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Land-use change impacts on ecosystem services value: Incorporating the scarcity effects of supply and demand dynamics

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ABSTRACT

We present a new model for quantifying the effects of changes in supply and demand on the scarcity value of ecosystem services under land-use change. We demonstrate its application by assessing the impact of rapid urbanization in the Guangzhou-Foshan Metropolitan Area (GFMA) in southern China from 1990 to 2010. Supply and demand curves were developed for both private-good and public-good ecosystem services based on published price elasticities. Change in ecosystem services supply was calculated using a well-established unit-value transfer method and change in demand was calculated as a function of population, wealth, and income elasticity. Naïve assessment (i.e. ignoring supply and demand effects on scarcity value) found a small (−4.4%) decrease in the value of physical supply of ecosystem services from US$4.631 billion in 1990 to US$4.430 billion in 2010. When the effects of changes in supply and demand were considered, the scarcity value of ecosystem services increased dramatically to US$33.774 billion (+629%) in 2010 driven by a strong increase in demand especially for public-good type services with poor substitutes, combined with a slightly reduced supply. A renewed focus on land-use planning is urgently required to ensure the sustainability of increasingly valuable ecosystem services for the wellbeing of burgeoning urban populations.

1. Introduction

Land-use change substantially alters the supply of ecosystem services with consequent impacts on human wellbeing (Deng et al., 2013; Millennium Ecosystem Assessment, 2005; Quintas-Soriano et al., 2016; Zhan, 2015). Valuation of ecosystem services in monetary terms provides an integrated, universal measure for evaluating and communicating the impacts of land-use change, and for justifying, prioritizing, and targeting investment in conservation and management (Gomez-Baggethun and Barton, 2013; TEEB, 2010). Assessments of the impacts of land-use change on ecosystem services value have overwhelmingly focused on valuing changes in the physical *supply* of ecosystem services (Haase et al., 2014; Jiang, 2017; Schägner et al., 2013). Change in physical supply has typically been assessed either by using land-use dynamics as a proxy for the spatial distribution of ecosystem-service-producing units (Costanza et al., 2014; Schmidt et al., 2016; Song and Deng, 2017), or by directly modelling the production of ecosystem services themselves (Bateman et al., 2013; Maes et al., 2012). The per-unit value of ecosystem services supply has been quantified using a variety of methods and is typically held constant over time to isolate the value of changes in physical supply (TEEB, 2010). However, beyond supply changes, the value of goods and services is affected by simultaneous changes in supply and demand via their effect on unmet demand and relative scarcity (Batabyal et al., 2003; Krautkraemer, 2005; Mankiw, 2018). The effects of supply and demand dynamics on the *scarcity value*—the value something has because it is rare and there is a large demand for it—of ecosystem services may be significant. Quantifying these effects is essential for providing a more complete picture of the impacts of land-use change on the value of ecosystem services to humanity and for guiding sustainable land-use planning.

The strongest effects on ecosystem services scarcity value occur in landscapes that are subject to significant supply-side and demand-side dynamics such as in rapidly urbanizing areas. The global human rush to cities (Seto et al., 2013, 2016) is resulting in the widespread conversion of adjacent land, such as forestland and cropland, to urban development (Estoque and Murayama, 2016; Güneralp and Seto, 2013;

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Poelmans and Van Rompaey, 2010) with a corresponding reduction in the physical supply of ecosystem services (Elmqvist et al., 2013). China, in particular, has been pushing the global frontier of urbanization since the 1978 Reform and Opening policy (Yao et al., 2014; Zhang et al., 2016) and urbanization has had major impacts on ecosystem services since this time (Li et al., 2016; Song and Deng, 2017; Xie et al., 2017). Several assessments of Chinese cities have reported declines in the value of ecosystem services supply following urban expansion (Li et al., 2010; Liu et al., 2012; Long et al., 2014; Su et al., 2014; Wu et al., 2013; Ye et al., 2018). However, urban regions are also important loci of ecosystem services *demand* (Baro et al., 2016; Haase et al., 2014; Kroll et al., 2012). Growing cities support more and more *beneficiaries* of ecosystem services (Eigenbrod et al., 2011), often with each beneficiary becoming wealthier and increasingly willing to pay for ecosystem services following socio-economic development (Yahdjian et al., 2015). Thus, while urbanization may decrease the physical supply of ecosystem services, when the impact of changes in supply and demand on the per-unit scarcity value of ecosystem services is considered, it is possible that the total scarcity value of these services will increase (Batabyal et al., 2003; TEEB, 2010; Villamagna et al., 2013; Zank et al., 2016).

