Ecosystem Services 28 (2017) 17–27

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Monetary value of urban green space as an ecosystem service provider: A case study of urban runoff management in Finland

Sveta Silvennoinen [a], Maija Taka [b], Vesa Yli-Pelkonen [c,*], Harri Koivusalo [b], Markku Ollikainen [d], Heikki Setälä [a]

[a] Dept. of Environmental Sciences, University of Helsinki, Niemenkatu 73, FI-15140 Lahti, Finland
[b] Dept. of Built Environment, Aalto University, P.O.Box 15200, FI-00076 Aalto, Finland
[c] Dept. of Environmental Sciences, P.O.Box 65, FI-00014 University of Helsinki, Finland
[d] Dept. of Economics and Management, P.O.Box 27, FI-00014 University of Helsinki, Finland

ARTICLE INFO

Article history:
Received 10 June 2016
Received in revised form 8 September 2017
Accepted 27 September 2017

ABSTRACT

The predicted increase in the number of urban flood events can result in substantial monetary losses to society. These costs may be alleviated by preserving ecosystem services, such as urban runoff management. We studied the monetary value of this ecosystem service by applying the replacement cost method in six catchments with varying land-use intensities in two cities in Finland. The economic analysis was based on metric data of urban runoff generation, provided by automatic monitoring stations in the catchments. A hydrological model was applied to estimate evaporation from impervious surfaces, and to simulate runoff in the catchments. Our results suggest that leaving green space unconstructed results in significant monetary savings. The cost of managing runoff correlated with land-use intensity. The ecosystem service value (ESV) was generally higher in catchments with high land-use intensity, low proportion of green space, and high costs of runoff management. Depending on the degree of imperviousness, the ESV ranged from 90,000–270,000 € ha^{-1}. Further, our results suggest that estimates of runoff generation and evaporation are key hydrological factors for assessing ESV. Our study demonstrates how the combination of field data and hydrological and monetary analyses can support regional planning in cold climates.

1. Introduction

Intensive land use is associated with drastic changes in vegetation cover and soil sealing, causing severe anomalies in the hydrological cycle (Schueler, 1994; Douglas, 2011; Illgen, 2011). Urban catchments – with highly disturbed soils – are characterized by high proportions of impervious surfaces resulting in increased surface runoff, decreased infiltration and evapotranspiration (ET), and the presence of dense and efficient drainage systems (Booth and Jackson, 1997; Burton and Pitt, 2002; Burian and Pomeroy, 2010). These changes in the hydrological cycle are manifested in increased frequencies and severities of urban flood events (Booth, 1991; Burton and Pitt, 2002; Kotola, 2003; Ogden et al., 2011), which are, specifically at high latitudes, predicted to become more frequent due to an increase in precipitation associated with climate change (Lehner et al., 2006; IPCC, 2007; Aaltonen et al., 2008; Perrels et al., 2008, 2010). Furthermore, untreated urban runoff – i.e. stormwater – is an important pathway for pollutants in urbanized catchments (Bäckström et al., 2002) and is an important source of the impairment of surface and ground water resources (Pitt et al., 1999; Burton and Pitt, 2002; Allan, 2004; Goonetilleke et al., 2005). There is growing concern that the increased volume and reduced quality of stormwater will result in increased monetary losses to society (Aaltonen et al., 2008; Bélanger, 2008; Perrels et al., 2008, 2010). To reduce urban runoff, urban green space and the ecosystem services (ES) it provides has been suggested as a feasible alternative to conventional stormwater management (e.g. Burian and Pomeroy, 2010; Liu et al., 2014).

The ecosystem services (ES) framework has become increasingly common in urban land-use and green-area planning, as urban ecosystems provide multiple ES, that are of great importance to the well-being of urban inhabitants. Furthermore, urban ES often provide justification for preserving the urban green infrastructure at substantial quantity and quality in urban planning and development. Urban runoff management (sometimes also called “flood protection”, depending on the context), as studied in this paper,

* Corresponding author.
E-mail addresses: sveta.silvennoinen@gmail.com (S. Silvennoinen), maija.taka@aalto.fi (M. Taka), vesa.yli-pelkonen@helsinki.fi (V. Yli-Pelkonen), harri.koivusalo@aalto.fi (H. Koivusalo), markku.ollikainen@helsinki.fi (M. Ollikainen), heikki.setala@helsinki.fi (H. Setälä).

https://doi.org/10.1016/j.ecoser.2017.09.013
2212-0416/

is categorised in regulation and maintenance services in the ES framework and is maintained by vegetation and soil associated with permeable surfaces (CICES, 2017). The simple use of ES framework is not, however, always unproblematic – for instance, due to a lack of empirical studies showing the actual magnitude of benefits (including monetary) to urban inhabitants or society. This is also the case with urban runoff management, as studies estimating the monetary value of urban soils in terms of storing rainwater, and thus mitigating urban runoff generation, are virtually non-existent.

Urban green infrastructure, such as trees, lawns and green roofs, are known to mitigate runoff problems through water harvesting and enhancing infiltration and evapotranspiration (Bélanger, 2008; Burian and Pomeroy, 2010; Liu et al., 2014). For example, Elmqvist et al. (2015) reported annual evapotranspiration of 1000 m^3 ha^{-1} in urban parks in Sacramento Ca, USA, and Peper et al. (2007) estimated that city street trees in New York, USA have an annual interception of 3.4 million m^3. However, despite the various benefits by urban green space, its continuous replacement with housing and other impervious surfaces makes the provision of ES vulnerable, and creates a trade-off situation between ecosystem services and city consolidation policies (Eigenbrod et al., 2011; Elmqvist et al., 2015).

