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Multi-site interactions: Understanding the offsite impacts of land use change on the use and supply of ecosystem services

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ABSTRACT

Managing the impacts of land use change on ecosystem services is essential to secure human wellbeing; but is a task often complicated by landscape-scale spatial dynamics. In this study, we focus on one type of spatial dynamic: multi-site interactions (MSI), which we define to occur when a change in the supply or use of an ecosystem service at one site affects that service at a second site. In search of empirical evidence of MSI, we reviewed 150 papers on one ecosystem service—nature-based recreation. We found many studies assessed impacts of land use change on this ecosystem service, but only 2% of studies quantified changes in its supply or use across multiple sites. Given this limited evidence in the literature, we propose a novel framework to describe the pathways through which MSI emerge and their likely consequences for ecosystem services across multiple sites. We illustrate the utility of this framework for understanding impacts on three other services: crop pollination, fuel wood production and flood mitigation. Obtaining empirical evidence of MSI is an important next step in ecosystem service science, which will help identify when interactions among sites emerge and how they can be best managed.

1. Introduction

Land use change has significant, widespread and long-lasting impacts on ecosystem services—the ecological attributes and functions that contribute to human wellbeing (Millennium Ecosystem Assessment, 2005). For example, tropical deforestation negatively impacts climate regulation (Foley et al., 2007), crop pollination (Kremen et al., 2002), and nature-based recreation (Naidoo and Adamowicz, 2005). Securing ecosystem services for long-term human wellbeing is therefore dependent on effective land management (Crossman et al., 2013; Lawler et al., 2014). This task requires knowledge of the pathways through which land use change impacts the supply of ecosystem services (Kremen, 2005) and their use by human beneficiaries (Arkema et al., 2013; Balmford et al., 2002; Ellis et al., 2015).

Land use change impacts ecosystem services through three basic pathways. (1) Land use change can modify the ecological structure and functions underpinning their ecological supply. For example, converting forests to cropland decreases carbon sequestration and storage (Fearnside and Laurance, 2004; Galford et al., 2015; Rudel et al., 2005). (2) Land use change can influence human demand for ecosystem services. Urbanization has been shown to reduce demand for local food production while increasing demand for environmental quality and cultural experiences (Yahdjian et al., 2015). (3) Land use change affects the non-natural capital (e.g. infrastructure) providing human access to, and thus use of, ecosystem services. Building a new road through a forest increases the use of its harvestable wood resources (Chomitz and Gray, 1996; Soares-Filho et al., 2004). This understanding of how land use change impacts ecosystem services is often used to inform land management decisions; however, these basic pathways do not explicitly capture landscape-scale spatial dynamics.

Impacts of land use change on ecosystem services are spatially dynamic and dependent on environmental and socio-economic landscape context (Bagstad et al., 2013; Crossman et al., 2013). In this study, we focus on one type of spatial dynamic—multi-site interactions (MSI)—which emerge when a change in the supply and/or use of an ecosystem service at one site affects its supply and/or use at a second site. Compared to other spatial dynamics, MSI have received considerably less attention in the ecosystem services literature. Previous work has described their outcomes as "offsite effects" and acknowledged

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their potential significance for achieving land management goals (Seppelt et al., 2011), but have not provided insight into the pathways through which MSI emerge or their impacts on ecosystem services across multiple sites. Without this causal understanding, managing MSI is, at best, reactive.

In other literatures, conceptually similar interactions have been well studied. For example, concepts of 'intensive land use' (Sonter et al., 2015) and 'urban teleconnections' (Seto et al., 2012) suggest that small-scale changes in land use in one location initiate extensive transitions in land use elsewhere. Further, 'tele-coupling' concepts suggest these interactions occur over very long distances (Liu et al., 2013) and indeed have implications for ecosystem services in both locations (Liu et al., 2016). Failing to understand these spatial dynamics can result in offsite impacts on natural resources (Eugenio et al., 2011) or result in unharnessed opportunities to achieve efficient regional-scale management (Sonter et al., 2013). An equivalent understanding of MSI in ecosystem services science is urgently needed. This requires understanding the pathways through which MSI emerge, identifying the conditions leading to their establishment, and quantifying the extent of resultant impacts on ecosystem services across multiple interacting sites. Such insight will aid land managers in deciding when additional resources should be allocated to manage MSI effects.

Within this context, the objectives of this paper are to: (1) describe MSI and how they differ from other spatial dynamics; (2) review the literature on one ecosystem service (nature-based recreation) in search for evidence of MSI; (3) develop a framework that describes the pathways through which MSI emerge and their likely consequences for ecosystem services among sites; and (4) illustrate the utility of this framework for assessing and managing impacts of land use change on three other ecosystem services: crop pollination, fuel wood production and flood mitigation.

