

Chapter 7

Ecosystem Service Evaluation

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Abstract With the development of the ecology research, the in-depth understanding of the characteristics of different types of ecological systems, ecosystem observation techniques progress, all kinds of ecosystem observation data to accumulate, an value analysis and evaluation of the ecosystem make it possible for understanding the ecological system evolution and discussing the sustainable development of ecosystem. All parts of the ecosystem including humans and their environment, ecosystem provide all kinds of ecological services to human through the process of its function. Ecosystem services (ESs) is considered as no value by the existing economic model and theory for a long time, only part of the ecological

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products have the market price, in order to obtain tangible ESs, human damage or even destroy some invisible ecological services at the same time, led to a decline in ESs. Since the mid-1990s, the Chinese ecologists widely study the ESs and its value assessment research, contenting forest, grassland, wetland, farmland, and marine ecosystems. Through the general laws of ecological service value method and the time spatial heterogeneity of ESs space model method, we assess the ESs value in whole and reflect its spatial and temporal heterogeneity. Value assessment method of ESs is developing constantly, widely used in the main are valued based on the price per unit area, based on the function of laws of value and dynamic laws of value based on the single function time three types. Three methods are widely adopted, they are based on the price per unit area, based on the function of laws of value, dynamic laws of value based on the single function time. In a new paradigm to investigate the relationship between ecosystem and economic system, so as to promote an efficient economic decisions for resource allocation in the economic system and ecological system of integrated system framework. To cultivate and develop effective market mechanism for ecological service has become one of the hot spot of ecological service research and ecosystem management. Researching on ESs consumption and building ecological system efficient continuous consumption mode, we can hold the direction of the rational utilization of ecological system, and it is of great practical significance to safeguard the ecological safety. On the basis of understanding the principle of ecosystem consumption and consumption measurement model, analyzing consumption process, analyzing consumption utility function (UF), and analyzing the consumption process, we can realize ESs, and this provide a scientific basis to optimize the structure of consumption of ESs, and to build efficient continuous consumption patterns (CPs).

Keywords Valuation methods · Spatial heterogeneity · Ecological compensation · Forest ecosystem service · Monetary value of FES · Wetland ecosystem service · Grassland ecosystem service · Agroecosystem service · Marine ecosystem service

1 Theory and Method

1.1 Introduction

Economists and ecological economists now recognize that nature is providing a wide range of services that were previously ignored, and have proposed the term ecosystem services (ESs) to encompass these services. The widely accepted definition for ES is the environment and its effectiveness that human beings must rely on, maintained by ecosystems or formed by ecological processes (Daily 1997), or the benefits people obtain from ecosystems (Costanza et al. 1997; WGMEA 2003a, b, c). Obviously, the economies of every country are all entirely based on the goods

and services provided by ecosystems, and human life itself depends on the ability of ecosystems to continuously provide multiple benefits.

Scientists have increasingly recognized that both economic goods and services and ecological goods and services are equally important to human welfare. In order to achieve environmental sustainability in policy and management practice, it is very important to determine ESs and evaluate these. The main purpose of this section is to summarize valuation methods for ES and the progress and contributions of Chinese ecologists in this field.

1.2 Valuation Methods of Ecosystem Services and Progress

1.2.1 Valuation Methods of Ecosystem Services

The value basis of ESs includes: (i) the value of ES which is a utility value; (ii) consumer surplus and producer surplus; and (iii) the willingness to pay or willingness to accept compensation.

ESs have multiple values. The value of ESs includes two parts: the use value and nonuse value. The use value includes direct use value and indirect use value; the nonuse value includes the heritage value and existence value. Except for the values mentioned above, there is an option value, which can be classified as either a use or nonuse value.

Valuation methods for ESs are challenging and there remains no internationally recognized or standardized valuation methodology. Existing valuation methods include Avoided Cost (AC), Replacement Cost (RC), Factor Income (FI), Travel Cost (TC), Hedonic Pricing (HP), Contingent Valuation (CV), Group Valuation (GV), and Marginal Product Estimation (MP).

1.2.2 Dynamic Change and Spatial Heterogeneity of Ecosystem Service Value

Valuation methods for ESs can assess the eco-services value of a certain region for a given period. Therefore, as research in this area deepens, temporal and spatial changes in ES values are receiving increased attention. Dynamics of ES value can be expressed by ES flow. The spatial heterogeneity of ES can be expressed by a space model.

1.2.3 Example Valuation of Ecosystem Services in China

Since the mid-1990s, Chinese ecologists have extensively studied and assessed ESs and accomplished outstanding achievements. For example, Li et al. (2002, 2008) organized experts to compile and publish a series of monographs including the

Study of Ecosystem Services, Theory, Methods and Applications of Ecosystem Services Valuation, and Ecological Compensation Mechanism and Its Policy in China. These books systematically summarize the fundamental theories and methods underpinning ES valuation and establish an ecological compensation system and policy for China. Ouyang et al. (1999a, b) evaluated ESs in China quantitatively and others have systematically explored ESs for different ecosystems, including forest (Zhao et al. 2003), grassland (Xie et al. 2001), river and farmland (Xiao et al. 2004). As to valuation methods for ESs, and Xie et al. (2003, 2008) posited an equivalent factor method for ESs. The development of these methods has played an important role in ES valuation in China. Unlike in other countries, ecological service valuation research has been directly used to promote the establishment of ecological compensation mechanism in China. In fact, some research results have been adopted directly by national authorities, for example, the *Evaluation Standards for the Ecosystem Services of Forest Ecosystems* has become the forestry industry standard in China and was officially issued by the State Forestry Administration (SFA) of China in 2008. ES valuation methods remain a sphere of development, and widely used methods can be divided into three types: (i) valuation methods based on the price of unit area; (ii) valuation methods based on the function value; and (iii) valuation methods based on temporal changes in a single function.

1.2.4 The Mechanism of ES Value

Most ESs are public goods; however, since there is no market or market development is far from perfect, they are always forgotten in the resource allocation of the social-economic system. In essence, the coordination between economy and ecology is a large challenge faced by many countries in the world. Although ecological degradation has an indivisible relationship with the market economy, market mechanisms are not the cause of ecological degradation but only intensify market failure for ESs. The cause of ecological problems lies in economic activity, rather than the market mechanism itself. Compared with nonmarket mechanisms, market mechanisms are more effective for resource allocation and remain a fundamental way to ease ecological degradation and protect and restore ecosystems. ESs provide a new paradigm to evaluate the relationship between the ecological and economic systems, and promote effective allocation of resources within a comprehensive framework composed of economic and ecological systems according to social and economic policies.

Trade form of ES: whether the supply and demand of ESs in the market are real or not, as long as they exist and the quantity or value of ES transfer occurs in time or space, it can be regarded as ES trade. There are three main forms of trade for ESs: (i) economic trade; (ii) the spatial transfer of ESs; and (iii) the transfer of ESs between different generations.

ES payment mechanisms have the potential to promote the formation of ecological service protection funds by creating new demands for ecological products

and services. The ES payment system is developing rapidly around the world and accumulating a lot of experiences in promoting the marketization and value realization of ESs. However, these are mainly case studies only and exploring the ‘market’ for ESs remains at an early stage and far from a ‘real’ ES market. Market mechanisms will fully play a role in resource allocation only under an ‘ideal’ market. Therefore, the fair, impartial, sustainable ES trade requires effective intervention from governments and robust international cooperation.

1.3 Conclusion and Discussion

ESs have emerged as a kind of theory and thought area within ecological economics. The theory and method of ecological service valuation is still being developed. The supply, consumption, and value of ESs will be gradually merged into the theory of ecological service valuation, and ES payment mechanisms will be established in a gradual manner.

ESs provided a new paradigm through which to evaluate the relationship between ecological and economic systems, promote the cultivation and establishment of ES markets in many countries, and accumulate experience in coordinating the relationship between economic development and ecological protection. However, the market for ESs development remains local and at a pilot stage, and effective government intervention is necessary for continued development. Legal and economic systems must be brought into the concept and framework of ESs. As a society, specialized departments and policy are needed to ensure the reasonable management and utilization of ESs.

2 Assessment of Forest Ecosystem Services in China

2.1 Introduction

Coupled human and natural systems (CHANS) are systems in which human and natural components interact (Liu 2007). According to Mooney and Ehrlich (1997), the idea that humans depend on natural systems dates back as far as Plato, but the first modern publication that addresses this issue is *Man and Nature* by George Perkins Marsh in 1864. Today, interactions between human and natural systems have emerged as concerns because human activities are globally connected. At the same time human societies and globally interconnected economies rely on ecosystems services and support (Millennium Ecosystem Assessment 2005). ESs are the conditions and processes through which natural ecosystems, and the species that make them up, sustain, and fulfill human life (Daily 1997), including provision services, regulation services, cultural services, and support services. It is now clear

that patterns of production, consumption, and well-being develop not only from economic and social relations within and between regions but also the capacity of other regions' ecosystems to sustain them (Arrow et al. 1995).

Valuation of ecosystems has continued (de Groot et al. 2002), but research and attention has expanded greatly since the estimation of the value of ESs and natural capital (Costanza et al. 1997). The development of science-based policy has been increasingly recognized as an method for protecting and managing the environment in the context of global change (Sun and Chen 2006; Daily and Matson 2008; Fisher et al. 2008; Mäler et al. 2008; Carpenter et al. 2009). The recent Millennium Ecosystem Assessment (MEA) provided a new general conceptual framework for estimating the value of ESs at the regional, national, and global scales (MEA 2005). In April 2011, a UK National Ecosystem Assessment (UK NEA) report was published and it was the first and relatively complete assessment of ESs at a national scale (UK NEA 2011). The UK NEA included four recognized services provided by all the main ecosystems: supporting, regulating, provisioning, and cultural services.

Here we focus on valuing China's forest ecosystems services (FES). Forests cannot only provide timber, but also critically represent important habitats and ESs (Miller and Tangley 1991; Mendelshon and Balick 1995; Pearce 1998, 1999). The ESs provided by forest ecosystems are diverse and difficult to quantify accurately at a national level. In the last two decades, the estimation of the value of FES at the national or regional scale has been the focus of ES research. For example, economic techniques for estimating the total economic value (TEV) of forests in Mexico was proposed (Adger et al. 1995), however, only a proportion of this value can feasibly be 'captured' within Mexico: much of the benefits of Mexico's forests fall outside its borders and is therefore not considered by forest users or national policy-makers. These benefits include maintaining water quality, reducing storm water runoff and erosion, improving air quality, regulating climate and carbon sequestration, providing habitat for wildlife, maintaining biodiversity, and providing a destination for recreation and tourism in addition to providing timber and non-timber resources, which were estimated in America (Krieger 2001). The economic value of Mediterranean forests, brought together forest valuations at the national level from 18 countries, is based on extensive local data and research findings in the context of institutions and new policy approaches for improving management at national, regional, and local levels (Merlo and Croitoru 2005). A study on the TEV of Amazonian deforestation during the period of 1978–1993 also suggested the value of FES from different points of view (Torrás 2000), and scientists combined the green income accounting and TEV approaches and applied the new framework to Brazil in order to assess the foregone economic benefits resulting from Amazonian deforestation. Canada also assesses the real value of its boreal ecosystems (Anielski and Wilson 2005). Assessment work was carried out in 1972, 1991, and 2000 in Japan (Wang 2005), and more recently in the UK (UK NEA 2011). All these studies indicate the high value of FES, which has important implications in the development of policy to protect and manage forests via ecological compensation.

