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Distinction, quantification and mapping of potential and realized supply-demand of flow-dependent ecosystem services

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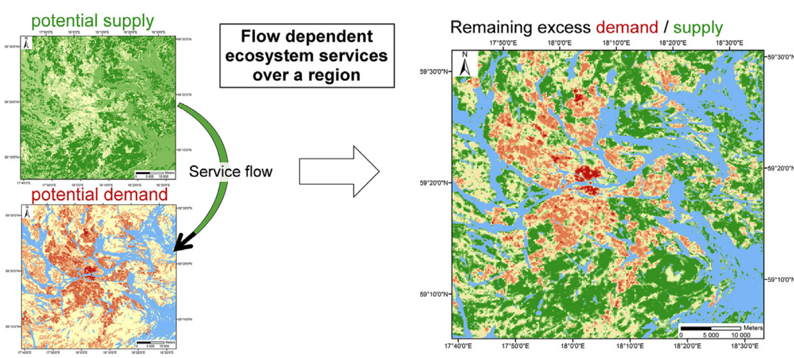
HIGHLIGHTS

- Quantitative distinction of potential and realized ecosystem service supply-demand
- Quantification and mapping of flows of ecosystem services through the landscape
- Simple and scalable quantification and mapping methodology
- Local climate regulation and storm water regulation in urban and peri-urban areas

GRAPHICAL ABSTRACT



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ABSTRACT

This study addresses and conceptualizes the possible dependence of ecosystem services on prevailing air and/or water flow processes and conditions, and particularly on the trajectories and associated spatial reach of these flows in carrying services from supply to demand areas in the landscape. The present conceptualization considers and accounts for such flow-dependence in terms of potential and actually realized service supply and demand, which may generally differ and must therefore be distinguished due to and accounting for the prevailing conditions of service carrier flows. We here concretize and quantify such flow-dependence for a specific landscape case (the Stockholm region, Sweden) and for two examples of regulating ecosystem services: local climate regulation and storm water regulation. For these service and landscape examples, we identify, quantify and map key areas of potential and realized service supply and demand, based for the former (potential) on prevailing relatively static types of landscape conditions (such as land-cover/use, soil type and demographics), and for the latter (realized) on relevant carrier air and water flows. These first-order quantification examples constitute first steps towards further development of generally needed such flow-dependence assessments for various types of ecosystem services in different landscapes over the world.

1. Introduction

Ecosystem services are defined as “the direct and indirect benefits people obtain from ecosystems” with different types of such services

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distinguished: supporting services, provisioning services, regulating services and cultural services (MEA, 2005). Overall, the ecosystem service framework is an anthropocentric utilitarian concept, with the value of services provided by ecosystems depending on the utility that people derive from their consumption, either directly or indirectly (UNEP, 2011). As such, there is also increasing recognition that scientific assessments of ecosystem services need to facilitate closer stakeholder engagement (Daily et al., 2009). Regulating services are of particular importance in urban and peri-urban areas (Bolund and Hunhammar, 1999), and advancing their quantification and mapping is essential for consideration and integration in urban planning (Gómez-Baggethun and Barton, 2013; Mörtberg et al., 2017). However, most ecosystem service studies still focus primarily on the supply side, without considering the water and/or air flow processes that carry some ecosystem services through the landscape, from source areas with excess service supply to other areas with excess human needs (demands) that can be met by the service supply flow from the source areas.

For example, Burkhard et al. (2012) define the supply and demand of a service over a given time period as: "the capacity of a particular area to provide a specific bundle of ecosystem goods and services" and "the sum of all ecosystem goods and services currently consumed or used in a particular area", respectively. However, the ecosystem service supply may be linked to its human beneficiaries by a service flow that occurs in the landscape between an area of excess service supply and an area of excess service demand, with the excess service supply from the first area then possibly only reaching, and thus only being able to meet (realize), a part of the excess service demand in the latter area (Fig. 1).

The total ecosystem service supply (potential supply in Fig. 1) in one area of the landscape may thus differ and needs to be distinguished from the service supply that is ultimately consumed (realized supply in Fig. 1). The service consumption may occur partly within the supply source area itself and partly in some other area, to which the service is carried, e.g., by air or water flow (see example services and their carrier flows in Fig. 1). In analogy, the total ecosystem service demand in an area (potential demand in Fig. 1) may differ and needs to be distinguished from the demand part that is actually met (realized demand in Fig. 1) by a corresponding realized supply.

