# SPECIES DIVERSITY AND COMMUNITY STRUCTURE IN FOREST FRAGMENTS OF GUANGZHOU, SOUTH CHINA

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**MA L, HUANG M, SHEN Y, CAO H, WU L, YE H, LIN G & WANG Z. 2015. Species diversity and community structure in forest fragments of Guangzhou, South China.** To study how fragmentation impacts tree species composition and community structure and provide information for efficient conservation of these fragments, we collected data from 138 forest fragments (referred to as fengshui woods by local people) in southern China and compared them with those collected from a well protected large natural reserve, the Dinghu Mountain Biosphere Reserve (Dinghu). Our data indicated that the forest fragments contained lower mean plot species richness compared with Dinghu but total species richness of the plots as a network and species richness variance among plots were higher in the fragments than in Dinghu. Results from regression analyses indicated that fragment age and fragment size were significantly related to community composition or structure. These results indicated that protecting the fragments would conserve greater diversity of regional tree species than a single large reserve. However, if resources are limited, our results suggest that it is possible to increase resource-use efficiency in conserving regional tree species diversity by choosing large adjacent fragments as a network favouring primary species and small fragments favouring secondary species. If such information is available, choosing the least number of fragments, which would include all regional tree species or the maximum number of tree species, would be the best conservation strategy.

Keywords: Fengshui woods, fragment shape indices, tree species richness, subtropical forest conservation

## INTRODUCTION

Habitat fragmentation is one of the main threats to biological diversity (Whitmore & Sayer 1992). It causes species loss and is the greatest single threat to biodiversity in tropical forests (Turner 1996). It increases the amount of edges exposed to other habitats (Ghazoul 1996) and progressively reduces the original habitat into smaller and smaller patches that become increasingly isolated and affected by edge effects (Faria et al. 2009). Edge is one of the critical landscape elements in fragmented forest landscape (Chen et al. 1993). Edge has offered habitat for new species while the original species are slowly diminishing (Ranta et al. 2013). Therefore, community composition and structure within the remnant patches change (Laurance et al. 1998), small fragments differ markedly in composition from the original forest, and species richness following fragmentation declines over time (Gigord et al. 1999).

Fragmentation has different ecological consequences depending on its spatial configuration on landscape as well as its temporal and spatial variations (Armenteras et al. 2003). Fragment size can explain a major part of tree diversity (Kohn & Walsh 1994). Species richness and abundance or density increase with increasing fragment size (Malcolm 1994). The shape of a patch is characterised by its size and edge length. For the same size, a fragment with an irregular shape tends to have larger edge length than one with a regular shape (Echeverria et al. 2007). Furthermore, isolation of forest fragments could reduce gene flow (Benitez-Malvido 1998) and increase heterogeneity among fragments (Bustamante & Castor 1998). Therefore, an understanding of the relationship between landscape characteristics and the ecological processes influencing distribution of species is required by resource managers as a basis for making landuse decisions (Giriraj et al. 2010).

According to ecological theories of fragmentation and isolation, the prospects for

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small, isolated urban forest remnants are bleak. Urban forest remnants are susceptible to loss of species, invasion by alien plants and human disturbance (Ranta et al. 2013). Human influence may play an important role in determining tree composition and structure in tropical forests (Honnay et al. 1999). However, the influence of human disturbance has generally not been the focus in fragmentation studies (Hobbs & Yates 2003). Thus, whether or not relatively small forest fragments are particularly vulnerable to ongoing anthropogenic disturbances is still not well understood (Echeverria et al. 2007)

Some studies have been conducted to determine ecological changes, including classifying floral and plant species of the remnants (Zhu et al. 2004). In this study we collected data in 138 forest fragments in Guangzhou, South China and divided these into two groups according the distance between each fragment and Guangzhou (fragment 1: within 60 km, fragment 2: greater than 60 km). This was then compared with data collected from 69 plots in the well protected Dinghu Mountain Biosphere Reserve (hereafter Dinghu) (Ye et al. 2008) to study the effects of landscape characteristics on tree species diversity and community structure of subtropical broadleaved monsoon forests. We also studied the value of forest fragments in reference to biodiversity conservation of the forests at landscape level.