In the last 30 years, forest resources in China have rapidly increased along with its economy. In 2008, the total area of forests was 195 million ha with a growing stock of more than 13 billion cubic meters (State Forestry Administration 2009a). Forested areas covered 20.36 % of the land base of China in 2008, a value that has tripled from 8 % 60 years ago. The Chinese government has announced a plan to expand forested areas by 40 million ha between 2005 and 2020 with carbon sequestration as the main policy objective. China is an important country in the world in terms of the importance of forests. Without a doubt, the benefits of afforestation and reforestation make an important contribution to environment improvement and economic development. The value of China's FES in forest ecology and forestry economics is an essential issue to consider. Based on the latest national forest resources survey (the seventh) and socioeconomic data, this section aims to show the monetary value of China's FES at a national scale in 2008, and to discuss the characteristics and implications of these assessments in an international context.

Research is committed to supporting policy action toward a sustainable use of forest resources nationwide, and the forest economic evaluation challenge has gradually reached the national policy agenda. The methodology and approaches for assessing FES and applying results are currently being developed in China, but uncertainty factors when assessing FES remain. Therefore, sharing research methods and results among scientists, forest managers, policy-makers, and the public in different countries is important. China has an exceptionally diverse climate, geography and hydrology and forest vegetation, and social and economic conditions differ between regions. While Chinese scientists and policy-makers desire to learn from the work of other countries, China's diverse conditions favor the development of a methodology that is applicable to other countries with different climatic, geographical, and hydrological conditions. China should play an important role in the development of environmental and forest management.

2.2 Data and Methods

2.2.1 Data Sources

Field measurement data consisting of ecological properties (e.g., net primary productivity (NPP), water, and soil conservation) and characteristic parameters were obtained based on 50 long-term research stations (consisting of 286 supplement stations) in the China Forest Ecosystem Research Network (CFERN). This network covers almost all forest ecosystems of all dominant trees in the country. The forest inventory dataset was also used. Although SFA data are available from 1973 to 2008 via seven national forest resources inventories (NFI), (1973–1976) (the 1st NFI), 1977–1981 (the 2nd NFI), 1984–1988 (the 3rd NFI), 1989–1993 (the 4th NFI), 1994–1998 (the 5th NFI), 1999–2003 (the 6th NFI), and 2004–2008 (the 7th NFI), only the period 2004–2008 (the 7th NFI) is complete and reports forest area,

timber volume, and some ecological parameters. Data recorded included the forest group (planted and natural forests), dominant tree species and age-class and so on. We used data from the 7th NFI. Social-economical public data released by authorities was also used in this assessment.

2.2.2 A Framework for the Ecological Valuation of Forest Ecosystem Services in China

We evaluated the valuation of forest ESs based on the framework in Fig. 1. The framework comprises four steps: (i) selection of indicators for the FES assessment; (ii) identification of units for assessing FES; (iii) calculation; and (iv) synthesis of the results.

Selecting Items for the FES Assessment

Forests are amongst the most biologically rich terrestrial systems in the world and provide us with a wide variety of ESs. Six items have been selected to assess the FES, including water conservation, soil conservation, carbon sequestration and oxygen release, nutrient accumulation, atmosphere environmental purification, and biodiversity conservation. Data from China are available for all the six measures. Water conservation service contains water quantity regulation and water quality purification, reflecting the role forests play in mitigating natural disasters such as droughts and floods, as well as clean drinking water. Water and soil erosion is widespread and affects all natural and human-managed ecosystems. It often causes soil deterioration (Marques et al. 2008), decline in land productivity (Pimentel and Kounang 1998), and is caused by a lack of vegetation protection (Canton et al. 2001; Ludwig et al. 2005). Soil conservation is an indicator to demonstrate the interaction between human and natural systems. The reasons for considering carbon sequestration and oxygen release are that forest ecosystems are important carbon sinks and have a close relationship with climate change. Forests account for around 50 % of total aboveground terrestrial organic carbon, as well deforestation and forest degradation are estimated to cause 20 % of annual greenhouse gas emissions (SCBD 2008). So this indicator can better understand the effects of human activities on natural systems and the responses of natural systems to human activities. Key publications such as the MEA (2005) and Red List of Threatened Species (IUCN 2004) indicate that a large and increasing number of forest ecosystems, populations, and species are threatened globally due to the loss and degradation of forest habitat, and thus this indicator is needed to assess the value of forest biodiversity conservation. With industrialization and increasing pollution, human living environmental issues are more and more remarkable. Forest functions by absorbing air pollutants and biochemistry cycles, and thus the indicators nutrient accumulation and atmosphere environment purification are therefore required.

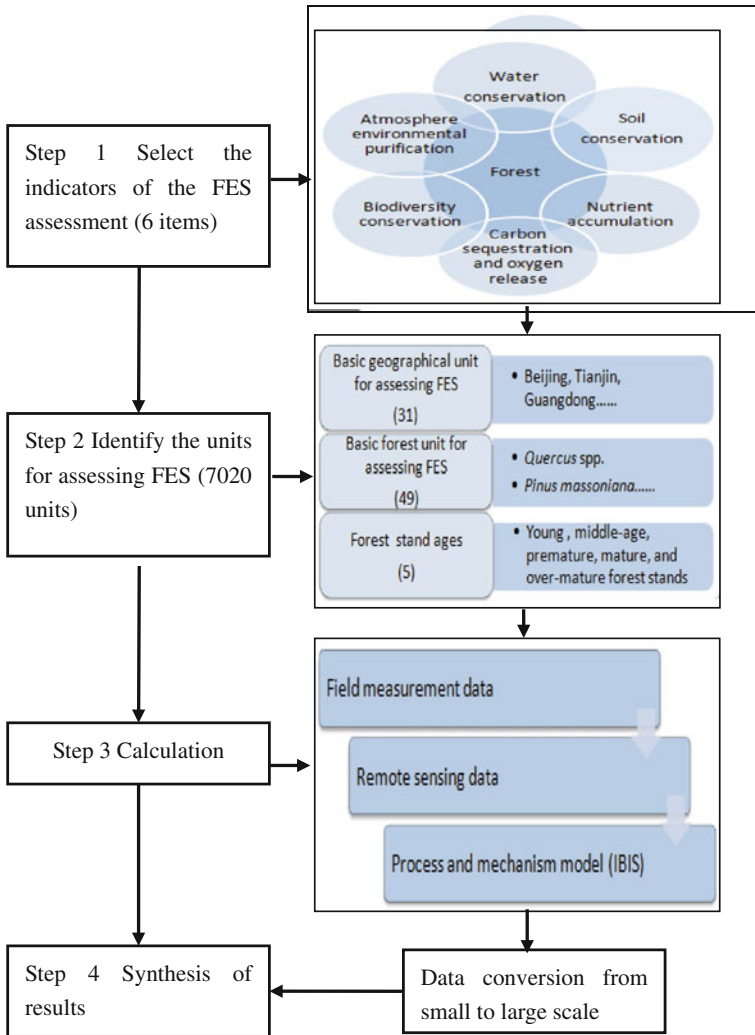


Fig. 1 Framework for evaluating FES in China

Identifying the Units for Assessing FES

Basic geographical unit China is a large country of varied topography, climate, forest vegetation, forest management systems, and social-economic development levels. In order to minimize differences in natural conditions and maximize the implication of the assessment results in policy-making, 31 administrative regions (provinces and municipalities directly under the Central Government) across the

Chinese mainland were used as assessment units. The value of FES in Hong Kong, Macau, and Taiwan was not included here.

Basic forest unit Forest vegetation was divided into 46 kinds of forests based on dominant tree species. In addition, a large area of economic forest (fruit trees, cork plantations, and rubber plantations), bamboo forest, and shrubbery woodland exists. These forests are difficult to classify based on dominant trees and are treated as three kinds of forests. In total, 49 kinds of forests were used in this assessment. In view of the effect of stand age on FES, each kind of forest was divided into five age-classes: young, middle-age, premature, mature, and overmature stands. Similarly, each kind of forest was divided into five age-group stands in a province based on the NFI in 2008 (SFA 2009a). When all age-class stands in all kinds of forests were found in a province, 245 age-class stands were involved in accounting FES at the provincial level. In general, the number of age-class stands was less than 245 in a province because some kinds of forests or some age-groups in a kind of forest were not present. Ultimately, 7020 assessment units with homogenization were used as accounting units at the national level.

Calculation Process

Based on field measurement data from forest ecosystem research stations, remote sensing data, and using process and mechanism models such as IBIS, we were able to convert data conversion across scales.

Synthesis of FES Results

An age-group stand was used as the basic forest unit for accounting the value of each FES. For each age-class stand in a province, the annual quantity of each FES provided by the stand was estimated based on local research station observations or published data. The unit price of each FES was determined based on relevant Chinese yearbooks or published data. For example, the price of nitrogen conserved in the stand was determined by referring to the current market price of nitrogen fertilizer (Wang and Yang 2008). For an age-class stand, the annual monetary value of each FES was obtained by multiplying the annual amount provided by the stand with the price per unit amount. For each FES, the total values for quantity and monetary could be obtained for a kind of forest, forest type, and province by summing the quantity and monetary value of each FES in different age-class stands within a province.

2.3 Conclusion and Discussion

2.3.1 Monetary Value of FES at a National Level

In 2008, the total value of the six FES (water conservation, soil conservation, carbon sequestration and oxygen release, nutrient accumulation, atmosphere environmental purification, and biodiversity conservation) was estimated to be 10.01 trillion CNY (1.48 trillion USDs) per year. The contribution of each ES to the total FES from highest to lowest was water conservation (40.51 %), biodiversity conservation (24.01 %), carbon sequestration and oxygen release (15.57 %), soil conservation (9.92 %), atmosphere environmental purification (7.92 %), and nutrient accumulation (2.07 %) (Fig. 2).

