

## ESTIMATION OF ABOVEGROUND BIOMASS FOR A DOMINANT HERBACEOUS SPECIES IN A NORTHERN SUBTROPICAL FOREST USING HEIGHT AND COVERAGE

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**Abstract.** An estimation of the aboveground biomass of herbaceous plants is of significant value for the evaluation of carbon storage in subtropical herbaceous layers. To estimate the aboveground biomass of eight common herbaceous species in subtropical forests in Anhui Province, China, single and mixed multi-species allometric models were established using the average height, coverage, and complex variables (average height was multiplied by the coverage) as independent variables. The results showed that the coverage and complex variables were strongly correlated with the aboveground biomass of herbaceous plants, which were suitable predictors for modeling. The complex variables, except for *Selaginella moellendorffii*, revealed a good fit accuracy when used as the prediction variable, with  $R^2$  values ranging from between 0.649 and 0.904. Compared with the allometric model of specific species, the  $R^2$  of the mixed species model was lower ( $R^2 = 0.49$ ); however, the MPE (Mean Predictive Error, MPE) was low and within the allowable error range (MPE = -8.599%). The nine optimal allometric models established in this study proved that average height and coverage possessed high predictive capacities for herbaceous biomass. This provided a new approach for the measurement and monitoring of forest productivity in subtropical areas.

**Keywords:** *biomass, herbaceous, height, coverage, allometric model*

### Introduction

Plant biomass refers to the total amount of organic matter that is accumulated by individual plants, populations, and communities within a certain time and space (Scurlock et al., 2002; Nam et al., 2018; Axmanová et al., 2012). Plant biomass reflects the level of plant productivity and is the basic manifestation of the accumulation of biomass and energy in ecosystems (Flade et al., 2020; Huang et al., 2021). The measurement of forest biomass in subtropical natural secondary forests, which are globally important carbon reservoirs, can reflect the complex relationships between the biomass cycling and energy flows of forests and the ambient environment (Xu et al., 2018; Zhang et al., 2018).

As special layers of forest ecosystems, understory herbaceous plants play an essential role in increasing species diversity, as well as the conservation of soil and water. They are also important carbon sinks, promote ecosystem nutrient cycling and energy flows, particularly in early forest succession (Kumar et al., 2018a, b, Venier et al., 2019). Estimating the productivity and carbon stocks of herbaceous plants, biomass is the most desirable indicator (Huang et al., 2021). This is particularly applies for annual

herbaceous plants, as their aboveground biomass closely approximate their annual productivity (MacDonald et al., 2012).

Previous studies have focused on trees and shrubs; thus, the biomass of the herb layer is often ignored, which can lead to an underestimation of forest carbon stocks (Axmanová et al., 2012; Porté et al., 2009). Although herbaceous plants are short and have low biomass (accounting for a small proportion of the biomass of ecosystems) they are extremely abundant and affect the functionality of entire forest ecosystems (Whigham, 2004).

Current research on herbaceous plants focuses on the attributes of vegetation communities, diversity, and distribution patterns (Teague et al., 2016), since less research has been conducted on the productivity of herbaceous plant biomass and the modeling thereof (Pottier et al., 2017; Oliveras et al., 2014a). Most investigations into herbaceous plant biomass employ the sample harvesting method; however, it is time-consuming and laborious and can be very destructive to the forest environment (Porté et al., 2009). With advances in remote sensing platforms, LiDAR remote sensing image technologies have gradually been applied to the estimation of biomass (Lefsky et al., 2005; Yang et al., 2020). At present, LiDAR is widely used in forestry, but very little research has been devoted to characterizing relatively short herbaceous vegetation (Kulawardhana et al., 2014), which may be due to the following. First, upper vegetation with high canopy closure limits the penetration capacity of lasers, thereby increasing the challenge of terrain estimation by LiDAR (Chassereau et al., 2011). Further, herbaceous vegetation is relatively short and has little variation in height and canopy characteristics, which requires highly precise data to achieve relatively accurate predictions (Rosso et al., 2006; Kulawardhana et al., 2014). Spaceborne LiDAR cannot obtain high-resolution forest parameters and is easily affected by fluctuations in terrain. However, the spatial resolution of airborne LiDAR is high, albeit the estimated forest biomass is less accurate for areas with complex vegetation structures and high spatial heterogeneity. This is particularly the case for understory herbs, as they are almost always located within forests just above the surface (Sarker et al., 2011). Furthermore, LiDAR is more suitable for the overall estimation of forest biomass over large areas, whereas the biomass estimation error in small areas is significant (Kaasalainen et al., 2015). Despite these limitations, several recent studies have reported the application of LiDAR for the estimation of aboveground biomass in wilderness and pasture vegetation with dominant herbaceous species (Streutker et al., 2006; Jimenez-Berni et al., 2018). With continuous advances in the accuracy of radar, the precise characterization of the vegetative biomass of terrestrial ecosystems will likely be realized in the near future.

Recently, allometric models have been utilized to estimate the herbaceous biomass, and earlier studies revealed that the herbaceous cover and height may be employed as predictors in allometric models (Röttgermann et al., 2000; Kumar et al., 2018a; Axmanová et al., 2012). MacDonald (MacDonald et al., 2012) employed the heights and covers of herbaceous vegetation to construct an allometric model to estimate the aboveground biomass of herbaceous vegetation in the riparian woodlands of the Canadian boreal plains. Herbaceous cover is a better indicator of biomass diversity than height, as herbaceous vegetation has limited intra-species variations in height within a given area (Muukkonen et al., 2006). Several studies have suggested that the estimation of herbaceous biomass based on the coverage model may be temporally and regionally affected; thus, the use of models to predict biomass under abundant precipitation will be more prone to errors (Ónodi et al., 2017). In accordance with Axmanova (2012), the

most promising model is the biomass estimate-median model, which is calculated using the median stand height and estimated cover of the herb layer.

Linear, exponential, logarithmic, and power functions have been frequently employed to develop biomass equations (Conti et al., 2013; Liu et al., 2014). Independent variables (e.g., basal diameter, height, wood density, or a combination of two variables) are the best fit for the development of biomass equations for shrubs. This has provided a reasonable reference for the establishment of allometric models for herbaceous plants (Ali et al., 2015; Huang et al., 2021).

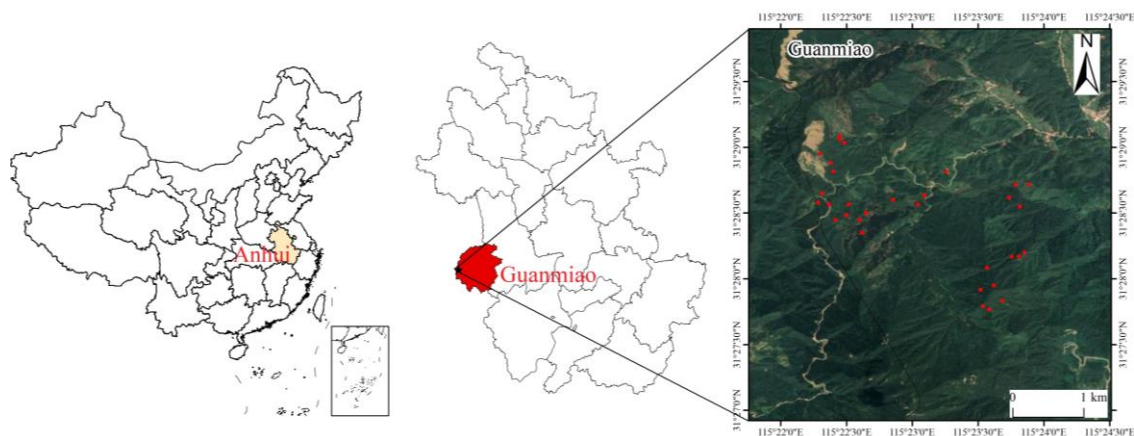
The forests of the Dabie Mountains are primarily located in the northern subtropical region, and represent the main type of vegetation in the terrestrial biomes of Central and Eastern China. They contain many tree species with high biomass and productivity at the regional scale, which are important for maintaining the global carbon balance (Ren et al., 2016; Huang et al., 2021; Jia et al., 2021). For this study, we selected eight common and extensively distributed herbaceous plants in the subtropics and used the H (average height, H) per unit area, C (coverage, C), and composite variable HC (product of the average height and coverage, HC) as predictor variables to construct single- and multi-species aboveground allometric models.

The aim was to employ conventional forest survey data to rapidly and accurately estimate the AGB (aboveground biomass, AGB) of herbaceous plants for future forest research. This, to provide basic data for the quantification and monitoring of forest productivity in subtropical regions, reduce uncertainties in the measurement of carbon in small area subtropical forest vegetation, while decreasing the ecological damage caused by the herb harvesting process.

## Materials and methods

### Study area

The study site was located in the Dabie Mountain forests of Guanmiao Township (80 km east of Jinzhai County (31°06' to 31°48' N and 115°22' to 116°11' E)), in Anhui Province, China (Fig. 1). This area has a humid subtropical monsoon climate with an average summer temperature of 26 °C and 2 °C in the winter, altitudes that range from 150~1353 m, and average annual precipitation of 1300 mm. The soil is mainly yellow brown loam (70% medium loam and sandy loam) which is, slightly acidic (pH 5.5~6.5) (Zhang et al., 2013).



