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Article

Consumption of Ecosystem Services: A Conceptual Framework and Case Study in Jinghe Watershed

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Abstract: The global ecosystem is changing due to human and natural causes, and only the human aspects of this interaction are within our control. This paper provides a critical analysis of the interactions between humans and the ecosystem in terms of the human consumption of ecosystem services to maintain a comfortable lifestyle. It starts by reviewing human consumption of ecosystem services, and then develops a conceptual framework that links ecosystem services with consumption of these services and ecosystem management to construct a general functional model of the factors that affect the consumption of ecosystem services. A case study is introduced to show how the model can be used to provide specific assessments of patterns of direct human consumption of ecosystem services in China's Jinghe watershed.

Key words: ecosystem service consumption; conceptual framework; utility function; Jinghe watershed of China

1 Introduction

With increasing populations and increasing consumption of ecosystem services, the pressure on existing ecosystems has been growing, leading to degradation of about 60% of the world's ecosystems (MEA 2005). The growing demand can no longer be met by tapping unexploited resources (Ayensu *et al*. 1999). It is estimated that total consumption of ecosystem services will continue to increase as the world's population increases, and that a large-scale ecosystem collapse is likely within 50 years if current global consumption levels are not cut by half (WWF 2006).

Although some scientists have studied coupled human-nature systems by modeling them as complex adaptive systems (Levin 1999; Gunderson and Holling 2001), most of the previous work has focused on ecological variables (e.g. landscape patterns, wildlife habitat, biodiversity) and human variables (e.g. socioeconomic processes, social networks, agents, structures of multilevel governance) (Schultz *et al*. 2007), using techniques such as the valuation of ecosystem services and changes (e.g. Costanza *et al*. 1998; de Groot and Hein 2007). There is an urgent need to establish models of human dependence upon and intervention in ecosystem services to improve our understanding of the interrelations between ecosystems and human consumption. Such studies will provide a more scientific basis for decision-making related to compensating for the adverse impacts of the consumption of ecosystem services.

2 Human consumption of ecosystem services: a conceptual framework

Analyzing ecosystem consumption first requires us to define this term. In this paper, we have defined it as consumption and utilization of ecosystem services and goods by humans, including those that are needed to sustain their livelihood (e.g. occupation of land to build

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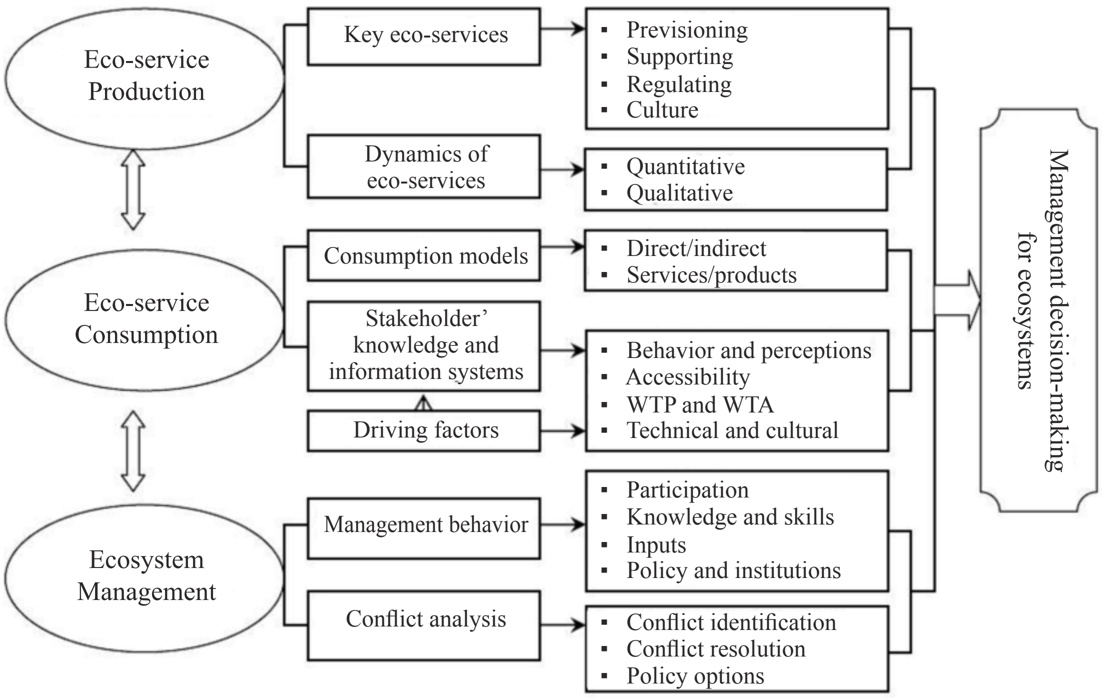

