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Relationship between aboveground biomass and measures of structure and species diversity in tropical forests of Vietnam

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ABSTRACT

Tropical forests play an important role in storing carbon through aboveground biomass (AGB) and are considered the highest biodiversity ecosystem on earth. However, the quantitative relationship between AGB and structure–species diversity is poorly understood. Twenty-eight 1-ha plots from old-growth tropical evergreen broadleaf forests and dry dipterocarp deciduous forests, distributed in six ecological regions throughout Vietnam, were used for large tree census (diameter at breast height $\geqslant$ 10 cm). Measures of biodiversity (species richness, Shannon index, and evenness) and of structure–species diversity (biomass–species and abundance–biomass–species diversities) were used to determine the patterns and strengths of relationship between each measure and AGB. The linear, logarithmic, and exponential patterns were found, however the former dominated. Negative linear and exponential patterns represented relationship between evenness and AGB, while positive linear and logarithmic relationships were most suitable for others. In general, site – specific relationships ($R^2 > 0.6$) were much stronger than inter – site relationships ($R^2 < 0.6$). Meanwhile, relationships between measures of biodiversity and AGB (the lowest $R^2 = 0.14$) were generally weaker than that between measures of structure–species diversity and AGB (the lowest $R^2 = 0.31$). This finding indicates that structure–species diversity is a sound index representing the role of tropical forest in storing biomass and may suggest that uneven-aged and multistoried plantations should be encouraged for carbon sequestration.

1. Introduction

Determining the relationship between biodiversity and various ecosystem functions has become a main focus of ecologists in the past 30 years. An important goal in ecology is to understand ecosystem structure through quantification of biodiversity and ecosystem processes and determining the relationships between them (Hooper et al., 2005; Keddy, 2005). One of the most common topics is the relationship between species richness and productivity (Waide et al., 1999; Mittelbach et al., 2001). However, most productivity – species richness studies have been conducted in grasslands (Hector et al., 1999; Tilman et al., 1996; Chalcraft et al., 2009), and only a few in forests (Caspersen and Pacala, 2001; Creed et al., 2009), perhaps because of the difficulty of using biomass as a surrogate for productivity in long-lived trees (Vance-Chalcraft et al., 2010).

The relationship between productivity and species diversity is usually positive (Tilman et al., 1996; Hector et al., 1999; Whittaker and Heegaard, 2003; Balvanera et al., 2006). However, Szwagrzyk and Gazda (2007) found a negative correlation between aboveground biomass and tree species diversity in natural forests of Central Europe, and the same conclusion was found for *Quercus* communities in China (An-ning et al., 2008). Meanwhile, positive (Caspersen and Pacala, 2001; Sagar and Singh, 2006; Houle, 2007) and no relationships (Vila et al., 2003) were found in other forests. These conflicting observations may be due to environmental differences between study sites as the diversity–productivity relationship is affected by environment. When environments are homogeneous, linear diversity–productivity relationships are observed, which may be positive or negative (Pianka, 1967; Silvertown, 1980; Guo and Berry, 1998). When environments are heterogeneous, unimodal relationships may occur (Mittelbach et al., 2001). However, such unimodal patterns are generally more typical for short- than long-lived plant communities (Vance-Chalcraft et al., 2010).

Species richness is the most widely used measure of biodiversity in diversity–biomass comparisons (Vance-Chalcraft et al.,

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2010; Martines-Sanchex and Cabrales, 2012). However, other measures, such as Simpson's diversity, Simpson's evenness, and rarity have also been used (Vance-Chalcraft et al., 2010). Beside numerous studies on the species diversity–productivity and carbon storage relationship, relationship between forest stand structural diversity and productivity has been much less studied. Wang et al. (2011) found a positive linear relationship between stand structural diversity and aboveground biomass in Canadian forests, all though it was quite weak. A positive relationship between structural diversity and forest growth in spruce-dominated forests was also reported (Lei et al., 2009), and a unimodal relationship between productivity and stem size diversity were also observed (Liang et al., 2005). A combination of measures of stand structure and species diversity may be a better proxy of aboveground biomass in long-lived tree communities than either species or stand structural diversity alone. Based on existing literature we hypothesize that increased levels of structural and species diversity lead to enhanced aboveground biomass in tropical forests of Vietnam.

2. Method

2.1. Study site

This study was conducted in six ecological regions in Vietnam covering a 10° latitudinal range and including tropical evergreen broadleaf and dry deciduous dipterocarp forests (Fig. 1, Table 1). Evergreen broadleaf forest is distributed throughout Vietnam at elevations from 0 to 1800 m above sea level. The large variation in soil and climate conditions within this altitudinal belt has led to an extraordinary diversity of forest formations, differing in composition, structure, and commercial value.