Characterizing the full supply chain of benefits from natural capital through to human well-being is a very active recent endeavor but no generally-accepted frameworks, methods, or indicators yet exist (Brunner et al., 2016; Kroll et al., 2012; Larondelle and Lauf, 2016). Conceptualization of demand for ecosystem services, traditionally quantified as beneficiaries' willingness-to-pay (TEEB, 2010), has been recently broadened to incorporate risk reduction, preferences and values, direct use, and consumption (Wolff et al., 2015) measured using diverse indicators such as population, social preferences, and monetary value (Baró et al., 2015; Caparros et al., 2017; Eigenbrod et al., 2011; Hynes et al., 2017; Pena et al., 2015; Raymond et al., 2009; Wolff et al., 2017). Recent studies have illuminated additional nuance in the supply chain of nature's benefits, quantifying the capacity, pressure, demand, and flow of ecosystem services (Burkhard et al., 2012; Schulp et al., 2014; Villamagna et al., 2013). These characteristics have been quantified and mapped for supporting planning and policy decisions for managing the unsustainable use of ecosystem services, and for comparing spatially-explicit scenarios of ecosystem services demand and supply to predict future unmet societal demand for ecosystem services (Bagstad et al., 2014; Baro et al., 2016; Brunner et al., 2016; Burkhard et al., 2012; Castro et al., 2014; Eigenbrod et al., 2011; Goldenberg et al., 2017; Kroll et al., 2012; Morri et al., 2014; Nedkov and Burkhard, 2012; Sturck et al., 2014; Sturck et al., 2015; Sutton, 2014; Verhagen et al., 2017; Vigl et al., 2017; Yahdjian et al., 2015; Zank et al., 2016). One popular approach involves comparing the availability of land required to meet local demand for provisioning-type ecosystem services like food/fibre relative to local land supply (Sutton et al., 2016). However, no ecosystem services studies have assessed the impact of changes in supply and demand on scarcity value.

For private-good, provisioning-type ecosystem services such as food, scarcity can often be mitigated via other inputs (Barnett and Morse, 1963; Batabyal et al., 2003). For example, distant land and manufactured inputs can be substituted for local land to produce the final demand for agricultural production at little extra cost. Markets usually exist for these types of services and prices can be readily observed. There is a significant tradition in economics of assessing how prices and land scarcity values change with shifts in land supply, productivity of substitute inputs, and demand shifts driven by population and wealth (Krautkraemer, 2005; Tahvonen, 2000). Comprehensive studies dating back to Barnett and Morse (1963) show little increase in scarcity value for most private-good ecosystem services as technological progress driven by research and development allows increasing production via substitution of manufactured inputs, even with degrading ecosystems. In contrast, public-good type ecosystem services such as the amenity value of open space, cannot easily be substituted by distant natural capital, technology, or other forms of capital (Batabyal et al., 2003; Sandhu et al., 2016). As predicted conceptually as early as Krutilla (1967), the scarcity value of what is essentially unmet demand for these ecosystem services can become very large as the services become increasingly rare relative to the quantity demanded (Batabyal et al., 2003; TEEB, 2010; Villamagna et al., 2013; Zank et al., 2016). Empirical work confirms that the scarcity value of public-good-type ecosystem services in cities can become large as demand increases and supply is limited. For example, Sutton and Anderson (2016) estimated that New Yorkers value Central Park at over \$70 million $ha^{-1} yr^{-1}$, a lower-bound estimate based on real-estate value. However, because public-good-type ecosystem services are not normally traded in markets, they don't provide readily observable scarcity price signals. Consequently, the economics literature is also devoid of assessments of how diminishing supply and growing demand influences scarcity value for these services.

Here, we present a broadly applicable model for quantifying the impact of land-use change on the scarcity value of ecosystem services in response to dynamics in supply and demand. We applied the model in assessing the impact of rapid urbanization on land-use and ecosystem services scarcity value from 1990 to 2010 in the rapidly urbanizing Guangzhou-Foshan Metropolitan Area (GFMA) in southern China. We first quantified the naïve value of supply of ecosystem services (i.e. ignoring influence of changing supply and demand on scarcity value) for 1990, 2000, and 2010 using the widely used unit-value benefits transfer method (Costanza et al., 1997; Xie et al., 2003, 2008) based on satellite-derived land-use maps and a matrix of value coefficients for nine ecosystem services from seven land-uses tailored to the GFMA. We then quantified the scarcity value of ecosystem services for 2000 and 2010 considering the influence of changing supply and demand from 1990. Price-elasticities of supply and demand were differentiated for public-good and private-good type ecosystem services, and the change in demand was calculated as a function of changes in population, wealth, and the income elasticity of demand for ecosystem services. Six valuation scenarios were calculated to unpack the individual and combined effects of supply and demand dynamics on scarcity value versus a naïve assessment of value, and to understand the impact of uncertainty in price-elasticity specification. We describe the implications of considering the effects of changes in supply and demand for ecosystem services scarcity value on land-use planning under rapid urbanization in China and more broadly.

2. Methods

2.1. Conceptual framework

We used an economic conceptualization where simultaneous changes in supply and demand influence the value of ecosystem services via their effect on relative scarcity (Fig. 1). Assuming downward-sloping demand and upward-sloping supply, reduced supply and rising demand increase the scarcity value which is reflected in the market price for private-good ecosystem services. But for public-goods, this effect is implicit and unobserved, and is reflected as unmet demand. In the context of rapid urbanization, reduced ecosystem services supply is driven by changes in land-use, in particular the conversion of high service-providing areas, such as forests, cropland, and water bodies, to built-up areas (Elmqvist et al., 2013; Haase et al., 2014). Conversely, increased demand is driven by increases in population and wealth, and changes in spending preferences (Wolff et al., 2017; Zank et al., 2016). However, the effect of changes in supply and demand on value depends on the type of ecosystem service (Geijzendorffer and Roche, 2014). To capture these effects, we classified ecosystem services broadly as either *private* or *public* goods (Costanza et al., 1997) and distinguish differential effects of supply and demand on scarcity value (Fig. 1).

Private-good type ecosystem services are typically provisioning services such as agricultural products, fresh water, and raw materials. Often priced in markets, these services are rival in consumption such