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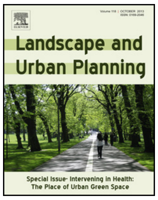


Research Paper

Biogenic volatile organic compound emissions in relation to plant carbon fixation in a subtropical urban–rural complex

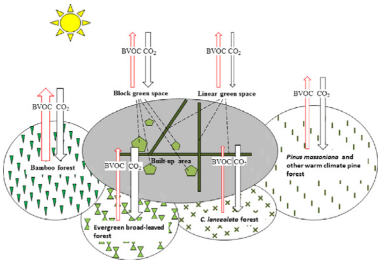
Peipei Guo[a], Kejian Guo[a], Yuan Ren[a], Yan Shi[a], Jie Chang[a], Akira Tani[b], Ying Ge[a,*]

[a] College of Life Sciences, Zhejiang University, 866 Yuhangtang Road, Zhejiang Province, Hangzhou 310058, PR China
[b] Institute for Environmental Sciences, University of Shizuoka, 52-1 Yada, Shizuoka 422-7 8526, Japan

HIGHLIGHTS

- Bamboo forest is the major contributor to the BVOC emissions also an important loss of carbon in low-latitude subtropical Ningbo.
- Contribution of carbon emitted as BVOC to NPP (BVOC/NPP ratio) for built-up areas is higher than rural forests (excluding bamboo forest).
- BVOC/NPP ratios between native and exotic tree species exhibit no significant difference.
- *G. biloba*, *L. chinensis* and *S. mukorossi* are the top three tree species with beneficial BVOC/NPP ratios in subtropical urban area.
- BVOC/NPP ratios increase with a drop in latitude.

GRAPHICAL ABSTRACT



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ABSTRACT

Changes in vegetation coverage and species composition have contributed to the alteration in biogenic volatile organic compounds (BVOC) emissions, which are regarded as losses of photosynthetically fixed carbon. This study estimates the amount of BVOCs carbon emitted in relation to carbon fixation for the built-up areas and rural forests in a subtropical urban–rural complex. Urban greenspace was subdivided into block greenspace and linear greenspace, while rural areas were characterized by four forest types. A field survey was conducted to assess the vegetation composition, biomass and foliar mass for each tree species. Results showed (1) the emissions intensity of BVOC in the greater Ningbo area is 4.48×10^6 g C km^{-2} yr^{-1}, the average emission intensity of the greenspace in the built-up areas (2.86×10^6 g C km^{-2} yr^{-1}) is higher than rural forests excluding bamboo forest (2.66×10^6 g C km^{-2} yr^{-1}); (2) the contribution of carbon emitted as BVOCs to net primary production (NPP) (BVOCs/NPP ratio) is about 4.3%, with 1.8% for the built-up areas which is lower than that for rural forests including bamboo forest (4.4%), but higher than rural forests excluding bamboo forest (0.96%); (3) the BVOCs/NPP ratio between native and exotic tree species exhibits no significant difference. The results suggest that BVOC emissions can be reduced while carbon sequestration can be increased by planting trees with low-emitting but high carbon fixation capacity in built-up areas, and by reducing bamboo forest while restoring broad-leaved forest in rural forests.

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* Corresponding author. Tel.: +86 571 8820 6465; fax: +86 571 8820 6465.
E-mail addresses: guokejian07@163.com (K. Guo), renyuanawj@163.com (Y. Ren), syan2050@yahoo.cn (Y. Shi), jchang@zju.edu.cn (J. Chang), atani@wing.ncc.u-tokai.ac.jp (A. Tani), geying@zju.edu.cn (Y. Ge).

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1. Introduction

A substantial amount of carbon is emitted by terrestrial vegetation as biogenic volatile organic compounds (BVOCs) (Kesselmeier, 2002). As an important precursor for tropospheric ozone (Wang, Bai, & Zhang, 2003), increases in BVOC emissions will lead to higher concentrations of secondary organic aerosols, which contribute to the formation of particulate matter (PM) affecting air quality. BVOCs are also potent greenhouse gases and significant air pollutants (Wu, Mickley, Kaplan, & Jacob, 2012). Previous studies have provided biogenic emission inventories from regional to global scales based on empirical models (Guenther et al., 2006; Gulden & Yang, 2006). Some researchers recommend using trees with low biogenic emissions to improve air quality in urban areas (Simpson & McPherson, 2011). In recent decades, BVOCs have been considered to contribute significantly to the loss of photosynthetically fixed carbon (Kesselmeier, 2002; Peñuelas & Staudt, 2010) and should be considered in the analyses of carbon budgets (Guenther, 2002).

A considerable percentage (as much as 10%) of photosynthesis assimilated carbon are released back into the atmosphere in the form of BVOCs (Langford et al., 2010), with isoprene and monoterpenes being the most prominent ones (Kesselmeier & Staudt, 1999). The carbon released as a plant/atmosphere VOC exchange is related to the uptake of CO_2 (i.e. net primary production, NPP) (Kesselmeier, 2002). Some research has shown that the carbon lost as BVOCs accounts for about 2% of the NPP for most plants at the species level, even reach higher values of 15–50% under certain conditions (Harley, Monson, & Lerdau, 1999; Sharkey & Loreto, 1993). It is estimated that the predicted annual global BVOC emissions of about 1.2 Pg C would result in the annual production of approximately 1.0 Pg C as CO_2 per year (Guenther, 2002).

