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The use of meteorological data to assess the cooling service of forests

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ABSTRACT

The climate regulation effects of forests have been extensively studied. Many evaluation methods exist to assess the climate regulation service on regional and global scales. However, the processes driving local scale effects are poorly understood. We established a new method, which combined the cooling effects of forest and cooling costs to assess the value of climate regulation of a local scale forest. The inhabitable value of cooling service of forests for the farming area and built-up area and the payable value only for the built-up area were considered separately. The climate regulation effects of a forest in Fanggan, a mountainous village of East China, were studied. In 2014, the economic value of the cooling effects of the forest was 3727 USD per ha per year. In the inhabitable area, only about 10% of this amount was practically payable in the built-up area for humans. This method provides a new way of incorporating cooling effects into climate regulation services.

1. Introduction

Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (TEEB Foundations, 2010; Braat and Groot, 2012). Ecosystem services contain a variety of services, such as supporting services, provisioning services, regulating services and cultural services (Daily, 1997; MEA, 2005a; Braat and Groot, 2012; Haines-Young and Potschin, 2013). Accurate assessments of ecosystem services are crucial for policy makers but there are many controversial issues, associated with assessments such as technological advances for data collection, direct measurement of variables, better understanding of human behavioral responses to policy changes (Ouyang et al., 2016).

Climate regulation includes global climate regulation (such as regulation by greenhouse gas or carbon sequestration) and micro and regional climate regulation, for example, local climate can be modified by trees or forest ecosystems, which may involve cooling or humidity changes (TEEB Foundations, 2010; CICES, 2013). Many studies have assessed the values of climate regulation services on a relatively large scale (Seidl and Moraes, 2000; de Groot et al., 2012; Figueroa and Pasten, 2015). In these studies, the cooling service resulting from evapotranspiration, surface albedo, photosynthetic activity and shade can produce lower temperatures (Farrugia et al., 2013).

To assess the economic value of climate regulation service provided by forest ecosystems, a series of indicators and methods, at different scales and targets, have been established (Costanza et al., 1997; Xie et al., 2003; Snyder and Twine, 2012; Ouyang et al., 2013). Among these methods, the Market Value (or Price) Method estimates economic values for ecosystem products or services that are bought and sold in commercial markets (Ecosystem valuation website, http://www.ecosystemvaluation.org/market_price.htm). The Willingness-to-Pay Method gives the values of ecosystem products or services based on willingness to purchase. Both methods are widely used (Costanza et al., 1997; Xie et al., 2003, 2008; Ouyang et al., 2013), but the cooling service of forests is rarely considered and evaluated separately from the climate regulation services. However, the cooling service (cooling part of climate regulation) of a forest is very important for humans during hot summer weather at local scale. Therefore, it is necessary to separate the cooling service of a forest from the climate regulation services.

One method (Ouyang et al., 2013) objectively assessed the climate regulation service of a forest combining the heat absorbing process by plant transpiration and the total cost of electricity used by air conditioning to achieve similar cooling effects. However, this method did not address the actual cooling effects of a forest due to lack of temperature data and did not consider other cooling processes of the forest, such as evapotranspiration, surface albedo,

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photosynthetic activity and shade. Thus, assessment of the actual cooling effects of the forest is crucial in understanding the forest role in mitigating local heat waves.

The benefits derived from ecosystem services consist of direct (such as food, wood, fuel, fresh water) or indirect (such as water and air purification) perceptible components. However, when using economic methods to evaluate the value of ecosystem services, welfare mostly refers to what people perceive and are likely to pay for (Costanza, 2008). Previous research mainly emphasized the directly perceived benefits for humans and ignored the indirect or less perceptible benefits. For example, humans are willing to pay for cooling service inside buildings, but they hardly understand or are unwilling to pay for cooling of the farmland and outdoor areas where they work. Therefore, the cooling service of a forest for a farming area is typically ignored and omitted in methods based on willingness-to-pay.

On a local scale, the climate regulation of an urban forest and other vegetation has been demonstrated (Bastian et al., 2012; Dobbs et al., 2014). Buyadi et al. (2013) showed that urban trees and vegetation play important roles in mitigating the urban heat island effect. Depietri et al. (2013) confirmed the role of the urban forests in lowering the temperature during a heat wave in Cologne, Germany. However, fewer assessments on cooling service provided by forests have been conducted in rural areas, although rural populations and agriculture may be impacted by local climate change (Chmielewski et al., 2004; Tao et al., 2006). Thus, it is important to evaluate the cooling service of forests in rural areas.

