Ecological Indicators 76 (2017) 256–274

Contents lists available at ScienceDirect

Ecological Indicators

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

Methodological and empirical considerations when assessing freshwater ecosystem service provision in a developing city context: Making the best of what we have

Gregg Brill[a,*], Pippin Anderson[a], Patrick O'Farrell[b]

[a] Department of Environmental and Geographical Science, University of Cape Town, Private Bag X3, Rondebosch, Cape Town, South Africa
[b] Natural Resources and Environment, Council for Scientific and Industrial Research, PO Box 320, Stellenbosch, South Africa

ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form
16 December 2016
Accepted 10 January 2017

Keywords:
Ecosystem services
Land-use change
Multiple data sets
Water quality
Urban protected area
Cape Town

ABSTRACT

This study contributes to both the methodological and empirical literature by developing an integrative approach to assessing temporal and spatial change in riparian ecosystem service delivery by drawing on available and diverse data sets. These data sets act as multiple lines of evidence in supporting comparisons between data sets to test the validity of developed methods and the application of such methods. In order to synthesise these data as well as to determine the fluctuations in riparian ecosystem service provision a scoring system was developed. Methodologically, the scoring system proved informative across the majority of ecosystem services categories, showing close to 80% similarity in outcomes when comparing the scoring method to trends in long-term water quality measurements. Other benefits of the scoring system included its design simplicity, cost-effectiveness, and applicability and replicability across various urban settings. Empirically, the data sets used support the findings of the ecosystem services scoring exercise and suggests that fluctuations in ecosystem service delivery through time and across the river reaches are linked to land-use change and other human activities. Findings suggest that as water leaves an urban protected area and travels across transformed and impacted landscapes, the results are poor water quality and diminished ability of rivers to yield ecosystem services the further the river flows into the urban setting. Urbanisation and changes in land-uses in developing city contexts is therefore shown to affect potential ecosystem services benefits, necessitating increasing management interventions.

1. Introduction

Since the first half of the twentieth century, there has been a significant transition from undisturbed to human-dominated landscapes across many areas of the globe (Sánchez-Azofeifa et al., 2003; Tscharntke et al., 2005). This transition has greatly impacted the functioning of ecosystems by altering their ability to meet human physical and social needs (Larondelle and Haase, 2013; Pickett et al., 2004). Demands on natural capital and ecosystem services (ES) keep growing steadily (Gómez-Baggethun et al., 2013) and we increasingly recognise that these human actions are the principal threat to the ecological and physical integrity of landscapes and ecosystems. Freshwater ecosystem systems are particularly vulnerable because rivers are dynamic and have recurrent disturbances (Everard and Moggridge, 2012; Nilsson and Bergren, 2000) with human demands and actions such as changes in land cover impacting on ecological processes, habitat and biota (Brown and Vivas, 2005), water quality, as well as the supply of specific ES (Burkhard et al., 2012) via numerous and complex pathways (Allan, 2004; Townsend et al., 2003) and across multiple scales. Although most urban river systems are heavily degraded (Everard and Moggridge, 2012; Findlay and Taylor, 2006), these systems are recognised as important natural ecological networks, providing critical cultural, provisioning and regulating services to city residents (Loomis et al., 2000; Zander and Straton, 2010).

River ecologists have long recognised that rivers and streams are influenced by the landscapes through which they flow (Allan, 2004; Everard and Moggridge, 2012). Protected areas within urban areas, such as national parks, contain ecological infrastructure including freshwater ecosystems, which provide valuable ES (Bolund and Hunhammar, 1999; Gómez-Baggethun et al., 2013; Larondelle and Haase, 2013). As water moves from these natural spaces into more disturbed and altered landscapes, the ecological and physical characteristics of the rivers typically change both through space, and as the urban land use and land cover develops and changes, through time, impacting on the ES that urban resi-

* Corresponding author.
E-mail addresses: greggbrill@gmail.com (G. Brill), pippin.anderson@uct.ac.za (P. Anderson), pofarrell@csir.co.za (P. O'Farrell).

http://dx.doi.org/10.1016/j.ecolind.2017.01.006

dents receive (Costanza et al., 2006; Reeves et al., 1995). However, it is difficult to assess the impacts on ES delivery as a result of land-use change so that approaches need to be developed to achieve a better understanding of these changes over time (Large and Gilvear, 2015; Wong et al., 2015).

Quantitative and/or qualitative data that allow us to understand change over time relating to the contribution of urban rivers and streams to the delivery of ES is scarce (Lundy and Wade, 2011). There is often a lack of long-term data for effective analyses, mapping and modelling of systems (Bertzky and Stoll-Kleemann, 2009; Large and Gilvear, 2015; Raudsepp-Hearne et al., 2010). This may be as a result of the expense of recording and measuring environmental variables, as well as a lack of capacity for data gathering and storage in developing regions (Millennium Ecosystem Assessment, 2005). Additionally, there is often little research focused on the influence of land use on the state and functioning of aquatic ecosystems, resulting in deficient, inadequate or non-existent data (Wong et al., 2015). This hinders our understanding of what ES are delivered under anthropogenically altered conditions (Bennett et al., 2009; Large and Gilvear, 2015). These data shortcomings make researching the impacts of land-use change on freshwater ecosystems that much more challenging, requiring creative and novel methodological research approaches in cities (Keeler et al., 2012).

