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A local-scale spatial analysis of ecosystem services and ecosystem service bundles in the upper Hun River catchment, China

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ABSTRACT

Spatially explicit analyses of ecosystem services are needed by policy-makers. The lack of spatial water supply data is an obstacle to spatially explicit analyses. In this study, the spatial water quality is obtained by taking water samples at key sites during key periods. The relationships between water quality and ecosystem services were analyzed at a small watershed scale, using areas ranging from 0.03 km^2 to 160.19 km^2. Our results shows that (1) water quality indexes are negatively correlated with the provision of regulating ecosystem services, except for NPP (net primary product). (2) That NPP is positively correlated with water quality indexes and crop field ratio suggests increasing NPP is correlated with degradation of water quality, because of the fertilization in croplands. (3) The growth of crop is the main contribution to the variation in NPP. Therefore, the relationship between NPP and forest area ratios can't reflect the real relationship between carbon sequestration and forest. (4) The ecosystem services bundles analysis at small watershed scale would benefit the understanding of local characteristics of interactions among ecosystem services and help making targeted policy meets the needs of local conditions in diverse landscapes.

1. Introduction

Ecosystem services are a range of goods and services that people obtain from ecosystems to sustain and fulfill human life (Millennium Ecosystem Assessment, 2005). The identification and evaluation of ecosystem services (Hwang et al., 2009; Sanchez-Canales et al., 2012; Ogden and Stallard, 2013), and the synergies and trade-offs of multi-ecosystem services for human well-being, are evolving fields of research (Holland et al., 2011; Butler et al., 2013), and play central roles in regional sustainable development planning (Frank et al., 2014; Reed et al., 2015). The publication of the Millennium Ecosystem Assessment (MA) highlighted the importance of scientific information to predict the likely consequences of policy decisions made on ecosystem modification for ecosystem services and human life. Multiple research perspectives focusing on this subject are emerging, including techniques to measure multi-ecosystem services, trade-offs among ecosystem services across spatial and temporal scales, and methods to create realistic end products that managers need based on the understanding of the relationship between ecological mechanisms and ecosystem services (Petrosillo et al., 2010; Raudsepp-Hearne et al., 2010; White et al., 2012; Potschin and Haines-Young, 2013; Scholes et al., 2013; Vihervaara et al., 2013; Polasky et al., 2014; Wang et al., 2015; Wong et al., 2015).

Watershed ecosystem management has been highlighted in recent years because of conflicting perceptions of benefits among stakeholders (Qiu and Turner, 2013; Fan and Shibata, 2014). For example, water quality is mainly affected by land use change on vegetation type (Randhir and Hawes, 2009; Ogden and Stallard 2013), while land use change is based on the development of forestry, agriculture, and habitats (Butler et al., 2013; Erol and Randhir, 2013). Therefore, the trade-offs in natural resource management of watersheds are informed by various beneficiaries. The ecosystem service-bundle approach is a useful tool for analyzing interactions among ecosystem services through identifying common ecosystem services trade-offs and synergies, and benefit management improvement of multifunctional landscapes (White et al., 2012; Simonit and Perrings, 2013). In the previous work, there are no empirical investigations of ecosystem services, but in the research of Raudsepp-Hearne et al. (2010), they define ecosystem service bundles as sets of ecosystem services that repeatedly appear together across space or time. The study scale of ecosystem service bundle analysis depends on the goals of the studies and ranges from the meter-scale spatial resolution to local scales such as the

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municipality and small watersheds (Raudsepp-Hearne et al., 2010; Qiu and Turner, 2013; Simonit and Perrings, 2013). To meet the needs of these studies, various methods such as empirical estimates, spatially explicit models, and remote sensing and measuring are used to provide ecosystem services data (Simonit and Perrings, 2013; Wang et al., 2015). However, the lack of primary data for most services in most places is still an outstanding problem (Naidoo et al., 2008). The land cover-based proxies, which are widely used, provide a poor fit to primary data for some ecosystem services (Eigenbrod et al., 2010). Water provision is considered one of the most difficult mapped ecosystem services to assess because of a lack of spatial data (Holland et al., 2011).

The Dahuofang catchment, as with many other catchments throughout the world, is facing the major challenge of how to reconcile land, water quality, carbon sequestration, soil fertility, and other ecosystem services management, with rapid population growth and economic development. Because of a lack of spatial water supply data, the study of relationships between water supply and other ecosystem services is restricted to assisting in overall policy development at national, provincial, municipal, and county scales. However, the overall policy would be difficult to implement in highly heterogeneous landscapes (Raudsepp-Hearne et al., 2010). Spatially explicit analyses of ecosystem services are required by policy-makers. Researchers have addressed the problem of the lack of spatial data for water supply ecosystem services analyses. Land cover-based proxies, spatially explicit models, and integration of water provision indicators have been used to resolve the lack of spatial data (Turner et al., 2007; Egoh et al., 2008; Holland et al., 2011; Qiu and Turner, 2013).