Some studies have considered these supply and demand links, so far mostly in conceptual terms, or for some specific ecosystem service example. In particular, Syrbe and Walz (2012) introduced the concepts of service providing area (SPA), benefiting area (SBA) and connecting area (SCA). These terms relate to the supply (SPA) and the demand (SBA) of services, with SCA then representing an area of required service flow in order to link the two. SPA and SBA can be identical, overlap, or be separated and thus in need of being linked through some type of service flow, as illustrated here explicitly in Fig. 1. Turner et al. (2012) further classified three main service-flow models: proximal (on different scales, e.g., pollination and food production), global (e.g., global climate regulation) and slope dependent (e.g., water flow regulation).

More concretely, Bagstad et al. (2013) developed a model for linking SPA and SBA, through a network of service source, sink and use regions, through which a beneficial carrier (useful service) or detrimental carrier (disservice) may travel. Serna-Chavez et al. (2014) have also proposed an indicator for the proportion of SBA that is supported through flows of services from SPA. Furthermore, the importance of flow processes for actual ecosystem service realization has been concretely quantified for the specific regulatory service example of nutrient retention by wetlands in the landscape (Quin et al., 2015). The actual trajectories of water flow through the landscape are for this example shown to largely determine the realized nutrient retention on the scale of whole catchments.

In this paper, we further conceptualize, concretize and quantify flows of ecosystem services through the landscape and their key implications for distinction, quantification and mapping of main differences between potential and realized service supply and demand, with main focus on air and water carrier flows. Differences between potential and realized service supply and demand may depend considerably on such air and water flows between corresponding areas in the landscape (Fig 1). For concrete exemplification and quantification of such service flows, we consider here two examples of regulating ecosystem services (also exemplified in Fig. 1): the service of local climate regulation (carried by air flow processes), and the service of natural storm water regulation and associated flood protection (carried by water flow processes). Natural storm water regulation is then distinguished from engineered such regulation, by dams and reservoirs; in the following we will use the short term storm water regulation to mean natural such regulation.

The first ecosystem service example of local climate regulation is selected in view of the impacts that ecosystems may have on local temperature (as well as on wind, radiation balance, and precipitation) through biogeophysical flow processes; for comparison, biogeochemical processes affect global climate through greenhouse gas dynamics. These biogeophysical processes may be important for avoiding local climate stress, not least due to effects of urban heat islands that may, for instance, in turn also influence human health (Rizwan et al., 2007). Furthermore, we consider the second service example of storm water regulation in view of the temporary storage of water that occurs in some ecosystems, which can reduce peak flows and mitigate high-flood events in times of intense precipitation. Such mitigation can prevent associated damages to e.g. infrastructures (Kalantari and Folkeson, 2013; Van der Sande et al., 2003) and also reduce the amount of polluted runoff from cities to nearby waterways (Pitt et al., 1995).

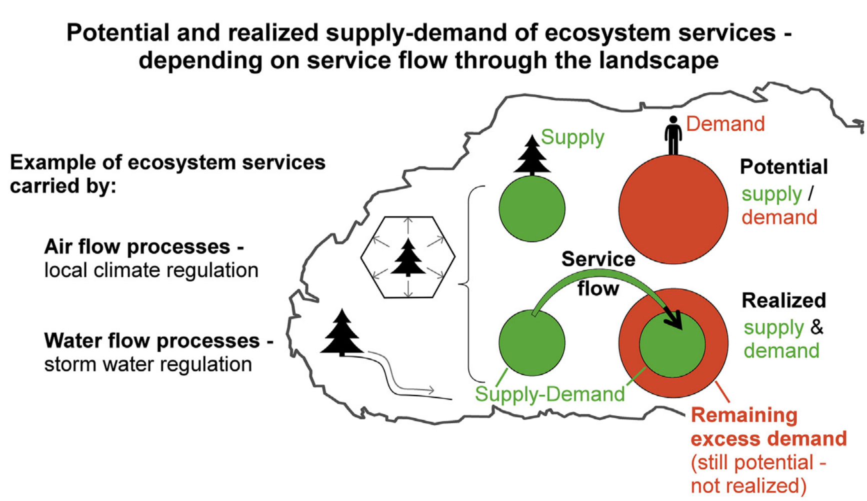

Fig. 1. Schematic illustration and distinction of areas of potential and realized supply and demand of an ecosystem service, and of the service flow between such areas in the landscape.