2.3.2 Monetary Value of FES at the Provincial Level

Sichuan provided the largest FES value (1059 billion CNY) and Shanghai was the least (2.31 billion CNY) (Fig. 3). The values for water conservation, biodiversity conservation, and carbon sequestration and oxygen release at the provincial level are the three largest fractions, and the value of nutrient accumulation was the smallest. The value of FES showed the different traits in spatial distribution. In general, southwestern provinces (e.g., Sichuan 10.57 %, Yunnan 10.24 %, and Guangxi 7.73 %) and northeastern provinces (e.g., Heilongjiang 8.57 % and Inner

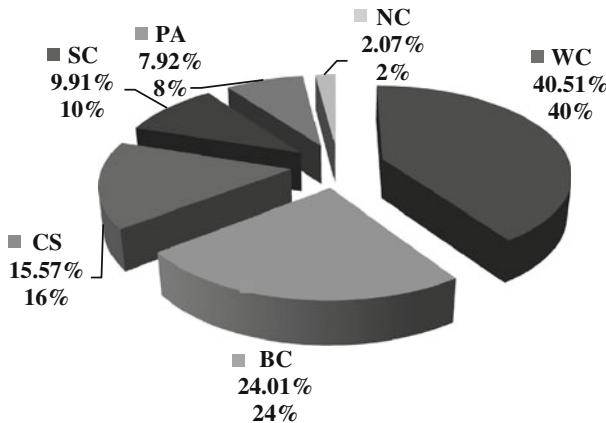


Fig. 2 Proportions of water conservation (WC), biodiversity conservation (BC), carbon sequestration (CS), soil conservation (SC), purification of the atmosphere (PA), and nutrient conservation (NC) of total value of FES (10.01 trillion CNY, 1.48 trillion USD) in China

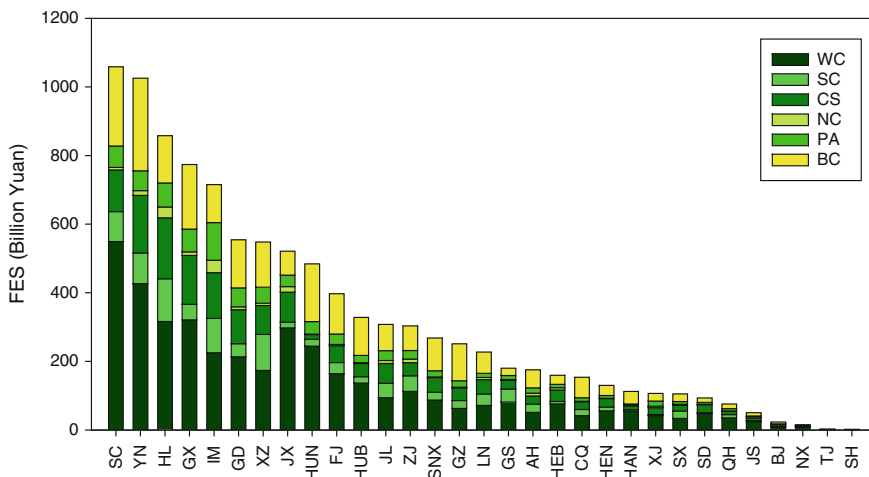


Fig. 3 Monetary value of water conservation (WC), biodiversity conservation (BC), carbon sequestration (CS), soil conservation (SC), purification of the atmosphere (PA), and nutrient conservation (NC) (billion CNY) provided by forests in 31 provinces. AH Anhui; BJ Beijing; CQ Chongqing; FJ Fujian; GS Gansu; GD Guangdong; GX Guangxi; GZ Guizhou; HAN Hainan; HEB Hebei; HL Heilongjiang; HEN Henan; HUB Hubei; HUN Hunan; IM Inner Mongolia; JS Jiangsu; JX Jiangxi; JL Jilin; LN Liaoning; NX Ningxia; QH Qinghai; SD Shandong; SH Shanghai; SNX Shanxi; SX Shanxi; SC Sichuan; TJ Tianjin; XJ Xinjiang; XZ Xizang (Tibet); YN Yunnan; ZJ Zhejiang

Mongolia 7.15 %) had higher contributions to the total national FES; Central and Eastern provinces (e.g., Jiangsu 0.51 % and Shanghai 0.02 %) had lower contributions (Fig. 4).

2.3.3 Per Unit Area FES Value at the Provincial Level

Variation in provinces exists in terms of mean FES per unit forest area ($\times 10^3$ CNY/ha). For instance, the highest FES per unit forest area was in Hainan (64×10^3 CNY/ha), and the lowest one in Xinjiang (16×10^3 CNY/ha). The mean FES per unit forest area for the whole country was 46×10^3 CNY/ha.

2.3.4 FES of Different Forest Types

Forty-nine kinds of forests were classified into four groups according to their contribution to the total FES: >10 % group (shrubbery and broadleaf forest), 5–10 % group (*Quercus* spp. forests, economic forests, conifer and broadleaf mixed forests, and *Pinus massoniana* forests), 1–5 % group (13 kinds of forests), and <1 % group (30 kinds of forests). The first two groups displayed a substantial contribution

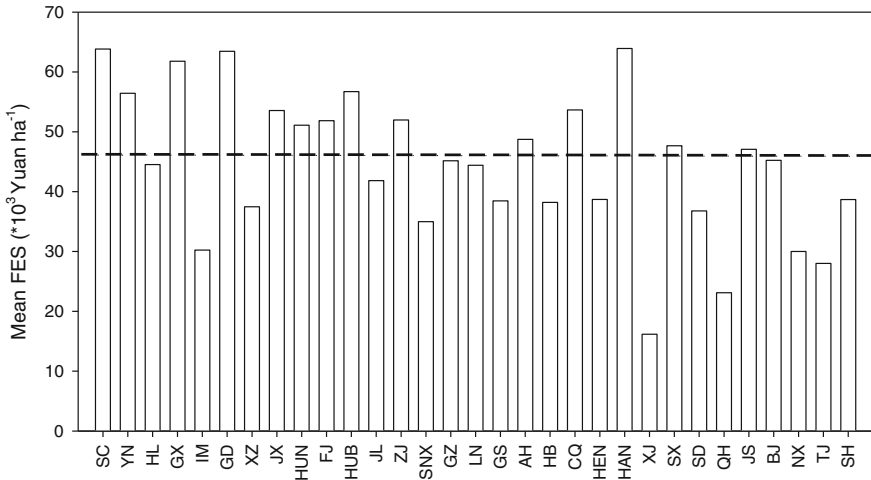


Fig. 4 The mean FES per unit area ($\times 10^3$ CNY/ha) for each province (column) and entire country (dash line). For province acronyms see the legend to Fig. 3

to total FES (57.79 %). As a single genus, *Quercus* spp. forests had the largest contribution to total FES (11 %), and as a species, *P. massoniana* had the largest contribution (5.00 %)

2.3.5 Characteristics of China's FES Value

High spatial heterogeneity of FES value and decoupling from GDP China has an unbalanced development for the economy and environment protection. Like economic production (e.g., GDP as an indicator), FES varied greatly among provinces (Fig. 4). The contributions of the FES value of provinces were decoupled from the contribution of GDP (in 2009) at the national level (Fig. 4). Large FES contributions arose from Sichuan, Yunnan, Guangxi, Heilongjiang, and Inner Mongolia, whereas large GDP contributions arose from Guangdong, Jiangsu, Shandong, Zhejiang, and Henan. The smallest FES contributors were from Shanghai, Tianjin, Ningxia, Beijing, and Jiangsu. In general, the largest FES contributors were undeveloped provinces and remote provinces are located in the northeast and southwest China. Large GDP contributors were the Eastern and Central provinces and metropolitan regions. As an extreme example, Shanghai is the most developed region in terms of economy, society, and technology, but its FES contribution is negligible at a national scale. Tibet, in southwest China, is an opposite example (Fig. 4). Given the pattern of decoupled FES and GDP across the country, special importance for economic compensation from higher GDP provinces to higher FES provinces in China is apparent.

Rapid increase in future FES Changes in ESs in the UK were investigated, showing that a decline or increase in ESs was dependent on the ecosystems of the previous years (UK NEA 2011). In contrast, China's FES value will rapidly increase in the coming decades as a large proportion of forests are young plantations (33.8 %) (SFA 2009a). These young plantations have great potential to grow in size and ecological function, and will likely result in a net increase in FES values. The Chinese government has announced a plan to expand the forested areas by 40 million ha between 2005 and 2020 because of the huge potential for sequestering atmospheric CO₂ (Pan et al. 2011). Therefore, forests in China are expected to increase in stock (stock density and total area) and ecological functions in all key aspects of FES, including carbon sequestration, nutrient accumulation, and water and soil conservation in the future.

Parts of plantations and economic forest in providing FES China has the largest area of plantation in the world, accounting for 38 % of its total forest area; more plantations are being planned over the next 10 years. Plantations play essential roles in providing FES and materials. This is a distinct feature compared to Canada, Russia, and the USA (FAO 2010). In particular, the plantation area of China is about 62 million ha (38 % of national forest areas), of which half is economic forest (32 million ha) (SFA 2009b). For economic forest, the annual direct economic income was 3.56 trillion CNY in 2008 (SFA 2009b) and provided 1.4 trillion CNY FES value, about 40 % of direct economic income.

Differences in FES demands by region Different regions and provinces have distinct demands for FES because of differences in geography, climate, and social development. For example, in the eastern plains of China, where the economy and society are developed, the function of forest ecosystems in the purification of air pollution is more favorable, while in the northwestern mountainous region, water conservation is vital. Similarly, such differences exist among countries. Relative to the larger need for the roles of water and soil conservation in China and Japan, the value of protecting biodiversity, landscape, culture, and tourism in the UK (UK NEA 2011) and Canada (Anielski and Wilson 2005) may be more important.

2.3.6 Policy Development for Ecological Compensation at a National Level

Relative to countries with balanced economic and environment development (e.g., Canada, USA, and UK), developing ecological compensation policy is especially important in China because of its distinct decoupled GDP and FES. In fact, much discussion in China has focused on how to determine economical compensation for underdeveloped regions with high FES from low FES but economically developed regions (Fei et al. 2004; Sun and Chen 2006). For establishing such a framework, quantifying the monetary value of ESs is important. In this sense, the assessed value

of FES could be used as a basis for establishing ecological compensation at a national level. For example, Sichuan, Yunnan, Heilongjiang, Guangxi, Inner Mongolia, and Tibet are the top five provinces (from 7.15 to 10.17 %) (Fig. 4) in terms of FES contribution to the national total, but are all located in undeveloped regions. In general, eastern provinces have higher GDP contributions, whereas northeastern and western provinces have higher FES contributions (Fig. 4).

Further, 58 % of forests fall under collective ownership in China, with the state owning remaining forests. Reforms to change the collective ownership forest system to private ownership in China are ongoing. This is considered a way to efficiently manage existing forests and increase new plantations in non-forest mountains (Zhao et al. 2010) and these private forests can be traded in a forest ownership trading center. This ongoing area of reform is considered a significant change in China's forestry system and the FES value in a stand should be taken into account in future trading.

Although current forest coverage across China is 20.36 % and it has 286.6 million ha of forested land (SFA 2009b), establishing forests in mountainous areas where commercial forests for timber production are not suitable is in high demand. Farmers are more interested in planting trees in those areas if their investments deliver through the consideration of FES values on the forest trading market, in addition to the direct benefits of forests.

