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Sampling adequacy estimation for plant species composition by accumulation curves—A case study of urban vegetation in Beijing, China

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ABSTRACT

Species accumulation curves are commonly used to evaluate sampling adequacy under natural conditions, but their performance in urban conditions still requires examination. The built-up area of Beijing, was chosen as a case study, and specific insight was gained into accumulation curves of plant species composition. The characteristics examined were plant species richness, percentage of alien plant species, chorotypes percentage (assemblages of species with similar geographical ranges), and the importance value of the dominant tree species. We showed: (1) the plant species accumulation curves significantly fitted the power function relationship, but the curves were nowhere near any asymptote, and the traditional method to locate an adequate sampling effort were found to be invalid in this case; (2) to evaluate the sampling adequacy for plant species composition, it was more appropriate to use the coefficient of variation for the first-order jackknife estimator as a substitute for species richness; (3) accumulation curves for the importance value of the dominant tree species, the curves for the percentage of alien species, and the curves for chorotypes percentages showed different accumulation trends compared to that of species richness. However, because they reached a steady state much sooner than species richness, the sampling effort required for adequate estimation of these indexes was generally below that for species richness. As shown in this study of a relatively complex species composition in the urban condition, the accumulation curves of different characteristics of a subject are a promising way to estimate sampling adequacy for complex research subjects.

1. Introduction

Though the urban landscape only accounts for 2.8% of the Earth's terrestrial surface, it accommodates 50% of the world's population (Millennium Ecosystem Assessment, 2005). As city sprawl and the urban population increases, the remaining habitats and biodiversity within cities will be increasingly disproportionate in importance (Crane and Kinzig, 2005). However, vegetation in urban ecosystems has experienced dramatic changes caused by human disturbance, leading to concerns that urban ecosystem functioning may be negatively affected.

Species composition remains a major concern in studies on urban vegetation. Researchers concerned that the high human impact in urban areas would reduce conservation success with respect to species diversity (Knapp et al., 2008a). The consideration of both the phylogenetic relationships and traits of species in addition to species richness is crucial for a detailed understanding of how species assemblages develop and change with a changing environment (Knapp et al., 2008b), and researches on species composition would greatly enhance our ability to preserve biological diversity in all types of human-modified environments (Sudha and Ravindranath, 2000).

Comprehensive surveys of the total species richness of an area are generally beyond the resources and expertise available, and stratified random selection has become the most frequently used alternative measures. However, the distribution of sampling effort across different strata of samples and evaluation of the adequacy of sampling remain critical issues. Taking several studies of urban vegetation for example, there are at least six different ways to distribute sampling effort (Table 1), and there is hardly any definite relationship between sampling size and study subjects. Thus, it is difficult to evaluate the adequacy of sampling effort merely by comparing it with reported publications.

The idea of the species–area relationship is a promising option. This relationship was originally envisioned as an empirical tool and was principally used to determine the optimal sample size, sample number, and the minimum area of a "community", and also to predict the number of species in areas larger than those sampled (Connor and McCoy, 1979). By determining species richness (S) of n plots, species area relationships can be directly fitted because of

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Table 1
Examples of six types of sampling effort distributions.

Type	Subjects	Plot size and sample size	Category	Reference
Type 1: according to area percentage with specialization for herbaceous	Urban parks	Proportional to area	Different kinds of parks	Li et al. (2006)
Type 2: according to area percentage with specialization for herbaceous	Urban and suburban parks	100 m^2 plot, 1% of park area	Trees and shrubs	Hermy and Cornelis (2000)
		4 m^2 plot, 0.2% of park area	Herbaceous vegetation	
Type 3: according to homogeneity	Urban home gardens and swidden fields	Two plots per field	Homogeneous fields	Wezel and Ohl (2005)
		Four plots per field	Inhomogeneous fields	
Type 4: according to microvariations in physiography and vegetation physiognomy	Vegetation of urban habitats	13 stands	Graveyards	Shaltout and El-Sheikh (2002)
		104 stands	Along railways	
Type 5: according to kind of landscape	Urban forest	100% sampling	Minor parks, offices, temples, etc.	Sudha and Ravindranath (2000)
		About 160000 m^2	Major parks	
		10000 m^2	Large industrial and commercial areas	
		About 40000 m^2	Residential areas	
Type 6: according to natural status	Urban plant communities	599 m^2 plot, six lots each	Residential neighborhoods	Turner et al. (2005)
		25 m × 25 m plot, four plots each	Seminatural urban parks	
		Four stands	Natural forest	

