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Dynamics of ecosystem services provided by subtropical forests in Southeast China during succession as measured by donor and receiver value

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ABSTRACT

The trends in the provision of ecosystem services during restoration and succession of subtropical forests and plantations were quantified, in terms of both receiver and donor values, based on a case study of a 3-step secondary succession series that included a 400-year-old subtropical forest and a 23-year history of growth on 3 subtropical forest plantations in Southeastern China. The 'People's Republic of China Forestry Standard: Forest Ecosystem Service Valuation Norms' was revised and applied to quantify the receiver values of ecosystem services, which were then compared with the emergy-based, donor values of the services. The results revealed that the efficiencies of subtropical forests and plantations in providing ecosystem services were 2 orders of magnitude higher than similar services provided by the current China economic system, and these efficiencies kept increasing over the course of succession. As a result, we conclude that afforestation is an efficient way to accelerate both the ability and efficiency of subtropical forests to provide ecosystem services.

1. Introduction

Ecosystem services research has become a focal area of investigation over the past decade (Fisher et al., 2009), as a result of the increasing severity of environmental problems and their associated negative effects on socioeconomic activities and human wellbeing. Valuing the ecosystem's contributions to socioeconomic wellbeing can help resource managers assess the effects of market failures, by measuring the cost of ecosystem losses to society in terms of the associated loss in economic benefits. The Millennium Ecosystem Assessment (MEA), a study of the condition and trends of global ecosystems, and the impacts on human well-being, i.e. ecosystem services, has raised public awareness of the valuable services provided by nature, including those of forests (Li, 2008; Chen et al., 2012). However, due to the significant difference in assessment indicators, calculation approaches and reference prices among various case studies, the research results of ecosystem services studies often cannot be easily compared or studied dynamically (Pimentel et al., 1997; Li, 2008; Zhang et al., 2010a). Furthermore, based on anthropocentrism, most of the ecosystem services valuation studies are focused on the receiver value of the goods and services to human beings, and lack a donor-side consideration of the problem (Campbell and Brown, 2012). However, donor and receiver values are two basic aspects of value and need to be accounted for in comprehensive strategy-making for an integrated consideration of and relative balance between the actual cost of the producer or donor value of a service and the willingness of the consumer to pay or receive payment for that service. Furthermore, the integration of these two aspects of value is essential for clarifying a system's efficiency in producing value. Biophysical process analysis, emergy evaluation and other methods used in ecosystem services valuation could shed light on these issues from the donor-side perspective (Odum, 2007). These studies reflect the transition from anthropocentrism towards ecocentrism, which calls for humanity to establish partnerships with nature, where nature is not only preserved for its present and future benefits to humanity (i.e., stewardship), but equal weight is given to determining what is best for the entire system (Liu et al., 2016). The complementary aspects of emergy analysis and environmental economics based ecosystem services valuations are

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getting more and more attention from scientists and governments at all scales (Patterson et al., 2006; Campbell, 2009; Lee and Huang, 2010; Campbell and Brown, 2012; Coscieme et al., 2014; Campbell and Tilley 2014a; Liu et al., 2014; Fang et al., 2015), but a comprehensive accounting system for ecosystem services evaluated from both the donor and receiver perspectives is still under development, as is integrated ecological-economic cost-benefit analyses, which is needed for comparison among different options for providing ecosystem services, which is fundamental for strategic decision- making (Coscieme et al., 2013).

In addition, most past ecosystem services studies have been isolated snapshots mainly focused on concepts and theories or on policies and compensation standards, and as a result dynamic and systematic studies are lacking for the most part (Yu and Peng, 2010). Such studies have been identified as a key factor for the further development of knowledge about ecosystem services and for their application in both the development of long-term ecological conservation and restoration practices (Liu et al., 2007). However, the dynamic trends of all ecosystem service functions develop within the structures of ecological networks are nonlinear; therefore, the relationships among them are complex and hard to predict, without the support of long-term monitoring studies (Yu and Bi, 2011).

To normalize and guide forest ecosystem services assessment in China, in May 2008 the State Forestry Administration of China issued the 'People's Republic of China Forestry Standard: Forest Ecosystem Service Valuation Norms' (referred to as 'Norms' in the following text), which proposed a suite of assessment formulae for 14 indices accompanied by reference prices for each service (Appendix A and B). Although there are still many controversies, deficiencies and problems that need further study, the Norms document developed the first general framework for forest ecosystem services assessment and provided guidance for the evaluation of forest ecosystem services research in China (Zhang et al., 2010a, 2010b). In most cases, 'Norms' represents the cost to replace an ecosystem service with an equivalent service performed through human work. It is important to note that by these replacement costs the values generated likely do not represent the marginal cost or benefit of forest loss or gain, i.e. the actual change in wellbeing when a forest expands or contracts. The values represent a maximum value, assuming that all ecosystem service loss would need to be replaced with human work.