2.3.7 Improving Assessment Methods

Barriers to the complete assessment of FES across an entire country remain (e.g., methodology) despite that a theoretical framework has been proposed to account the value of all ESs (e.g., supporting, provisioning, regulating, and cultural services) (Costanza et al. 1997). UK NEA (2011) and Merlo and Croitoru (2005) exercised a relatively more complete FES assessment at the national scale in UK and in some Mediterranean countries. However, the current assessment in China only includes parts of the FES. Specifically, the aesthetic values, cultural heritage, and educational values of ecosystems are not considered because of a lack of methods for assessing the FES values of ecosystems, other than water conservation, soil conservation, carbon sequestration and oxygen release, nutrients accumulation, atmosphere environment purification, and biodiversity conservation.

International timber trading may transfer some of the FES observed in a country to losses of forests in other countries (Mayer et al. 2005). China is not self-sufficient in wood products and needs to import round wood and pulp from other countries. Thus, the effects of international trade should be considered when calculating the net FES value when accounting FES in a country.

An important feature of China's FES assessment is its close combination with data from national forest resources surveys conducted nationally at 5-year intervals. This means it is possible to produce a regular assessment of FES at a provincial and national level into the future.

3 Assessment of Wetland Ecosystem Services in China

3.1 Introduction

It is well known that wetlands are an important component of the terrestrial landscape, performing significant ESs such as climate regulation, flood storage, water supply, and biodiversity conservation. Increasing human land use has put wetlands at risk. The Organization of Economic Cooperation and Development (OECD) estimates that the world may have lost 50 % of its wetlands since 1900, and land conversion for agriculture is the principal cause (OECD/IUCN 1996). Once thought to be wastelands, wetlands have been extensively drained for economic development. Direct land conversion for agricultural drainage, forestry, and urban construction has caused widespread degradation and destruction of wetlands.

In the mid-1990s, an article titled *The Value of the World's Ecosystem Services and Natural Capital* represented the beginning of TEV estimation of our planet. The services of ecological systems and natural capital stocks that produce them are critical to the functioning of the earth's life support system (Costanza et al. 1997).

Loss or degradation of wetland habitats can result in a loss of biodiversity, reduction in water supply and water storage, and increased soil erosion. Additionally, wetland conversion for industrial and agricultural purposes has directly or indirectly contributed to an increase in atmospheric concentrations of major greenhouse gases. How to recognize or understand these functions generally remains a challenge and it is very important to introduce value estimation. Restoration actions that enhance both biodiversity and ESs are necessary worldwide. In order to achieve the goal of 'no net loss' of wetland function, we should establish wetlands compensation accounts to balance any loss.

3.2 Wetland Ecosystem Services and Value Estimation

3.2.1 Wetland Ecosystem Services

Ecosystem functions refer variously to habitat, biological or system properties or processes of ecosystems. Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions. For simplicity, we will refer to ecosystem goods and services together as ESs. A large number of wetland services have been identified such as carbon sequestration and greenhouse gases emissions, flooding regulation, biodiversity, nutrient cycling, water supply, waste treatment, food production, and sediment retention.

Wetlands regulate biogeochemical cycling, play an important role in the global carbon budget and exchange greenhouse gases such as carbon dioxide (CO₂) and

methane (CH₄) with the atmosphere. According to the Chinese Second Soil Survey, wetland soil organic carbon (SOC) density ranges from 14.1 to 60.0 kgC/m² (Pan 1999). Wetland SOC density ranged from 13.9 to 47.3 kgC/m² in the Sanjiang Plain, northeastern China (Ma et al. 1996). Recent global concerns over increased atmospheric CO₂ have furthered interest in SOC changes and the carbon sequestration capacity of various ecosystems, especially wetlands. CH₄ is a very potent greenhouse gas, and CH₄ emissions from natural wetlands account for 20 % of global emissions (Liu 2004).

Flooding regulation, storm protection, or drought recovery of wetland habitat responding to environmental variability are mainly controlled by wetland vegetation structure. For example, the porosity of vegetation roots was up to 71–93 % and maintains flooding. The mean depth of marshlands is 30 cm, so natural marshlands can store 17.15×10^8 m³ of water. Taking into account the Sanjiang Plain, Liu et al. (2007) indicated that maximum soil water storage was 46.97×10^8 m³.

Wetland habitats are keystones of biodiversity reservation. Patchy shapes, area and corridor length influence species migration. Endangered waterfowl and other species that rely on wetlands have become threatened or extinct in areas where wetland habitat has been destroyed (Liu 2005).

3.2.2 The Coupling of Wetland Structure, Process, and Service

Land use changes impact GHG emissions because of the growing human population. Although the greenhouse effect is a global issue and under global influence, one should consider the effect of these gases on our local and regional climates. Wetland ESs such as gas regulation have become one of the key issues in environmental and ecological scopes (Liu et al. 2013). What influence do changes in ecosystem structure and process have on services? This is a key question when trying to improve wetland services.

Flood pulse supports floodplain biological productivity functions, but under disturbance by people, hydrological regime changes may impact the flood pulse. After wetlands are drained, they are converted from CO₂ sinks to CO₂ sources, leading to carbon cycles. In the long run, there is a potential to influence global warming (Lu 2004).

3.2.3 Wetland Ecosystem Service Estimation and Dynamic Change

The value coefficients of different wetlands ESs are listed in Table 1. There is much research on the types of natural wetland services and their values, but little research on the ESs of constructed wetlands.

Compared to the value coefficients of different services, we must consider regional heterogeneity when estimating ESs. Services are affected by different geography, ecology, and climates, so the values of these services also differ.

Table 1 The value coefficient of different wetland ecosystem services (CNY/(ha, year))

	Gas regulation	Climate regulation	Water storage	Soil formation and conservation	Waste treatment	Biodiversity maintenance	Food production	Raw materials	Recreation and culture	Sum
Nation	1573	-	-	2	-	-	-	-	-	1575
Poyang Lake	598	-	301	2008	-	-	-	-	-	2906
Yangtze River Estuary	-	-	716	-	1585	1328	-	-	2235	5863
Wetland Reserve	-	-	-	-	-	5063	-	-	-	5063
Rice paddy	-	-	-	16	-	-	-	-	-	16
Global	1104	37,674	31,665	-	34,171	2523	2125	880	12,077	122,218

Note China's wetland area is 6594×10^7 ha; this table is from Liu et al. (2008)

Worldwide, wetlands have had the fastest rate of loss amongst all ecosystem types. Many studies have investigated marshland loss and landscape changes in some portions of the Sanjiang Plain or over the whole region. Land use changes have spatial and temporal patterns, and correspondingly, ESs exhibit dynamic change. The value of wetland ESs may decline when wetlands shrink.

3.3 Conclusion and Discussion

Ecological economic methods could be an effective way to value wetland ESs. These methods clarify the conceptual difference in the functions and services of ecosystems and reveal the relationship among structure, process, and service. This approach also identifies the different services of different wetland types and means the indirect value of ESs are easily understood. In the future, dynamic changes in service estimation should stimulate wetland conservation and restoration.

Considering environmental and human factors, we should give priority to dominant services across different wetland types. Ecological compensation should be implemented for loss of wetland and other ecosystems. Monitoring station network data are critical in wetland service estimation, such as for the service of biodiversity.

4 Assessment of Grassland Ecosystem Services in China

4.1 Introduction

ESs are the foundation that sustain and fulfill human life and development (Daily 1997; Ouyang et al. 1999a, b). Grasslands are the largest and most important terrestrial ecosystem in China and play a major role in maintaining ecological safety, forage production, soil erosion prevention, biodiversity conservation, and carbon sequestration (Xie et al. 2003). Costanza et al. (1997) valued grassland ESs at a global scale and showed that the valuation of global grassland is 9.06×10^{10} USD, accounting for 7.3 % of total terrestrial ESs. Zhao and Ouyang (2004) and Min et al. (2004) studied the ESs of Chinese grasslands and the Inner Mongolia steppes, respectively, and found that grassland ESs are important for maintaining ecological conditions and the development of society (Zheng et al. 2009). However, several grassland ecosystems and their services have been degraded across China because of the rapid development of local economies, increased population, and animal husbandry (Xu et al. 2005; Yu et al. 2005). It is important to understand how human actions impact the ESs of grasslands so that these precious resources can be managed in a sustainable way. Here, I report on a study of the impacts of human

disturbance on ESs in the Inner Mongolian steppes region, including grazing, non-grazing, and reclamation.

4.2 Site Description

The study area is located in experimental pasture at the Meteorological Bureau of Xilinhaote City, China (116°04'N–117°05'N, 43°26'E–44°08'E). The region has a temperate semiarid continental climate, with a windy and dry spring, a warm and rainy summer, a very short autumn, and a long and cold winter. Precipitation is 300 mm and the annual average air temperature is -0.1 °C. The site is located in the central region of Inner Mongolia typical steppe, composed of the following species: *Stipa krylovi*, *Leymus chinensis*, *Cleistogenes squanosa*, *Anemarrhena asphodeloides*, *Allium anisopodium*, *Allium ramosum*, *Salsola collina*, and *Carex duriuscula*. The soil is characterized as chestnut soil. There are experimental plots for non-grazing of different times (2, 7 and 17 years), and grazing plots are located outside non-grazing plots.

4.3 Conclusion and Discussion

4.3.1 Impact of Disturbance on Biomass

Cultivation and grazing decrease biomass in the ecosystem and non-grazing increases it. The net productivity of the ecosystem is highest for farmland and smallest for grassland under grazing; grassland under non-grazing for 7 and 2 years is higher than that for 17 years. The valuation of production of goods is biggest for the farmland ecosystem from grassland. Non-grazing can raise the valuation of production of goods, and the longer the banned-grazing period, the larger the valuation.

4.3.2 The Impact of Disturbance on Carbon Storage

Cultivation leads to a sharp decrease in soil carbon storage; non-grazing distinctly leads to increases in the carbon storage of soil, litter, and aboveground plants and roots. Topsoil (0–20 cm) carbon storage is affected strongly by human disturbance rather than deep soil. Topsoil (0–20 cm) organ carbon densities are ranked in the descending order as follows: grassland non-grazing for 17 years (4.47 kg/m^2) > grassland banned-grazing for 7 years (4.23 kg/m^2) > grassland banned-grazing for 2 years (4.01 kg/m^2) > grazing grassland (3.70 kg/m^2) > farmland (2.27 kg/m^2). Total carbon storage is ranked in the descending order as follows: grassland non-grazing for 17 years

$(9.44 \text{ kg/m}^2) > \text{grassland non-grazing for 7 years } (9.09 \text{ kg/m}^2) > \text{grassland non-grazing for 2 years } (8.82 \text{ kg/m}^2) > \text{grazing grassland } (8.78 \text{ kg/m}^2) > \text{farmland } (4.72 \text{ kg/m}^2)$.