Fig. 1 Coupled human-ecosystem interactions: a conceptual framework. WTP represents the "willingness to pay" and WTA represents the "willingness to accept".

residences or factories). At the local level, consumption of ecosystem services includes both goods and services that are locally available for consumption, because in local areas, especially in vast rural areas of the developing world, people usually rely very much on local production to meet their consumption demand. Therefore, in this study, locally available services are considered and included in the analysis. As far as the major category of consumption goods and services are concerned, we exclusively consider "non-exhaustible" service and leave out the exhaustible ones, e.g. those related to mining and waste disposal, etc.

Fig. 1 shows a conceptual framework for analyzing the interactions involved in the production, consumption, and management of ecosystem services. Ecosystems provide us with a spectrum of essential life-support functions (Deutsch *et al*. 2005). To analyze human consumption of, and reliance on, these functions in a specific area, it is essential to begin by identifying site-specific categories of ecosystem services. This includes all entire or partial services, including those categorized as provisioning, supporting, regulating, and cultural services.

Humans consume ecosystems services either directly or indirectly. To meet their essential living needs, humans directly consume foods including cereals, fruits, vegetables, and animal products and byproducts, as well as fuelwood, crop residues, and animal dung for both cooking and heating (e.g. Bhatt and Sachan 2004). Humans also consume ecosystem services indirectly. For example, humans do not directly use the ecosystem's soil formation service; although changes in this service affect people through the resulting impact on the provisioning service of food production (MEA 2005). Table 1 summarizes the major forms of direct and indirect consumption of dryland ecosystem services.

It is necessary to point out that the classification of

Table 1 Major direct and indirect forms of consumption of dryland ecosystem services identified in the literature*.

Direct consumption	Indirect consumption
Agriculture	Biodiversity [2]
Food crops [1-4, 9]	Carbon sequestration [2, 5]
Fruit trees [4, 9]	Water purification [2]
Animal feed [3, 9]	Flood prevention [1]
Vegetables [1, 2]	Ecotourism [2]
Animal husbandry	Recreation [2, 5, 6]
Meat and meat products [1, 3, 9]	Social cohesion [1]
Milk and egg products [1, 3]	Waste treatment [6]
Fuel	Soil formation [6]
Wood [1, 6-9]	Climate regulation [1, 6]
Dung [1, 7, 8]	Culture [6]
Forestry	
Firewood [1-4, 7, 8]	
Timber [2, 5]	
Roofing materials [2, 9]	
Fiber	
Wood, jute, cotton, hemp, silk, wool [1]	
Fresh water [1-4]	

Sources: 1 MEA (2005); 2 Kaplowitz and Hoehn (2001); 3 Deutsch and Folke (2005); 4 Ayensu *et al*. (1999); 5 Turner *et al*. (2003); 6 Costanza *et al*. (1998); 7 Madubansi and Shackleton (2007); 8 Brouwer *et al*. (1997); 9 de Groot and Hein (2007).
* Irreversible consumption is excluded.

direct and indirect consumption services is a relative concept, and it relies on consumer selection between competing uses of the services. For example, wood or timber from the forest would not be available for consumption as fuelwood once it has been used as raw materials to construct furniture. In addition, direct and indirect consumption of services are sometimes interrelated; for example, in China's Wolong natural reserve, household consumption of fuelwood affects the quantity of panda habitat (Liu *et al*. 2007), illustrating how direct consumption of services (fuelwood) can be coupled with indirect consumption of different services (e.g. biodiversity). Moreover, interrelations between direct and indirect consumption also arise during the conversion of services into different forms, such as the conversion of a forest into agricultural land. This can increase a country's food supply while decreasing the supply of goods and services that may be of equal or greater importance, such as clean water, timber, biodiversity, or flood control (MEA 2005).