**Figure 1.** Map of the study area

The vegetation type in the study area is subtropical broadleaved forest, with typical cover layers that are dominated by *Carya dabieshanensis*, *Castanea mollissima*, *Quercus acutissima*, and *Cyclobalanopsis glauca*. The common understorey shrubs species include *Rhododendron daurici*, *Camellia japonica*, *Lindera glauca*, and *Alangium chinense*, whereas typical herbaceous species are *Aster indicus*, *Microlepia marginata*, *Pteris multifida*, *Liriope graminifolia*, *Dryopteris uniformis*, *Liriope muscari*, *Selaginella moellendorffii*, *Cyrtomium fortunei*, and *Phaenosperma globosa*.

### Experimental method

Subsequent to a survey of herbaceous plants in the research area, eight of the most important perennial species (*Aster indicus*, *Microlepia marginata*, *Pteris multifida*, *Liriope graminifolia*, *Dryopteris uniformis*, *Liriope muscari*, *Selaginella moellendorffii*, and *Cyrtomium fortunei*) were selected as representatives (*Table 1*; *Table A2*). To keep the environmental as stable as possible, 32 sample plots were selected in the study site, where all stands were deciduous broadleaf forests with slopes that ranged from 15° to 30° (*Table A1*).

**Table 1.** Top 20 herbaceous plants in the study area with importance values

Species	Relative dominance (%)	Relative frequency (%)	Importance value (%)
<i>Liriope graminifolia</i>	0.7447	0.0056	0.2862
<i>Aster indicus</i>	0.2622	0.0014	0.1223
<i>Liriope muscari</i>	0.2736	0.0113	0.1116
<i>Cyrtomium fortunei</i>	0.2181	0.0127	0.0911
<i>Microlepia marginata</i>	0.1458	0.0099	0.0718
<i>Pteris multifida</i>	0.1595	0.0183	0.0663
<i>Dryopteris uniformis</i>	0.1405	0.0127	0.0660
<i>Selaginella moellendorffii</i>	0.1157	0.0042	0.0632
<i>Liriope spicata</i>	0.1248	0.0042	0.0605
<i>Oplismenus undulatifolius</i>	0.0986	0.0141	0.0562
<i>Rubia cordifolia</i>	0.0927	0.0197	0.0470
<i>Lithospermum zollingeri</i>	0.0663	0.0169	0.0348
<i>Lysimachia christinae</i>	0.0523	0.0141	0.0333
<i>Lygodium japonicum</i>	0.0441	0.0141	0.0294
<i>Phaenosperma globosa</i>	0.0402	0.0212	0.0287
<i>Parthenocissus tricuspidata</i>	0.0522	0.0197	0.0281
<i>Gynostemma pentaphyllum</i>	0.0238	0.0141	0.0280
<i>Lysimachia capillipes</i>	0.0400	0.0212	0.0270
<i>Lophatherum gracile</i>	0.0309	0.0183	0.0210
<i>Viola arcuata</i>	0.0174	0.0226	0.0208

Data is derived from one of our species diversity surveys

Five 1 m × 1 m sampling squares were established in each sample plot using the five-point sampling method (The eight herbaceous species did not necessarily occur within the same square at the same time). The average heights and cover (in 1 m<sup>2</sup>) of the eight herbaceous species in the sample squares were recorded in August 2020. The heights

were measured using a steel tape measure, refer to the methods of previous people whereas the cover through visual cover estimation (all cover values were taken at 5%, 10%, 15%, 20% ..... 100%) (Ónodi et al., 2017), visually estimate was performed by the same person throughout the study according to previous recommendations (MacDonald et al., 2012).

To reflect the actual annual productivity of perennials, we sampled only the biomass for that particular year, which excluded belowground components, standing dead biomass, and litter (Axmanová et al., 2012). The fresh weight of each plant and 0.5 kg of fresh sample from each plant was transferred to the laboratory, after which all samples were dried in an oven (BGZ-30, Boxun, China) at 105 °C for 48–72 h to a constant weight. Finally, the dry weight (0.01 g) of each species was weighed using an electronic balance (UW820S, SHIMADZU, Japan) (Table 2).

**Table 2.** Sample of aboveground biomass modeling data for eight herbaceous plants

Species	Classification	N	H (m)	C (%)	AGB (kg/m <sup>2</sup> )
<i>Microlepia marginata</i>	Pteridophyta	41	0.10-0.82	5-60	0.002-0.101
<i>Cyrtomium fortunei</i>	Pteridophyta	37	0.11-0.69	5-80	0.001-0.143
<i>Liriope graminifolia</i>	Angiospermae	42	0.08-0.24	5-90	0.002-0.160
<i>Pteris multifida</i>	Pteridophyta	44	0.08-0.53	5-50	0.005-0.019
<i>Selaginella moellendorffii</i>	Pteridophyta	37	0.10-0.42	5-70	0.001-0.029
<i>Liriope muscari</i>	Angiospermae	34	0.13-0.57	5-80	0.005-0.285
<i>Aster indicus</i>	Angiospermae	42	0.30-0.68	5-70	0.002-0.062
<i>Dryopteris uniformis</i>	Pteridophyta	50	0.13-0.68	5-85	0.002-0.178

N, number of individuals per species; H, average height (m); C, coverage (%); AGB, aboveground biomass (kg)

### Data analysis

All statistical analyses were performed in R (4.0.4). Predictor variables for the biomass of each component and allometric models for each species were examined via anomalous observations to verify the accuracy of field and laboratory data. We randomly selected from nine to 13 samples (20% of total samples) for each species as model test samples, while the remaining individuals were used as model samples. The relationships between aboveground biomass components and measured variables, including the C, H, and HC (H×C) were assessed using regression analysis and, implemented through the ‘Basic Trendline’ package (Mei et al., 2018). Linear and nonlinear regression equations were utilized for model fitting, with model forms including:

$$W = ax + b \quad (\text{Eq.1})$$

$$W = ax^b \quad (\text{Eq.2})$$

$$W = ax^2 + bx + c \quad (\text{Eq.3})$$

where W denotes the AGB (kg/m<sup>2</sup>), x is H (m), C (%), HC, and a, b, c are the model parameters.

The optimal model was screened according to  $R^2$  and AIC (Akaike information criterion, AIC), while the RMSE (root mean square error, RMSE), MAE (mean absolute error, MAE), and MAPE (mean absolute percentage error, MAPE) of each model were calculated. Formulas for the accuracy of each estimation were:

$$y = [\sum_{i=1}^n y_i] / n \quad (\text{Eq.4})$$

$$\text{RSS} = \sum_{i=1}^n (y_i - \hat{y})^2 \quad (\text{Eq.5})$$

$$\text{TSS} = \sum_{i=1}^n (y_i - \bar{y})^2 \quad (\text{Eq.6})$$

$$R^2 = 1 - \frac{\text{RSS}}{\text{TSS}} \quad (\text{Eq.7})$$

$$\text{AIC} = -2\ln(L) + 2n \quad (\text{Eq.8})$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (y_i - y)^2}{n}} \quad (\text{Eq.9})$$

$$\text{MPE} = \frac{100\%}{n} \sum_{i=1}^n \frac{y - y_i}{y} \quad (\text{Eq.10})$$

where  $y_i$  is the estimated biomass ( $\text{kg/m}^2$ );  $y$  is the measured biomass ( $\text{kg/m}^2$ );  $\hat{y}$  is the mean of the measured values of  $y$  ( $\text{kg/m}^2$ );  $L$  is the likelihood of the fitted model, and  $n$  is the number of samples.