4.3.3 The Impact of Disturbance on Anti-wind Erosion

Wind erosion rates (WER) of grassland soil increase as wind speed rises, but are limited by the amount of erodible soil. In general, the WER of farmland soil is unlimited because of its deep plough layer. The WER and wind erosion amount (WEA) in banned-grazing grasslands are lower than that under grazing, and the longer the banned-grazing period the less the WEA and WER. In cultivated land the WEA and the WER are more than for natural grasslands and the differences between them increase with wind speed. Non-grazing reduces the loss in valuation due to wind erosion, and cultivation and grazing can increase this. Value loss rates ranked in the descending order are: farmland (initial stages of cultivation) > farmland > grassland under grazing > grassland non-grazing for 2 years > grassland non-grazing for 17 years.

4.3.4 The Impact of Disturbance on Soil Nutrient Content

Cultivation and grazing lead to a decrease in soil nutrient content, especially topsoil, and cultivation affects it more significantly than grazing. Non-grazing increases soil nutrient content, which increases with the time of banned-grazing. Using valuation by biology nutrient pools, the value of the nutrient circle maintaining service is 1302.54 CNY/(ha year) for farmland, 571.87 CNY/(ha year) for grassland non-grazing for 2 years, 556.09 CNY/(ha year) for grassland non-grazing for 7 years, 551.65 CNY/(ha year) for grassland non-grazing for 17 years, and 441.03 CNY/(ha year) for grassland under grazing. Subtracting the cost for farmland, the value of farmland is only 2284.37 CNY/(ha year). Using valuation by soil nutrient pools, the value of the nutrient circle maintaining service is 3911.52 CNY/(ha year) for grassland non-grazing for 17 years, 3813.43 CNY/(ha year) for grassland non-grazing for 7 years, 3665.09 CNY/(ha year) for grazing grassland, 3648.77 CNY/(ha year) for grassland non-grazing for 2 years, and 2893.43 CNY/(ha year) for farmland.

4.3.5 The Impact of Disturbance on Biodiversity Nutrient Content

Non-grazing does not affect the composition of dominant species markedly, but does affect the dominance of species. Non-grazing enhances the biodiversity of grasslands at an early stage, but as non-grazing time extends, biodiversity and the richness of grasslands decline. Water conditions affect biodiversity distinctly and appropriate non-grazing times and better water conditions favor the restoration of grassland biodiversity. The decline in biodiversity of grasslands in this region can be ascribed to over grazing and drought.

5 Assessment of Agroecosystem Services in China

5.1 Introduction

Agroecosystems have become integrated crop production systems with significant human disturbance. Compared to natural ecosystems, the crop production function of agroecosystems has intensified while impairing other ESs such as gas and water regulation, soil conservation, and biodiversity maintenance (Fowler and Mooney 1990; Wood et al. 2000; Tilman et al. 2002). In recent years, agro-ESs have become more and more scarce because of demands from rapid global development (Tilman et al. 2001; Foley et al. 2005). This has resulted in increasing concern about the values and services of agroecosystems across the world. The biodiversity of agroecosystems was the physical basis for ESs (Wall et al. 2010). There have been many studies on agro-ESs, including production supply, carbon sequestration, soil conservation, nutrient cycling and water regulation, and comprehensive assessments of agro-ESs (Xie et al. 2005; Swinton et al. 2007; Sandhu et al. 2008; Porter et al. 2009; Yoshikawa et al. 2010). The passive effects (e.g., nonpoint pollution, CH₄/N₂O emissions and heavy metal pollution) of agricultural production on human society and the environment have also been explored (Liang et al. 2007; Köel-Knabner et al. 2010; Xiao et al. 2010). Farmers and government organizations have realized the importance of the tradeoff between the advantages and disadvantages of agricultural production. The various effects of agricultural production systems (e.g., integrated, conventional and organic agroecosystems, and combined food/forest systems) on the services of different agroecosystems have been compared (Yang et al. 2007; Xiao et al. 2011). Only multifunctional agricultural production systems maximize welfare supported by agro-ESs. To manifest the effects of ESs of agroecosystems to human well-being, three main studies have been conducted and will be discussed in this section.

5.2 Assessments of Ecosystem Services by Agroecosystems in China

5.2.1 Ecosystem Services by Wheat-Maize Croplands on the North China Plain

Field investigations were conducted at Luancheng Agro-Ecosystem Experimental Station of the Chinese Academy of Sciences in Hebei from 2006–2007 (Xiao et al. 2011). Field data were then used to evaluate the ESs of wheat-maize croplands in the North China Plain. ESs analyzed included primary products, gas regulation, soil organic matter (SOM) accumulation, water regulation, and nitrogen transformation. The results showed that primary products from croplands accounted for 5.04–5.71 t/(ha year) of wheat grain, 6.69–8.24 t/(ha year) of maize grain, 8.58–9.72 t/(ha year)

Table 2 Assessment of ecosystem services by wheat-maze agroecosystems CNY/(ha year)

Services types	2006		2007	
	N1	N2	N1	N2
Primary production	19,679	21,210	19,267	19,233
Gas regulation	37,346	41,384	36,256	36,141
SOM accumulation	2033	967	2033	967
Water regulation	-215	-230	-173	-188
N transformation	2977	-962	2900	-1424
Integrated values	61,897	62,484	60,356	54,809

Note In the integrated values of ecosystem services of the wheat-maize agro-ecosystem, the value for N₂O emissions was just counted once, though it was calculated both in gas regulation and nitrogen transformation. N₂O emission values were -78 CNY/(ha year) (N1), -114 CNY/(ha year) in 2006 and -73 CNY/(ha year) and -79 CNY/(ha year) (N2) in 2007

of wheat straw, and 6.97–8.58 t/(ha year) of maize straw. As for cropland gas regulation: O₂ and N₂O emissions were 24.99–28.64 t/(ha year) and 0.72–1.13 kg/(ha year), whereas CO₂ and CH₄ assimilations were 34.23–39.22 t/(ha year) and 3.39–5.70 kg/(ha year), respectively. While cropland SOM accumulation was 1.13–2.39 t/(ha year), that of water consumption was 2890–3830 m³/(ha year). Soil nitrogen content dropped considerably at a rate of -107.73 to 5.33 kgN/(ha year) after one crop rotation. The TEV of cropland ESs was estimated at 5.48×10^4 to 6.25×10^4 CNY/(ha year), three times the value of food production. Based on these results, the effects of nitrogen fertilizer on the welfare of cropland ESs appear complicated. Nitrogen application led to economic loss due to increasing nitrogen transformation, simultaneously, increased economic value of primary production, gas regulation, CO₂ fixation, and O₂ release. Most ES studies have focused on the positive effects of ecosystems on human welfare, but a balanced and reasonable approach is to analyze the positive and negative effects of cropland ESs on human welfare (Table 2).

5.2.2 Ecosystem Services by Rice Paddy Ecosystems in Suburban Shanghai

The rice paddy is one of the most important farmland systems in China, responsible for more than one-third of total food production. Rice paddy ecosystems cannot only provide food, but also support many ESs such as gas regulation, water regulation, flood controlling, SOM accumulation, nutrient transformation, and environment purification. In 2002, we executed a field experiment in a rice paddy ecosystem at Wusi Farm, Shanghai to examine the ESs of rice paddies under different levels of nitrogen application (Xiao and Xie 2009). We investigated

primary production, gas regulation, nutrient transformation, SOM accumulation, water regulation, and environment purification and their values. The results of primary production indicated that the rice seeds and stalks and their values increased with N application. Gas regulation showed that rice paddies absorbed CO₂ from the atmosphere; O₂ emissions and N₂O emissions by rice paddies increased with N addition, but CH₄ emissions decreased with N addition. The economic value of gas regulation by rice paddies with 375 kgN/ha was the highest. Nitrogen transformation indicated that among different sources of nitrogen inputs, nitrogen application provided the most nitrogen input and the harvest and ammonia volatilization were the most important nitrogen outputs. According to this study, nitrogen transformation resulted in economic loss and these increased with nitrogen addition. SOM showed that rice planting increased the content of SOM, and the quantities of SOM accumulation and their values increased with N application. Rice cultivating consumed water resources, and the ridge of the rice paddies controlled flooding as a reservoir with a height of 5 cm. Comprehensive evaluation indicated that ESs by rice paddies in Wusi Farm provided many benefits to society in the range of 3.83–4.85 × 10⁴ CNY/ha. The ESs by rice paddies with 375 kgN/ha of N application yielded the highest economic value. However, the economic values of the ESs by these rice paddies did not have significant advantage over those without N application. The economic loss of environmental damage by N application comprised the benefits supported by rice paddies. Therefore, to maximize the benefits of ESs and the sustainability of rice production, the government should control the release of nitrogen fertilizer and improve nitrogen application technologies to improve the efficiency of nitrogen application (Table 3).

Table 3 Assessment of ecosystem services from a rice paddy agro-ecosystem at Wusi Farm in 2002 CNY/ha

Services types	N0	N225	N375	N525
Primary production	6469	7694	11,769	13,181
Gas regulation	36,858	34,586	37,810	30,808
N transformation	628	-5264	-9956	-14,992
SOM accumulation	3160	4073	8731	8936
Water regulation	1891	1891	1891	1891
Environment purification	941	941	941	941
Integrated values	48,322	41,250	48,518	38,290

Note In the integrated values of ecosystem services of the rice paddy agroecosystem, the value for N₂O emissions was counted once, though it was calculated both for gas regulation and nitrogen transformation

5.2.3 Evaluation of Ecosystem Services Provided by 10 Typical Rice Paddies in China

Based on a reference review, this study investigated ESs supported by 10 typical rice paddies in six rice planting regions of China (Xiao et al. 2011). The services were primary production, gas regulation, nitrogen transformation, SOM accumulation, and water regulation and flood control. The results indicated that grain production of the 10 rice paddies was between 4.71 and 12.18 t/(ha year); straw production was 4.65–9.79 t/(ha year); gas regulation was calculated to emit O₂ ranging from 8.27 to 19.69 t/(ha year) and to assimilate greenhouse gases ranging from –2.13 to 19.24 t/(ha year) (in CO₂ equivalent); nitrogen transformation was estimated as nitrogen input from 209.70 to 513.93 kgN/(ha year) and nitrogen output of 112.87–332.69 kgN/(ha year); SOM accumulation was between 0.69 and 4.88 tC/(ha year); water regulation was estimated to consume water resources of 19,875 m³/(ha year) and to support water resources of 6430 m³/(ha year); and flood control of several of the rice paddies was calculated to be 1500 m³/(ha year) (Table 4). The integrated economic value of ESs of these rice paddies was estimated at 8605–21,405 USD per ha per year, of which 74–89 % of the value can be ascribed to ESs outside primary production. The integrated economic value of the ESs of the 10 rice paddies was higher when nitrogen fertilizer was applied in the range of 275–297 kgN/(ha year). Until now, the economic value of the rice paddy ecosystem has been underestimated as only the economic value of grain and straw production were previously calculated. As more and more forestland and grassland

Table 4 Integrated economic values per unit area of ecosystem services for 10 rice paddies in China

Sites	Primary production	Gas regulation	Nitrogen transformation	SOM accumulation	Water regulation	Integrated economic values
Guangzhou	3013	11,557	287	2538	444	16,525
Changshu	2665	15,095	317	852	387	18,351
Chengdu	2219	11,654	–71	2063	385	15,407
Taoyuan	3564	14,735	264	3487	367	21,405
Yingtian	2556	4610	58	2509	359	9677
Bijie	2166	5486	497	1145	414	8605
Fengqiu	1484	7532	–1498	494	387	8657
Shenyang	2622	14,353	381	739	32	17,002
Hailun	1810	13,687	632	979	–22	16,338
Lingwu	2283	16,719	–906	1213	–204	18,878

Note All values are USD/(ha year). As values of grain and straw harvest in nitrogen transformation and primary production were recalculated, only the economic value of primary production was calculated in the integrated value. As the economic value of N₂O emission was also recalculated in gas regulation and nitrogen transformation, only the economic value of N₂O emission in gas regulation was calculated in the integrated value

is lost to urban and industrial uses, cropland, especially rice paddies, will become more ecologically important to society. The economic value of ESs supplied by rice paddies, outside primary production, are therefore worthy of increased research attention.