2. Spatial dynamics: ecosystem service distribution, flow and MSI

Two types of spatial dynamics are currently considered in the ecosystem services literature: spatial distribution and flow. In this section, we briefly summarize how each dynamic affects the impacts of land use change on ecosystem services. We then propose MSI as a third spatial dynamic, which relates to and is often initiated by spatial distribution or flow, but would not necessarily be detected from analyzing either spatial dynamic alone.

2.1. Spatial distribution of ecosystem services

Ecosystem services are unevenly distributed across landscapes, according to their ecological supply and their consequent use by humans (Chan et al., 2006; Fisher et al., 2009; Villamagna et al., 2013). For example, the distribution of pest control agents varies with altitude, and their contributions to crop yield depend on the distribution of farms along this elevation gradient (Poveda et al., 2012). Ecosystem services are also influenced by landscape-scale spatial patterns. For example, their supply can depend on landscape characteristics, such as habitat fragmentation (Gret-Regamey et al., 2014), while their use by humans can depend on the quantity and distribution of forested landscapes (e.g. Sonter et al., 2016). Therefore, land use change impacts the supply and use of ecosystem services differently in different places (Bateman et al., 2013; Chaplin-Kramer et al., 2013; Polasky et al., 2008) and changes in landscape characteristics can cause non-linear changes in ecosystem services when thresholds are crossed (Mitchell et al., 2015a).

2.2. Flow of ecosystem services

Ecosystem services are also spatially dynamic in their flow across a landscape. Services can flow from sites of supply to sites of use, and human beneficiaries flow from where they reside to where they use these services (Fisher et al., 2009). For example, native bees that supply crop pollination services flow from natural habitat to farms of pollinator-dependent crops to forage (Kremen et al., 2007), and tourists flow from their homes to national parks to enjoy natural recreation opportunities (Wood et al., 2013). As a result, impacts on a service's supply in one location may affect its use elsewhere: e.g. removing upstream wetlands affects downstream flood mitigation (Mitsch and Gosselink, 2000; Watson et al., 2016). Land use change can also impact these processes of flow directly (Bagstad et al., 2013; Mitchell et al., 2015b). For example, landscape fragmentation can affect access to and use of recreational sites (Kovacs et al., 2013). Therefore, land management requires information on both the flow of ecosystem services, and how land use change impacts these flows over space and time (Mitchell et al., 2015b; Tallis et al., 2008; Villamagna et al., 2013).

2.3. Multi-site interactions

MSI are a related spatial dynamic, which occur when a change in the supply and/or use of an ecosystem service at one site affects its supply and/or use at a second site. The change in ecosystem services at the first site may emerge due to changes in its supply, use or demand (as described in Section 1). Within our definition, the term "site" refers to the location at which the ecosystem service is used or enjoyed by people, i.e., where supply and demand meet. Interactions between these sites are driven by the flow of ecosystem services and people across the landscape, but manifest as relative changes in the flows between sites.

For example, two bird watching sites used for nature-based recreation interact if changes in the supply of bird watching opportunities to one site (e.g. through habitat degradation) cause a change in their supply to a second site (e.g. by increasing its relative quality as bird habitat). These two bird watching sites also interact if changes in the use of one site (e.g. due increased access) cause a change in their use at the second site (e.g. by diminishing its relative appeal). Similarly, increasing the quality of pollinator habitat may increase crop pollination on one nearby farm (e.g. due to increased pollinator visitation), but in turn reduce pollination at another farm (due to pollinators shifting their visitation away from the first farm).

Sites would not be considered to interact if they responded independently to a similar perturbation. For example, the following would not be considered MSI: a loss of bird habitat that simultaneously decreased birds at multiple bird watching sites; increasing surrounding pollinator habitat increased bee abundance and visitation to multiple farms. These examples represent similar changes in flow to multiple sites, rather than interactions among sites.

As these examples suggest, failing to understand MSI could lead to unexpected offsite impacts of land use change on ecosystem services that aggregate across multiple sites. In this study, we limit our discussion to interactions between sites for a single ecosystem service, although acknowledge that multiple services may be affected by MSI, for example, through changes in interactions among bundled services (Bennett et al., 2009).

3. Literature review: in search of msi evidence

3.1. Methods

We reviewed the literature on one ecosystem service—nature-based recreation—in search of evidence for MSI. Specifically, we addressed three questions: (1) To what extent does land use change impact ecosystem services via MSI? (2) Are there conceptual similarities in how MSI emerge? (3) What are the barriers to studying MSI from the published literature? Our review focused on nature-based recreation