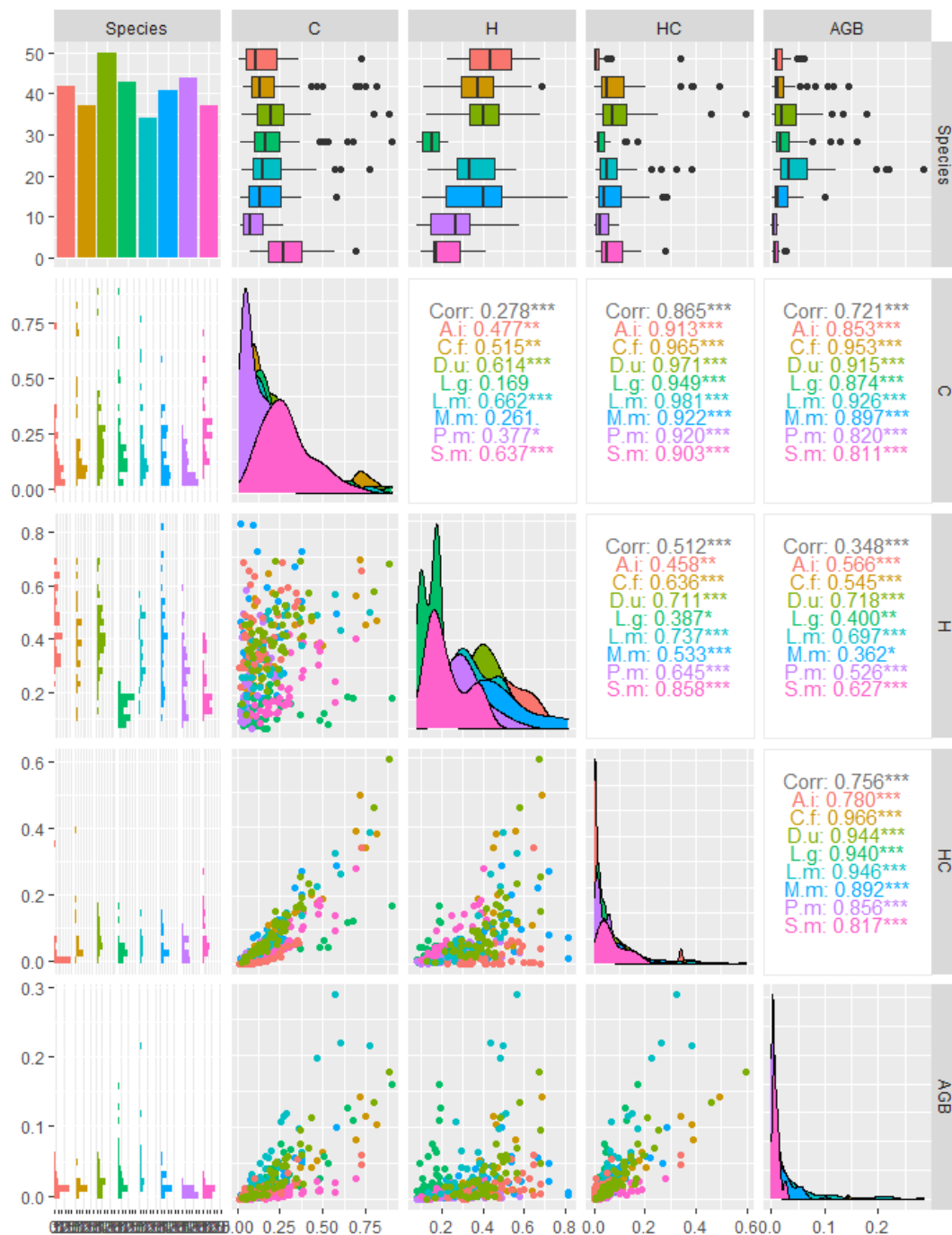
## Results

### *Correlation of height and cover with aboveground biomass*

To select predictors with higher accuracy as independent variables for model development, Pearson correlation analysis was initially performed between the H, C, HC and aboveground biomass (AGB) of eight herbaceous species. The results revealed that H, C, HC, and AGB had highly a significant positive correlation ( $p < 0.001$ ), among which HC had the highest correlation coefficient of 0.700 with AGB, followed by C with a correlation coefficient of 0.646 (*Fig. 2*). The correlation between the biomass and measured variables revealed that compared with H, C and HC were more correlated with the aboveground biomass of herbaceous plants and more suitable as predictor variables for model construction.

### *Allometric model construction and model testing for eight herbaceous plants*

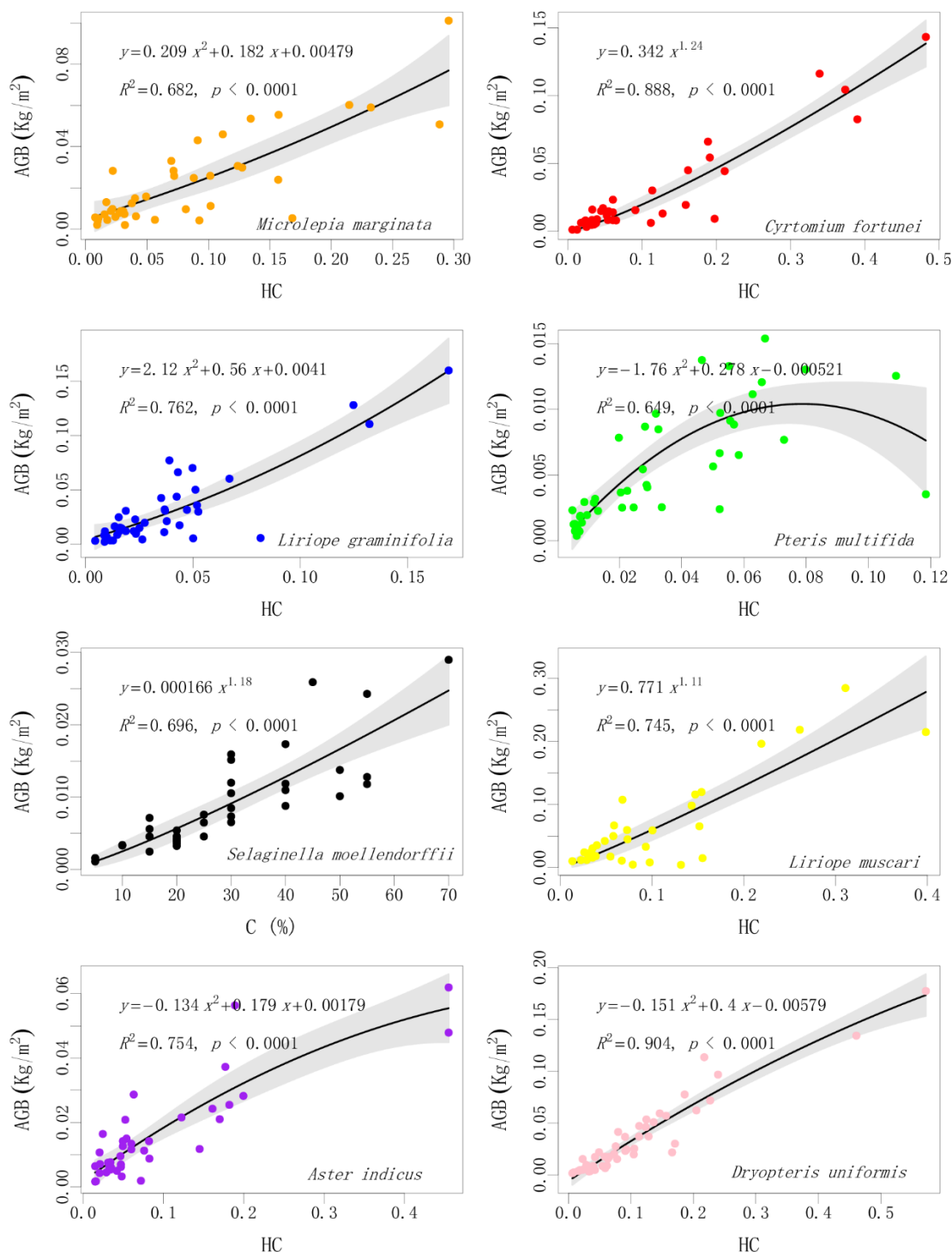
Linear and nonlinear regression models were employed to estimate the biomass of each herbaceous species. To verify the predictive ability of H, C, and HC for AGB, allometric models were developed using H, C, and HC, respectively. The optimal model was selected based on the  $R^2$  and AIC values of the models (a larger  $R^2$  indicated the stronger explanatory power of the model for the predictor variables, and smaller AIC values indicated a lower model error). Model parameters (a, b, c) were also estimated for the allometric models of eight herbaceous and mixed species (*Table 3*).



**Figure 2.** Pearson correlation between herb layer biomass and measured variables. *H*, average height (m); *C*, coverage (%); *HC*, the height is multiplied by the coverage; *AGB*, aboveground biomass; *M.m*, *Microlepis marginata*; *C.f*, *Cyrtomium fortune*; *L.m*, *Liriope muscari*; *P.m*, *Pteris multifida*; *S.m*, *Selaginella moellendorffii*. *L.g*, *Liriope graminifolia*; *A.i*, *Aster indicus*; *D.u*, *Dryopteris uniformis*. \*Significance is at  $p < 0.05$ . \*\*Significance is at  $p < 0.01$ . \*\*\*Significance is at  $p < 0.001$

From the point of view of the allometric models finally selected, none of the linear model ( $W = ax + b$ ) was selected, the linear model ( $W = ax^2 + bx + c$ ) and the power exponential model ( $W = ax^b$ ) were more suitable for fitting the herbaceous allometric

model, they have a higher  $R^2$  and a lower AIC (Table 3). Among the eight herbaceous plants fitted, HC was the best predictor of AGB, except for *Selaginella moellendorffii*. The accuracy of the model fit for the eight single species was generally good, where the  $R^2$  ranged from 0.606 to 0.904. The best fits were for *Dryopteris uniformis* ( $R^2 = 0.904$ ,  $p < 0.001$ ) and *Cyrtomium fortunei* ( $R^2 = 0.888$ ,  $p < 0.001$ ), which explained 90.4% and 88.8% of the aboveground biomass (AGB), respectively (Fig. 3).



