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Historical influences on the current provision of multiple ecosystem services

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ABSTRACT

Ecosystem service provision varies temporally in response to natural and human-induced factors, yet research in this field is dominated by analyses that ignore the time-lags and feedbacks that occur within socio-ecological systems. The implications of this have been unstudied, but are central to understanding how service delivery will alter due to future land-use/cover change. Urban areas are expanding faster than any other land-use, making cities ideal study systems for examining such legacy effects. We assess the extent to which present-day provision of a suite of eight ecosystem services, quantified using field-gathered data, is explained by current and historical (stretching back 150 years) landcover. Five services (above-ground carbon density, recreational use, bird species richness, bird density, and a metric of recreation experience quality (*continuity with the past*) were more strongly determined by past landcover. Time-lags ranged from 20 (bird species richness and density) to over 100 years (above-ground carbon density). Historical landcover, therefore, can have a strong influence on current service provision. By ignoring such time-lags, we risk drawing incorrect conclusions regarding how the distribution and quality of some ecosystem services may alter in response to land-use/cover change. Although such a finding adds to the complexity of predicting future scenarios, ecologists may find that they can link the biodiversity conservation agenda to the preservation of cultural heritage, and that certain courses of action provide win-win outcomes across multiple environmental and cultural goods.

1. Introduction

Land-use change has led to substantive alterations in the amount and quality of services that ecosystems can provide (Dearing et al., 2012; Tianhong et al., 2010; Zhao et al., 2006). While mapping ecosystem services is a necessary first step in developing strategies for their maintenance (Chan et al., 2006; Davies et al., 2011; Naidoo et al., 2008; Raudsepp-Hearne et al., 2010a), it presents a static picture of current/contemporary distributions (e.g., Lautenbach et al., 2011; Jiang et al., 2013). To understand how best to manage ecosystem service provision in response to land-use/cover (LU/LC) change, an expanding body of work has developed model-based scenarios to predict likely future consequences (Kareiva et al., 2011; Nelson et al., 2009; UKNEA, 2011). These studies often highlight a decline in some services as human development (e.g. urbanisation, intensification of agriculture) proceeds. Counter-intuitively, even though ecosystem services are increasingly degraded (MEA, 2005), human well-being continues to improve globally. One possible explanation may be that time-lags exist between the effects of human-driven land transformations and present-day provision of ecosystem services (Raudsepp-Hearne et al., 2010b).

Indeed, time-lags and feedbacks are a common and widespread response to perturbations in many biological systems (Foster et al., 2003; Nicholson et al., 2009). Historical land-use change has been shown to influence ecosystem function in a broad range of studies,

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with legacy effects that can last tens, hundreds or even thousands of years (Foster et al., 2003; Szabo and Hedl, 2011). For example, time-lags in extinction processes following habitat loss have been documented across several taxa (Kuussaari et al., 2009; Tilman et al., 1994). Given that many long-lived plants, or those with certain life-history traits (e.g. clonal propagation, extensive seed banks) are able to persist for long periods after conditions become unfavourable (Eriksson, 1996), services underpinned by vegetation are perhaps the most likely to be subject to a legacy of past land-use. For instance, plant species diversity in grassland is often heavily influenced by historical management (Gustavsson et al., 2007; Pärtel et al., 1999) and, similarly, harvesting and wildfires in forest habitats can limit annual carbon stored over 60 years later (Gough et al., 2007). Vegetation carbon storage is primarily determined by tree size (e.g., Davies et al., 2011) and thus has a strong link to past land-use and management.

Likewise, legacies can also be expected in a social context, which could influence the provision of cultural ecosystem services, such as the number of recreational visitors to a particular location, or the values that people associate with a certain site. For example, in the built environment, features can act as "icons" (Hull et al., 1994). Such icons can convey a connection with the past, self-identity and a sense of community for local residents. Indeed, a central aim of built cultural heritage preservation is to enhance the continuity of the historical environment. This, in turn, helps to connect people with both place and culture, thereby contributing to how desirable a place is to live and/or to visit (e.g., Ashworth, 2008).

There is therefore a need to quantify the extent to which historical land-use determines the distribution of present-day ecosystem service provision. An analysis of this type is particularly pertinent within human-dominated regions, such as urban areas, where shifts in landcover are dynamic, changing rapidly in response to policy (Dallimer et al., 2011; McDonald et al., 2010). Urbanisation is a major driver of land-use change globally (Seto et al., 2012), and will continue to be given that the proportion of the world's population that lives in cities is predicted to rise to 70% over the next 40 years (United Nations, 2013). Furthermore, towns and cities are set to expand disproportionately, as increases in the area of urbanised land generally outpace population growth (Liu et al., 2003; ONS, 2012b).

