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Assessment of ecosystem services and dis-services of an agro-ecosystem based on extended emergy framework: A case study of Luancheng county, North China

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ABSTRACT

An agricultural ecosystem provides provisioning, regulating and supporting services for humans. At the same time, it consumes the resources of other ecosystems, including the investment of economic resources and can generate useless or harmful services, collectively called dis-services. Here, we built a framework for assessing agricultural ecosystem services and dis-services based on emergy analysis of Luancheng County, China. We analysed the inputs and outputs of the agricultural ecosystem from the three aspects of consumption of resources, ecosystem services and ecosystem dis-services and explored the variations in inputs and outputs from 1984 to 2008. We then proposed composite indexes for measuring the sustainable development of the agro-ecosystem. Our analysis showed that the agricultural ecosystem consumed a lot of resources, especially the nonrenewable ones; provisioning services were the largest services and provisioning dis-services were the largest dis-services. Both provisioning services and dis-services increased yearly as purchased nonrenewable inputs increased. The overall evaluation of the Luancheng agricultural ecosystem showed it to be a serious consumer system and thus not developing sustainably. The farming community should take steps, such as controlling excess inorganic fertilizer input, increasing organic fertilizer use and improving water and fertilizer use efficiency to ensure sustainability.

1. Introduction

Ecosystem services, defined as the benefits human beings derive from the ecosystem, has become the focus of ecosystem research in recent years (Brander et al., 2013; Daily and Matson, 2008; Kinzig et al., 2011; Rey Benayas et al., 2009; Schröter et al., 2005; Tallis et al., 2008). Ecosystem services have been authoritatively classified into provisioning services, regulating services, supporting services and cultural services (Lü et al., 2012; Millennium Ecosystem Assessment, 2005). However, considering the relationship between ecosystems and human beings, this classification framework ignored the negative impact of the ecosystem, especially the agro-ecosystem, which accounts for one-third of the land area (FAOSTAT, 1999). While an agro-ecosystem provides important provisioning services, it also creates dis-services and consumes resources from other systems. The consumption of water, emissions of greenhouse gases and discharging of underutilized fertilizer adversely affect human beings. Ecosystem dis-services are relatively new concepts with no consensus on their definition. They could represent reduced productivity or increased production costs or can be considered as ecosystem functions disturbed or damaged by human activities or even unwanted effects (Lyytimäki et al., 2008; Swinton et al., 2007; Zhang et al., 2007). In this study, we classify the adverse outputs contrasting with benefits or ecosystem services as the ecosystem dis-services.

Monetary valuation methods (like market prices method for direct valuations and contingent valuation method, travel cost method for indirect valuations) have been used widely to estimate the value of ecosystem services because they assign the different services a uniform value to allow for direct comparison (Egoh et al., 2008; Jenkins et al., 2010; Naidoo and Ricketts, 2006; Olschewski et al., 2010; Yang et al., 2008). In addition, costing or pricing could make decision-makers more profoundly intuitive in their

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understanding of ecosystem benefits to humans. However, monetary methods have some limitations because: (1) product pricing is mainly based on human labor or investment, ignoring or underestimating natural inputs. For example, water resources, including the underground water used for irrigation is free; farmers merely pay for the irrigation equipment and electricity cost; (2) traditional economic value is affected by market, such as the relationship between supply and demand. This has resulted to different prices for the same products in different years; (3) the willingness-to-pay and contingent evaluation methods often used for the services without market prices rely on human preferences while capturing the value of ecosystem entities only narrowly and anthropocentrically (Rugani and Benetto, 2012; Rugani et al., 2013). As a result, the value of ecosystem services is usually not objective.

Emergy analysis is an ecological valuation method based on thermodynamic principles, which translates different inputs and outputs of an ecosystem into the same solar emjoule (sej) unit using solar energy as the base energy (Herendeen, 2004; Lan et al., 2002; Odum, 1996). According to the emergy theory, value does not rely on human preferences and willingness to pay, but instead it stems from the work of the biosphere to develop and stabilize an ecosystem structure, growth, organization and diversity (Dong et al., 2012). The emergy theory estimates the ecocentric value rather than the humancentric value (Rugani et al., 2013). It could quantify some ecosystem services that are difficult to evaluate otherwise but its limitations have also been highlighted (Cleveland et al., 2000; Ingwersen, 2010). The widespread use of GIS (Geographic Information System) and geospatial data has emerged as an important support in planning and environmental decision-making processes (Mellino and Ulgiati, 2014). Since natural resources are not uniformly distributed across the landscape, it was suggested that an emergy-GIS approach may also be useful for making decisions on how the limited resources can be used and managed sustainably within an existing area (Mellino et al., 2014).