## MATERIALS AND METHODS

### Study area

Guangzhou is located at 22° 26'–23° 56' N and 112° 57'–114° 03' E. It is the capital of Guangdong province, China with an area of 7434 $km^2$ and a population over 6.4 million people. It is the economic and cultural centre of the province. It is in the southern part of the subtropical–humid climate zone with mean annual precipitation of 1690 mm and mean air temperature of 21.8 °C. Typhoons and thunderstorms occasionally damage trees and the mild climate permits continuous vegetation growth throughout the year. Some wetlands and water bodies are found near the Pearl River. Pre-urbanisation natural vegetation is composed of evergreen broadleaved rain forests dominated by tree species in the families Lauraceae, Moraceae and Caesalpiniaceae; these species are still common in the urbanised Guangzhou (Lee et al. 2007).

Dinghu was used as our control to assess the value of the forest fragments for conservation of subtropical tree species diversity at landscape scale. It covers 1155 ha of low mountains and hilly landscapes and is characterised by a south subtropical monsoon climate with mean annual temperature of 20.9 ºC. It is covered by well-protected subtropical and tropical monsoon evergreen broadleaved forest. The reserve has similar rainfall and temperature regimes as the forest fragments in Guangzhou. The structure of the forests is complex with three tree layers (top, middle and low), one shrub layer and one herb layer (Ye et al. 2010).

### Selection of fragments for field data collection

In Guangzhou, there are many semi-natural fragments of typical lower subtropical evergreen broadleaved forests near local villages, usually well protected for religious reasons (Liu et al. 2002) and generally called 'fengshui woods' by the local people (Figure 1).

We selected 138 fragment forests in Guangzhou based on the following criteria: relatively well protected areas that were distributed within the same altitudinal range and had similar rainfall and temperature regimes. The sizes of the fragments ranged from 10,428 to 411,399 $m^2$ with a mean size of 82,822 $m^2$. A total of 138 sampling plots (20 m × 20 m each) was established at the centre of every fragment. Each plot was divided into four contiguous 10 m × 10 m subplots and in each subplot, species and dbh (diameter at breast height > 1 cm) values of all shrubs and trees were determined and recorded. Dbh was measured for every tree in the plot. Species were classified according to their light requirement for germination, i.e. primary species (shade tolerant) and secondary species (shade intolerant). Secondary species regenerate only in clearings and at forest edges (Mandujano & Arroyo-Rodriguez 2006).

To quantify human disturbance, we measured: (1) size ($m^2$) of the villages beside each forest fragment, (2) distances (m) from the centre of each forest to its nearest downtown and (3) the distance (m) between each forest