5.3 Conclusion and Discussion

In this section, we reviewed research on the ESs of agroecosystems and estimated the economic value of ESs of (1) wheat-maize croplands in Luancheng County, Hebei, (2) rice paddy fields in suburban Shanghai, and (3) 10 typical rice paddy fields across China. The results indicate that primary production was the core service delivered by these agroecosystems. Gas regulation, water conservation, nutrient maintenance and transformation, and environment purification also contribute to human well-being.

Agroecosystems support food and other critical ESs to people, but impair human well-being by the addition of chemical fertilizers, pesticides, and herbicides. This tradeoff between food production and the impassive effects remain a major challenge for the implementation of sustainable agriculture. Compared with natural ecosystems, intensive agro-systems supply much more food and relatively fewer ESs, such as gas regulation, water regulation, and nutrient transformation. The impassive effects of intensive agriculture on social-economic systems counteract the human well-being supplied by food and fiber production in the long run. Agroecosystems with a natural buffer belt and those that compromise primary production and other ESs are better choices for achieving primary products, other ESs and sustainable agriculture. The future direction of sustainable agriculture will be to manage agroecosystems by optimizing human well-being supported by both primary production and other ESs.

6 Assessment of Marine Ecosystem Services in China

6.1 Introduction

ESs refer to the natural environmental conditions and their benefit formed by ecosystems through ecological processes, on which humankind relies on for survival (Daily 1997). Since the early 1990s, studies on ESs have rapidly progressed and become one of the dominant research topics and frontlines (Daily 1997; Costanza et al. 1997). The promulgation of the MEA by the United Nations in 2005 has drawn broad attention and concern from the governments of many countries and a wide variety of sectors of society. To date, almost every type of ecosystem on

earth has been assessed and we have gradually recognized the great value of natural ecosystems to our long-term survival and development.

Marine ESs refer to the products and services provided for the survival and development of human society by specific marine ecosystems within a given period of time and through certain ecological processes. Compared to our knowledge of land systems, our recognition and understanding of seas and oceans are relatively poor. In particular, the complexity and uniqueness of marine ecosystems and the applicability of assessment methodologies means assessments of marine ESs and their values are extremely difficult.

6.1.1 Progress in Basic Research on Ecological Theories

The formation and realization of ESs requires the support of complex ecological processes. Changes in the size of an ecosystem are influenced by changes in biodiversity. Many ecologists have conducted in-depth research on relationships between ESs and biodiversity (Naeem and Li 1997; Loreau et al. 2001; Hemminga and Duarte 2000). A number of researchers have also focused their efforts on the formation mechanisms of ESs, including sources of ESs and methods for realizing their value (Zhang et al. 2006; Wu 2006) and the influence of human activity on ESs (Holmlund and Hammer 1999).

Naeem and Li (1997) found that biodiversity can strengthen the stability of ecosystems and that biodiversity can prevent population loss and functional reduction: the higher the species number, the more stable the ecological system. Hemminga and Duarte (2000) stated that the correlations between biodiversity and ecosystem functions/services are very complex. To study these correlations is very important to elucidate the impacts of biodiversity on ecological system function, and is also helpful when explaining reasons for protecting biodiversity rather than protecting individual species alone. Using seaweed as a case study, Hemminga and Duarte (2000) analyzed the supporting function of biodiversity for the function and services of various ecosystems. Holmlund and Hammer (1999) defined fish ESs as the maintenance of functions and elasticity of ecosystems and called these ecological services derivatives of human demands. Holmlund and Hammer (1999) stated that overexploitation of fishes globally not only reduces the total allowable catch and the capability of population regeneration but also threatens ecological services provided by fish populations, reduced biodiversity, ecological functions and our welfare.

Zhang et al. (2006) analyzed ESs supported by major ecological processes, including photosynthesis, respiration, biological pump functions, decomposition, mineralization, calcification, bioturbation processes, nitrogen cycle processes, biotransport, and bioabsorption. Referring to the classification methods of ESs developed by Costanza et al. (1997), Wu (2006) divided ecological service functions of a mangrove ecosystem in Guanxi, China into three types (resource function, environmental function, and humanity function) and analyzed in the formation processes for each service function.

6.1.2 Progress in Basic Research on Economic Theories

The evaluation of the value of ESs requires the support of economic theory. Costanza et al. (1997) analyzed the characteristics of ESs and stated that the total value of resources was the sum of producer surplus and consumer surplus. Due to the requirement of curve estimation for ESs and the difficulty in calculating consumer surplus, a contingent valuation method (CVM) based on public surveys on the willingness to spend on environmental quality improvement or willingness to accept the tolerance of environmental loss, plays an important role in evaluation of the nonmarket values of ESs (Loomis et al. 2000).

Stephen et al. (2002) expounded the economic and ecological meaning of values and corresponding methods for evaluation techniques. Values based on utility commodities and services reflect people's willingness to acquire them or the willingness of accepting compensation for giving them up, whereas values based on trade reflect the values of commodity and trade services. In the evaluation of market values, this value reflects the marginal values of the commodities or services. However, in the evaluation of the nonmarket values, indirect estimation methods are required. This method is new and a supplement method for the classical value theory or a replacement of energy value theory, and is also one of the methods for value evaluation on the natural assets recommended by ecologists and economists. Time can be also used as a means for value evaluation (Farber et al. 2002). The ecological footprint (EF) method based on material flow within ecosystems can be used to carry out calculations and assessments by converting a variety of human consumption and activity into land area (Rees 1992). Thus, evaluation methods for monetization are not the only standard method for the value evaluation of ESs. Due to convenience, this is the most common method used to evaluate the value of ESs.

Chinese researchers have conducted some research on economic theories for the assessment of marine ESs. Based on labor theory of value and utility theory of value, Wang et al. (2005) investigated the value theory of marine ecological resources. Zheng et al. (2006) analyzed the role of ESs in meeting human requirements from the angle of welfare economics. They stated that both the ESs and human welfare influenced and interacted mutually. Through definition and content analysis of ecological assets, Zheng et al. (2007) analyzed asset attributes from the aspects of revenue, scarcity, and rights.

6.1.3 Progress in Research on Value Assessment Methods

Types of Marine Ecosystem Service Values

Analysis and classification of the components of marine ESs are the basis for carrying out value evaluation of ESs. Pearce et al. (1989), McNeely et al. (1990), Turner et al. (2001) have conducted substantial research on the components of ESs and methods for assessment. Pearce et al. (1989) proposed a theory of the TEV of

natural resources that includes utilization values, existence values, and selection values. The utilization values can be divided into direct utilization values and indirect utilization values. The selection values include the individual's future utilization values, other peoples' future utilization values and future generations' utilization values. McNeely et al. (1990) stated that biological resources can be divided into direct values and indirect values. The former can be further divided into consuming utilization values and producing utilization values, whereas the later can be further divided into nonconsuming utilization values, selection values, and existence values. When Turner et al. (2001) discussed the utilities of wetlands and their management, he divided the TEV of wetlands into utilization values and non-utilization values. The utilization values included direct utilization values, indirect utilization values, and selection values. The non-utilization values included existence values and heritage values. Pearce et al., McNeely et al., and Turner laid the foundation for theoretical research on the classifications of natural assets and the values of ESs. It is generally accepted that the TEVs of ESs can be divided into utilization values and the non-utilization values. The TEVs of marine ESs can be correspondingly divided into utilization values and non-utilization values also. Currently available assessment technologies can easily distinguish direct utilization values from nondirect utilization values; however, due to overlaps among selection values, heritage values and existence values, it is difficult to clearly distinguish these from one another.

Economic Assessment Methods for the Value of Ecosystem Services

The value assessment methods for marine ESs are mainly divided into three types: the conventional market assessment methods, replacement market assessment methods, and proposed market assessment methods. For each marine ES, several methods can be used to conduct assessments. Selection of the assessment method is determined by the characteristics, application scope of the assessment methods, and obtainability of data.

6.1.4 Applied Research

Research on the assessment of marine ESs has mainly been static assessments and few studies have addressed dynamic assessments. More research has been conducted on the specific types of ecological systems than on ecosystems at a regional scale. More applied research has been conducted on direct assessments than applied research on conclusive assessments.

Taking studies conducted by Chinese researchers as examples, in recent years Chinese scientists have begun to pay attention to applied research on the management of functional assessments of offshore-coastal ESs. For example, Peng and Hong (2006) established a series of ecological-economic models and conducted an assessment and applied research on the value evaluations of ESs for the Xiamen.

Shi et al. (2008, 2009a, b) examined bay and island ESs and methods of assessment for Sangguo bay (Shi et al. 2008) and the Miaodao Islands (Shi et al. 2009a, b). They constructed assessment models for detecting the sensitivity and uncertainty of ES values (Shi et al. 2009a, b). Zheng et al. (2009a, b) constructed cost–profit analytic models for marine aquaculture patterns based on the value theory of marine ESs, and provided a feasible framework for incorporating ESs and their value assessment into marine management.

6.2 *Characteristics of Marine Ecosystem Services and Their Values*

6.2.1 The Alien Land Realization of Marine Ecosystem Services

Compared to land ESs, the alien land realization of marine ESs is especially prominent. Due to the connectivity and dynamics of marine ecosystems, the values of marine ESs are not usually realized locally. For example, climate regulation and oxygen generation provided by marine ESs are usually realized at a global scale. Furthermore, organisms within marine ecosystems can swim and migrate at a larger scale and these characteristics result in marine ESs follow an obvious alien land realization (Zhang et al. 2006).

Alien land realization makes the value assessment of marine ESs difficult. Due to alien land realization of marine ESs, it is difficult to evaluate precisely what proportion is contributed by alien land during the specific assessment process. It is also difficult to determine the range of temporal and spatial scales for certain services.