**Figure 3.** Aboveground biomass (AGB) in relation to predictors. H, t average height; C, coverage;  $R^2$ : coefficient of determination; predictors are described in Table 2

**Table 3.** Best allometric models for estimating the aboveground biomass of eight herbaceous plants

	Species	Equations	Predictor variable	Model parameter			R <sup>2</sup>	AIC	SEE
				a	b	c			
Specific species	<i>Microlepia marginata</i>	$W = ax^2 + bx + c$	HC	0.2094	0.1819	0.0048	0.682***	-238	0.0125
	<i>Cyrtomium fortunei</i>	$W = ax^b$	HC	0.3416	1.2380		0.888***	-221	0.0117
	<i>Liriope graminifolia</i>	$W = ax^2 + bx + c$	HC	2.1205	0.5601	0.0041	0.762***	-216	0.0174
	<i>Pteris multifida</i>	$W = ax^2 + bx + c$	HC	-1.7640	0.2778	-0.0005	0.649***	-385	0.0026
	<i>Selaginella moellendorffii</i>	$W = ax^b$	C	0.0002	1.1776		0.696***	-304	0.0038
	<i>Liriope muscari</i>	$W = ax^b$	HC	0.7710	1.1070		0.745***	-125	0.0362
	<i>Aster indicus</i>	$W = ax^2 + bx + c$	HC	-0.1343	0.1791	0.0018	0.754***	-267	0.0074
	<i>Dryopteris uniformis</i>	$W = ax^2 + bx + c$	HC	-0.1511	0.3999	-0.0058	0.904***	-300	0.0115
Multi-species	Pteridophyta	$W = ax^2 + bx + c$	HC	0.1982	0.1953	0.0010	0.844***	-1036	0.0224
	Angiospermae	$W = ax^2 + bx + c$	HC	-0.8468	0.6725	-0.0042	0.435***	-431	0.148
	All species	$W = ax^b$	HC	0.2852	0.9500		0.490***	-1434	0.0261

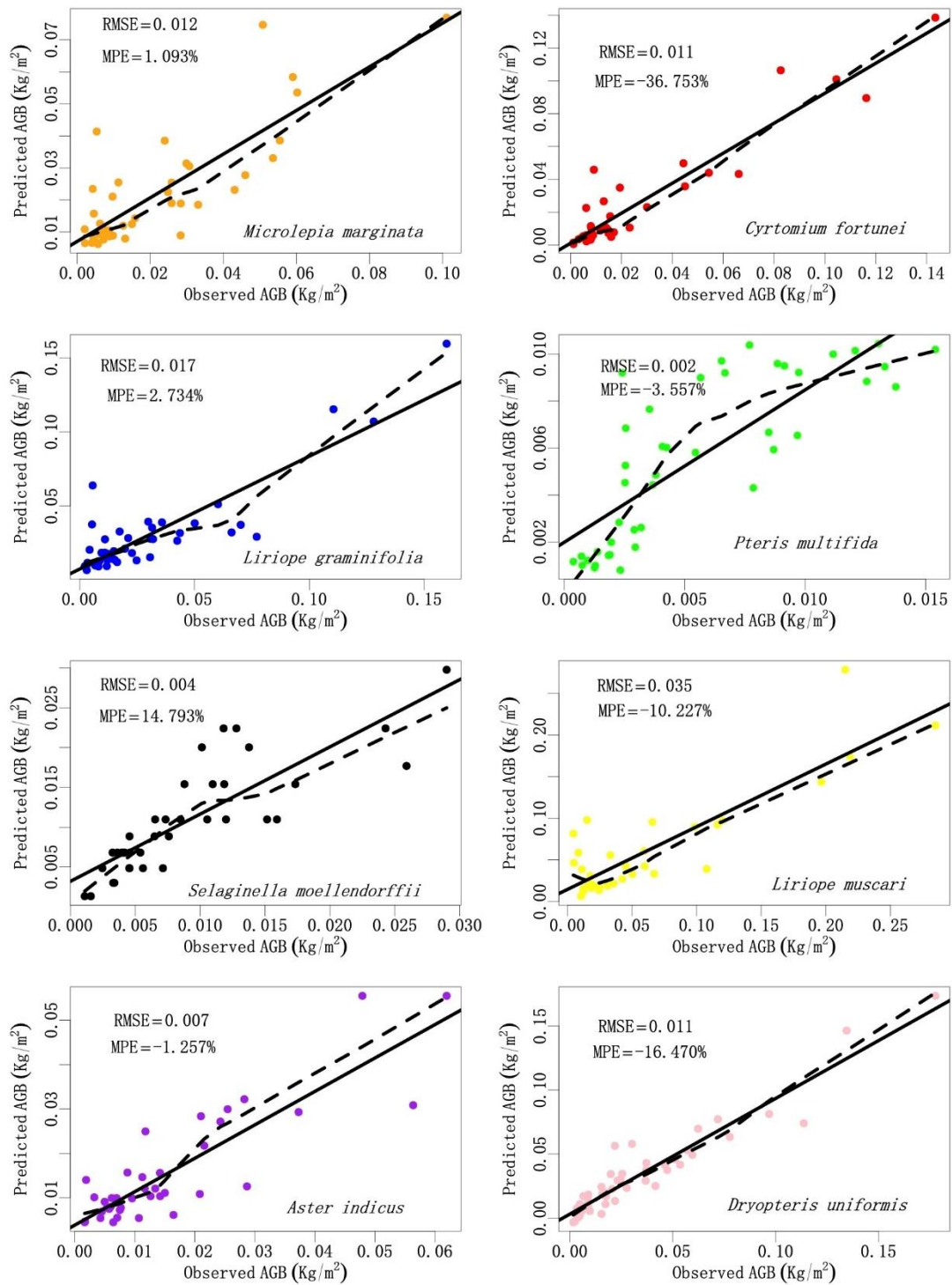
H, average height (m); C, coverage (%), HC, the average height is multiplied by the coverage; (a, b, c), biomass coefficients; R<sup>2</sup>, coefficient of determination; AIC, Akaike information criterion; SEE, standard error of the estimation, \*\*\*Significance is at  $p < 0.001$

The model accuracy of the mixed multi-species allometric model based on the sum of the AGB of all relevant species was lower in contrast to the species-specific allometric model, with the best prediction model of  $R^2 = 0.49$ . The AGB of the different species was overestimated (MPE > 0) or underestimated (MPE < 0) in the prediction model (Figs. 4 and 5). Among them, the AGB of *Microlepia marginata*, *Liriope graminifolia*, and *Selaginella moellendorffii* were overestimated; however, *Cyrtomium fortunei*, *Pteris multifida*, *Liriope muscari*, *Aster indicus*, *Dryopteris uniformis*, and the multi-species were underestimated.

## Discussion

For herbaceous plants, the height (H) and coverage (C) were shown to be predictor variables for the creation of allometric models (MacDonald et al., 2012; Pottier et al., 2017). Compared with the multiple regression model, the unary regression model was simpler. To make the model more convenient for practical applications, while maintaining model accuracy (referring to previous modeling methods) (Kumar et al., 2018a; Huang et al., 2021; Dou et al., 2019), we selected three variables (H, C, and HC) and three models (linear, quadratic, and power function) to develop species-specific and multi-species aboveground biomass equations.

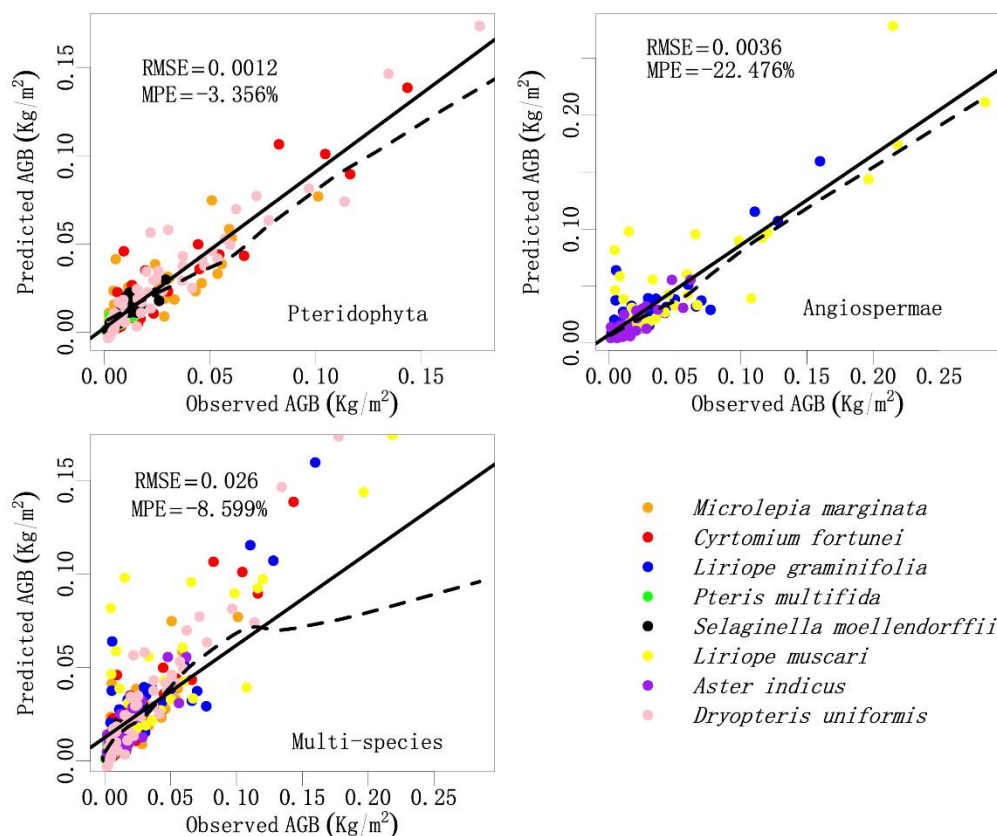
The results revealed that the one-dimensional quadratic linear regression and power function models were used most frequently, and these two underlying models were also often used in allometric models for tree and shrub species (She et al., 2015; Yang et al., 2017; Huang et al., 2021). Although the power function is widely recognized in the allometric growth model of plants, it did not always improve the predictive ability of the model in our research (Pottier et al., 2017). In the 11 groups of models established for the eight herbs in our research (Table 3), the relationship between C and AGB was primarily a power function relationship; however, the relationship between H and AGB tended to be linear.