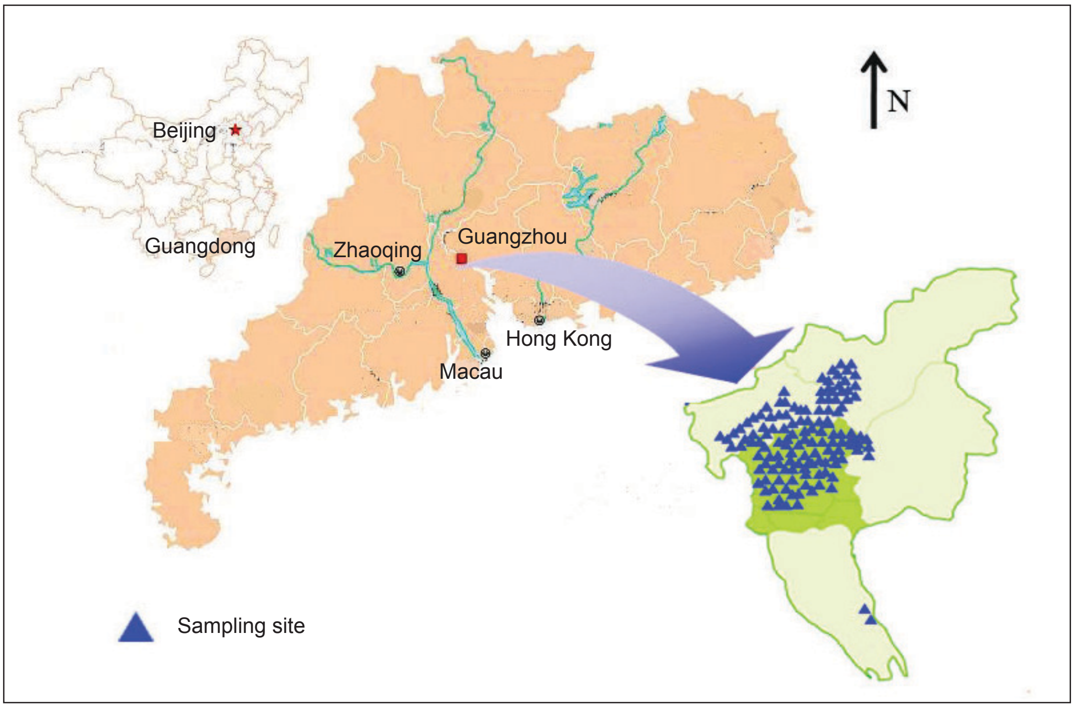


**Figure 1** Distribution of native forest fragments in the study area in south China

and the nearest road. All work was conducted with handheld global positioning system (GPS) and Google Earth. First, we located the edge of these villages and forests with handheld GPS and measured the size using Google Earth. Second, the centre of each forest was chosen as the geometric centre of the shape of each forest. Finally, we measured the distances above. We then chose the smallest values, one each from the 138 size and 138 distance values (Freitas et al. 2010). All 138 size and 138 distance values were divided by the smallest values of size and distance respectively. Finally, we added up all these values for each fragment to obtain data with respect to human disturbance (Fernandez-Juricic et al. 2003).

We also obtained spatial attributes of forest fragments from Google Earth. Patch size and isolation (distance between one forest fragment and the nearest one to it) were measured. Fragment shape index (IF) was calculated as

$$IF = P/2\sqrt{A} \times \pi$$

where P and A are the fragment perimeter (m) and area ($m^2$) respectively (Mandujano & Arroyo-Rodriguez 2006). This index ranged from 1–5, with 1 representing circular fragment and 5, completely irregular shape (Echeverria et al. 2007). The age of each forest fragment was estimated by the mean age of four trees with the largest dbh (Wulder et al. 2009). In the reserve, we established 69 sampling plots (20 m × 20 m) randomly and collected corresponding data using the same methods as for the 138 fragments.

## Data analyses

Species richness and abundance are the total number of species and individuals per species respectively, based on plants with dbh > 1 cm in each plot. Total basal area (sum of $\pi \times (dbh \times 0.5)^2$ for all individuals, $m^2\ ha^{-1}$) and density (number of individuals per ha) were determined for each tree species in each plot.

We assessed differences in the species diversity (species richness) between two groups of plots in the fragments and in the reserve using species accumulation curves. To do so, plots in the fragments and in the reserve were randomly sampled 100 times to obtain mean species diversity for each number of plot from 2 to 68 (Colwell et al. 2004). For plot number 1, diversity is the mean of the 69 plots and for plot number 69, it is the cumulative diversity of the previous plots.