Among terrestrial ecosystems, tropical and subtropical forests have superior ability to provide ecosystem services due to their relatively high biodiversity and NPP. However, the rapid loss and degradation of these forests is a serious problem that is now gaining public attention (Kremen et al., 2000; Agrawal et al., 2008; FAO, 2014). Forest restoration is considered to be one of the most efficient tools to deal with some environmental problems, e.g. global climate change and soil erosion etc. (Liu et al., 2008), but these problems have been perceived by some conservationists and economists, as a diversion, a delusion, or far worse a waste of money (Aronson et al., 2006). Such attitudes make it vital to incorporate ecosystem services and the efficiencies with which they are provided into economic analyses by considering their fundamental ecological economic characteristics and origin in biophysical processes.

Many scientists believe that when ecosystem services are considered to be free subsides an increase in scarcity will not be felt until an ecosystem service becomes limiting to an economic activity, at which point the cost to the social economy would likely be much more than if an investment in natural capital had been made prior to economic limitation (Coscieme et al., 2014; Campbell and Tilley, 2014b). Environmental-economic assessment of ecosystem services highlights the essential contributions of nature to human economic and social systems at all scales from a specific ecosystem to the world as a whole. However, due to the lack of a straightforward link between the assessments of ecosystem services and ecosystem processes, the applicability of the assessment results to develop ecosystem management strategies and to evaluate ecological economic trade-offs is still weak.

Low latitude subtropical forests play an essential role in establishing an ecological balance and improving environmental quality in southeast China, which has been seriously degraded under heavy population pressure and rapid development of local economies over the past few decades (Yu and Peng, 1996). Both government and scientists have paid special attention to the conservation and restoration of lower subtropical forests since the 1950s, with the goal of enhancing regional environmental quality and sustainability and some advancements in our understanding have been made both through the exploration of ecological theory and through observing the behavior of subtropical forests (Zhou et al., 2006). Specifically, the selection and implementation of a suite of forest restoration modes has been shown to be outstanding in providing some specific ecosystem services, such as water and soil conservation, carbon fixation and oxygen release, and biodiversity conservation *etc.* (Peng, 2001, 2003). However, the dynamic patterns determining ecosystem service values in subtropical forests and in classical subtropical forest plantations have not been explored yet, although this is essential information needed for forest management on both spatial and temporal scales.

The trends of the ecosystem service values of subtropical forests and plantations, following succession and restoration, were disclosed in this study based on a long-term field measurement program at two national forest field research stations in Guangdong Province, Southeast China, *i.e.* Heshan and Dinghushan Forest Ecosystem Research Stations. The formulae and prices given by the 'Norms' document were applied and adjusted to assess the receiver or replacement values of 8 ecosystem services, *i.e.* water regulation, water purification, soil fixation, soil fertilizer conservation, carbon sequestration, oxygen release, nutrient accumulation in biomass, and biodiversity conservation on three subtropical forest plantations in southeast China at Heshan station, *i.e.*, a conifer plantation (CP), an *Acacia* plantation (AP), and a mixed native species plantation (NP); and a three-stage long-term secondary succession series of subtropical forest in Dinghushan, *i.e.*, a pine forest (PF), a mixed conifer and broadleaved forest (MF), and a monsoon evergreen broadleaf forest (EF). Simultaneously, the biophysical donor value of these ecosystem services was quantified by the emergy method. Then, a comparison was done between the environmental economic receiver values and the emergy values to obtain a more holistic view of the different dimensions of value. This comparison quantified the efficiencies of subtropical forests and plantations in providing ecosystem services relative to the current Chinese economic systems for providing the same services.

2. Location and methods

2.1. Location and sites

All three forest plantations located at Heshan National Field Research Station of Forest Ecosystems (HNFRSFE, 22°40′N, 112°53′E) were planted in 1984 on grassy slopes that were formerly regional monsoon evergreen broadleaf forest, for the purpose of studying forest restoration. This area is located on low hills with an altitude of less than 100 m. This location is controlled by a typical monsoonal climate, with mean annual precipitation of 1800 mm and mean annual temperature of 21.7 °C. The soil in HNFRSFE is composed mainly of lateritic red earth and mountain yellow-brown earth in a vertical distribution. The main species planted in NP was *Schima wallichii*, whereas, *Pinus massonina* and *Cunninghamia lanceolata* dominated in CP, and *Acacia mangium* dominated in AP. Measurements and studies showed a significant development of both community structure and function of the three plant communities during over 20 years of self-organization, without the application of specific management activities after planting (Lu et al., 2015).

A three-stage long-term secondary succession series (SS) of sub-