Key socioeconomic factors that drive human consumption of ecosystem services include the equity and security of access to ecosystem services, income level, educational attainment, policy intervention and institutional settings, the stakeholders' behavior and perceptions, their preference and willingness to pay (WTP) for services and their willingness to accept (WTA) consumption of those services, as well as technical and cultural differences.

The ultimate goal of studying the consumption of ecosystem services is to improve management of the coupled human and ecological systems. An effective management framework should have a broad spatial coverage that includes factors extending from global to regional scales, within which human interventions change ecosystems to meet their own needs. Active participation of local people is crucial for management, as it allows managers to benefit from their knowledge and technical expertise, as well as their participation in the conservation of ecosystem services.

Management of ecosystems is usually performed to meet specific purposes, such as meeting human consumption requirements. Therefore, some ecosystem processes or functions may be enlarged or compressed in association with these purposes. Management actions may occur during various phases of ecosystem processes; for instance, management or control of inputs (e.g. nutrients, pollutants, water, sediments, and gas) may change the structure and function of a specific ecosystem (Fig. 2). Management also refers to boosting or restraining certain processes (e.g. production) in order to control or adjust the quality and quantity of ecosystem output. Management sometimes intentionally controls the final outputs through selective harvesting of ecosystem *products.*

3 Measuring the consumption of ecosystem services

3.1 Direct measurement of ecosystem consumption

Direct measurement methods can measure the values that arise from the direct utilization of ecosystems, for example, through the sale or consumption of a piece of fruit. All production services and some cultural services (such as recreation) have a direct use value. Direct measurements can be based on either physical or monetary approaches:

- Physical measurements estimate the actual quantities of goods and services that are used, for instance, by measuring the weight of cereals that are harvested or the number of fish that are caught. The measurement is usually expressed as a total weight or as a weight consumed per capita. Volumes of goods consumed can also be considered a physical measurement. The problem with using physical measurements is that the units may vary among different ecosystem services (e.g. weight of food versus energy consumption to produce that food). In addition, weights are less directly tied to human preferences compared to other attributes such as monetary costs.
- Monetary measurements use price as a proxy for the quantity of goods and services traded in a market. In this sense, the market price is a measure of the marginal willingness to pay (WTP) and it can be used to derive an estimate of the economic value of an ecosystem goods and services. When goods and services are not traded in a market, and are instead bartered or consumed by the person who possesses the

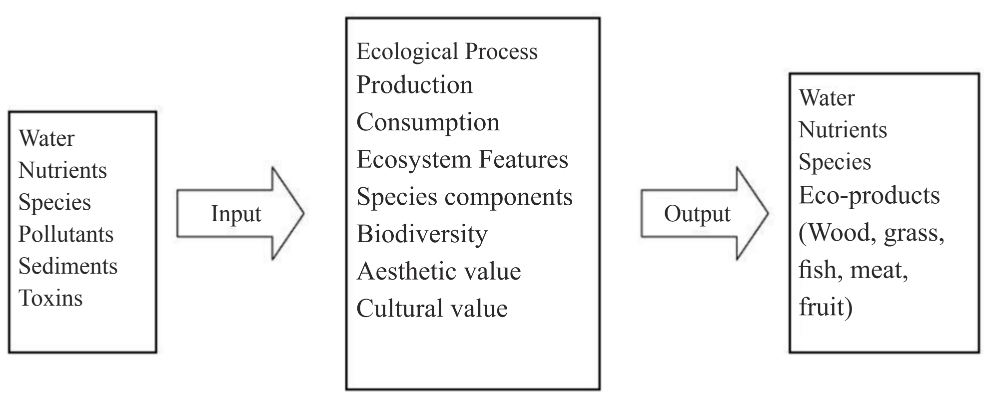

Fig. 2 A simplified ecosystem model that illustrates the importance of production and consumption (modified from Maltby *et al*. 1999).