**Figure 4.** Relationships between observed aboveground biomass and predicted aboveground biomass. RMSE, root mean squared error; MPE, mean predictive error

Several studies have used the herbaceous clump diameter as a predictor variable to construct models (Wang et al., 2012, 2014); however, in practice, it was found that measuring the herbaceous shrub diameter would involve additional field work, which was not consistent with the original intent of establishing the model (Axmanová et al.,

2012; Oliveras et al., 2014b). It has been suggested that H is the best predictor (Poorter et al., 2015); however, the present correlation analysis indicated that although H, C and the combined HC variable of both were significantly correlated with the AGB. The correlation of H with the AGB was lower than that of both C and the combined variable HC, as shown in *Figure 2*.



**Figure 5.** Relationships between observed aboveground biomass and predicted aboveground biomass (multi-species). Predictors are described in *Figure 4*

This may have been related to the growth characteristics and sampling time of herbaceous plants. The sampling time for this study was August, when the growth height and stability of most herbaceous plants reached their peak, and the height difference between the same species was small (Tremblay and Larocque, 2001; He et al., 2014). Our results suggested that the two independent variables C and HC had a high explanatory capacity for assessing the AGB across all species. This, aligned with similar variable-biomass relationships found for understory species in other studies (MacDonald et al., 2012; Poorter et al., 2012). In this study C and the combined variable HC were selected as predictor variables for the AGB. From the optimal model of the eight herbaceous plants, the equations fitted with HC and C as predictor variables had low SEE and AIC values and a high  $R^2$ , as shown in *Table 3*. However, species-specific models might not be generally applicable for all types of forest ecosystems, as the growth environments and site conditions of herbaceous vegetation have a significant influence on the accuracy of the herb allometric model (Axmanová et al., 2012). Aboveground biomass may be affected by abiotic conditions, such as light,

precipitation, temperature, soil nutrients, soil thickness, etc. Furthermore, anthropogenic disturbances such as grazing and logging will also impact the estimation of aboveground herbaceous biomass (Poorter et al., 2012), which may limit the scope of the model. The accuracy of the mixed species biomass model for ferns ( $R^2 = 0.844$ ) was significantly higher than that for angiosperms ( $R^2 = 0.435$ ), mainly because differences in the height to diameter ratios of stalks between different fern species was small, while angiosperms had greater morphological differences (Whigham, 2004). In comparison, the multi-species (all species) mixed allometric model was found to have a lower  $R^2$  in contrast to the species-specific allometric models. This phenomenon was due to a higher of species (Pteridophyta, Angiospermae) which increased the differences in H and C between them (MacDonald et al., 2012). For example, in terms of height, *Aster indicus* and *Selaginella moellendorffii*, are members of a group of herbs with taller stems and sparse leaves, whereas *Liriope muscari* and *Liriope graminifolia* have relatively low stems and dense leaves. In addition, since there were significant differences in biomass between plants with the same cover (Wang et al., 2021; Pottier et al., 2017) (Table A3). The ferns *Selaginella moellendorffii*, *Microlepia marginata* in contrast to *Aster indicus* overlap more fronds with the same cover compared to each other, the model accuracy of mixed species model was influenced.

Although the  $R^2$  of the multi-species was lower than the specific species, from the perspective of the average prediction error, the error range of the multi-species model was not high (only 8.599% lower than the observed value) (Fig. 5). The decreased average prediction error may have been derived from the neutralization of the prediction errors of different specific species (Kachamba et al., 2016; Asrat et al., 2020). The use of mixed species models in field work can improve work efficiency.

Since the belowground biomass of perennial herbaceous plants always remains relatively constant, and their aboveground biomass occupies the majority of its annual productivity (Pottier et al., 2017; Axmanová et al., 2012), the aboveground biomass of only eight herbaceous plants was considered for our study. Previous investigations revealed that it was difficult to obtain the entire extent of underground roots. Root systems inevitably lose many fine roots during extraction and cleaning, which maybe increases uncertainty when determining the root biomass (Huang et al., 2021; Ma et al., 2020). Existing allometric models show that the accurate estimation of underground plant allometric models significantly lower than that for aboveground biomass. In addition, the acquisition of underground biomass is time consuming and it is difficult to separate the roots from soil in the field for herbaceous plants. Although the calculation of belowground biomass was not included in this study, from the results of earlier studies, the root-shoot ratios of herbaceous plants in different regions were observed to be significantly different due to the influences of the growth environment (Bonser et al., 2003; Flanagan et al., 2013). The belowground biomass of herbs in the alpine steppe and desert of the Gobi area accounted for ~80% of the total biomass, while the underground biomass of herbs in the subtropical forest accounted for ~30% (Oliveras et al., 2014b; Wang et al., 2018; Niklas, 2005).

## Conclusion

The following conclusions were drawn through the development of allometric models for the eight herbaceous plants: (1) Herbaceous height (H) and cover (C) can be used as predictor variables to develop herbaceous allometric models, where the

combination of the two variables (HC) is the best predictor variable. (2) The morphological characteristics of various herbaceous species will affect the selection of predictive model indicators; thus, the overall precision of the models. This is particularly the case when the height and coverage of different species are significantly varied, as the accuracy of the multi-species allometric model will be reduced and the scope of applications limited. (3) For the estimation of herbaceous biomass in the field, a multi-species allometric model can be selected to reduce the workload in the field and decrease environmental damage. These results can provide a useful reference for the selection of biomass predictors of herbaceous plants in subtropical forests. However, the growth environments and site conditions of herbaceous vegetation have a significant influence on the accuracy of herb biomass models. The use of an allometric model to estimate the AGB of the herb layer is suitable only for accurate estimations in specific small-scale areas. When applying corresponding biomass models beyond a given study area, the herbal data of the localized area should be used for testing. The values of the dependent variables beyond the range of this study will also need to be verified. For the estimation of large-scale biomass, LiDAR remote sensing imaging technology may be used, which can save time and labor.

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## APPENDIX

**Table A1.** Sampling location information

Site	Longitude and latitude	Slope (°)	Altitude (m)	Dominant herbaceous species
1	115°22'17"E 31°28'35"N	WS 18~27	729	<i>Aster indicus</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
2	115°22'23"E 31°28'39"N	SW 25~30	741	<i>Aster indicus</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i>
3	115°22'36"E 31°28'27"N	S 18~25	748	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Liriope graminifolia</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
4	115°23'03"E 31°28'34"N	S 15~20	762	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i>
5	115°23'03"E 31°28'49"N	S 23~28	673	<i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
6	115°23'03"E 31°28'38"N	SW 20~26	627	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
7	115°23'04"E 31°28'43"N	SW 23~29	694	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Cyrtomium fortunei</i>
8	115°23'51"E 31°28'12"N	S 24~28	750	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i>
9	115°23'49"E 31°28'33"N	S 25~30	779	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
10	115°23'44"E 31°28'37"N	S 19~23	786	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
11	115°23'47"E 31°28'43"N	SE 21~25	787	<i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
12	115°22'51"E 31°28'36"N	S 17~24	796	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
13	115°23'31"E 31°27'53"N	SE 23~29	813	<i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
14	115°23'37"E 31°27'57"N	S 24~26	821	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
15	115°23'35"E 31°27'46"N	SE 15~19	785	<i>Aster indicus</i> , <i>Microlepia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>

16	115°23'41"E 31°27'50"N	SE 15~17	770	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
17	115°23'34"E 31°28'05"N	SW 17~21	735	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
18	115°23'31"E 31°27'58"N	SW 19~25	564	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
19	115°22'27"E 31°29'05"N	S 19~23	569	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
20	115°22'27"E 31°29'02"N	SE 20~23	586	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
21	115°22'18"E 31°28'57"N	S 20~23	548	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
22	115°22'19"E 31°28'39"N	S 19~25	560	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
23	115°22'24"E 31°28'49"N	S 22~27	578	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
24	115°22'29"E 31°29'02"N	S 21~24	555	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
25	115°22'37"E 31°28'21"N	SW 19~25	639	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> ,
26	115°22'30"E 31°28'29"N	SE 20~24	626	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
27	115°22'33"E 31°28'34"N	S 22~24	597	<i>Aster indicus</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
28	115°22'40"E 31°28'27"N	SW 19~25	596	<i>Aster indicus</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> ,
29	115°22'31"E 31°28'31"N	SW 20~25	605	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Cyrtomium fortunei</i>
30	115°22'39"E 31°28'30"N	SW 15~19	588	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
31	115°22'22"E 31°28'34"N	SE 19~23	613	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>
32	115°22'25"E 31°28'27"N	S 15~17	617	<i>Aster indicus</i> , <i>Microlepidia marginata</i> , <i>Pteris multifida</i> , <i>Liriope graminifolia</i> , <i>Dryopteris uniformis</i> , <i>Liriope muscari</i> , <i>Selaginella moellendorffii</i> , <i>Cyrtomium fortunei</i>