To study the influence of fragment size (log transformed), shape, isolation, age and human disturbances on the number of individuals in different dbh ranges (1–10, > 10–20, > 20–30, > 30–40, > 40–50 and > 50 cm), we analysed species richness (total, primary, secondary and primary/secondary species), species abundance (total, primary, secondary and primary/secondary species), and basal area (total, primary, secondary and primary/secondary species) using generalised linear models performed in R statistical software using the Vegan package (Gotelli & Colwell 2001). We used Akaike information criterion (Carstens et al. 2010) to identify the best fit model and the results were used to evaluate the effect and uncertainty of variables. Species richness and abundance were considered as community composition traits or variables, and basal area and the number of individuals in different dbh ranges as community structure traits or variables. For all these variables, values were standardised by subtracting mean value of the variables and dividing by standard deviation. This allowed for a direct comparison of the relative importance of these explanatory variables (Raghubanshi & Tripathi 2009).

## RESULTS

### Floristic composition

The numbers of individual trees with dbh ≥ 1 cm, families, genera and species in the plots of the fragments and Dinghu are summarised in Table 1. In a total of 207 plots, we identified 368 species. The three most common species were *Syzygium hancei*, *Psychotria asiatica* and *Schima superba* from the familes Myrtaceae, Rubiaceae and Theaceae respectively. These accounted for 7.9, 6.7 and 4.3% respectively of the 19,469 individuals observed. There were 87 and 157 more species in fragment 1 and 2 than those in the Dinghu respectively. In the forest fragment plots (fragments 1 and 2), the families with the highest number of individuals were Rubiaceae, Euphorbiaceae and Fagaceae which accounted for 12.3, 10 and 6.1% respectively of the 10,660 plants recorded. In the plots of Dinghu, the families with the highest number of individuals were Lauraceae, Myrtaceae and Rubiaceae, which accounted for 14.3, 13.6 and 9.8% respectively of the 8,809 plants recorded. The 69 plots in fragment 1 have the most families, genera and species than those in fragment 2 and Dinghu but Dingu had the most individuals.

### Species richness

Range, mean and variance of species richness were 5–35, 17.5 and 55.5 for the plots in fragment 1, 3–58, 21.3, 113 in fragment 2 and 4–43, 24.36 and 32.4 in the reserve respectively (Figure 2). Number of tree species increased differently with increase in number of plots between fragment 1, fragment 2 and Dinghu (Figure 2). As number of plots increased from 1 to 5, tree species richness of Dinghu increased faster than those of fragments 1 and 2 but slower from plots 5 to 69.

### Vegetation structure

Distribution of the number of trees at different dbh values are shown in Figure 3. Dbh of trees in the plots of fragment 1 varied between 1 and 94 cm with a mean of 10.7 cm, and 67.5% of the trees were in the dbh range of 1 to 10 cm. Dbh of trees in the plots of fragment 2 varied between 1 and 210.7 cm with a mean of 9.5 cm and 74% of the trees were in the dbh range of 1 to 10 cm. In the Dinghu plots, dbh range was from 1 to 110 cm with a mean of 6.43 cm and about 83% of the trees were in the dbh range of 1 to 10 cm. Basal area of trees in fragments 1 and 2 were

**Table1** Number of species, genera and families of trees and stem density based on individuals with dbh > 1 cm in the 69 plots in the forest fragments and in the Dinghu reserve

| Characteristic | Fragment 1 | Fragment 2 | Dinghu | All plots (n = 207) |
|---|---|---|---|---|
| Family | 55 | 61 | 49 | 66 |
| Genes | 122 | 154 | 85 | 178 |
| Species | 204 | 274 | 117 | 368 |
| Number of individuals | 4601 | 6059 | 8809 | 19469 |
| Stem density (stems $ha^{-1}$) | 1692 | 2164 | 3192 | 3251 |

