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Research Paper

Using unmanned aerial vehicle data to assess the three-dimension green quantity of urban green space: A case study in Shanghai, China

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ABSTRACT

Urban green space (UGS), which plays an important role in reducing the problems associated with urbanization, needs to be evaluated by metrics. Three-dimension green quantity (3DGQ), a quantitative index that measures the crown space occupied by a growing plant, is often used to evaluate the extent, and the environmental and climatic benefits of UGS. The objective of this study was to measure the 3DGQ of Paotaiwan Wetland Park (PWP) in Shanghai, China. Implementation of the 3DGQ index was supported by remote sensing (RS) images taken by an unmanned aerial vehicle (UAV). The 3DGQ calculations for 100 species of trees were used to calculate the 3DGQ of the UGS in PWP. The environmental and climatic benefits of UGS in PWP were also evaluated. The 3DGQ for the whole PWP was 668,624.13 m^3. The mixed woods in the PWP annually absorbed 1,635.57 t CO_2, 2.03 kg SO_2, 735.48 t dust, and 2,254.49 t of O_2. There was 367.74 t of diurnal transpiration. The lowered temperature of the PWP in the transpiration scope at 100 m altitude was 1.8 °C. The use of a UAV to assess UGS could help planners and policy makers to improve the environmental and climatic benefits of UGS.

1. Introduction

Cities around the world are becoming increasingly hot, congested, crowded, and polluted (Wolch, Byrne, & Newell, 2014). Fortunately, the impacts can be mitigated by green space, which can moderate some of the urban heat island effects (Feyisa, Dons, & Meilby, 2014; Kong, Yin, James, Hutyra, & He, 2014), and improve microclimate regulation (Neuenschwander, Hayek, & Grêt-Regamey, 2014), air filtering (Kabisch, 2015), water cleaning, noise reduction, and rainwater drainage (Derkzen, Teeffelen, & Verburg, 2015; Schäffler & Swilling, 2013; Yang, Zhang, Li, & Wu, 2015). The importance of urban green space (UGS) to urban environments (Munton, 1983; Szulczewska et al., 2014) means that the planning and design of UGS are becoming increasingly important, especially with regards to sustainable development practices in growing metropolitan areas (Erickson, 2006; Li, Wang, Paulussen, & Liu, 2005). Furthermore, in order to improve the planning and design of UGS, landscape metrics that can qualify and assess the climatic functions of UGS are needed.

The Green Index (GI), i.e., percentage area of green space, as an objective measurement of greenness, is regarded as having the greatest influence on ecological performance when developing indicators for the ecological performance of urban areas in the United Kingdom (Whitford, Ennos, & Handley, 2001). Other traditional indices that are internationally used to evaluate the extent of UGS are also two-dimensional, such as the number and area of parks in a city, area of parks per capita, and percentage of park area compared to city urban area (Chiesura, 2004; Xiaojun, 2009). Furthermore, there are some other indices related to the instrumental functions of urban forests, such as total leaf surface areas (Duursma & Falster, 2016), the canopy cover (Parmehr, Amati, Taylor, & Livesley, 2016), total leaf biomass (Nowak & Crane, 2002), leaf area density (Béland, Widlowski, & Fournier, 2014), leaf area index (Xiao, McPherson, Ustin, & Grismer, 2000), and green plot ratio (Ong, 2003). The green view index, which was developed to evaluate the visibility of urban forests, can be used to evaluate the visual impact of various planning and management practices on urban forests (Li et al., 2015). However, none of the above indexes can function as a three-dimension green quantity (3DGQ), which accurately reflects the regression models of plant species (Yamada et al., 2007) and provides a basis for evaluating the environmental and climate benefits of UGS (Cheng, Matteo, Zhongke, & Siyu, 2013).

3DGQ is defined as the three-dimension volume of the leaves and stems of plants in an area (Fig. 1), and can be estimated by ground surveys and remote sensing (RS) technology (Yamada et al., 2007).