From an economic point of view, diminishing urban green areas and thus the deterioration of urban runoff management and other ES have traditionally resulted not only in a significant loss of citizens' welfare, but also in direct monetary losses due to increased investments on expensive technical solutions replacing the services carried out by urban green space (Bélanger, 2008; van Zoest and Hopman, 2014; Elmqvist et al., 2015). However, for instance in the USA and Western Europe, the conversion of urban green areas to built-up i.e. – grey areas – is becoming less common, as the multiple benefits of green areas to urban inhabitants are being realised.

Nevertheless, the incorporation of ecological processes into urban planning, for example through increasing the proportion of permeable surfaces in urban areas, has proven to be challenging, since investment decisions in many countries are traditionally based on financial analyses that do not account for the benefits of ES (van Zoest and Hopman, 2014). However, a growing number of studies report substantial monetary benefits associated with ES provided by urban green space, e.g. related to urban runoff management (see Elmqvist et al., 2015). The reported economic values, mostly derived from methods that indirectly estimate stormwater reduction capacity via, e.g. canopy interception models, range from 0.34 € m^{-3} (Vargas, 2009) up to 200 € m^{-3} (American Forests, 2002).

The aims of this study were to (1) determine the economic value of the ecosystem service that urban green space can provide in terms of urban runoff management, in six urban catchments with different land-use intensities in the cities of Helsinki and Lahti, southern Finland; (2) assess how the estimated ecosystem service value (ESV) will change in the time span of 40 years, when climate change impacts the urban runoff volume and the costs of a conventional stormwater system; and (3) drawing on these analyses of ESV, examine whether it is economically beneficial to use urban vegetated areas for runoff management instead of relying only on conventional pipe-based drainage. The monetary value of the ecosystem service is defined in this paper as the net savings in technological solutions (conventional pipe-based drainage) when urban runoff is managed with the same service provided by green space.

This study was conducted at high latitudes, which introduce unique setting for ecosystem services. The four distinct seasons – with a prolonged cold season and soil frost – together with compact urban settlements, require carefully designed runoff management solutions. However, planning of such solutions is hindered by a lack of urban runoff data across seasons. The study sites, belonging to a Long-Term Socio-Ecological Research (LTSER) network (Setälä et al., 2010), have been intensively studied in terms of urban hydrology (Taka, 2012; Krebs et al., 2013, 2014; Valtanen et al., 2013, 2014). Based on our previous research on urban runoff (Krebs et al., 2013, 2014; Valtanen et al., 2013), we hypothesized that: i) preserving urban green areas results in substantial monetary savings for society via the ecosystem service of urban runoff management; and ii) ESV is higher at high land-use intensity, where costs of managing runoff are predicted to be higher. Importantly, unlike previous studies, the value calculations here are based on a combination of rarely-available urban empirical hydrological data and model results. By using microscale urban runoff data as an input into the ESV evaluation, we aimed to identify the prospects of using urban green space to manage seasonal urban runoff volumes. As our approach is based on these data, it can be utilized in similar urban regions with no accurate time series data of runoff available. Thus, the current study aims at providing a cost-effective and quantitative model to serve land-use planning and management, and related decision-making.

2. Material and methods

2.1. Study catchments

The study was conducted in the cities of Helsinki (60°10′N, 24°56′E; population of 635,000), and Lahti (60°59′N, 25°39′E; population of 120,000) in southern Finland. The six study catchments are classified into three land-use intensity categories (hereafter High, Intermediate and Low), thus representing different degrees of sealed surfaces and population densities (Fig. 1). They form part of the international LTSER network. These catchments were chosen to represent urban land cover with varying intensity, and they all have separate sewer systems, which discharge runoff to the receiving surface water systems without any treatment. Finally, they are closely located within the city and relatively similar in size.

The main characteristics of the six urban catchments are presented in Table 1. High catchments (L1, H1) represent urban core areas with a high impervious fraction, intensive land-use, high traffic volume, with fragmented green spaces mainly located in public park areas and residential yards. The Intermediate catchments (L2, H2) represent urban/suburban areas, while the Low catchments (L3, H3) are situated in suburban/residential areas characterized by single-family houses. In the Intermediate and Low catchments, the percentage of pervious areas is clearly higher than in the High catchments, and typical green spaces are urban forests, parks, residential yards and gardens. The catchments in Helsinki and Lahti differ in bio-geographical characteristics and local topography, and population densities of the High and Intermediate catchments of Lahti are considerably higher compared with Helsinki (Table 1). When looking only at the impervious fractions of the catchments, the classification is relational, i.e., the urban density classes 1–3 reflect the relative TIA differences within each study area.

2.2. Data collection

Runoff measurements were conducted in Lahti from December 2008 to August 2010, and in Helsinki from December 2010 to November 2014. Runoff was monitored at a measurement station located at the catchment discharge outlet, equipped with a runoff probe (ultrasonic flow sensor Nivus PCM4) placed into a stormwater pipe. Flow rate (l s^{-1}) and precipitation (mm) were measured continuously at 1-min intervals throughout the study periods (intervals were increased to 2 or 3 min during the freezing winter