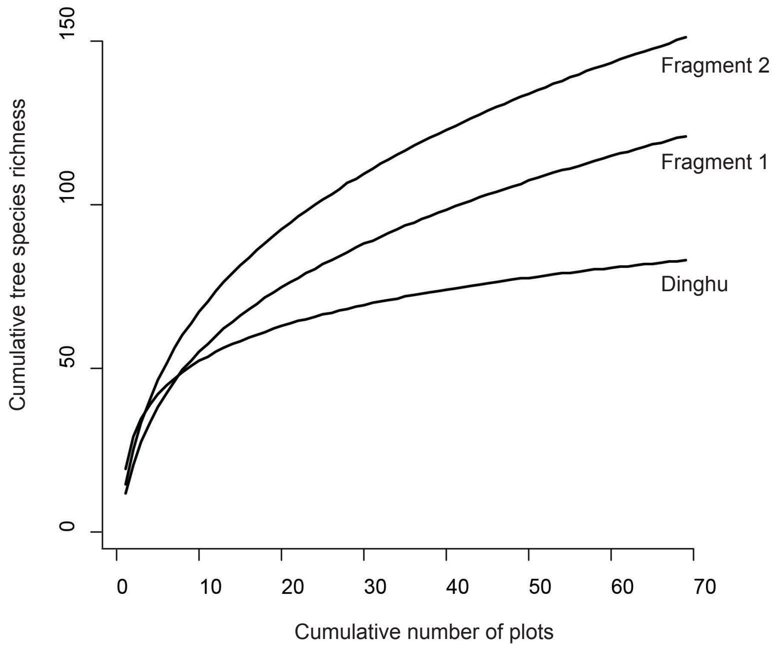


**Figure 2** Species richness plotted for different number of plots based on trees with diameter at breast height > 1 cm in our survey

38.2 and 46.9 $m^2$ $ha^{-1}$ respectively. These values were significantly ($t = 4.5$, $df = 97$, $p < 0.001$, $t = 5.1$, $df = 80$, $p < 0.001$ respectively) higher than 27.29 $m^2$ $ha^{-1}$ in the reserve. The biggest plot basal area was 85.6 $m^2$ $ha^{-1}$ in fragment 1, 200.1 $m^2$ $ha^{-1}$ in fragment 2 and 47.7 $m^2$ $ha^{-1}$ in Dinghu. Density of trees was lower in forest fragments than in the reserve (Table 1).

## Relationship between vegetation and fragment characteristics

Results of multiple regression analysis are summarised in Tables 2 and 3. Fragment size was significant in six of the eight community composition and one of the four community structure variables based on basal area of plots in fragment 2. However, fragment size was only significant in one of the community compositions and one of the community structure variables in fragment 1. Fragment size was positively related to species abundance, richness and basal area of both secondary and primary species in fragment 2. Fragment age was positively significant for three of the four basal area variables and for number of individuals in dbh ranges > 30–40, > 40–50 and > 50 cm but negatively on number of individuals of plants within dbh > 10–20 cm and > 20–30 cm of fragment 1. The same trend was found in fragment 2. Human disturbance was positively significant for primary/total species basal area only in fragment 2. Shape index was positively significant on 2 of 4 basal area variables in fragment 1 (Table 2). Isolation was negatively significant for species richness and primary species richness but positively significant for the basal area in fragment 1. Isolation also had significant influence on both community composition and structure.

## DISCUSSION

We observed that the 138 plots, namely, fragments 1 and 2 in the forest fragments which contained 87 and 157 respectively more species than those in the Dinghu, although all had the same number of sampling plots. Minimum, maximum and mean species richness values were smaller. However, the variance of species richness was larger for the plots in fragments 1 and 2 than in Dinghu respectively. These findings support the theory that although small

