* and *Sapium discolor*, with a sum IV of 4.76 contributed 6~11% importance to the composition of the top 20 dorminant species and the top 10 canopy species, respectively. It is possible that new niches are created by disturbances such as typhoons and artificial plantations. Large disturbed areas might result from landslides due to heavy rains or artificial plantations. Small disturbances might be twig self-shaving, tree falls, hunting trails, medical plant collection, etc. Due to nearly no barriers between the Lienhuachih FDP and the surrounding human developments, the pioneer species can easily invade and colonize the forest gaps and disturbed areas, and then develop greater numbers. The alternate natural and artificial disturbances may also encourage the development of a great amount of sub-canopy and shrub species which are composed of rapidly growing saplings for recruitment. This is might be why the shrubby *B. cochinchinensis* and the sub-canopy *R. cochinchinensis* have great numbers of individuals resulting in major contributions to IV and dorminance.

Both L-shaped and inverse J-shaped patterns of size-class structure analysis included 69 species comprising 67.6% of the total

102 analyzed species. The great numbers of small-sized individuals in these 2 patterns imply that most current species in this study site display good recruitment with rich sapling resources. The forest stand structure had a reverse J-shaped curve for tree and for seedling/sapling size-class distributions, which indicated that the forest as a whole is probably adequately regenerating (McLaren et al. 2005). When new niches occur, those with many saplings would generally have great chances for regeneration of forests through species competition. On the contrary, species with the bell-shaped pattern with only a few saplings usually face understory inhibition of sapling development and the fate of exclusion after elimination of young trees. The fluctuating pattern, also similar to a multi-modal size-class distribution pattern, may result from the numbers of individuals in different size classes being controlled by external physical stresses or internal physiological rhythms, such as periodicity of reproduction (Fan et al. 2005).

**Comparisons with other lowland FDPs in Taiwan and other FDPs of the world on islands**

Among the 4 low-elevation FDPs in Taiwan, the Lienhuachih FDP has the lowest basal area per hectare, whereas the Fushan FDP has the highest (Table 4). This might be because of the great proportion of small trees and shrubs at the Lienhuachih FDP. However, the number of individuals is very high in the Nanjenshan FDP instead of the Lienhuachih FDP because the strong windward effect of monsoon results in numbers of small-diameter trees in high densities (Sun et al. 1996). The woody plant density of the Lienhuachih FDP was still higher than that of the Fushan FDP in the north and the Kenting FDP in the south. This is possibly due to forest management, aboriginal development of the Thao, and local agricultural reclamation at the Lienhuachih FDP (Lu et al. 2001). Both the Fushan FDP and Kenting FDP are located in conservation areas (Su et al. 2007, Wang et al. 2004), and intact forests usually contain large-sized trees but are distributed at low densities.

For the diversity of those trees with DBH ≥ 1 cm and ≥ 10 cm, Fisher's alpha diversity of the Lienhuachih FDP was the highest in Taiwan, higher than that of the Nanjenshan FDP and much higher than that of the Fushan FDP. However, it was obviously lower than the BCI, Palanan, and Sinharaja FDPs. In general, the greatest diversity occurs in humid tropical rainforests with no dry seasons. As a result, the Lienhuachih FDP with obvious dry and wet seasons should show not as high diversity. It is surprising that the diversity of those trees with DBH ≥ 30 cm and ≥ 60 cm for most canopy trees at the Lienhuachih FDP

**Table 4. Fisher's alpha diversity (per 1 ha) index of different ranks of diameter at breast height for CTFS forest dynamics plots on islands**

| Size class (cm) | Lienhuachih (Taiwan) | Fushan* (Taiwan) | Najenshan+ (Taiwan) | Luquillo+ (Puerto Rico) | Palanan+ (Philippines) | Sinharaja+ (Sri Lanka) | BCI+ (Panama) |
|---|---|---|---|---|---|---|---|
| ≥ 1 | 15.7 | 12.1 | 15.6 | 13.5 | 43.4 | 24.4 | 34.6 |
| ≥ 10 | 14.0 | 9.9 | 14.0 | 9.3 | 36.5 | 20.4 | 35.6 |
| ≥ 30 | 10.6 | 5.9 | 5.5 | 8.8 | 16.0 | 14.1 | 23.9 |
| ≥ 60 | 8.9 | 2.8 | | 5.8 | 4.0 | 4.3 | 17.8 |

* Data of Fushan adopted from Su et al. 2007.

+ Data of others than Lienhuachih and Fushan adopted from Losos and Leigh 2004.

was much higher than those at the Fushan and Nanjenshan FDPs. Prior to this comparison, biodiversity and species richness of Nanjenshan and the Hengchun Peninsula were considered superior than those in other areas of Taiwan. It is also surprising that the canopy diversity of the Lienhuachih FDP was only lower than that of the BCI FDP in Panama. This indicates that the high canopy diversity at Lienhuachih results from the maintenance of natural species richness, influences of aboriginal activities and forest management, and natural disturbances by typhoons, and landslides from the steep topography generating new niches for recruitment. All disturbances including the introduction of cultivation such as *Prunus* and being too close to artificial forest management near the eastern boundary encourage pioneer species to colonize the newly generated niches. That is why 2 pioneer species were in the top 30 dominant species. The Liehuachih FDP is a forest that combines the characteristics of natural diversity and disturbed niches in succession, so its floristic diversity is high and rich.

## CONCLUSIONS

The floristic composition of the Lienhuachih FDP is dominated by the Fagaceae and Lauraceae. This is considered to be characteristic of the *Machilus-Castanopsis* forest zone. The under-canopy species, *R. cochinchinenesis* and *B. cochinchinensis*, are very dominant due to the large numbers of individuals. Two pioneer and canopy species, *M. paniculatus* and *S. discolor*, as a part of the composition of the top 20 dominant species and the top 10 canopy species indicate that the Lienhuachih FDP with mingled niches may involve natural and artificial disturbances. Certain numbers of rare species, unexpected pioneer species and waste cultivated species result in the high floristic diversity in the Lienhuachih FDP. Patterns of the size-class structure including a majority of small-sized individuals for 98 of the analyzed 102 species indicate that most current species in this study site display good recruitment with rich sapling resources. Among low-elevation FDPs in Taiwan, the Lienhuachih FDP has a higher density of individuals than the Fushan FDP and Kenting FDP, but much less than the Nanjenshan FDP. For diversity (Fisher's alpha diversity), the Lienhuachih FDP is the highest among these 4 plots. Compared to other CTFS forest dynamics plots on islands, Fisher's alpha diversity (per 1 ha) index of the subtropical Lienhuachih FDP was similar to that of the Luquillo FDP in Puerto Rico but much lower than that of other FDPs in the tropics. However, it is surprising that the canopy diversity of the Lienhuachih FDP was only lower than that of the BCI FDP in Panama. Due to the maintenance of natural species richness, influences of the aboriginal activities, forest management, and the natural disturbances by typhoons, and landslides from steep topography which generate new niches for recruitment, a high and rich floristic diversity of the Liehuachih FDP in a forest combining the characteristics of natural diversity and disturbed niches in succession can be maintained.

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