To understand the cooling service of a forest on a local scale, we studied the cooling service of a forest in Fanggan, a mountainous village in East China. Fanggan has significantly greater forest coverage (86.90%) than surrounding areas. We defined the cooling service value of forests for humans in two ways: the inhabitable value (USD per ha per year of the area where people farm and live, including croplands, orchards etc. and built-up area), and the payable value (USD per ha per year of the built-up area, including houses, hotels, and businesses). Using the official meteorological data of Fanggan village and four sites in the surrounding area, we addressed the following questions: (1) What are the cooling effects of the forest, during the hot summer, at Fanggan? (2) What are the inhabitable values and payable values of the forest cooling service? (3) What is a good assessment method that combines the actual cooling effects of the forests and estimated cooling cost?

2. Methods

2.1. Research area and meteorological data

Fanggan was the research area. It is a small mountainous village with forest coverage of 86.90% and 579 residents within a 12 ha area. Fanggan is located in the middle of Shandong Province in East China (Fig. 1). It has a typical warm temperate continental monsoon climate with four distinct seasons, including a hot, rainy summer. The mean annual temperature of this area is about 12 °C, the mean annual precipitation is about 750 mm, and the frost-free period is approximately 200 d. The dominant landscape types are mountains and hills lower than 1000 m. The village lies at the junction of three cities: Laiwu, Jinan, and Taian.

The forest in Fanggan is mixed, with the dominant tree species being *Robinia pseudoacacia*, *Pinus tabuliformis*, *Pinus koraiensis* and *Quercus acutissima*. The tree composition and species in the surrounding areas are similar. One difference among the study sites is that trees in Fanggan village are protected from harvest and the forested area there is greatest.

The Shiyunshan automatic meteorological station, located on a hilltop close to Fanggan, was used to monitor and record surface climate factors including temperature, precipitation, air humidity and wind. Four other automatic meteorological stations are located at four sites outside of Fanggan, where the forest coverages are lower. These four sites are dominated by farmland, building land, or dwarf shrubs, all lower than 1000 m. These sites were used as controls to evaluate of the cooling service of the forests in Fanggan during the summer months (June to September) (Fig. 1).

The daily maximum, minimum and mean temperatures for each site from June to September from 2010 to 2012 were sorted from 24-h records of each meteorological station. Monthly rainfall of each station from June to September was also collected. The raw meteorological data from the Shiyunshan station, Xueye Lake station, and Dawangzhuang station were provided by the Meteorological Bureau of Laiwu city. Data from Duozhuang and Xiagang stations were provided by Jinan and Taian Meteorological Bureaus, respectively.

2.2. Effects of elevation and forest coverage

There might be elevation effects combined with the temperature differences between Fanggan and the other four sites. The <Guidance on the Global Observation System> and <Specification of the ground meteorological observation> (China Meteorological Administration, 2003; WMO, 1993) require that the ground observation site of a weather station should be located in a place that reflects the larger range of meteorological elements of the local area and avoids the influences of local terrain (He, 2011). The temperature data of the five meteorological stations represent the conditions in villages in which they are located. To rule out the effects of elevation, the elevations of the five villages were determined (Table 1). The mean elevation difference between Fanggan and the lower elevations of the four villages is 100 m. So, the temperature difference caused by elevation was estimated to be 0.6 °C (Xu, 1993; You and Li, 2005).

The forest coverage around each meteorological station was calculated combining interpretation of a remote sensing image, field investigation, and confirmation by local governments. The correlations among mean temperature, mean max temperature of summer months, and forest coverage were analyzed using Spearman Correlation analysis with a bootstrap sampling and two-tailed significance test.

2.3. Evaluations based on existing methods

To evaluate the cooling service of the forests in Fanggan and to compare the advantages and disadvantages of different methods, we used three methods from previous studies and a new method that combined meteorological data and cooling costs. One of these methods was developed by Costanza et al. (1997). The second one was modified by Xie et al. (2003, 2008) and based on Costanza et al. (1997). The third method was proposed by Ouyang et al. (2013). We named the three existing methods as the Costanza method, the Xie method, and the Ouyang method. The effects of the exchange rate and inflation rate (Trading Economics Website, http://zh.tradingeconomics.com/china/inflation-cpi) were adjusted by converting all estimations into USD in 2014.

Based on willingness-to-pay and the supply-demand relationship of ecosystem services, Costanza et al. (1997) determined the climate regulation service of a temperate forest to be 88 USD per ha per year. The total climate regulation service value of the Fanggan village was calculated by multiplying this value by the area (ha) of forests and an inflation rate between 1997 and 2012. Based on the modified Costanza method and a questionnaire survey of 700 ecologists to obtain the equivalent value per unit area of global ecosystem services, Xie et al. (2008) determined the climate regulation service of a forest as 367 USD per ha per year (2014) per ha