Dahuofang reservoir supplies water to the central cities in Liaoning Province, China. The economy of the catchment area upstream of the reservoir is based mainly on agriculture and forestry. Because of agricultural sprawl, agricultural pollution causes environmental problems such as deterioration in water quality and land degradation. To stop the agricultural expansion, decision-makers have adopted the policy of returning farmland to forest. However, this policy cannot be implemented because of (1) the diversity of landscape–farming conditions in local sub-catchments vary, so the overall policy is unable to meet the needs of local conditions; and (2) Agriculture is the mainstay of the Dahuofang reservoir catchment's economy.

We initiated river water sampling in 2006. To better reflect the spatial variation in water quality (Ye et al., 2014), we increased the number of water sample sites from 30 to 104 (Fig. 1) in year 2011–2013. We used the sampling data to explore the following questions at small watershed scales:

(1) What are the relationships between water quality, carbon sequestration, soil fertility, and land use? Do these relationships involve synergies or trade-offs?
(2) How many ecosystem service bundles identified in our study according to the feature of our study area and what is the spatial distribution of those ecosystem services bundles?

2. Methods

2.1. Study area

The upstream catchment area of the Dahuofang reservoir is located in Liaoning Province, northeastern China (Fig. 1), extending from 41°47′52⬠–42°28′25⬠N, and 124°20′06⬠–125°28′58⬠E. The area covers 2.5×10^5 ha, 78% of which is covered by forest. The altitude of the region ranges from 150 to 1086 m and the average altitude is 470 m.

The area has a temperate continental monsoon climate. The mean annual temperature is 6.6 °C with a mean minimum temperature of −27.6 °C and a mean maximum temperature of 36.5 °C. The mean annual precipitation is 788 mm (data provided by the Qingyuan County Forestry Bureau).

There are six soil types in this area: brown soil, dark-brown soil, turfy soil, albic soil, boggy soil, and paddy soil. Cultivated land is always near the river. Agriculture and forestry are the economic base of the study area, accounting for 60% and 30% of its income, respectively.

2.2. Data sets and methods

Water supply is the most important of all hydrological services. The water supply services includes two main providing services which are good water quality and enough water quantity provided by an ecosystem (Holland et al., 2011). In our study area, the deterioration in water quality and land degradation are the most outstanding environmental issues should be reconciled, so the trade-offs among water quality and other ecosystem services are concerned in this study. We established 104 water sampling sites throughout the study area (Fig. 1). Water samples were obtained before, during, and after the wet season (May, July, and September, respectively) from 2011 to 2013. The data used in this study were from the wet season only, because previous studies found that water quality was most significantly related to land use in the wet season (Ye et al., 2014). Because water quality in this region was affected by activities such as the indiscriminate discharge of domestic sewage, the application of chemical fertilizer,

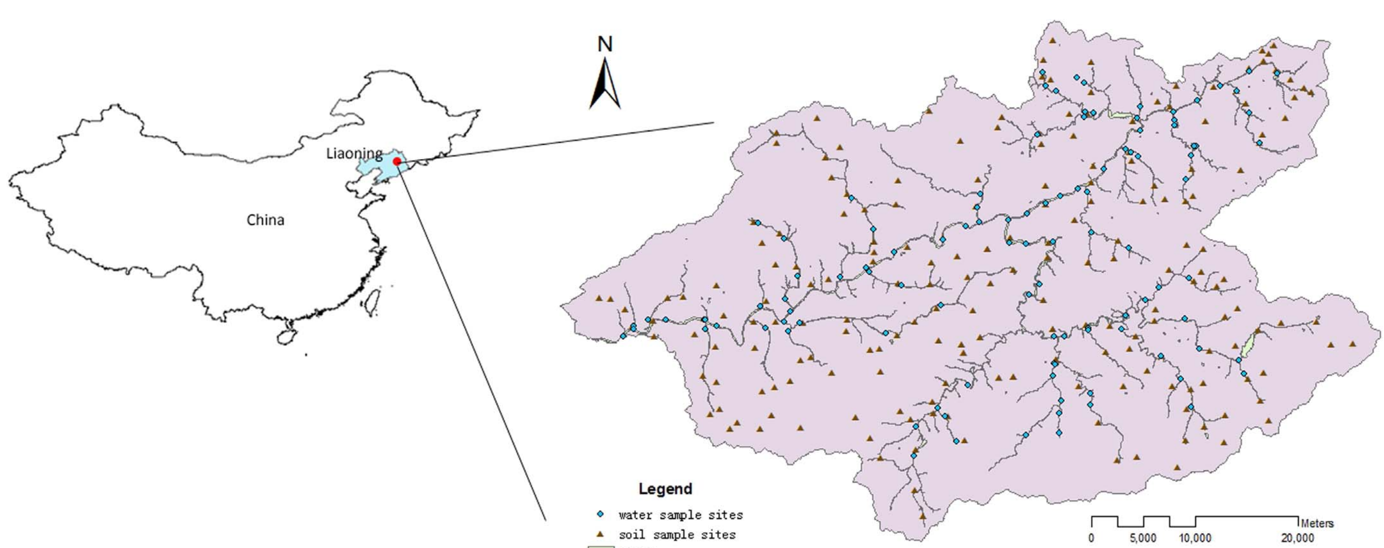

Fig. 1. Location of the study area and sample sites.

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