6.2.2 Temporal and Spatial Scales of Marine Ecosystem Services and Regional Dependence

The formation of marine ESs is dependent on ecosystem structure and processes at certain spatial and temporal scales. Only within certain spatial and temporal scales can the ESs play a leading role and cause significant impacts (Zhang et al. 2007). Different types of ESs confer different utilities for humans in different temporal and spatial scales. For example, the material supply service of an ecosystem is usually more closely related to the interest of local residents, whereas the regulatory services and supporting services of the ecosystem are usually related to the interests of people at regional, national, and global scales. Cultural services are closely related to interest-related aspects at the local-global scale. How large the temporal scale the formation of marine ESs depends on is a difficult point that has attracted research

attention. For example, ESs such as marine tourist/entertainment and climate regulation can be realized at regional and global scales, but the size of the selected scope of the scale of the assessment is an important factor that influences the size of the assessment results.

Marine ESs are displayed as utilities that marine ecosystems provide for people. However, the value realization of some marine ESs relies on local social and economic conditions. For example, different coastal leisure/entertainment values (an ES) at the same period of time differ. The leisure/entertainment values in the regions where population density is high and the economy is well developed are usually higher than for regions where the population density is low and the economy is less developed. Even for the same coast, due to changes in the levels of economic and social development over different periods of time, leisure/entertainment values also change. Thus, marine ESs have obvious characteristics of regional dependence.

6.3 Problems with Value Assessments of Marine Ecosystem Services

6.3.1 Deficiencies in Systematics, Theory, and Methods

Scientific systems for the theory and methods of value assessment of marine ESs have not been established. Currently, there is a deficiency in systemic studies on the formation mechanisms of marine ESs and routes for realizing service values. A majority of applied research in this area comprises simulated applications of theories and methods for land ESs. However, due to the systematics and dynamics of marine ecosystems they differ greatly from land ecosystems and the application of these methods influences the accuracy of the value assessment of marine ESs. Taking the value assessment of the nonmarket ESs as an example, due to differences in social and economic development status, public psychological characteristics, recognition level, understanding level and exploration and utilization intensity, hypothetical market assessment technologies (such as conditional value methods) widely applied to assessments on land ecosystems are less commonly applied to marine ecosystems due to large errors. This influences the value assessment of nonmarket ESs.

6.3.2 Further Improvements

Due to a lack of background multidisciplinary knowledge, our recognition of marine ecosystems is not adequately deepened. Additionally, it is difficult to acquire data and we usually place emphasis on assessment of the utilization values (the direct utilization values and the indirect utilization values) and not the

assessment of non-utilization values (selection values, heritage values, and existence values). Thus, our value assessment of marine ESs is neither complete nor perfect.

Due to different regions, differences in possession of research data and differences in the understanding of the contents of marine ESs and the application of different assessment methods, the comparability of assessment results across studies is greatly reduced.

6.4 Conclusions and Discussion

6.4.1 Basic Research on Mechanisms of Marine Ecosystem Services and Theories for Value Realization

The reason why current research on marine ESs is not adequately deepened is mainly due to the complexity of marine ecological processes and the relatively low level of marine exploration and utilization. We are still not clear what the sources of many marine ESs are and this leads to incorrect evaluations or omission of parts of ESs. Due to the characteristics of alien land realization and regional dependence, when we conduct value evaluation we must have a clear understanding of the routes and processes of realization of their values so that we can accurately grasp evaluation criteria. Thus, strengthening basic research on the formation mechanisms of marine ESs and theories for realization of their values is the only method for deepening and maturing our understanding of marine ESs.

6.4.2 The Uncertainty of Value Assessments

The accuracy of value assessments of marine ESs is consistently a tough problem in this field of research. In reviewing the entire assessment process, the main errors are outlined below.

Limitation of Assessment Methods

We do not have mature methods for the assessment of nonmarket values. Methods such as substitute cost, conditional value, shadow project, and TC are usually applied to evaluate nonmarket values. These methods have their own applicability scope and prerequisites. For example, when the substitute cost method is applied to assess the value of marine ESs and when certain ecosystems have two or more substitute products or services, determining which product or service is the most suitable becomes critical for whether the evaluation is accurate or not. When the conditional value method is applied to study a person's willingness to pay, the interviewed person's level of the recognition and understanding of ESs usually

influence their willingness to pay. We always place our hope on reducing errors through larger samples; however, these errors cannot be eliminated entirely this way.

The Weak Reliability of the Selected Assessment Criteria

Spatial heterogeneity exists between the supply of marine ESs and value realization. During the assessment process, due to the limitation of available data, criteria used for assessment of ecosystems in other regions are frequently cited. Attention should be paid to conversion at certain temporal and spatial scales to avoid errors.

Differences in Researcher Recognition of Marine Ecosystem Services

Differences in researcher recognition of marine ESs are an important factor causing assessment errors. Different researchers have conducted classifications and defined assessment methods based on their own understanding of the ecosystem and no uniform criteria for value assessment exist.

We must quickly establish the accuracy of value assessments for marine ESs, perform comprehensive assessments on the distribution characteristics of a variety of key factors and conduct research into uncertainty, so that we can provide a relatively complete description for regional marine ESs and their value.

6.4.3 Applied Research on Management Based on the Values of Marine Ecosystem Services

Research on marine ESs has mainly been static assessments at different spatial scales, which do not truly reflect the responses and feedback of marine ecosystem to man-made interference. An assessment of ESs forms a bridge between our recognition of nature and ecosystems and management decisions. Assessments are also the basis for ecological protection, ecological restoration, and ecosystem management (Ouyang 2007). The goal of marine management based on ecosystems is to make the supply capability of the ESs optimal through standardization and optimization of regional human activity. Thus, to conduct research on the responses of, and feedback from, marine ESs to human interference is needed to transition research into a decision-making process.

Due to the limitation of our recognition of marine ecosystems and assessment methods, our current attempt to conduct a complete and reliable value evaluation on ESs is impossible to realize. The purpose of assessment on marine ESs is mainly to uniformly incorporate nature and ecosystems into our economic system; the ultimate goal is to apply the values of ESs. Often, we study only a few ESs that have already been influenced by human activities and this could be a focal point for our research on marine ESs into the future.

7 Assessment of Regional Ecosystem Services in China

At the beginning of the twenty-first century, the impact of ecological degradation on human welfare and economic development increased at a global scale. The MEA was an important international cooperation plan initiated by the United Nations at a critical turn of the century aimed at depicting the health condition of the earth's ecosystem through international cooperation and meeting the scientific requirements of decision-makers. The MEA was announced by the Secretary General of the United Nations, Kofi Annan, in June 2001 and the assessment report was officially released on March 30, 2005.

The MEA is an integrated assessment on ecosystem and human well-being at multiple spatial scales, such as the community, basin, nation, region, and globe. Due to high variability of ecosystems across space and time, the MEA deployed a series of Sub-Global Assessments at all scales to ensure the evaluation results were helpful for the effective management of ecosystems.

The Chinese Ministry of Science utilized the MEA scientific conceptual framework and ecosystem assessment methods during the successful implementation of the Western China Development Strategy and consequently launched the Western China Ecosystem Assessment (MAWEC) as part of a Sub-Global Assessment of the MEA. In April 2001, the MAWEC project was officially recognized by the MEA as one of five first draft Sub-Global Assessment projects. In March 2005, the MAWEC and MEA reports were simultaneously released in Beijing.

The integrated ecosystem assessment of western China was based on the framework of the MEA and proved to be a comprehensive assessment of the status quo, evolution law and future scenarios of macrostructures and service functions of ecosystem in western China. This platform was also a driving mechanism of ecosystem change and the relationship between ecosystems and human well-being.

The MAWEC developed an integrated ecosystem process simulation and earth information science system using multitier ecological zoning and information systems to develop models for analyzing ESs. Data collected from nine areas representative of 'typical' ecologies and socioeconomic conditions were used for in-depth assessment and modeling at the local level. Trends and scenarios for water and food supply services of various ecosystems, carbon storage, and biodiversity were analyzed by combining developed models with geographical information systems (GIS). Additionally, a method of surface modeling population spatial distribution (SMPD) was developed to analyze the relationship between ESs and human well-being. Integration of multi-scale information and discrepancies with GIS data were handled through the development of high precision surface modeling (HPSM).

Through in-depth research in these nine typical areas, MAWEC revealed key conflicts between ESs and human well-being in different ecological zones and systems, refined some effective human-ecosystem relationship optimization

models, and offered good examples to guarantee the sustainability of western China ecosystems.

The results of the integrated ecosystem assessment of western China show that due to the driving forces of climate change and human activities, in the past 20 years all kinds of ecosystems in western China have experienced different degrees of degradation. For example, the area of permanent snow and ice continued to decrease and desert area increased, but ecosystem diversity increased (important carbon sequestration in China). As for the carrying capacity of ecosystems, the surrounding metropolitan areas (parts of Gansu, Shaanxi, Ningxia, and Guizhou) showed signs of overload, but the western area on the whole exhibited marginal potential carrying capacity.

The results of the future scenario analysis showed that in the next 50–100 years, due to increasing biological temperature in western China, rainfall will increase. In addition to human-driven systematic ecological restoration and reconstruction, ecosystem diversity and forest cover will increase, productivity for all kinds of ecosystems will increase and carbon sequestration will strengthened. However, rising temperatures will lead to a constant shrinking of the permanent snow zone on the Qinghai Tibet Plateau and northwest China and the area of desert will expand at a low rate.

The food supply function of ecosystems in western China will rise on the whole. Food area in the northwest increases greatly. The food supply potential of eastern parts of Inner Mongolia, Guangxi, Yunnan, and the Qinghai Tibet Plateau will fall slightly or experience less obvious change. Though there are increases in other regions, the increase was significantly lower than that of northwest China. According to analysis of population growth, the carrying capacity of ecosystems in western China guarantees population development over the next century.

In the next 50–100 years, if China engages in effective ecosystem protection and restoration according to western China development plans, ecosystems in western regions will show a benign development trend. If the intensity of human activities goes beyond the regulation range of ecosystems, western ecosystems will maintain their current trend of degradation and this may even accelerate.