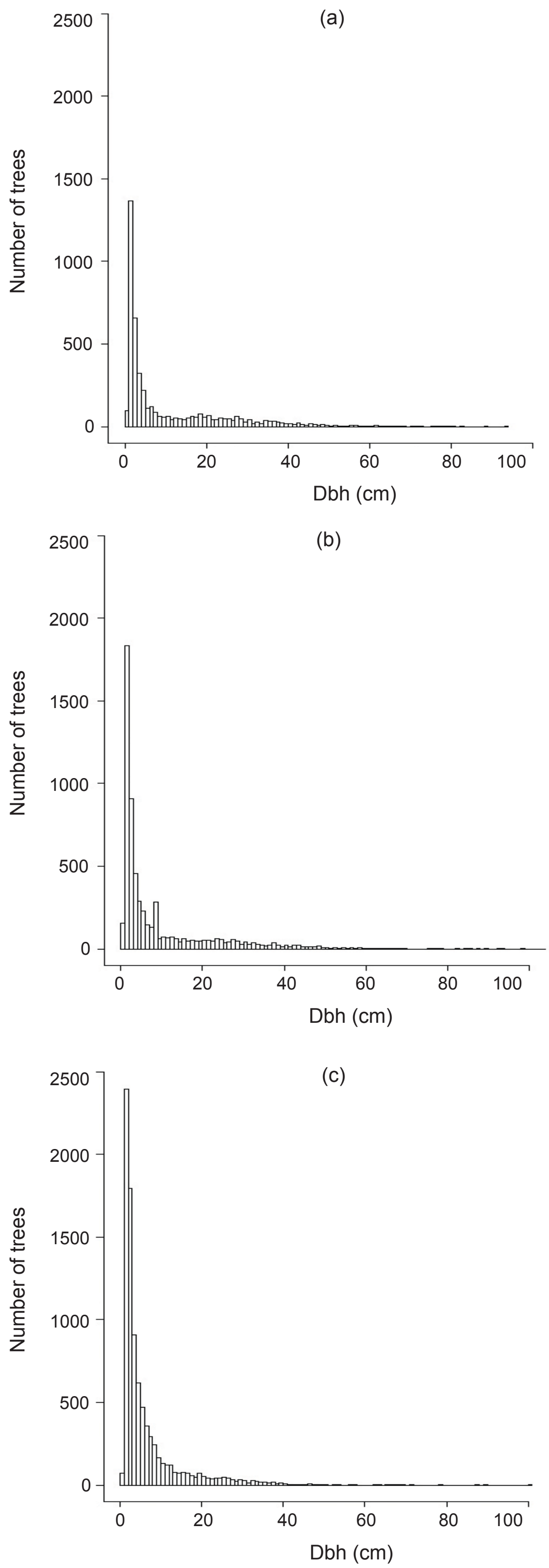


**Figure 3** Distribution of trees by dbh in (a) fragment 1, (b) fragment 2 and (c) Dinghu reserve; dbh = diameter at breast height

forest fragments are poor in species and may contribute little to the conservation of biological diversity individually; they can contain large amounts of species diversity and play important roles in maintenance of regional diversity as a network (Simberloff & Gotelli 1984, Honnay et al. 1999). These indicate that it is possible that more regional species diversity can be conserved in a fragment network than in a single large continuous reserve if enough fragments are included within a conservation programme. They also indicate that if resources are limited in conservation programme, it is possible to select and conserve fragments with high species richness to increase resource-use efficiency.

The curves of species richness by number of plots showed that when the number of plots was less than 5, species richness increased as number of plots increased more slowly and was smaller for the same number of plots in fragment 1 than in Dinghu. The same trend was found in fragment 2 when the number of plots was less than 5. However, when the number of plots increased from 5 to 69, the opposite occurred. This must have resulted from the higher variance in species richness between plots in the fragment network than in Dinghu. Difference in species richness variance between fragments might be due to the fact that environmental conditions were more heterogeneous (Wang 2009) between these fragments than in Dinghu. More heterogeneous environmental conditions may select more diverse plant species as different species may require different habitat conditions. Areas for fragments are discontinuous and distributed in different areas which may vary more in environmental conditions compared with the rest of the reserve. Fragments are also in different sizes and shapes that influence their physical conditions differently (Zhu et al. 2004).