goods or services, a shadow price must be constructed based on the cost of substitutes or the benefit derived from the goods (Munasinghe and Schwab 1993). Monetary values are attractive measurements for informing public policy because they offer a yardstick for comparison that can theoretically accommodate dissimilar ecosystem services using a consistent unit of measurement. The drawback to using monetary approaches is the difficulty in assigning a monetary value to many ecosystem services, such as the formation of soil or clean air services. Because good data is available on quantities of food, fuel, both in terms of consumption and on the expenditures to obtain these goods and services, we analyzed basic household consumption for our study area (described in section 5) using both mass-based and monetary approaches.

The contingent valuation method (CVM), in which respondents are asked how much they would be willing to pay for the consumption of specific goods or services, has been widely developed and applied to model the consumption of non-marketed goods (e.g. Nunes and van den Bergh 2001). WTP represents the demand side of the market. To represent the supply side, analysis focuses on what producers would be willing to accept (WTA) in order to provide goods and services or what consumers would be willing to accept to give up specific goods and services, or in exchange for other goods and services. WTA is an appropriate measure when beneficiaries own the resource that provides goods and services or when service levels are being reduced (MEA 2005).

3.2 Indirect measurement of ecosystem consumption

The indirect approaches to measuring consumption use a link with marketed goods and services to represent the WTP for the goods and services. Such measurements are closely related to the economic choices of consumers. The following methods are used to indirectly estimate the consumption of ecosystem services:

- Hedonic pricing, in which the value of goods and services is determined by both internal and external factors and is applicable where environmental amenities are reflected in the prices of specific goods, such as property. For example, this approach can be used to examine real estate values and estimate the contribution of environmental services to the total value of the real estate and to compare this proportion with that of other attributes that buyers of real-estate value (Robertson and Swinton 2005).
- The "travel cost" method examines the amounts that consumers are willing to spend to gain access to ecosystem goods and services (Smith 1993). For instance, this approach can be used to place a value on the consumption of recreational services by counting the amount of money that consumers spend (e.g. traveling to a national park, and the cost of the ticket to enter a park) to obtain the service.
- The "averting behavior" method can be used to analyze services related to the purification services of some ecosystems (Harford 1984). For example, this category includes defensive expenditures (e.g. purchasing a water filter to obtain clean water), the purchase of environmental surrogates (e.g. bottled water), or relocation to somewhere where cleaner water is available (similar to the travel cost method). WTP could be used for measuring such averting payments with respect to ecosystem services.
- The "damage function" approach can be used where the loss of an ecosystem function will cause economic or other kinds of damage (e.g. through an increased flood risk) (Yin and Li 2001).

The hedonic pricing, "averting behavior" method and "damage function" approach were adopted in this study. Most ecosystem services are consumed in forms of specific goods, so the consumption amounts of ecosystem services can be counted by evaluating these specific goods. Averting behavior prevalently exists in indirect consumption since the ecosystem services are not directly available, certainly we can estimate the amounts of ecosystem services with reference to the expenditure or cost in the averting behavior. The loss of some important ecosystem services to daily life and industrial production will bring damages to the economy and other areas. These damages, if measurable, can also reflect the amounts of corresponding ecosystem services consumed.

4 A model for the consumption of ecosystem services

Based on the preceding discussion, we formulated a simple model to express the factors that influence the consumption of ecosystem services in a specific region:

$$E_c=E_{dc}+E_{idc} \quad (1)$$

Where:

E_c = total ecosystem service consumption

E_{dc} =direct consumption

E_{idc} =indirect consumption

Consumption of ecosystem services is a function of the following factors:

$$E_c=f(X_{av},X_{ac},X_{bev},X_{hz},X_{inc},X_{pri},X_{pol},\ldots X_n) \quad (2)$$

Where:

X_{av}: availability of ecosystem goods and services

X_{ac}: accessibility of the goods and services

X_{bev}: consumer behavior

X_{hz}: persons per household

X_{inc}: income

X_{pri}: price

X_{pol}: policy variable

n: the number of factors included in the analysis.

