Global Ecology and Conservation 3 (2015) 628–644

Contents lists available at ScienceDirect

Global Ecology and Conservation

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

Original research article

Hydrological evaluation of a peri-urban stream and its impact on ecosystem services potential

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HIGHLIGHTS

- Hydrological and biological evaluation framework in a peri-urban sub-basin.
- Artificial flood control has negative impacts on hydrological integrity.
- Organisms ecological traits can be used as indicators of the ecosystem's condition.
- Natural vegetation and hydro-geomorphology sustain potential HESs provision.

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form 13 February 2015
Accepted 14 February 2015
Available online 20 February 2015

Keywords:
Hydrological alterations
Peri-urban sub-basin
Basin management
Aquatic biodiversity
Ecosystem services

ABSTRACT

Rivers are aquatic systems with a unidirectional flow. These systems are highly diverse habitats that support a great variety of organisms, which vary in shape and function, and sustain a diverse range of hydrological ecosystem services (HESs). The HESs provided by rivers varies based on complex hydro-geomorphological dynamics and their relationship with the functional processes of the basin. Land use changes in transition zones, where ecosystem functions are compromised, affect the basin, especially basins close to or on the periphery of urban areas. Such is the case for Mexico City, where 60 m^3 of water is consumed per second, 30% of which is imported from outside sources.

The rivers of the Magdalena–Eslava sub-basin are among the few remaining surficial water sources in Mexico City. These rivers are located in an area classified as a Soil Conservation Zone, which has been intensely managed for decades. The aims of this paper are (1) to perform a hydrological evaluation of two urban streams and identify their relationship with the provision of hydrological ecosystem services via (i) a hydraulic balance analysis, (ii) a hydro-geomorphological characterization of each stream, (iii) an estimate of present and potential hydraulic erosion, (iv) the determination of physicochemical and bacteriological parameters and (v) a description of macroinvertebrates, macroalgae and their habitats in order to (2) identify the impacts of socio-economic dynamics on the responses of this rural-urban lotic system. Our results show that water flow, forest cover and hydro-geomorphologic heterogeneity are key to sustaining ecosystem functioning, especially in the high and middle sections of the basin. The highest potential provision of water for direct use was recorded in the sub-basin's middle section; however, the stream channels in that section have lost their natural water flow due to a water management infrastructure built

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http://dx.doi.org/10.1016/j.gecco.2015.02.008

to regulate flow during the rainy season. This intervention can be viewed as a regulation of HESs as water management infrastructure alters the transport of sediment and reduces available natural habitat. The provision of quality water in the lower area of the sub-basin has been seriously compromised by the establishment of illegal urban settlements. A relationship between biologically diverse ecological traits and their response capabilities was established and can be considered an indicator of current HES potential. Therefore, this sub-basin may constitute an example of good management and maximizing potential HESs in an urban-rural setting based on improved management strategies that could be applied in other developing nations.

1. Introduction

Rivers are aquatic, temporally heterogeneous systems with unidirectional flow (Kang and Kazama, 2014). These systems can be viewed as complex networks of intersecting primary channels and tributaries (Thorp et al., 2010). Rivers are highly diverse habitats, supporting a great variety of organisms with adaptations that allow them to provide many different ecosystem services (ESs), which benefit humans through direct and indirect effects (MEA, 2005). However, the great majority of rivers in the world are impacted by urbanization, primarily by increased impervious surfaces that alter the hydrological regime (Konrad and Booth, 2005; Walsh et al., 2005), especially in large urban conglomerates such as Mexico City. As a result, the patterns of energy and matter distribution in the local watersheds and their ecosystems have also been altered, both spatially and temporally. These patterns include evapotranspiration, surface runoff, discharge, nutrient availability (nitrogen and phosphorus), soil erosion and sedimentation (He et al., 2000).

Urban development modifies runoff to streams – along with the resulting rate, volume and timing of streamflow – and influences the structure and composition of lotic communities (Miltner et al., 2004; Konrad and Booth, 2005). The flow regime controls aquatic habitat conditions because it is strongly related to the physicochemical characteristics of the stream (Tetzlaff et al., 2005). Other urbanization implications, mainly in low-order streams, include modifications to peak flow, total runoff, stream morphology and water quality, which lead to changes in the input and uptake of nutrients by organisms. The magnitude of these changes is the result of the spatial arrangement of urbanization (Miltner et al., 2004; Jacobson, 2011). Urban streams can be especially impacted by rapid and short-term runoff rates, mainly as a combined result of sewers and storm water overflows (Tetzlaff et al., 2005).

Given these particular conditions, the interaction between ecological and social characteristics should be considered in urban aquatic ecosystems because human interventions can have substantial effects on urban streams and their protection (Walsh et al., 2005). Therefore, the development of a system of readily measurable hydrological and biological indicators, which can describe current stream conditions, the health of the watersheds and associated water resources, is essential for their protection and sustainable use (He et al., 2000). Appropriate indicators can be used to track environmental modifications and their effects on ES provision and human health, and they can provide support for strategic planning initiatives and proposed freshwater policies and best management practices (He et al., 2000).

The ES concept has become increasingly used due to an increase in ecosystems management. This concept makes tangible the relationship between ecosystems and the services they can provide, revealing a direct relationship between the natural world and human well-being (Dobbs et al., 2014). Ecosystem services are classified in accordance with the Millennium Ecosystem Assessment (MEA) into four large groups: provision, regulation, cultural and support.

The provision capacity of hydrological ecosystem services (HESs) is highly dependent on the hydro-geomorphological characteristics of a basin as well as its biodiversity. Provision also depends on the existence of stochastic physical disturbances, the stability of habitat conditions and their influence on ecosystem functions (Benda et al., 2004).

In a lotic system, gradual change in the characteristics downstream has an impact on the biological assemblages present and, in turn, on the capacity of ESs (Thorp et al., 2010; Larondelle and Haase, 2013).

Because the majority of urban landscape components are complex and strongly interconnected with adjacent ecosystems, change in land use along the river system in the transition zone between ecosystems in urban basins can affect functional processes (Radford and James, 2013; Lauff et al., 2014; Dobbs et al., 2014).

Knowledge of how landscape structure and socio-demographic traits are related to ES capacity has increased in the last decade. This information has helped urban planners and policy makers to guide city growth and development plans (Dobbs et al., 2014; Lauff et al., 2014; Larondelle and Haase, 2013). In cities where ES capacity is provided by rivers, particularly in developing countries, ES capacity has been greatly reduced due to inadequate or excessive water management (Jujnovsky et al., 2012). Therefore, having a baseline of the existing spatio-temporal state of hydrological and biological conditions constraining ES capacity on a local or regional scale becomes important for planning for environmental and cultural sustainability (Lauff et al., 2014). Urban areas have been able to expand considerably in recent years, largely due to the application of the ES concept, which is enabling these urban areas to achieve local ecosystem independence. The Mexico Basin serves as an example of the potential down-river impacts of urbanization. The basin consumes 77 m^3/s of water, of which 71% comes from groundwater, 2% from springs and surficial water sources and 27% from the Lerma–Cutzamala Basin, which is located over 100 km from the city (Mazari-Hiriart et al., 2014). Among the few surficial water sources in