Our results indicated that the vegetation structures of the forest fragments (fragments 1 and 2) and Dinghu were different. The plots in fragment 2 had the biggest trees with the largest basal area but lower stem density than those in the Dinghu. Dinghu had the smallest trees with the smallest basal area but the highest stem density than in fragments 1 and 2. There were more big trees (dbh > 30 cm) in fragment 1 (477, 10.4%) and fragment 2 (525, 8.7%) than in Dinghu (207, 2.3%). These may be due to human disturbances and edge effects in the

**Table 2** Summary of multiple regression analyses between the community characteristic variables and log transformed fragment size, human disturbance (Dist), forest age, isolation and shape index (SI) of fragment 1

| Community variable | AIC | Coefficient of fragment variable selected by regression | | | | |
|---|---|---|---|---|---|---|
| | | Size | Dist | Age | Isolation | SI |
| Community composition | | | | | | |
| Total species abundance | 143 | | | | | -0.26* |
| Primary/total species abundance | | | | | | |
| Primary species abundance | | | | | | |
| Secondary species abundance | | | | | | |
| Total species richness | 162 | | | | -0.15* | |
| Primary/total species richness | 187 | 0.22* | | | -0.18* | |
| Primary species richness | 170 | | | | -0.19* | |
| Secondary species richness | | | | | | |
| Community structure based on basal area | | | | | | |
| Total species basal area | 70 | | | 0.69*** | 0.07* | 0.16* |
| Primary/total species basal area | 177 | | | 0.34** | | |
| Primary species basal area | 92 | 0.10* | | 0.63*** | 0.09* | 0.20* |
| Secondary species basal area | | | | | | |
| Community structure based on number of individuals within dbh range (cm) | | | | | | |
| 1–10 | 149 | | | | | -0.29* |
| > 10–20 | 182 | | | -0.43** | | |
| > 20–30 | 181 | | | -0.32* | | 0.57*** |
| > 30–40 | 191 | | | 0.39** | | |
| > 40–50 | 163 | | | 0.67*** | | |
| > 50 | 133 | | | 0.97*** | | |

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; AIC = Akaike information criterion, dbh = diameter at breast height

fragments but did not affect Dinghu. Significant effects on the basal area of primary/total species indicated the existence of human disturbance in fragment 2. Although forest fragments are usually well protected for religious reasons (Liu et al. 2002), they are minimally disturbed by nearby villagers for wood materials to be used as fuels and their livestock may feed on the plants in the fragments. Therefore, stem density in the fragments would be reduced, especially the understorey layer (Zhu et al. 2004). Reduced stem density and edge effects could enhance light levels, which could accelerate the growth of trees (Honnay et al. 1999) in the fragments.

Results indicated that fragment size had significant effects on most of the community structure variables based on basal area and composition variables. It was positively related to total, primary and secondary species abundance; total, primary and secondary species richness and total species basal area in fragment 2. These agree with findings reported for subtropical forests (Liu et al. 2002). Effects of fragment size on the community structure based on basal area are due to its effects on community composition based on the richness of the primary and secondary species, as generally, the more the individuals, the larger the basal area. Our results may be explained by the smaller fragments that have more edge effects and higher light availability than the bigger ones, thereby enhancing germination, establishment and growth of the shade intolerant secondary species but suppressing these of the shade tolerant primary trees (Mandujano & Arroyo-Rodriguez 2006). Isolation also has significant effects on most of the community structure variables based on basal area and composition variables both in fragments 1 and 2. It is negatively related to community composition (species abundance and richness) but positively related to community structure (species basal areas and dbh ranges). This indicated that the distance between these fragments might influence community composition and structure. These adjacent forest fragments may act as a network with higher species diversity. Therefore, if conservation is aimed at protecting primary species, large fragments and more adjacent forest fragments are better choices than smaller fragments located farther apart.

