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Scale and context dependence of ecosystem service providing units

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ABSTRACT

Ecosystem services (ES) have been broadly adopted as a conceptual framing for addressing human nature interactions and to illustrate the ways in which humans depend on ecosystems for sustained life and well-being. Additionally, ES are being increasingly included in urban planning and management as a way to create multi-functional landscapes able to meet the needs of expanding urban populations. However, while ES are generated and utilized within landscapes we still have limited understanding of the relationship between ES and spatial structure and dynamics. Here, we offer an expanded conceptualization of these relationships through the concept of service providing units (SPUs) as a way to plan and manage the structures and preconditions that are needed for, and in different ways influence, provisioning of ES. The SPU approach has two parts: the first deals with internal dimensions of the SPUs themselves, i.e. spatial and temporal scale and organizational level, and the second outlines how context and presence of external structures (e.g. built infrastructure or larger ecosystems) affect the performance of SPUs. In doing so, SPUs enable a more nuanced and comprehensive approach to managing and designing multi-functional landscapes and achieving multiple ES goals.

1. Introduction

Are we unwittingly eroding the landscapes we need to sustain life and well-being? How can we assess the indirect effects of landscape change on human livelihoods and quality of life? Ecosystem services (ES)[1] have been broadly adopted as a conceptual framing for addressing human nature connections (European Commission, 2011; UK National Ecosystem Assessment, 2011) and to illustrate the ways in which humans depend on ecosystems for the generation of goods and services that contribute to human well-being (Daily, 1997; Millennium Ecosystem Assessment, 2005). ES are generated and utilized within landscapes, and we still need to develop the understanding of the landscape – ES connection. In this article we offer an expanded conceptualization of these relationships through the concept of service providing units (SPUs)[2] as a way to assess and discuss the structures and preconditions that are needed for, and in different ways can help plan and manage for, provisioning of ES.

In 2005, Claire Kremen asked what we need to know about the ecology of ES, at that time focusing on the organisms performing functions that could translate into services. These she called "ES providers", acknowledging that these would be found at different ecological levels (e.g. species or communities) depending on the service in question (Kremen, 2005). Addressing similar issues, Luck and co-authors (2003) introduced the concept of SPUs in ecological research. Sharing much the same foundation as ES providers, SPUs emphasize the physical site for the interaction

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[1] ES is short for "ecosystem services".

[2] SPU is short for "service providing unit".

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that may eventually become a service in addition to organisms. Two main conceptualizations of SPUs have previously been used: as situated organisms and as physical places (e.g. Burkhard et al., 2009; Luck et al., 2003). We do not see these as mutually exclusive conceptualizations but rather as complementary perspectives; the SPUs can be, for example, individuals of a certain tree species, a specific land cover or use, or a specific site like a sacred grove, and they only exist actively when they provide ES to human beneficiaries. In this paper we use SPUs, defined by the smallest distinct physical unit that generates a particular ES and is addressable by planning and management, to explore the dimensions of ES generation within landscapes. We see landscapes of different scales as representations of multi-dimensional social–ecological systems (Berkes and Folke, 1998; Liu et al., 2007), made up by the different features of an area of land including landforms, water bodies, climate conditions, ecosystems and human elements such as land use, buildings and transportation structures, and interacted with by humans. All the factors shaping landscapes also potentially influence the generation of ES.

The ES research community is steadily accumulating knowledge about how internal qualities of SPUs such as species identity, structural diversity/biodiversity or habitat composition can affect ES provisioning (e.g. Maes et al., 2012). What is less well known is how spatial structures, configurations and dynamics at multiple scales may influence the output from specific SPUs, which are always situated in a specific landscape context. Spatially explicit information about ES is increasingly demanded from landscape and land-use managers and spatial/regional planners (e.g. Daily and Matson, 2008; Kienast et al., 2009). Landscape ecology, geography, architecture, planning and many other disciplines with explicit interest in spatial dynamics offer insights that could inform the future direction of ES studies, not least in heterogeneous mosaic landscapes such as cities (Gomez-Baggethun et al., 2013). Such insights come from studies on vulnerability (Turner et al., 2003), spill-over effects (e.g. Blitzer et al., 2012), complementarity (Colding, 2007; Dunning et al., 1992), trade-offs and synergies (Haase et al., 2012), sense of place and place making (Stedman, 2003), and size thresholds (Groffman et al., 2006).