**Table A2.** Major species classification

Species	Family	Genus
<i>Liriope graminifolia</i>	Liliaceae	<i>Liriope</i>
<i>Aster indicus</i>	Asteraceae	<i>Aster</i>
<i>Liriope muscari</i>	Liliaceae	<i>Liriope</i>
<i>Cyrtomium fortunei</i>	Dryopteridaceae	<i>Cyrtomium</i>
<i>Microlepia marginata</i>	Dennstaedtiaceae	<i>Microlepia</i>
<i>Pteris multifida</i>	Pteridaceae	<i>Pteris</i>
<i>Dryopteris uniformis</i>	Dryopteridaceae	<i>Dryopteris</i>
<i>Selaginella moellendorffii</i>	Selaginellaceae	<i>Selaginella</i>
<i>Liriope spicata</i>	Liliaceae	<i>Liriope</i>
<i>Oplismenus undulatifolius</i>	Poaceae	<i>Oplismenus</i>
<i>Rubia cordifolia</i>	Rubiaceae	<i>Rubia</i>
<i>Lithospermum zollingeri</i>	Boraginaceae	<i>Lithospermum</i>
<i>Lysimachia christinae</i>	Primulaceae	<i>Lysimachia</i>
<i>Lygodium japonicum</i>	Lygodiaceae	<i>Lygodium</i>
<i>Phaenosperma globosa</i>	Poaceae	<i>Phaenosperma</i>
<i>Parthenocissus tricuspidata</i>	Vitaceae	<i>Parthenocissus</i>
<i>Gynostemma pentaphyllum</i>	Cucurbitaceae	<i>Gynostemma</i>
<i>Lysimachia capillipes</i>	Primulaceae	<i>Lysimachia</i>
<i>Lophatherum gracile</i>	Poaceae	<i>Lophatherum</i>
<i>Viola verecunda</i>	Violaceae	<i>Viola</i>

**Table A3.** All observational data

No.	Species	C (%)	H (m)	HC	AGB (g)
1	<i>Microlepia marginata</i>	5	0.336	0.0168	0.0131
2	<i>Microlepia marginata</i>	10	0.306	0.0306	0.0088
3	<i>Microlepia marginata</i>	25	0.365	0.0913	0.0431
4	<i>Microlepia marginata</i>	40	0.421	0.1684	0.0053
5	<i>Microlepia marginata</i>	20	0.463	0.0926	0.0043
6	<i>Microlepia marginata</i>	60	0.493	0.2958	0.1011
7	<i>Microlepia marginata</i>	35	0.664	0.2324	0.0590
8	<i>Microlepia marginata</i>	15	0.477	0.0716	0.0283
9	<i>Microlepia marginata</i>	5	0.352	0.0176	0.0045
10	<i>Microlepia marginata</i>	25	0.406	0.1015	0.0259
11	<i>Microlepia marginata</i>	15	0.587	0.0881	0.0249
12	<i>Microlepia marginata</i>	30	0.413	0.1239	0.0307
13	<i>Microlepia marginata</i>	40	0.721	0.2884	0.0508
14	<i>Microlepia marginata</i>	10	0.721	0.0721	0.0258
15	<i>Microlepia marginata</i>	5	0.549	0.0275	0.0079
16	<i>Microlepia marginata</i>	5	0.819	0.0410	0.0063
17	<i>Microlepia marginata</i>	5	0.412	0.0206	0.0089
18	<i>Microlepia marginata</i>	5	0.483	0.0242	0.0060
19	<i>Microlepia marginata</i>	10	0.153	0.0153	0.0072
20	<i>Microlepia marginata</i>	15	0.189	0.0284	0.0088

21	<i>Microlepia marginata</i>	25	0.538	0.1345	0.0536
22	<i>Microlepia marginata</i>	25	0.279	0.0698	0.0331
23	<i>Microlepia marginata</i>	15	0.376	0.0564	0.0046
24	<i>Microlepia marginata</i>	25	0.407	0.1018	0.0113
25	<i>Microlepia marginata</i>	15	0.213	0.0320	0.0021
26	<i>Microlepia marginata</i>	30	0.523	0.1569	0.0240
27	<i>Microlepia marginata</i>	5	0.186	0.0093	0.0021
28	<i>Microlepia marginata</i>	40	0.393	0.1572	0.0555
29	<i>Microlepia marginata</i>	30	0.425	0.1275	0.0299
30	<i>Microlepia marginata</i>	40	0.537	0.2148	0.0602
31	<i>Microlepia marginata</i>	10	0.103	0.0103	0.0052
32	<i>Microlepia marginata</i>	10	0.221	0.0221	0.0283
33	<i>Microlepia marginata</i>	10	0.816	0.0816	0.0097
34	<i>Microlepia marginata</i>	20	0.188	0.0376	0.0126
35	<i>Microlepia marginata</i>	10	0.218	0.0218	0.0098
36	<i>Microlepia marginata</i>	25	0.197	0.0493	0.0158
37	<i>Microlepia marginata</i>	5	0.196	0.0098	0.0041
38	<i>Microlepia marginata</i>	10	0.316	0.0316	0.0074
39	<i>Microlepia marginata</i>	5	0.154	0.0077	0.0057
40	<i>Microlepia marginata</i>	15	0.268	0.0402	0.0150
41	<i>Microlepia marginata</i>	25	0.447	0.1118	0.0460
42	<i>Cyrtomium fortunei</i>	15	0.234	0.0351	0.0050
43	<i>Cyrtomium fortunei</i>	10	0.317	0.0317	0.0047
44	<i>Cyrtomium fortunei</i>	10	0.121	0.0121	0.0011
45	<i>Cyrtomium fortunei</i>	20	0.637	0.1274	0.0130
46	<i>Cyrtomium fortunei</i>	15	0.431	0.0647	0.0080
47	<i>Cyrtomium fortunei</i>	35	0.453	0.1586	0.0194
48	<i>Cyrtomium fortunei</i>	10	0.547	0.0547	0.0147
49	<i>Cyrtomium fortunei</i>	80	0.467	0.3736	0.1045
50	<i>Cyrtomium fortunei</i>	10	0.248	0.0248	0.0032
51	<i>Cyrtomium fortunei</i>	10	0.377	0.0377	0.0060
52	<i>Cyrtomium fortunei</i>	5	0.114	0.0057	0.0011
53	<i>Cyrtomium fortunei</i>	20	0.567	0.1134	0.0301
54	<i>Cyrtomium fortunei</i>	5	0.348	0.0174	0.0062
55	<i>Cyrtomium fortunei</i>	10	0.388	0.0388	0.0089
56	<i>Cyrtomium fortunei</i>	40	0.404	0.1616	0.0450
57	<i>Cyrtomium fortunei</i>	45	0.469	0.2111	0.0444
58	<i>Cyrtomium fortunei</i>	20	0.453	0.0906	0.0156
59	<i>Cyrtomium fortunei</i>	20	0.302	0.0604	0.0232
60	<i>Cyrtomium fortunei</i>	70	0.689	0.4823	0.1434
61	<i>Cyrtomium fortunei</i>	20	0.235	0.0470	0.0170
62	<i>Cyrtomium fortunei</i>	10	0.326	0.0326	0.0160
63	<i>Cyrtomium fortunei</i>	50	0.377	0.1885	0.0661
64	<i>Cyrtomium fortunei</i>	15	0.296	0.0444	0.0149
65	<i>Cyrtomium fortunei</i>	50	0.382	0.1910	0.0543
66	<i>Cyrtomium fortunei</i>	10	0.234	0.0234	0.0079

67	<i>Cyrtomium fortunei</i>	20	0.302	0.0604	0.0081
68	<i>Cyrtomium fortunei</i>	10	0.261	0.0261	0.0070
69	<i>Cyrtomium fortunei</i>	50	0.223	0.1115	0.0061
70	<i>Cyrtomium fortunei</i>	15	0.402	0.0603	0.0140
71	<i>Cyrtomium fortunei</i>	15	0.357	0.0536	0.0083
72	<i>Cyrtomium fortunei</i>	5	0.445	0.0223	0.0074
73	<i>Cyrtomium fortunei</i>	10	0.203	0.0203	0.0065
74	<i>Cyrtomium fortunei</i>	70	0.557	0.3899	0.0826
75	<i>Cyrtomium fortunei</i>	10	0.321	0.0321	0.0083
76	<i>Cyrtomium fortunei</i>	50	0.395	0.1975	0.0092
77	<i>Cyrtomium fortunei</i>	10	0.521	0.0521	0.0117
78	<i>Cyrtomium fortunei</i>	75	0.452	0.3390	0.1163
79	<i>Liriope graminifolia</i>	5	0.088	0.0044	0.0031
80	<i>Liriope graminifolia</i>	50	0.105	0.0525	0.0299
81	<i>Liriope graminifolia</i>	15	0.085	0.0128	0.0034
82	<i>Liriope graminifolia</i>	15	0.077	0.0116	0.0034
83	<i>Liriope graminifolia</i>	20	0.079	0.0158	0.0121
84	<i>Liriope graminifolia</i>	55	0.093	0.0512	0.0501
85	<i>Liriope graminifolia</i>	10	0.086	0.0086	0.0082
86	<i>Liriope graminifolia</i>	25	0.110	0.0275	0.0197
87	<i>Liriope graminifolia</i>	90	0.188	0.1692	0.1598
88	<i>Liriope graminifolia</i>	30	0.173	0.0519	0.0358
89	<i>Liriope graminifolia</i>	20	0.183	0.0366	0.0110
90	<i>Liriope graminifolia</i>	10	0.235	0.0235	0.0109
91	<i>Liriope graminifolia</i>	10	0.088	0.0088	0.0022
92	<i>Liriope graminifolia</i>	10	0.098	0.0098	0.0068
93	<i>Liriope graminifolia</i>	15	0.156	0.0234	0.0095
94	<i>Liriope graminifolia</i>	35	0.125	0.0438	0.0174
95	<i>Liriope graminifolia</i>	20	0.112	0.0224	0.0120
96	<i>Liriope graminifolia</i>	20	0.132	0.0264	0.0043
97	<i>Liriope graminifolia</i>	15	0.098	0.0147	0.0087
98	<i>Liriope graminifolia</i>	15	0.112	0.0168	0.0145
99	<i>Liriope graminifolia</i>	50	0.100	0.0501	0.0054
100	<i>Liriope graminifolia</i>	30	0.166	0.0498	0.0702
101	<i>Liriope graminifolia</i>	25	0.156	0.0390	0.0771
102	<i>Liriope graminifolia</i>	15	0.167	0.0251	0.0149
103	<i>Liriope graminifolia</i>	15	0.107	0.0161	0.0152
104	<i>Liriope graminifolia</i>	65	0.192	0.1248	0.1280
105	<i>Liriope graminifolia</i>	20	0.184	0.0368	0.0320
106	<i>Liriope graminifolia</i>	50	0.134	0.0670	0.0602
107	<i>Liriope graminifolia</i>	20	0.212	0.0424	0.0437
108	<i>Liriope graminifolia</i>	10	0.154	0.0154	0.0248
109	<i>Liriope graminifolia</i>	10	0.135	0.0135	0.0163
110	<i>Liriope graminifolia</i>	20	0.236	0.0472	0.0316
111	<i>Liriope graminifolia</i>	10	0.187	0.0187	0.0120
112	<i>Liriope graminifolia</i>	70	0.189	0.1323	0.1105