Age of forest fragments had significant positive relationship with community structure based on three of the four basal area variables and number of trees at all dbh ranges except dbh < 10 cm in fragment 1. This is not surprising because, generally, older trees are bigger. The same phenomenon was observed in fragment 2. Fragment age had significant positive effects on total species basal area and the basal area of primary tree species. Fragment age did not have significant effects on basal area of secondary species. We also observed significant positive relationships between total and primary tree species richness and between total and primary tree species basal area. Furthermore, the numbers of trees with dbh > 40 cm were 101 and 35 for the primary and secondary species respectively in fragment 1 which indicated that most of the big trees were primary tree species. Therefore, fragment age had significant effects on community structure based on basal area, which was attributable to its positive effects on the number of big primary trees in the forest fragments.

The distance between forest fragments and Guangzhou also influenced community composition and structure (Table 3). As distance increased from fragments 1 to 2, the performance of variables changed. Isolation had significant effects on community composition and species basal area in fragment 1. However, in fragment 2, isolation and fragment size had significant effects on community composition and structure together. These results indicated

**Table 3** Summary of multiple regression analyses between the community characteristic variables and Log transformed fragment size, human disturbance (Dist), forest age, isolation and shape index (SI) of fragment 2

| Community variable | AIC | Coefficient of fragment variable selected by regression | | | | |
|---|---|---|---|---|---|---|
| | | Size | Dist | Age | Isolation | SI |
| Community composition | | | | | | |
| Total species abundance | 215 | 0.48** | | | -1.65*** | |
| Primary/total species abundance | 197 | | | | 1.2** | 0.2* |
| Primary species abundance | 227 | 0.44* | | | -1.24* | |
| Secondary species abundance | 199 | 0.44** | | | -1.57*** | |
| Total species richness | 189 | 0.57*** | | | -2.58*** | |
| Primary/total species richness | | | | | | |
| Primary species richness | 178 | 0.45*** | | 0.25* | -2.85*** | |
| Secondary species richness | 213 | 0.54** | | | -1.38** | |
| Community structure based on basal area | | | | | | |
| Total species basal area | 125 | 0.17* | | 0.89*** | | |
| Primary/total species basal area | 201 | | 0.56* | | | |
| Primary species basal area | 145 | | | 0.69*** | 0.9** | |
| Secondary species basal area | 219 | | | | -1.38* | |
| Community structure based on number of individuals within dbh range (cm) | | | | | | |
| 1–10 | 213 | 0.46** | | | -1.67*** | |
| > 10–20 | 203 | | | -2.87** | | |
| > 20–30 | – | | | – | | |
| > 30–40 | 195 | | | 0.26* | | |
| > 40–50 | 178 | | | 0.34** | 0.96* | |
| > 50 | 115 | | | 0.73*** | | |

*p < 0.05, **p < 0.01, ***p < 0.001; AIC = Akaike information criterion, dbh = diameter at breast height that factors influencing the community composition and structure varied depending on distance. Human disturbances influenced the effect of fragment size on community composition and structure in fragment 1. Fragments located near the city may be subjected to much more disturbance by the local people or construction (Metzger 2000).

## CONCLUSIONS

In this study, effects of fragment age on community structure were due to effects on basal area and number of big primary trees in the fragments. Fragment size influenced community composition based on species richness and on structure based on basal area. Fragment size was related to species richness. Basal area had positive relationship with primary tree species but negative with secondary tree species. Isolation was negatively related to both community composition and structure. Therefore, if resources are limited and information on species richness of the fragments is not available in a conservation programme, choosing big fragments will favour primary tree species over secondary tree species. The optimum strategy would be to choose multiple large and multiple small fragments.

Fragments had lower mean plot abundance compared with Dinghu but higher total species richness and species richness variance between plots. These indicated that the fragments had lower species diversity individually but higher species diversity as a network compared with one reserve. Therefore, protecting the fragments will conserve more regional species diversity than a single reserve. Doing so will also protect local traditional culture since these fragments are protected as fengshui woods for religious reasons. On the other hand, if resources are limited, it is possible to choose fragments with high species richness to increase resource-use efficiency in a conservation programme for regional tree species diversity. A network of several adjacent forest fragments may be the best choice.

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