In response to global environmental change and intensified human activity affecting ecosystems in western China, the following policy stages are necessary:

- (1) According to ecological function zoning, conduct regional targeted ecological construction, guide the behavior of people in particular ecological zones and ecological systems, and avoid blind development.
- (2) Adopt building a water-saving society as a basic strategy. Adapt measures to local conditions to develop the utilization and protection of water resources. For example, develop and utilize water resources of international rivers properly; develop soil reservoirs, forest reservoirs, and reservoirs; change slopes to terraces or flat farmland; conserve water through farmland; and conduct afforestation and water conservation.
- (3) Implement desertification control projects and protect vegetation. Protect existing vegetation and strictly prohibit random deforestation, disordered mining,

- farming, and grazing. Define ecological imbalanced areas which are difficult to restore or are sharply deteriorating as ‘Depopulated zones’ or ‘No animal areas’ in order to facilitate ecological balance and recovery in these regions.
- (4) Ecological environmental construction is a long-term and complicated systematic project. Given the scale of households over a vast area, simple government investment and fiscal subsidy policy is insufficient for change: there is an urgent need to establish a complete policy system that ensures ecological environmental construction in western China. In particular, all economic activity in the desertification area requires judicial management and strict monitoring.
 - (5) Taking water and soil resources carrying capacity and ecological environment capacity as the premise and the structure-function-balance-efficiency principle of the ecosystem, optimize system structure and enhance system function; combine ecological construction with economic development; vigorously promote industrialization of agriculture; and cultivate ecological economic systems to break the vicious spiral of vulnerability-poverty and fragility.
 - (6) Implement ecological compensation mechanisms across China. Long-term investment of people, money and materials are needed in the middle and upper reaches of rivers to implement ecological management and protect vegetation and water and enhance ecological environmental security downstream; sacrifice economic interests to some degree in these areas. The nation should take responsibility, duty and authority into consideration. Establish comprehensive economic compensation mechanisms in ecosystem function benefit areas and ecosystem function protection and provision zones, and realize common prosperity in eastern and western China.

8 Consumption of Ecosystem Services

8.1 Introduction

According to the MEA, approximately 60 % of ESs are degraded or used unsustainably and human activity is a major driver of these changes (MEA 2005). In recent decades, research has focused on ES studies and especially the concepts and theories underpinning this concept (Daily et al. 2000; Ouyang et al. 1999a, b) and economic assessments of global, regional, and typical ES (Costanza et al. 1997; Turner et al. 2003; Ouyang and Wang 2000; Zhao et al. 2000; Xie et al. 2001). The MEA has addressed the interrelationship between ES changes and human well-being and this has become a way forward for ES studies (MEA 2003).

Given recent population growth, rapid economic growth and associated changes in lifestyle, the human utilization and consumption of goods and services provided by natural ecosystems are changing rapidly. Here, we aim to summarize research progress on human consumption of ES and highlight major challenges into the future.

8.2 Conceptualization and Measurement of Ecosystem Service Consumption

Consumption is a process whereby humans use goods and services to meet basic needs and demands for survival (Shen, 2008). Ecosystem service consumption (ESC) is defined as the human utilization and occupation of natural ecosystems' goods and services in order to meet demands for production and living (Zhen et al. 2010). Therefore, ESC includes individual consumption and production consumption; the latter refers to the utilization of other ES in order to produce certain kinds of ES, for instance, food provision service depends on soil formulation, soil and water conservation, and other services. Individual consumption refers to our daily consumption, utilization, and occupation of ES. Consumption behavior significantly influences human consumption features, which can be divided into the six aspects of who, when, what, where, why, and how (i.e., 5WH). Due to differences in consumption behavior, different CPs can be identified. CP reflects main consumption features over a certain time period, and includes components of consumption, level of consumption, structure of consumption, approach of consumption and trends in consumption, expressed as follows (Zhen et al. 2008):

$$E_c = E_{dc} (f(X_a, X_{hz}, X_{gen}, X_{edu}, X_{bev}, X_{cmr}, X_{inc}, \dots, X_n) + E_{idc})$$

where E_c = total ES consumption; E_{dc} = direct ES consumption, of which, X_a : accessibility to ES, X_{hz} : household size; X_{gen} : sex; X_{edu} : educational attainment; X_{bev} : consumption behavior; X_{cmr} : type of consumers; X_{inc} : income of consumers; and E_{idc} = indirect consumption, which includes consumption of regulation and supporting services like water and soil conservation and soil formation for the production of goods and services.

Both physical and monetary assessments can be used to evaluate ESC. (1) Physical measurements directly assess the actual quantity consumed and are commonly used for measuring food, fuel wood, water, raw materials, medicine, and other goods consumed. Some ES are indirectly consumed for producing directly consumed goods and services and therefore the total consumption of ES should include both of direct and indirect consumption. For example, for food consumption, we need to calculate both the food quantity consumed and other ES such as the water and soil nutrients necessary for food production. (2) Monetary assessment is normally used for marketable goods where market prices are available and values can be calculated. For ES that do not yet have market value, alternative methods can be used such as the CVM to determine willingness to pay and willingness to accept by stakeholders through intensive questionnaires measuring landscape amenity. Those are only few of the commonly used methods for ESC, however, specific methods for ESC quantification would need to be identified and applied during actual case studies.

8.3 Case Studies of the Consumption of Ecosystem Services

8.3.1 Consumption Pattern and Accessibility

CPs are affected by the availability and accessibility of ES. Based on household questionnaires in the Mongolian Plateau in 2006, we found that herders relied heavily on ES produced locally such as meat, milk, and products (Zhen et al. 2010) (Table 5). To reduce risks, herders normally combine different consumption items and diversify their consumption. Mongolian herders tend to accept diversified meat consumption like mutton, beef, and horse meat, while Inner Mongolian herders used different fuels such as fuel wood, crop straw, and animal dung. Accessibility to ES is affected by distance, time, and the costs involved in obtaining the ES. We selected fuel wood consumption to investigate the influence of accessibility to fuel wood resources on consumption in the upper stream of the Jinghe watershed on the Loess Plateau. Through surveys, we found that fuel wood collection intensity decreased from 2000 to 2005 as some households had given up fuel wood collection due to poor accessibility.

In recent years, an increasing number of Chinese studies have focused on relationships between ES production and consumption. The EF has been widely applied to the calculation of land resources required for producing consumption items (Xu et al. 2002; Jiao et al. 2010). Dong et al. (2006) estimated the balance between ES

Table 5 Consumption patterns of ecosystem services on the Mongolian Plateau

Consumption pattern		Proportion of household surveyed (%)	
		Mongolia ($N = 150$)	Inner Mongolia ($N = 102$)
Meat	Mutton	4.7	8.3
	Beef	0.7	13.9
	Mutton + beef	15.4	75.0
	Mutton + horse meat	13.4	0
	Beef + horse meat	0.7	0
	Mutton + beef + horse meat	64.4	0
Dairy	Milk	33.6	83.3
	Butter	2.0	0
	Milk + butter	58.4	0
Fuel	Fuel wood	18.8	0
	Dried grass	0.7	0
	Animal dung	38.9	27.8
	Fuel wood + straw	0	5.6
	Fuel wood + animal dung	19.5	44.4
	Fuel wood + coal	2.0	0
	Dried grass + animal dung	0	11.1
	Straw + animal dung	2.7	8.3

Source Zhen et al. (2010)

supply and consumption in Taicang city, Jiangsu using the methods of alternative cost, shadow price, and protection cost and found that total production and consumption remained balanced from 1996 to 2001, but after 2001 consumption increased quickly leading to a rapid decline in net value between production and consumption. Consequently, total consumption exceeded total production.

8.3.2 Utility Function Derived from ES Consumption

The ultimate purpose of consumption is to achieve maximum utility function (UF). In ES consumption studies, UF refers to the consumption behavior, preferences, and choices of consumers (Lui 2009). The Cobb–Douglas function is adopted to analyze UF of imperfect substitution consumption types (Varian and Repcheck 2006) and the main variables used for the analysis include quantity of the items consumed and preference (represented by cost). This method identifies the appropriate and alternative combinations of different consumption items if certain UF is desired (Fig. 5). Based on household survey data in the Jinghe watershed, we found that when the consumption of grains, vegetables and fruits, and meat, egg, and milk were 200, 200, and 26.6 kg, respectively, the UF was 123. However, when grain consumption remained unchanged, vegetable and fruit consumption declined by 100 kg and an additional 102.4 kg of meat, egg, and milk was needed in order to maintain the same UF, meaning the total cost will be increased by 546 CNY.

Expenditure on food is important for UF. An ideal UF can be reached through readjustment of the quantity of each of the food items consumed (Table 6) and this is useful when identifying a rational consumption structure with high UF but with lower cost and resource use.

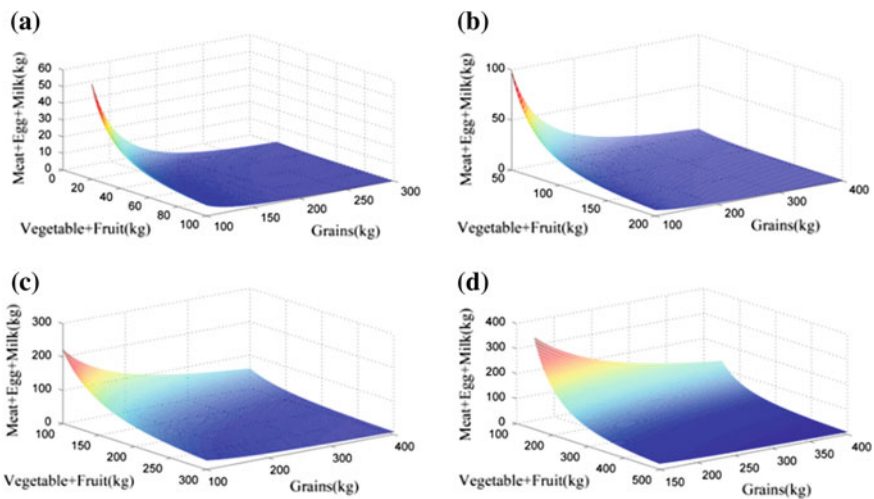


Fig. 5 The utility function

Table 6 Utility function and associated consumption patterns under different expenditure levels

Expenditure (CNY/year)	≤500		500–1000		1000–1500		>1500	
UF/person	60		78		125		179	
Consumption/person year	AC ^a	MUFC ^b	AC	MUFC	AC	MUFC	AC	MUFC
Grains (kg)	162	151	200	184	221	221	275	246
Vegetable + fruit (kg)	30	27	95	76	194	177	309	283
Meat, egg and milk (kg)	8.4	6.4	17.9	17.6	37.2	32.7	46.9	43.2
Actual expenditure (CNY/year)	393	353	726	639	1216	1127	1727	1573

Source Household survey in the Jinghe watershed 2008

^aActual consumption

^bConsumption under MUF

8.4 Conclusion and Discussion

Human consumption of ES significantly impacts natural ecosystems, and it is important to examine interactions between ESs and socioeconomic systems (Li 2008). Here, we conclude that humans directly (e.g., provisioning services) and indirectly (e.g., regulation and cultural services) consume ES and that both physical and monetary methods are being used for these assessments. CPs are affected by the availability and accessibility of ES. The UF can be achieved through different combinations of ES types and quantities consumed.

Many challenges exist in this field of study. For example, there would be cross-calculations on indirect consumption when considering food consumption for items such as water and soil conservation, soil formation, primary production, and nutrition circulation. It is necessary to explore the relationship between production and consumption regions when consumed ES are transported from other regions and in-depth case studies are required here. The UF needs to be further investigated to establish functional relationships between consumption and its utility in order to maximize resource use while meeting our basic consumption needs.

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