113	<i>Liriope graminifolia</i>	5	0.179	0.0090	0.0118
114	<i>Liriope graminifolia</i>	20	0.176	0.0352	0.0425
115	<i>Liriope graminifolia</i>	20	0.189	0.0378	0.0212
116	<i>Liriope graminifolia</i>	15	0.154	0.0231	0.0228
117	<i>Liriope graminifolia</i>	50	0.163	0.0815	0.0057
118	<i>Liriope graminifolia</i>	25	0.172	0.0430	0.0662
119	<i>Liriope graminifolia</i>	10	0.187	0.0187	0.0307
120	<i>Liriope graminifolia</i>	20	0.185	0.0370	0.0309
121	<i>Pteris multifida</i>	20	0.276	0.0552	0.0133
122	<i>Pteris multifida</i>	10	0.198	0.0198	0.0078
123	<i>Pteris multifida</i>	10	0.317	0.0317	0.0097
124	<i>Pteris multifida</i>	10	0.325	0.0325	0.0085
125	<i>Pteris multifida</i>	10	0.282	0.0282	0.0087
126	<i>Pteris multifida</i>	5	0.157	0.0079	0.0008
127	<i>Pteris multifida</i>	5	0.113	0.0057	0.0007
128	<i>Pteris multifida</i>	10	0.465	0.0465	0.0138
129	<i>Pteris multifida</i>	5	0.243	0.0122	0.0032
130	<i>Pteris multifida</i>	5	0.097	0.0049	0.0023
131	<i>Pteris multifida</i>	10	0.275	0.0275	0.0054
132	<i>Pteris multifida</i>	20	0.334	0.0668	0.0154
133	<i>Pteris multifida</i>	5	0.262	0.0131	0.0023
134	<i>Pteris multifida</i>	25	0.263	0.0658	0.0121
135	<i>Pteris multifida</i>	10	0.225	0.0225	0.0038
136	<i>Pteris multifida</i>	5	0.174	0.0087	0.0029
137	<i>Pteris multifida</i>	20	0.314	0.0628	0.0112
138	<i>Pteris multifida</i>	5	0.579	0.0290	0.0041
139	<i>Pteris multifida</i>	5	0.129	0.0065	0.0010
140	<i>Pteris multifida</i>	5	0.235	0.0118	0.0029
141	<i>Pteris multifida</i>	15	0.486	0.0729	0.0077
142	<i>Pteris multifida</i>	20	0.262	0.0524	0.0097
143	<i>Pteris multifida</i>	30	0.363	0.1089	0.0126
144	<i>Pteris multifida</i>	20	0.278	0.0556	0.0091
145	<i>Pteris multifida</i>	10	0.336	0.0336	0.0026
146	<i>Pteris multifida</i>	15	0.389	0.0584	0.0065
147	<i>Pteris multifida</i>	15	0.139	0.0209	0.0025
148	<i>Pteris multifida</i>	5	0.112	0.0056	0.0013
149	<i>Pteris multifida</i>	5	0.105	0.0053	0.0013
150	<i>Pteris multifida</i>	15	0.348	0.0522	0.0024
151	<i>Pteris multifida</i>	10	0.079	0.0079	0.0014
152	<i>Pteris multifida</i>	5	0.408	0.0204	0.0037
153	<i>Pteris multifida</i>	5	0.125	0.0063	0.0004
154	<i>Pteris multifida</i>	5	0.146	0.0073	0.0018
155	<i>Pteris multifida</i>	15	0.334	0.0501	0.0057
156	<i>Pteris multifida</i>	15	0.348	0.0522	0.0067
157	<i>Pteris multifida</i>	20	0.399	0.0798	0.0130
158	<i>Pteris multifida</i>	10	0.287	0.0287	0.0043

159	<i>Pteris multifida</i>	5	0.191	0.0096	0.0020
160	<i>Pteris multifida</i>	5	0.491	0.0246	0.0025
161	<i>Pteris multifida</i>	20	0.284	0.0568	0.0088
162	<i>Pteris multifida</i>	50	0.237	0.1185	0.0035
163	<i>Pteris multifida</i>	5	0.143	0.0072	0.0007
164	<i>Pteris multifida</i>	5	0.148	0.0074	0.0019
165	<i>Selaginella moellendorffii</i>	30	0.173	0.0519	0.0159
166	<i>Selaginella moellendorffii</i>	15	0.125	0.0188	0.0056
167	<i>Selaginella moellendorffii</i>	25	0.245	0.0613	0.0076
168	<i>Selaginella moellendorffii</i>	30	0.417	0.1251	0.0073
169	<i>Selaginella moellendorffii</i>	45	0.376	0.1692	0.0259
170	<i>Selaginella moellendorffii</i>	40	0.387	0.1548	0.0119
171	<i>Selaginella moellendorffii</i>	15	0.361	0.0542	0.0046
172	<i>Selaginella moellendorffii</i>	5	0.137	0.0069	0.0011
173	<i>Selaginella moellendorffii</i>	10	0.123	0.0123	0.0033
174	<i>Selaginella moellendorffii</i>	5	0.134	0.0067	0.0016
175	<i>Selaginella moellendorffii</i>	15	0.098	0.0147	0.0045
176	<i>Selaginella moellendorffii</i>	15	0.143	0.0215	0.0071
177	<i>Selaginella moellendorffii</i>	10	0.163	0.0163	0.0034
178	<i>Selaginella moellendorffii</i>	20	0.134	0.0268	0.0042
179	<i>Selaginella moellendorffii</i>	20	0.176	0.0352	0.0041
180	<i>Selaginella moellendorffii</i>	25	0.163	0.0408	0.0046
181	<i>Selaginella moellendorffii</i>	20	0.227	0.0454	0.0040
182	<i>Selaginella moellendorffii</i>	15	0.134	0.0201	0.0025
183	<i>Selaginella moellendorffii</i>	20	0.173	0.0346	0.0046
184	<i>Selaginella moellendorffii</i>	55	0.356	0.1958	0.0118
185	<i>Selaginella moellendorffii</i>	50	0.173	0.0865	0.0101
186	<i>Selaginella moellendorffii</i>	55	0.307	0.1689	0.0128
187	<i>Selaginella moellendorffii</i>	40	0.287	0.1148	0.0110
188	<i>Selaginella moellendorffii</i>	70	0.403	0.2821	0.0290
189	<i>Selaginella moellendorffii</i>	25	0.186	0.0465	0.0065
190	<i>Selaginella moellendorffii</i>	40	0.265	0.1060	0.0088
191	<i>Selaginella moellendorffii</i>	20	0.157	0.0314	0.0054
192	<i>Selaginella moellendorffii</i>	30	0.167	0.0501	0.0085
193	<i>Selaginella moellendorffii</i>	50	0.387	0.1935	0.0138
194	<i>Selaginella moellendorffii</i>	30	0.218	0.0654	0.0152
195	<i>Selaginella moellendorffii</i>	20	0.135	0.0270	0.0033
196	<i>Selaginella moellendorffii</i>	30	0.163	0.0489	0.0065
197	<i>Selaginella moellendorffii</i>	40	0.351	0.1404	0.0173
198	<i>Selaginella moellendorffii</i>	30	0.193	0.0579	0.0120
199	<i>Selaginella moellendorffii</i>	30	0.221	0.0663	0.0105
200	<i>Selaginella moellendorffii</i>	20	0.175	0.0350	0.0036
201	<i>Selaginella moellendorffii</i>	55	0.248	0.1364	0.0243
202	<i>Liriope muscari</i>	30	0.513	0.1539	0.1200
203	<i>Liriope muscari</i>	50	0.158	0.0790	0.0050
204	<i>Liriope muscari</i>	20	0.466	0.0932	0.0333

