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Measurement methods and applications for beneficial and detrimental effects of ecological services

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ABSTRACT

Ecosystem service refers to a wide range of conditions and processes provided by natural ecosystems to help sustain and enhance human life. However, not all ecological conditions or processes are beneficial; some are restrictive or even detrimental under certain circumstances. The nature of the effects depends on time, space and specific target groups. Some locally detrimental phenomena might be beneficial at larger scales, and vice versa. Nature frequently causes detrimental impacts on human beings through disasters such as earthquakes, tsunamis, ice, sandstorms, flooding, drought, soil erosion, fire, disease and biological intrusion, even though these events might be beneficial to natural evolution. And such natural disasters can in turn be caused by human overuse of natural resources and destruction of the environment. On the other hand, human beings do not always destroy nature, but in fact can play a beneficial role through ecological design, engineering and management – activities which could be considered as the human eco-service contribution to nature. To avoid the misleading point of view that nature is always a servant of mankind, the mono-directional ecosystem service concept should be expanded to one of mutual services. Measurement methods of ecological services were put forward, including space, time, equivalent, pattern and order measuring methods. Case studies of urban land evaluation, ecological space accounting, water and energy equivalents assessment were performed in Changzhou city, Taihu basin and Yangzhou city of PR China applying spatial, pattern and equivalent measurement methods.

1. Introduction

Ecosystem service is one of the current hot topics in ecosystem research (Calvet-Mir et al., 2012; Costanza et al., 1997; Daily, 1997; Jansson, 2013; Norberg, 1999; Wang et al., 2004). Since the concept of ecosystem service was explicitly put forward, this area has become a hot spot in the international ecology and ecological economics fields. The publication of Costanza et al., 1997 "The global evaluation of the ecosystem services and natural capital" caused great stir and controversy in academic circles.

Much of the world is experiencing rapid urbanization, and many peri-urban open spaces have been built over, resulting in a steep decline in ecosystem services at the municipal and regional levels (Seto et al., 2012). Urban ecosystem services are defined as those services provided by the urban ecosystem and its components (Bolund and Hunhammar, 1999; Kroll et al., 2012; Gómez-Baggethun and Barton, 2013; Larondelle and Haase, 2013; Radford and James, 2013). These refer to the ability of an urban ecosystem to provide tangible or intangible natural products, environmental resources, and commonweal that maintain the production, consumption, distribution, restoration, and regulation activities of human society in urban areas (Wang et al., 2004). Since 1980's, Wang et al. have finished many systematic research works and published many related papers and books on ecological services (Wang et al., 2004, 2010, 2011).

An ecosystem can produce both services and disservices. For example, ecosystem services provided in urban areas include air purification, climate regulation, noise reduction (Bolund and Hunhammar, 1999; Jansson, 2013), waste treatment, food production and distribution, water flow regulation and runoff mitigation, urban temperature regulation, moderation of environmental extremes, pollination and seed dispersal, recreation and cognitive

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development, and wildlife habitat (Gómez-Baggethun and Barton, 2013). Ecosystem disservices in urban areas include air quality problems, view obstructions, allergies, accidents, fear and stress, damages to infrastructure, and habitat competition between humans and wildlife (Gómez-Baggethun and Barton, 2013; Li et al., 2011). Ecosystem services to agriculture include soil formation and fertility, nutrient cycling, soil retention, pollination, pest control, water provision and purification, genetic diversity and climate regulation; ecosystem disservices to agriculture include pest damage, competition for water from other ecosystems, and competition for pollination services (Zhang et al., 2007). The disservices of urban green space include water and energy consumption, greenhouse-gas (GHG) and volatile organic compounds (VOC) emissions (Pataki et al., 2011). The disservices of irrigated urban ecosystems are depletion of scarce water resources and excess runoff which contributes to water pollution and eutrophication (Pataki et al., 2011). Escobedo et al. (2011) integrated the concepts of ecosystem services (benefits) and disservices (costs) when assessing the efficiency of using urban forests to mitigate pollution. The development of urban forest management alternatives that mitigate pollution should consider scale, context, heterogeneity, management intensity and other social and economic co-benefits, tradeoffs, and costs affecting stakeholders and urban sustainability goals.