Urban development has profound impacts on ecosystem service provision (Güneralp et al., 2013; Seto et al., 2012; Tianhong et al., 2010; Zhao et al., 2006), not least because the costs and benefits of green infrastructure (the network of greenspaces, water and other vegetated features in towns and cities) are rarely considered in expanding cities. This is despite the plethora of studies which have demonstrated the importance of urban green infrastructure in supporting the delivery of multiple services, such as temperature mitigation (Myint et al., 2013; Park et al., 2012; Susca et al., 2011), pollution reduction (Manes et al., 2012; Pugh et al., 2012), biological carbon storage (Davies et al., 2011), promoting human health and well-being (Mitchell and Popham, 2007; Ward-Thompson et al., 2012; Dallimer et al., 2012a; Irvine et al., 2013, Keniger et al., 2013), facilitating good social relations (Kuo and Sullivan, 2001; Sullivan et al., 2004), and the provision of habitat for biodiversity (Davies et al., 2011; Goddard et al., 2010; Dallimer et al., 2012b). The social and cultural value of urban greenspaces is also important (Barau et al., 2013; Gomez-Baggethun and Barton, 2013; Tzoulas et al., 2007).

Here, for a suite of eight ecosystem services delivered by urban greenspaces (Table 1), we examine the influence of historical landcover on present-day service provision within the city of Sheffield, UK. Using the UK National Ecosystem Assessment classification (UKNEA, 2011), we do this for one regulatory service (above-ground carbon storage), multiple dimensions of two cultural services (number of recreational users and the quality of recreational experience in terms of the self-reported psychological well-being of visitors to urban greenspaces) and three measures of wild species diversity (species richness and density of two highly visible and charismatic taxonomic groups; plants and birds). The choice of services was influenced by the desirability of having a spatially and temporally synchronous primary dataset likely to span a broad range of potential historical relationships. We were thus constrained to a combination of measures that was compatible with the resources available for data collection. However, if anything, the eight measures are biased towards those with a cultural dimension, which are often thought of as more difficult to quantify (UKNEA, 2011).

2. Materials and Methods

2.1. Study System

Sheffield (53°22′N, 1°20′W) is a typical large city in England (Jenks and Jones, 2010) and has a human population of 552,700 (ONS, 2012a). It lies at the confluence of five rivers, the Loxley, Rivelin, Porter, Sheaf and Don. A sixth, the Blackburn, enters the city on its eastern fringes where it joins the Don (Fig. 1). The rivers have a long history of human exploitation and their physical properties have been critical in determining the development of Sheffield (Crossley and Cass, 1989). Riparian zones therefore make an ideal system to investigate land-use legacies on ecosystem service provision and form the focus of this study.

Industrial output and the human population of the city peaked in the 1950s, and both contracted rapidly through the latter half of the 20th century, resulting in large areas of vacant former industrial land by the mid-1980s (Hey, 2005), much of which has subsequently been redeveloped. Pollution and environmental degradation followed the rapid urbanisation and, despite the early recognition of the importance of greenspaces associated with rivers (Abercrombie, 1924), the Don remained highly polluted until the 1980s (Firth, 1997). Much of this particular river is still dominated by large-scale industrial and commercial use. Despite this history of human exploitation, long-established public parks and networks of footpaths are located along the Porter, Rivelin and Sheaf that pass through residential areas of south and west Sheffield. More recent redevelopment initiatives have incorporated new public greenspaces and access routes along the city's waterways. In parallel, there has been a renewed focus on the appreciation of the historical importance of the city's rivers (e.g., Griffiths, 1999; Kendall, 2005). Given that riparian areas are distributed throughout the urban, suburban and more rural periphery of the city, they have the potential to deliver a range of ecosystem services to urban dwellers and we can expect that there would be an historical aspect to their provision.

2.2. Survey Design

To ensure that the sampling adequately covered the environmental variation across the riparian zones in the study area at the present time, we followed Gradsect survey design principles (Austin and Heyligers, 1989), by characterising Sheffield according to present-day landcover and river features (Dallimer et al., 2012b). This provided 81 survey points in the urban area and immediate rural surroundings. To further extend the variability covered, an additional 26 survey sites were placed along rivers at increasing distances from the urban centre, giving 107 locations in total (Fig. 1). Although we wished to generate data covering the complete suite of ecosystem services across all sites, sample sizes were constrained for a number of measures (Table 2). This was primarily due to logistical difficulties associated with resource-intensive data collection, or access restrictions being put in place while fieldwork was ongoing.