the variations in plot size, A (Koellner et al., 2004). However, it is not possible to use the direct fit procedure under urban conditions because most urban green space is severely fragmented and there is a limitation on the variation in plot size. In such cases, species accumulation curves can be used instead. A species (or higher taxon) accumulation curve records the total number of species identified during the process of data collection, as additional individuals or sample units are added to the pool of all previously observed or collected individuals or samples (Gotelli and Colwell, 2001). Because an accumulation curve shows only one particular random ordering of all samples in the dataset (Gotelli and Colwell, 2001) and is unable to generate the expected number of species in a small collection drawn at random from the large pool of individuals (Simberloff, 1978), repeated rearrangement is conducted to calculate an average species accumulation, and this "randomized" or "smoothed" species accumulation curve (Colwell and Coddington, 1994) is also called a "rarefaction curve" (Gotelli and Colwell, 2001). This method explicitly recognizes the nonlinearity of the relationship between area and species number (Koellner et al., 2004).

Recently, the most used curves in estimating sampling adequacy are still only the species accumulation curves or rarefaction curves, which are curves plotted from samples taken randomly within a given area (Gotelli and Colwell, 2001; Gray et al., 2004; Magurran, 2004). Although some other research on sampling adequacy has also examined curves for the importance value of the dominant species (Wang and Li, 1986) and the community coefficient (Deng et al., 1999), curves for other important characteristics of species composition remain to be studied.

However, in plant species composition studies, three other important characteristics besides species richness were also commonly concerned. Alien plant species percentage was one of those characteristics, because alien plants represent a considerable part of almost all urban floras (Kowarik, 1990; Pyšek, 1998; Clemants and Moore, 2003). The characteristics of dominant plant species was the second one, as the dominant plant species were reported to be significantly important, especially since a small subset of popular species contributes the bulk of urban forest stock (Sudha and Ravindranath, 2000; Jim, 2002). Chorotypes – assemblages of species with similar geographical ranges – which correspond to particular historical and/or ecological factors, was also broadly studied as a classical approach to the analysis of plants species distribution (Teneb et al., 2004; Thuiller et al., 2006; Real et al., 2008).

Similar to species richness, the other important characteristics of species composition, like species origin and chorotypes, may display some kind of constant association with sampling area. However, adequate samples for the analysis of species richness may not be necessarily sufficient for the analysis of the other characteristics of species composition. This may be particularly so for species origin, e.g. the alien percentage in a city or a region, considering that it is vastly different in different parts of a city; it is a concern that the alien percentage, as commonly reported in urban plant studies, may not represent the plant species origin composition of the city. Therefore, it requires more assessment of whether the samples taken are adequate to estimate species richness, the composition of the dominant tree species, the alien percentage and the chorotype composition.

The main concern in this paper is the performances of accumulation curves in assessing the sampling adequacy of different aspects of species composition in urban vegetation, including species richness, alien percentage, chorotypes percentage, and the importance value of the dominant tree species. Firstly, the performances of randomized species accumulation curves in Beijing vegetation were tested and the substitute for species richness, the coefficient of variation (CV) for the first-order jackknife estimator, was compared, to test the validity of traditional techniques in the urban situation. Secondly, other relative accumulation curves were analyzed to test the consistency of sampling adequacy in different aspects of species composition. Thirdly, the accumulation variation of species composition characteristics with sampling effort were calculated, and some suggestions concerning the validity of accumulation curves in assessing sampling effort in the investigation of urban vegetation for studies of urban plant species composition are proposed.

2. Materials and methods

2.1. Study sites

The study was carried out in the built-up area within the fifth ring road of Beijing (Fig. 1). The city is located in the northeast of