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Original article

Assessing urban vacant land ecosystem services: Urban vacant land as green infrastructure in the City of Roanoke, Virginia

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ABSTRACT

The research reported here quantifies the ecosystem services and values of vacant land using the City of Roanoke, Virginia as a study site. Aerial photo interpretation with ground-truthing was used to identify and catalog vacant parcels of land within the city limits and the results mapped using the i-Tree Canopy and i-Tree Eco models to define land cover classes and quantify ecosystem structure and services. An analysis of urban forest cover in Roanoke's vacant land reveals that this area has about 210,000 trees, with a tree cover of 30.6%. These trees store about 97,500 t of carbon, valued at $7.6 million. In addition, these trees remove about 2090 t of carbon (valued at $164,000), and about 83 t of air pollutants (valued at $916,000) every year, which is high relative to other land uses in Roanoke. Trees on vacant land in the city are estimated to reduce annual residential energy costs by $211,000 for the city's 97,000 residents. The structural value of the trees growing on vacant land is estimated at $169 million. Information on the structure and functions of urban forests on vacant land can be used to evaluate the contribution made by urban vacant land's green infrastructure to improving environmental quality. The methodology applied to assess ecosystem services in this study can also be used to assess ecosystem services of vacant land in other urban contexts.

Introduction

The urban cores of many contemporary American cities are slowly becoming decentralized, with many losing significant numbers of residents, businesses, and industries between 1950 and 2010 (Hall, 2010). This loss of population has led to an increase in the number of vacant lots, often in the urban core. These vacancies become "urban voids" or negative spaces in the urban fabric. Decentralization is most common in post-industrial cities such as St.Louis, Philadelphia, and Detroit. For example, since 1950, Detroit has lost over 50% of its population, 165,000 industrial jobs, and 147,000 housing units (Hall, 2010); between 1978 and 1998, there were 108,000 demolitions and only 9000 new buildings constructed in the city (Oswalt, 2008). As the population of Detroit continues to decline, an estimated 2400 properties become newly vacant every year (Daskalakis et al., 2001) and approximately 32% of the city's land area is now vacant property (King, 2012), more than twice the average in large U.S. cities (Bowman and Pagano, 2004). While Detroit is an extreme case, many cities have vacant land. However, due to a lack of public interest, policies, and economic investment, vacant land often becomes wasted, underused or under-appreciated space. Can urban vacant land perhaps be a valuable resource? Re-imagining urban vacant land is critical to the preservation of our traditional urban environment and quality of life. To achieve this we need to be more open to alternative ways to "reuse wasted land" in urban areas. Can vacant land be valuable ecological resource? Perhaps it can enhance ecosystem health and promote a better quality of life for city residents?

Urban infrastructure consists of the systems that provide services or benefits to people and communities, such as roads for transportation and storm sewers for rainfall runoff removal, but green infrastructure not only provide the primary service for a single benefit, but multiple benefits in the form of environmental and cultural services. The definitions of "green infrastructure (GI)" are numerous. According to the U.S. Environmental Protection Agency (EPA), GI is an "adaptable term used to describe an array of products, technologies, and practices that use natural systems – or engineered systems that mimic natural process – to enhance overall environmental quality and provide utility services" (USEPA, 2011). The EPA suggests that green infrastructure could reduce

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the volume of urban stormwater runoff, provide community benefits and also reduce the need for public monetary commitments (Grumbles, 2007). In the late 1980s, the National Science Foundation supported an urban ecology educational effort that used city parks, rights of way, and vacant lots as "nature's classrooms" (Bowman and Pagano, 1998). Similar thinking is evident in Portland Oregon's Metropolitan Greenspaces Program (Poracsky and Houck, 1994). This program changed the land use general labels to make them more positive, exchanging labels such as "vacant" or "undeveloped" to biological labels such as "greenspace" or "greenbelt" (Bowman and Pagano, 1998). Rather than being a negative symbol of urban problems, vacant land began to be considered as "fortuitous landscapes." This new way of thinking is apparent in the title of Timothy Beatley's book, "Biophilic Cities: Integrating Nature Into Urban Design and Planning" (Beatley, 2011).

Urban vacant land is not normally thought of as green infrastructure, partly because the potential community benefits provided by these spaces are not recognized. One way of addressing this failure is to conduct a comprehensive assessment of urban forests to estimate the environmental benefits and ecosystem services they provide; and thus, demonstrating the role of trees on vacant parcels play in creating healthy, livable and sustainable cities. Therefore the purpose of this paper is to provide such a demonstration of how urban vacant land can function as a form of green infrastructure providing ecosystem services and values, such as air pollution removal, carbon sequestration and storage, and energy saving, as well as the structural value of the trees themselves. In most cities, air pollution is a major environmental problem (USEPA, 2014). Carbon dioxide is the major cause of climate change and also has a strong relationship with energy consumption from power generation (Cox et al., 2000), while the structural value of trees on vacant land can add to our understanding of the compensatory value of vacant land and lead to better urban forest management of vacant land (Nowak et al., 2002a).