The traditional ecosystem service evaluation methods include mainly physical assessments and value assessments. A physical assessment quantifies various ecosystem services from the material perspective. The value assessment method, however, is the main method of evaluating ecosystem services; it includes: the marketing value method, the opportunity and cost method, the shadow price and shadow project methods (replacement cost method), the cost analysis method, the human capital method, the asset value method, the travel cost method, the contingent valuation method (inclination spot-sampling method), and the model evaluation method (Gómez-Baggethun et al., 2010; Gómez-Baggethun and Barton, 2013; Polasky et al., 2011). Previous ecosystem service researches have focused mainly on the ecosystem's beneficial services, and rarely included detrimental effects. Furthermore, in terms of measurement methods, former research has been mainly on value and quality evaluation.

2. Methodology

2.1. From ecosystem services to ecological services

There are a number of definitions of ecosystem service, of which the Daily (1997) and Costanza et al. (1997) definitions are representative. Costanza et al. (1997) defined ecosystem services as "benefits that humans obtain directly or indirectly from ecosystem functions." Daily (1997) referred to ecosystem service as "a series of conditions and processes provided by natural ecosystems to sustain human life." Ecosystem services were defined as direct and indirect contributions from ecosystems to human well-being (TEEB, 2010, 2013), and were divided into 15 classes by Daily and 17 by Costanza. Norberg (1999); however, classified ecosystem services by ecology standards into three categories: population maintenance, exogenous materials filtration, and the creation of biological organization through the evolutionary selection process.

Launched by the United Nations Secretary General Kofi Annan in June 2001, the New Millennium Ecosystem Assessment systematically studied current status, development trends of ecosystems and human well-being, scenario analyses and response mechanisms (MA, 2005a,b). The report pointed out that we have 10 ecosystems on earth: farmland, arid land, forest land, urban land, water bodies, coastal zones, oceans, polar regions, mountains and islands. These ecosystems provide 11 ecosystem services: the provision of fresh water, food, wood/fuel/fiber, special products and industries from biodiversity, biodiversity regulation, nutrient cycling, soil fertility, air quality and climate, human infectious diseases, waste management and reduction, natural disaster regulation, cultural and recreational services. The above 11 ecosystem services can be summarized as provision, support/regulation, and cultural ecosystem services.

The Millennium Ecosystem Assessment (MEA) is a comprehensive evaluation of the relationship between humanity and nature, and includes three parts: estimation of the current status and historical succession trends of global ecosystems, scenario analysis, and response mechanisms. The MEA systematically discusses 11 ecosystem services provided by nature, including provision, support and regulation, cultural and aesthetic values, etc.

We have referred to ecosystem service as the ability of nature to provide tangible or intangible natural products, environmental resources, and ecological profit and loss for the production, consumption, circulation, reduction and management activities of human society (Wang et al., 2004).

The complete list of the types of ecosystem services is:

- Provision function: providing water, energy, air, soil, mineral resources, biological material, etc., for human production and sustenance.
- Incubation function: soil ripening, atmosphere stabilization, soil and water conservation, hydrology regulation, breeding habitat.
- Regulating function: regulating local climate, purifying the environment, mitigating disasters, biological control of harmful organisms, biodiversity maintenance.
- Circulation function: nutrient cycling, waste recycling, pollination, genetic diffusion, pollutant diffusion.
- Support function: providing land, landscapes and aesthetic environments for social development, scientific research and education, tourism and leisure, and spiritual life.

Human demands for survival and development have the following aspects: material needs, security needs, health needs, spiritual needs, cultural needs and social needs. The survival and development of human beings require both social and natural ecological services. Services such as providing direct material, energy and information services – e.g., raw materials, labor, capital, technology, and equipment are called social ecosystem services because they are generally able to be exchanged through the market. Services such as those needed to maintain the life support system for human survival and development, and thus to indirectly support social and economic activities, are generally difficult to exchange commercially through the market and are therefore called natural ecosystem services (Wang et al., 2004).

Ecosystem services should also include the services of ecological factors and ecological processes. This study expands the concept of ecosystem service to ecological services, including both the services of natural ecosystems to people (provision, support, cultivation, circulation and regulation functions), and the services of human beings to nature (production, construction, restoration, transportation and cultural regulation) as well as services provided by a single ecological factor or ecological process. This new concept refers to a mutual interaction between people and nature, each providing the other with promoting or restricting conditions and potentials through which sustainable relationships can either be maintained or deteriorate. The measurement approach for these beneficial and detrimental ecological services through land, water, and energy exchanges are introduced and discussed using typical case studies in China.