It is important to try to understand many different ecosystem theories in relation to each other and examine if they are contradictory or form a pattern that can be used to give a better understanding of the nature of ecosystems (Jørgensen et al., 2007). Jørgensen and Nielsen (2012) stated that a complete diagnosis focusing on the ecosystem services could be developed by the use of complementary indicators such as emergy and eco-exergy. Pulselli et al. (2011) considered ecosystem services as a counterpart of emergy flows to the ecosystem. Although several related studies have tried to link the ecosystem services to emergy analysis (e.g., Campbell and Tilley, 2014a,b; Coscieme et al., 2014; Dong et al., 2012; Pulselli et al., 2011; Vassallo et al., 2013; Watanabe and Ortega, 2014), there are few reports on ecosystem dis-services. Ecosystem services research started in 1997 and has developed considerably since 2005 (Ma et al., 2013), while 'ecosystem dis-services' within the scope of ecosystem services received some attention only ten years later in 2007 (Zhang et al., 2007). Evaluations of ecosystem dis-services have increased recently, using mainly a monetary valuation method which is the same as ecosystem services evaluation (Chang et al., 2011; Yuan et al., 2011). Thus, development of a new ecosystem services valuation framework based on emergy analysis, but including both the positive and negative ecosystem function is necessary.

In this study, we aimed to develop a comprehensive evaluation framework that considers ecosystem services and dis-services, based on emergy analysis. We analysed the structure of inputs and outputs in a typical agro-ecosystem and explored the variations in structural components and ecosystem services sustainability indexes from 1984 to 2008.

2. Materials and methods

2.1. Study area

The study area was located in Luancheng County (114°41′E, 37°53′N), a typical high production agro-ecosystem in North China (Fig. 1). The area is characterized by warm temperate continental monsoon climate with an annual mean temperature of 12.7 °C with the highest temperature (26.4 °C) in July and lowest (3.9 °C) in January, a mean solar radiation value of 724 kJ/(cm^2 a) and annual sunshine of 2521.8 h. Annual precipitation is about 536 mm, two-thirds of which is concentrated in summer. The geomorphology is piedmont alluvial plain and topography is flat with meadow cinnamon soil type. The groundwater resource is abundant with salinity of 0.5–1.0 g/L and water table is shallow. However, the water table has continued to decline in successive years due to severe overexploitation for irrigation. The contradiction between water scarcity and irrigation of the agro-ecosystem has increasingly intensified in this region.

2.2. Methods

2.2.1. Conceptual framework for evaluating ecosystem services

Ecosystem services have become the focus of ecosystem evaluation and any ecosystem can be evaluated, including the agricultural ecosystem. The Millennium Ecosystem Assessment (MA) defined the ecosystem services as the benefits people obtain from the ecosystem and provided an evaluation framework which divided ecosystem services into provisioning services, regulating

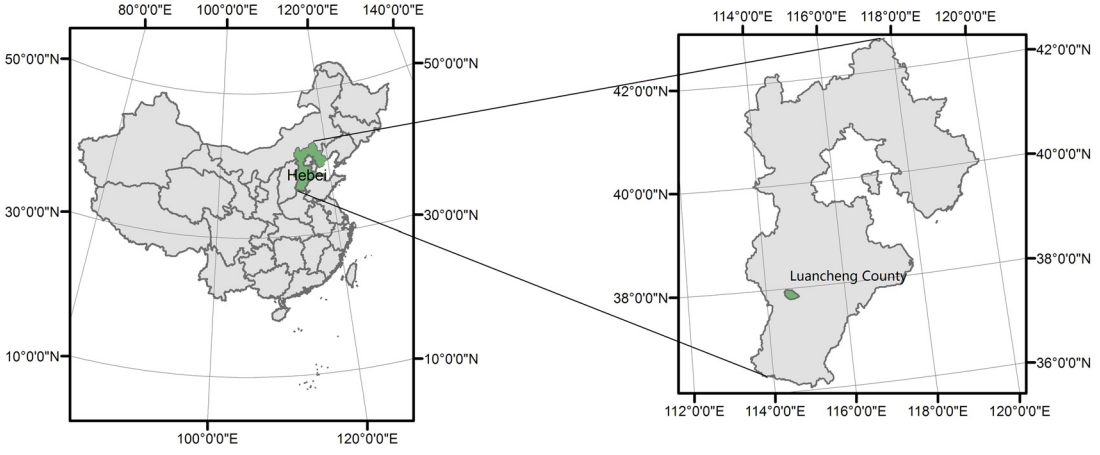

Fig. 1. Map of China showing the location of Luancheng County.