205	<i>Liriope muscari</i>	50	0.263	0.1315	0.0046
206	<i>Liriope muscari</i>	50	0.195	0.0975	0.0085
207	<i>Liriope muscari</i>	10	0.386	0.0386	0.0185
208	<i>Liriope muscari</i>	10	0.331	0.0331	0.0183
209	<i>Liriope muscari</i>	10	0.352	0.0352	0.0310
210	<i>Liriope muscari</i>	15	0.485	0.0728	0.0598
211	<i>Liriope muscari</i>	15	0.385	0.0578	0.0502
212	<i>Liriope muscari</i>	30	0.490	0.1470	0.1161
213	<i>Liriope muscari</i>	25	0.271	0.0678	0.1078
214	<i>Liriope muscari</i>	25	0.293	0.0733	0.0452
215	<i>Liriope muscari</i>	20	0.273	0.0546	0.0177
216	<i>Liriope muscari</i>	80	0.498	0.3984	0.2149
217	<i>Liriope muscari</i>	30	0.477	0.1431	0.0985
218	<i>Liriope muscari</i>	20	0.502	0.1004	0.0593
219	<i>Liriope muscari</i>	40	0.379	0.1516	0.0658
220	<i>Liriope muscari</i>	55	0.565	0.3108	0.2847
221	<i>Liriope muscari</i>	45	0.487	0.2192	0.1965
222	<i>Liriope muscari</i>	15	0.226	0.0339	0.0237
223	<i>Liriope muscari</i>	10	0.288	0.0288	0.0124
224	<i>Liriope muscari</i>	5	0.263	0.0132	0.0106
225	<i>Liriope muscari</i>	15	0.323	0.0485	0.0425
226	<i>Liriope muscari</i>	10	0.398	0.0398	0.0357
227	<i>Liriope muscari</i>	10	0.334	0.0334	0.0250
228	<i>Liriope muscari</i>	60	0.435	0.2610	0.2186
229	<i>Liriope muscari</i>	10	0.305	0.0305	0.0185
230	<i>Liriope muscari</i>	10	0.351	0.0351	0.0161
231	<i>Liriope muscari</i>	20	0.293	0.0586	0.0671
232	<i>Liriope muscari</i>	10	0.225	0.0225	0.0121
233	<i>Liriope muscari</i>	50	0.310	0.1550	0.0153
234	<i>Liriope muscari</i>	50	0.134	0.0670	0.0113
235	<i>Liriope muscari</i>	10	0.261	0.0261	0.0245
236	<i>Aster indicus</i>	15	0.480	0.0720	0.0019
237	<i>Aster indicus</i>	5	0.410	0.0205	0.0107
238	<i>Aster indicus</i>	5	0.680	0.0340	0.0077
239	<i>Aster indicus</i>	10	0.540	0.0540	0.0150
240	<i>Aster indicus</i>	10	0.470	0.0470	0.0140
241	<i>Aster indicus</i>	10	0.600	0.0600	0.0134
242	<i>Aster indicus</i>	25	0.490	0.1225	0.0216
243	<i>Aster indicus</i>	10	0.470	0.0470	0.0070
244	<i>Aster indicus</i>	5	0.650	0.0325	0.0057
245	<i>Aster indicus</i>	5	0.610	0.0305	0.0053
246	<i>Aster indicus</i>	5	0.490	0.0245	0.0164
247	<i>Aster indicus</i>	15	0.310	0.0465	0.0095
248	<i>Aster indicus</i>	15	0.340	0.0510	0.0101
249	<i>Aster indicus</i>	10	0.420	0.0420	0.0050
250	<i>Aster indicus</i>	35	0.520	0.1820	0.0255

251	<i>Aster indicus</i>	5	0.300	0.0150	0.0064
252	<i>Aster indicus</i>	25	0.680	0.1700	0.0210
253	<i>Aster indicus</i>	5	0.410	0.0205	0.0043
254	<i>Aster indicus</i>	25	0.330	0.0825	0.0088
255	<i>Aster indicus</i>	15	0.400	0.0600	0.0117
256	<i>Aster indicus</i>	35	0.460	0.1610	0.0243
257	<i>Aster indicus</i>	25	0.580	0.1450	0.0118
258	<i>Aster indicus</i>	10	0.350	0.0350	0.0059
259	<i>Aster indicus</i>	35	0.570	0.1995	0.0282
260	<i>Aster indicus</i>	10	0.290	0.0290	0.0045
261	<i>Aster indicus</i>	10	0.470	0.0470	0.0062
262	<i>Aster indicus</i>	20	0.380	0.0760	0.0112
263	<i>Aster indicus</i>	20	0.410	0.0820	0.0142
264	<i>Aster indicus</i>	5	0.300	0.0150	0.0017
265	<i>Aster indicus</i>	10	0.480	0.0480	0.0032
266	<i>Aster indicus</i>	10	0.340	0.0340	0.0053
267	<i>Aster indicus</i>	5	0.420	0.0210	0.0071
268	<i>Aster indicus</i>	10	0.310	0.0310	0.0075
269	<i>Aster indicus</i>	5	0.320	0.0160	0.0017
270	<i>Aster indicus</i>	70	0.650	0.4550	0.0479
271	<i>Aster indicus</i>	30	0.590	0.1770	0.0373
272	<i>Aster indicus</i>	15	0.330	0.0495	0.0142
273	<i>Aster indicus</i>	15	0.350	0.0525	0.0208
274	<i>Aster indicus</i>	15	0.330	0.0495	0.0126
275	<i>Aster indicus</i>	10	0.630	0.0630	0.0287
276	<i>Aster indicus</i>	35	0.540	0.1890	0.0564
277	<i>Dryopteris uniformis</i>	70	0.650	0.4550	0.0619
278	<i>Dryopteris uniformis</i>	10	0.372	0.0372	0.0053
279	<i>Dryopteris uniformis</i>	10	0.289	0.0289	0.0058
280	<i>Dryopteris uniformis</i>	15	0.363	0.0545	0.0086
281	<i>Dryopteris uniformis</i>	40	0.512	0.2048	0.0623
282	<i>Dryopteris uniformis</i>	30	0.351	0.1053	0.0254
283	<i>Dryopteris uniformis</i>	20	0.294	0.0588	0.0066
284	<i>Dryopteris uniformis</i>	35	0.487	0.1705	0.0302
285	<i>Dryopteris uniformis</i>	10	0.347	0.0347	0.0037
286	<i>Dryopteris uniformis</i>	5	0.314	0.0157	0.0038
287	<i>Dryopteris uniformis</i>	5	0.126	0.0063	0.0017
288	<i>Dryopteris uniformis</i>	25	0.243	0.0608	0.0174
289	<i>Dryopteris uniformis</i>	25	0.364	0.0910	0.0232
290	<i>Dryopteris uniformis</i>	10	0.393	0.0393	0.0079
291	<i>Dryopteris uniformis</i>	25	0.373	0.0933	0.0246
292	<i>Dryopteris uniformis</i>	5	0.167	0.0084	0.0025
293	<i>Dryopteris uniformis</i>	40	0.415	0.1660	0.0218
294	<i>Dryopteris uniformis</i>	10	0.423	0.0423	0.0048
295	<i>Dryopteris uniformis</i>	15	0.435	0.0653	0.0175
296	<i>Dryopteris uniformis</i>	5	0.364	0.0182	0.0047

297	<i>Dryopteris uniformis</i>	5	0.455	0.0228	0.0049
298	<i>Dryopteris uniformis</i>	15	0.264	0.0396	0.0087
299	<i>Dryopteris uniformis</i>	25	0.418	0.1045	0.0198
300	<i>Dryopteris uniformis</i>	10	0.331	0.0331	0.0033
301	<i>Dryopteris uniformis</i>	15	0.257	0.0386	0.0063
302	<i>Dryopteris uniformis</i>	15	0.411	0.0617	0.0090
303	<i>Dryopteris uniformis</i>	20	0.212	0.0424	0.0173
304	<i>Dryopteris uniformis</i>	15	0.387	0.0581	0.0176
305	<i>Dryopteris uniformis</i>	10	0.287	0.0287	0.0097
306	<i>Dryopteris uniformis</i>	45	0.483	0.2174	0.1136
307	<i>Dryopteris uniformis</i>	25	0.453	0.1133	0.0473
308	<i>Dryopteris uniformis</i>	25	0.293	0.0733	0.0205
309	<i>Dryopteris uniformis</i>	15	0.421	0.0632	0.0157
310	<i>Dryopteris uniformis</i>	30	0.413	0.1239	0.0462
311	<i>Dryopteris uniformis</i>	20	0.398	0.0796	0.0415
312	<i>Dryopteris uniformis</i>	30	0.487	0.1461	0.0594
313	<i>Dryopteris uniformis</i>	40	0.567	0.2268	0.0719
314	<i>Dryopteris uniformis</i>	80	0.576	0.4608	0.1344
315	<i>Dryopteris uniformis</i>	35	0.684	0.2394	0.0968
316	<i>Dryopteris uniformis</i>	85	0.673	0.5721	0.1775
317	<i>Dryopteris uniformis</i>	20	0.378	0.0756	0.0276
318	<i>Dryopteris uniformis</i>	25	0.513	0.1283	0.0372
319	<i>Dryopteris uniformis</i>	25	0.499	0.1248	0.0535
320	<i>Dryopteris uniformis</i>	20	0.453	0.0906	0.0368
321	<i>Dryopteris uniformis</i>	15	0.326	0.0489	0.0219
322	<i>Dryopteris uniformis</i>	20	0.565	0.1130	0.0371
323	<i>Dryopteris uniformis</i>	40	0.465	0.1860	0.0777
324	<i>Dryopteris uniformis</i>	20	0.389	0.0778	0.0153
325	<i>Dryopteris uniformis</i>	5	0.457	0.0229	0.0154
326	<i>Dryopteris uniformis</i>	30	0.521	0.1563	0.0571
327	<i>Dryopteris uniformis</i>	20	0.682	0.1364	0.0509