This study contributes to both the empirical and methodological literature by exploring how anthropogenic-driven changes in urban riparian landscapes in a developing region impact on the supply of ES. There were two objectives in this study. The first considered the development of a novel assessment approach, using available and diverse data sets. These data sets acted as multiple lines of evidence, supporting the outcomes from comparisons between the assessment approach and long-term water quality data. The second objective was to validate the assessment approach by applying it to case-study rivers in a developing city context. We integrate land-use changes and contrast these with long-term water-quality data to assess the levels of ES provision of three case study rivers in the city of Cape Town, South Africa, across a multidecadal period. These rivers flow from a protected area into the metropolitan environment where the impacts of land-use change and the ability of measured indicators to capture change can be assessed. Gradients of landscape change and variations in water quality over time and along river reaches are related to the capacity of these freshwater systems to supply ES.

2. Study area

2.1. Cape Town

The city of Cape Town is located on the south-western tip of southern Africa (Fig. 1) and occupies an area of roughly 2460 km^2 with a population of 3.7 million people (StatsSA, 2011). The city has a varied topography, with mountain ranges in the south-west and east, a low-lying highly-urbanised region in the centre known as the Cape Flats, coastal areas on the southern and western borders and agricultural areas in the north-east (Rebelo et al., 2011). Considerable changes to the landscapes around Cape Town have occurred since European arrival in the 1600s. Much of the native forests and natural vegetation has been removed, making way for agriculture, formal and informal residential areas, as well as commercial and industrial centres (Anderson and O'Farrell, 2012). Changes to the landscape through development and urban sprawl, such as an increase in hard surfaces (Trombulak and Frissell, 2000) continue to impact on natural areas in Cape Town (Turok and Watson, 2001). The amount of natural versus disturbed vegetation cover is also of concern as there are high incidences of plant species which are threatened with extinction (Rebelo et al., 2011).

The waterways and waterbodies of Cape Town have been pivotal in the history of the Cape shaped by the region's political and social history as well as by nature and technology (Brown and Magoba, 2009). These water systems have provided numerous ES and were a driving factor in historic engagements with the region (Anderson and O'Farrell, 2012; O'Farrell et al., 2012). This social engagement has placed tremendous demands on natural resources and urban infrastructure in and around the rivers of Cape Town and has had a substantial effect on the ecological integrity and functioning of the city's riparian landscapes and systems (Brown and Magoba, 2009). River courses have also been redirected, excavated, canalized and silted up with eroded sediment (Water Research Commission, 2007). These changes to freshwater systems are further compounded by pollution which is often discharged via stormwater outlet pipes or washed directly into rivers. Further, the hardening of the catchments has increased peak stormwater runoff during rainstorms well beyond natural levels (Brown and Magoba, 2009; Lundy and Wade, 2011) so compounding many other land-management issues. Many of Cape Town's rivers are described as being in a poor state with efforts to rehabilitate them often hampered by the duration and scale of change since their pre-disturbance condition (Anderson and O'Farrell, 2012).

2.2. Rivers under review

This study focused on three rivers in Cape Town, namely the Liesbeek, Sand and Silvermine Rivers (Fig. 1). These rivers were selected because their headwaters are in Table Mountain National Park (TMNP), their varying degrees of anthropogenic impacts over time and the availability of municipal records of water-quality monitoring.

2.2.1. Liesbeek River

The Liesbeek River, which is approximately 9 km long, is situated in the oldest urbanised river valley in South Africa. Records of indigenous use are limited, but major extraction and use was seen from the 1650s (Brown and Magoba, 2009). The headwaters of the Liesbeek River flow from the eastern slopes of Table Mountain where the vegetation is largely indigenous and undisturbed. The course of the Liesbeek River follows a north-north-east striking fault zone (Brown and Magoba, 2009). Water abstraction occurs along much of the river's path causing the flow to reduce during the summer months (Water Research Commission, 2007). Approximately 40% of the river's course is canalized (City of Cape Town, 2005).

2.2.2. Sand River

The Sand River is approximately 4 km long (City of Cape Town, 2005). The Sand River catchment area is located in TMNP and feeds a number of other rivers in the area. There are confluences with the Diep River and Brommersvlei Stream in the upper reaches of the catchment. The gentle gradient of the landscape in which the Sand River is located allows the river to follow the course of the underlying palaeovalleys (Brown and Magoba, 2009), flowing in a southerly direction. A reduction in summer flow in the Sand River is due to invasive tree species and water abstraction. Approximately 75% of this river is canalized (City of Cape Town, 2005).

2.2.3. Silvermine River

The Silvermine River is approximately 11 km long. The river's headwaters are in TMNP. The river course is controlled by the major lineaments in the surrounding geomorphology (Brown and Magoba, 2009) and flows in a south-westerly direction. There is a reduction in summer flows in the Silvermine River as a result of water abstraction (City of Cape Town, 2005). Alien invasive plants reduce flow all year round (Brown and Magoba, 2009). Although