In general, the emissions of BVOC are highly species specific (Kesselmeier & Staudt, 1999), and have obvious temporal and spatial variability, as the emissions depend on geographical position and environmental factors, mainly temperature and photosynthetically active radiation (PAR) (Guenther, Zimmerman, Harley, Monson, & Fall, 1993; Kesselmeier & Staudt, 1999). In addition, there are many other factors influencing biogenic emissions, including land use changes, increasing atmospheric CO_2 concentrations and enhanced UV radiation, etc. (Peñuelas & Staudt, 2010). The changes in emissions can lead to unforeseeable consequences for the biosphere's structure and function, and could become an even more significant component in local and regional carbon budgets as they increase in response to global changes in climate (Peñuelas & Staudt, 2010).

Urbanization involves one of the most extreme forms of land use change which leads to a radical change in the structure of vegetation and its species composition (Shochat, Warren, Faeth, McIntyre, & Hope, 2006). Compared with rural forests, urban areas are generally covered with a different set of species (Smith, Thompson, Hodgson, Warren, & Gaston, 2006). Most of the plant species in urban areas have been selected for their ornamental characteristics and many ornamental plants are strong emitters of BVOCs (Niinemets & Peñuelas, 2008). Furthermore, because trees grown in urban areas are generally separated far from each other, with most leaves exposed to high light, the BVOC emissions are much greater than for shaded leaves (Guenther et al., 1995). Due to the urban-heat-island effect, urbanized areas experience higher temperatures than natural areas (Luo, Sun, Ge, Xu, & Zheng, 2007). In addition to the effect of landscape management, all these factors contribute to higher tree production than in the surrounding uncultivated land (Kaye, Mcculley, & Burke, 2005). Several studies have estimated BVOC emissions in urban areas (Chang et al., 2012; Karl et al., 2004), yet the contribution of biogenic emissions to the carbon cycle for urban areas have not been given due consideration.

As a typical city undergoing rapid urbanization, the built-up area in Ningbo increased from 152 km^2 in 2002 to 450 km^2 in 2012 (Ningbo Statistical YearBook, 2012). This rapid expansion of the urban area has contributed to the change of vegetation coverage and composition, and regional air quality and the carbon cycle are therefore affected (Chang et al., 2012; Shochat et al., 2006). Using a stratified random sampling design, we conducted field surveys for urban vegetation to get a more accurate vegetation data. The aim of our research was (1) to analyze differences of BVOCs/NPP ratios among tree species in a subtropical urban–rural complex, (2) to compare BVOCs/NPP ratios among different types of urban greenspace with rural forests, and (3) to discuss the limitations and uncertainties in the study as well as contributing to a better understanding of the role of BVOCs emitted in the carbon cycle in a subtropical urban–rural complex.

2. Study site and methods

2.1. Study site

This study was conducted in Ningbo area (lat 28°51′N–30°33′N, long 120°55′E–122°16′E) (Fig. 1), located at the center of the eastern coast of China. Ningbo is a typical city that is undergoing rapid urbanization, has a land area of 9816 km^2 and a total population of 7.6 million (Ningbo Statistical YearBook, 2012). Ningbo has a northern subtropical monsoon climate with an annual average temperature of 16.2 °C, with the highest in July of 28.1 °C and lowest in January of −4.2 °C. The annual average precipitation is approximately 1375 mm, most of which is concentrated between the months of May and September. The urban landforms are hills densely covered with river networks. The area can be divided into three parts with flood plain and river networks in the middle area, hilly regions in the southwest and east and a coastal area in the east. The entire urban forest system covers an area of 361,620 ha with forest coverage of 50.2%. The main tree species include *Cinnamomum camphora* (Linn.), *Koelreuteria integrifoliola*, *Elaeocarpus sylvestris* (Lour.), *Salix babylonica* (Linn.), *Magnolia grandiflora* (Linn.) for the built-up area, rand *Pinus massoniana* (Lamb), *Phyllostachys pubescen* (Mazel), *Cunninghamia lanceolata* (Lamb.) Hook., *Castanopsis carlesii* (Hemsl.), *Schima superba* (Gardn) and *Lithocarpus glaber* (Thunb.) for the rural forests.

2.2. Sampling design

Stratified random sample method (Nowak, Walton, Stevens, Crane, & Hoehn, 2008) was used to investigate the urban vegetation of Ningbo. The category "general greenspace" can cover a wide variety of habitat structures (e.g. recreational areas, clumps of trees, patches of grassland, green corridors along roads and rivers). In built-up areas, the greenspace was classified as two types: block greenspace (such as public parks and residential greenspace), and linear greenspace (such as street trees and riparian greenspace). Field data were collected from 206 plots, 126 random samples for the block greenspace (30 m × 30 m) and 80 for the linear greenspace (40 m × 10 m). The sample number is comparable to the recommended 200 plots for an urban vegetation survey (Nowak et al., 2008). For the outer suburban forest, 264 plots (20 m × 20 m) were established to record species composition, tree density and the characteristics of each forest type. There are four main forest types: evergreen broad-leaved forest, *P. massoniana* and other temperate pine forest, *C. lanceolata* forest and bamboo forest. Aerial images taken in 2010 were used to stratify our field samples and to determine the center point of each sample plot. We used Garmin 60CXs GPS to locate the plot centers. All live trees larger than 5 cm in diameter at breast height (*DBH*) were surveyed within each plot. Tree