Methods

To assess the ecosystem services and values derived from urban vegetation, the i-Tree model (www.itreetools.org) was used. This software is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak et al., 2008a). The results from the i-Tree model can then be used to identify the urban forest structure in order to improve urban forest policies, planning, and management (e.g., Nowak et al., 2011). The model also provides data to support the potential inclusion of trees within environmental regulations, and determine how trees affect the environment and consequently enhance human health and environmental quality in urban and rural areas (Nowak et al., 2011). In this study, the i-Tree Eco model was used to assess the green infrastructure value of vacant land in the City of Roanoke, Virginia.

An i-Tree Eco analysis is usually based on a random sampling or inventory of urban forest characteristics from a study area in order to estimate the urban forest structure and ecosystem services for a particular urban area. However, in this study we were also interested in identifying the forest structure and ecosystem services of different types of vacant land. In most cities, different types of vacant land are not equally represented or evenly distributed across the city and a random sample may not capture all vacant land types in the city. Therefore, a proportionally weighted, stratified random sampling of the study area was used. It was stratified to assure that all types of vacant land were represented, but the sample of each type of vacant land was proportional to the area that each type occupied within the city to provide an accurate estimate of the total ecosystem services provided by each vacant land type. This study used 5 different categories of vacant land as strata to assess the ecosystem services associated with each vacant land type in Roanoke. In addition, ecosystem services were compared among vacant, commercial, industrial, and residential lands throughout Roanoke. This land use differentiation was done to determine if vacant lands represent structural assets with economic value similar to that of other land use in the city.

The precision and cost of the estimate is dependent on the sample and plot size. Generally, 200 plots (0.04 ha each) in a random sample will produce a 12% relative standard error for an estimate covering the entire study area (Nowak et al., 2008b). As the number of plots increase from 200 to 500, the relative standard error will decreases on the total number of trees to 7.7% (a 36% reduction) (Nowak et al., 2008b) and provides more precise estimates. However, as the number of plots increases, so does the time and cost of field data collection. The estimates of ecosystem services values obtained here match well with other field estimates of ecosystem services (e.g., Nowak et al., 2008a, 2013; Morani et al., 2014).

Study area

The City of Roanoke, Virginia was selected as the site for this study. The age and industrial heritage of the city have resulted in a range of vacant parcel types and conditions that provide an excellent opportunity to define and assess vacant land categories. The City of Roanoke became a hub for railroad and other industrial activities in the first half of the 20th century, when the city's population grew from 21,495 in 1900, to 91,921 in 1950 (Blakeman et al., 2008). However, as economic conditions and technologies changed, many traditional manufacturing operations and industries closed and ceased production in the city. As a result, there are many left-over industrial areas with underused or abandoned properties (Blakeman et al., 2008). The city has a current population of 97,032 (US Census Bureau, 2010), and covers an area of 113.3 km^2. Roanoke enjoys a mild climate that is classified as a humid subtropical climate and has a monthly high temperature of 7.6 °C in January and 28.6 °C in June. It has a mean annual precipitation of 1047.7 mm (NowData – NOAA Online Weather Data, 1981–2010). The City of Roanoke is located in Southwest Virginia, at about 37°16′N and 79°56′W, in the valley and ridge region of the state.

Aerial field sampling of vacant lots

In quantifying urban forest structure and ecosystem services in a city, i-Tree results are typically stratified by land use. Vacant land is only one of many land use classes and most of the time is not subdivided into different classes of vacant land. Different types of vacant land have different physical characteristics. Therefore, dividing vacant land into smaller, more homogeneous types can help assess variations in vacant land and offer a more precise picture of the role that vacant land plays in providing different forest structure and ecosystem services. The vacant land in Roanoke was categorized into 5 types that are described below.

Within Roanoke, 1000 points on Google Maps aerial imagery were photo-interpreted, using i-Tree Canopy to estimate the amount of each type of vacant land in the city. Each point that fell upon a vacant parcel was classified into one of the vacant types through the aerial photo-interpretation process (Table 2). Photo-interpreted estimates of vacant land types and their associated land cover are beneficial for providing essential information related to natural resources and development planning and policies at the local to national scale (Nowak and Greenfield, 2010). After the area of each vacant land type was determined, field plots were laid to assess the ecosystem services derived from the trees on these