This article will offer an expanded conceptualization of ES through their relationship to SPUs and in doing so present a more detailed approach for planners and managers to help them understand and integrate the context dependent nature of ES generation into the ES discourse and practice. We illustrate the usefulness of this approach by addressing SPUs in urban settings and how they can provide – under different circumstances – different ES. We then discuss how spatial properties may influence the landscape ability to deliver multiple ES and point to the most prominent gaps in current knowledge to suggest future research directions.

2. Internal dimensions and contextual factors

It seems provident to disentangle how and when internal and contextual factors matter to enable answers to questions not only of where ES are generated, but also under what conditions, of what quantity and quality, and for whom, as well as to advance our scientific understanding and help find practical ways of working with ES. We suggest a two-part approach for defining and describing SPUs. The first part deals with internal dimensions of the SPUs themselves, i.e. spatial and temporal scale and organizational level. The second draws on perspectives from fields of study such as landscape ecology, planning, geography, economic and vulnerability research to highlight how context and presence of external structures (e.g. built infrastructure or larger ecosystems) affect the performance of SPUs. Methods for addressing and analyzing these different dimensions are currently being developed (Burkhard et al., 2011; Frank et al., 2012; Koschke et al., 2012; Syrbe and Walz, 2012), and we do not review these efforts here, but instead focus on the conceptual advantages of combining internal dimensions of the SPUs and context dependences of SPUs into one comprehensive approach to ES analysis/assessment. Table 1 illustrates core components of this approach by describing the relationship between urban ES, the relevant SPUs and their scalar and contextual dimensions.

2.1. Internal dimensions of SPUs

2.1.1. Spatial scale

Although processes operating at different scales interact and influence each other (Gunderson and Holling, 2002), there is often one scale, level or range where a specific process or function can be best analyzed (Holling, 1992). ES emerge when a minimum scale threshold is met. The scale threshold relevant for the analysis of a given ES can vary widely, from large regions to small parcels of land or individual trees (Hein et al., 2006; Martín-López et al., 2009), and depends on the management or research question. Some ES may be adequately analyzed by focusing on a single spatial scale. For example, the nutrient contribution of vegetables grown in an allotment garden can be examined at the level of single plants, whereas amenity services provided by urban parks can be examined at the site level and processes of carbon sequestration by forests to regulate global climate can be analyzed at the global level. Addressing a single spatial scale may not always adequately capture some ES. Harvest of fish may be supplied at the levels of plot (e.g. pond), ecosystem (e.g. lake), continent (e.g. river) and biome (e.g. ocean), with more fish available for harvest as the spatial scale increases. Once the scale threshold is crossed the provision of an ES may increase in a linear or non-linear fashion with increasing size of the SPU, depending on the dynamics of the ES being assessed. Spatial scale can also change the SPU itself; aggregation of one type of SPU can eventually lead to the formation of other types of SPUs in the sense that the aggregation provides also other ES, or co-benefits. For example, urban street trees when considered as singular SPUs, may provide cooling and air pollution removal benefits, but when connected as elements in the larger urban forests, they can in addition serve as corridors between urban green patches and therefore contribute to a larger suite of ES. SPUs sometimes coincide with the service benefiting areas (Syrbe and Walz, 2012) but often they do not. For example, recreation and food provisioning associated with allotment gardening take place primarily within the garden site (Andersson et al., 2007) while carbon sequestration benefits are independent of where the sequestration takes place (Hein et al., 2006).

2.1.2. Temporal scale

The ability of SPUs to provide ES can vary over time. For example, enjoyment of nature has been shown to follow the flowering and breeding season while recreation related to beaches is more common during the summer (Martín-López et al., 2009). Some regulating ecosystem services, such as carbon sequestration and air purification, are markedly reduced during winter months when most deciduous trees have dropped their leaves (Black et al., 2000). Other ES, and thus their SPUs, are activated only during specific events. For example, an urban wetland SPU functions as a provider of flood mitigation services only during major rain events (Kubal et al., 2009) and cooling effects by urban vegetation become most important during heat waves (Depietri et al., 2011). Similarly, Koch et al. (2009) demonstrate multiple time scales at which coastal protection is influenced by natural processes including hours of the day, seasonal, decadal as well as occurrences of extreme events. For example, coastal protection is generally highest when the tide is low but there are multiple non-linear processes and relationships in place that may