Dry deciduous dipterocarp forest has a more limited, distribution being restricted to dry sites in the Central Highland at elevations between 200 and 800 m above sea level on gentle slopes, where there is a monsoon climate with a 5–6 months marked dry period and annual precipitation of 1200–1600 mm (Tran, 1991). This forest type has an open canopy and is composed of small to medium-size xeric species (Konkris, 1965). Most tree species shed leaves during the dry season and form new leaves before the beginning of the rainy season. This type of forest is characterized by four tree species: *Shorea obtusa* Wall, *S. siamensis* Miq., *Dipterocarpus tuberculatus* Roxb, and *D. obtusifolius* Teysm. Some other common species are *D. intricatus* Dyer, *Pterocarpus macrocarpus* Kurz, *Xylia xylocarpa* (Roxb.) Taub. var *kerrii* (Craib & Hutch.) Nielsen, *Adina cordifolia* Hook.f., *Lannea coromandelica* Merr., *Terminalia* spp., and *Vitex* spp.

All six studied sites were located in natural forest reserves or in rarely disturbed areas, in which vegetation was characterized as old-growth forest. In general, cut stumps were rarely found.

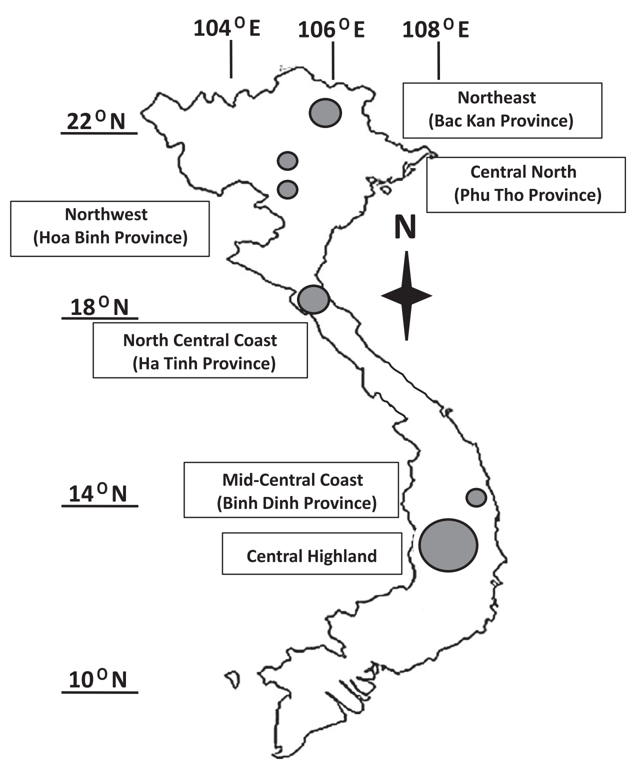

Fig. 1. Distribution of study sites.

2.2. Data collection

In each study site typical three to five 1-ha plots of 100 × 100 m^2 each (Table 1) were established for tree census. Only stems with diameter at breast height (DBH) greater than or equal to 10 cm were identified to species in the field and measured for DBH. Specimens of unknown species were collected and later identified by experienced taxonomists.

2.3. Aboveground biomass (AGB)

AGB of each measured individual stem was estimated using the following allometric equations (Bao, 2009):

$$AGB_f = 0.2626DBH^{2.3955} \quad (1)$$

$$AGB = 0.454AGB_f^{1.032} \quad (2)$$

where AGB_f and AGB are individual stem fresh and dry biomasses in kg, respectively.

Then, AGB of a plot was calculated as the sum of the biomass of the individual trees in each plot.

2.4. Biodiversity

Three measures of biodiversity: species richness, Shannon index, and Shannon evenness were calculated separately for each plot in each study site. Species richness (S) is number of species found in a plot. Shannon index (H'; Magurran, 1988) was calculated as:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i) \quad (3)$$

where p_i is the stem proportion of species ith.

Shannon evenness (J') was calculated as:

$$J' = \frac{H'}{\ln S} \quad (4)$$

2.5. Structure–species diversity

Biomass accumulation or carbon sequestration in a stand are affected by external factors (climate, geographical location etc.) and internal factors including species richness, population structure, diversity of horizontal distributions of stems, diversity of stem diameter etc. Therefore, an index combining all internal factors may better represent AGB – diversity relationship of a stand than a single one.

Two indices that represent the variation in stand structure, species diversity and biomass were calculated for each plot: (1) the