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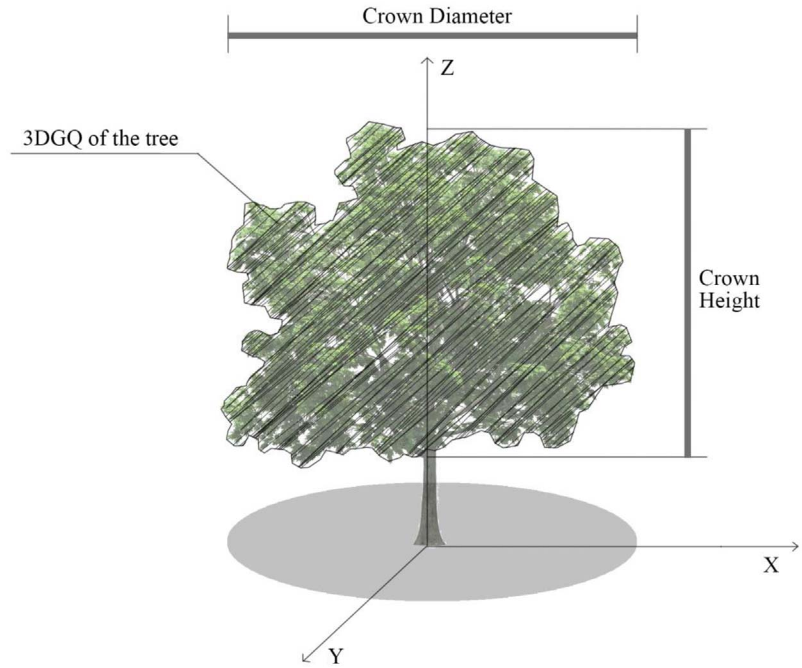

Fig. 1. Diagram of the definition of three-dimension green quantity (3DGQ). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

However, it is difficult to calculate a 3DGQ for large areas using ground surveys, so it has gradually been replaced by RS technology, which can classify vegetation (van Beijma, Comber, & Lamb, 2014; Yu et al., 2014). The 3DGQ regression models of some species of trees (Jianhua & Tianzong, 1995; Král et al., 2010), as well as the methods used to estimate the ecological environmental benefits of UGS by 3DGQ (Keith, Mackey, & Lindenmayer, 2009), have been studied in previous investigations. The aim of this study was to estimate the 3DGQ of trees in Paotaiwan Wetland Park (PWP), Shanghai, China, and to measure the park's environmental and climate benefits. An unmanned aerial vehicle (UAV) was used to collect data to make our calculations more accurate and precise. Overall, we present a straightforward methodological approach that can estimate the 3DGQ of trees. We believe that the 3DGQ of plants in many different areas needs to be estimated in order to measure the environmental and climatic benefits of green space. Our approach and findings are applicable to other UGSs around the world.

2. Materials and methods

2.1. Study area

This study was conducted in PWP, a park in the eastern Chinese city of Shanghai (121°50′E, 31°40′N) (Fig. 2a). Shanghai is the most important city in terms of China's economic development. It has a registered population of 18.6 million, covers an area of 634,050 ha, and is located at the mouth of the Yangtze River (Chang Jiang). Its climate belongs to the subtropical moist marine climate zone, and has four distinct seasons, large amounts of sunshine, and sufficient rainfall. PWP, a riverside urban wetland forest park located to the east of Baoshan district, Shanghai (Fig. 2b) on the southern bank of the Yangtze River, is the largest wetland park in Shanghai. It was established in 2007, with a surface area of 60.84 ha, including 50.00 ha mud flat wetland (Fig. 2c). With an average elevation of 6.74 m, it has a coastline length of 1974.13 m and is about 230 m wide. PWP is one of the city's main green spaces and is its most visited park. It has a green coverage of 81.60%. The PWP contains 11,494 trees that cover 100 species, which is why PWP was selected for this study.

Paotaiwan was built as a naval fort by the Qing government and was an important military base between the Yangtze River and Huangpu River (Dan & Xiaoxiao, 2006). After 1949 and the founding of the People's Republic of China, Paotaiwan was converted to an important coastal defense fort. In the 1960′s, after Paotai Mountain had been filled and piled by steel slag, this place became a parking lot, a stope, a steel bay, and a homeless person's residence, which caused serious damage to the ecological environment. Its geographical features, caused by the confluence of the Huangpu River and the Yangtze River (Fig. 2b), led the Shanghai government to plan and build the PWP to improve the local environment and celebrate local history and culture.

2.2. Data collection

The authority who issued the permission for the study area was the PWP Service. Data for the research included RS images, records from the PWP greening reformation project in 2009, and field surveys. The RS images consisted of 426 UAV high resolution images, which were acquired on July 20, 2013. The UAV had a 3.0 m fixed-wing platform, an 18.5 kg take-off weight, and a 62 cc gasoline engine. The flying platform was controlled by a YS-09 autopilot system (Zero UAV (Beijing) Intelligence Technology Co., Ltd.). The UAV could fly autonomously based on coordinates programmed in during mission planning. UAV aerial images, with approximately 5616 by 3744 pixels, were taken at an altitude of 300 m along 12 film flight lines. The PWP greening reformation project records from 2009 were used to obtain the tree species information. Field surveys conducted in August and October 2013 marked species and counted the number of different tree