The availability of ecosystem goods and services determines the spatial and temporal variations in consumption patterns and in total consumption within a region. Accessibility can be expressed as the distance between consumer locations and the goods and services. This distance is normally described using a nonlinear function, and a threshold is usually assessed to quantify the accessibility. For example, in China's Wolong natural reserve, a distance threshold was assigned to analyze fuel wood consumption and panda protection (Liu *et al*. 2003). This distance threshold can be analyzed using the travel cost method. A study in Thailand confirmed that the "accessibility" of mangrove areas was an important determinant of whether a mangrove area would be cleared to permit shrimp farming (Barbier 2005).

The number of persons in a household and distribution of household are important factors that drive consumption and ecosystem changes. Several studies have demonstrated relationships between population size, number of households, size of household (number of persons in a household), and consumption (Liu and Zhen 2007). First, more households mean more housing units, and this generally increases the amount of land and materials needed to support house construction. Second, smaller households have a lower efficiency of resource use per capita because certain goods and services (e.g. space, construction materials) are shared by more people in larger households (Liu *et al*. 2003). Government policy on the conservation of nature could also be a factor that affects household size. For example, a natural forest conservation program in China's Wolong natural reserve led to the formation of a large number of new households in 2001 because many households decided to split into smaller units so that they could more effectively access government subsidies (amounting to 20 to 25% of the average household income) given to households as part of the program, thereby increasing the demand for fuel wood and for the land used for house construction (Liu *et al*. 2001).

Income level affects the purchasing power, WTP, and WTA of consumers. MEA (2005) concluded that wealthier populations normally consume ecosystem services at a higher rate than poor ones, as they control more ecosystem services than do the poor. For instance, the rich can buy a consumption service from elsewhere if it is not available locally. Income also influences demand for and the structure of the consumption. A study in middle-income developing countries found that rising incomes will probably lead to increased demand for protein in human diets (Robertson and Swinton 2005). The resulting change in price will have strong impacts on consumption patterns and on total consumption. Similarly, Xu *et al*. (2006) found that the price of electricity affected consumer consumption of fuel wood in the Wolong natural reserve.

Consumer behavior can be expressed using consumer preferences (i.e., consumer choices and limitations) and the possibility of consumption. A Cobb-Douglas utility function can be used to represent a household's preferences for, and choice of, which ecosystem goods and services to consume (Varian 2006). This approach is based on the principle of human preference satisfaction by the utilization of ecosystem goods or services (MEA 2005), or based on the need for certain ecosystem goods or services or their usefulness to consumers. This analysis is based on the consumption of a single perishable item and on a real money balance. A Cobb-Douglas type of household utility function can be represented as follows:

$$U = \prod_{i=1}^{R} X_i^{ai} \qquad \sum_{i=1}^{R} a_i = 1 \qquad a_i > 0 \tag{3}$$

where U is the utility derived from the consumption of n goods or services, X_i is the quantity of goods i that are consumed, and a_i is the preference for the consumption of goods i, which can be calculated as the proportion of a consumer's money that is spent on each of the n consumption items.

5 Case study of human consumption of ecosystem services

To demonstrate how our model can be used to analyze the consumption of ecosystem services, and illustrate the conclusions that can be drawn, we have performed a simplified case study. In the case study, we focused on the consumption of food, but have simplified the study by examining only the direct quantities of food that are consumed, consumption preferences, and the indirect effects of family income on consumption patterns. This case study was designed to demonstrate how the analytical approach is scalable and can be applied to progressively more complex analyses simply by adding factors.

Jinghe watershed, a mountainous watershed located in the northwestern China and covering 31 counties of Ningxia Hui Autonomous Region, Gansu and Shannxi provinces, is a strategic area in the development of northwestern China. The watershed is an important irrigation water source of the Guanzhong Plain – a food bowl for the country downstream. It is a transitional area between arid to semi-arid and humid areas of the country. It now serves as a land link and a detour between marginal regions of northwestern part of the country and those of the middle part of the country (Fig. 1). The watershed is unique with a combination of slope mountainous land upstream (e.g. Guyuan and Jingyuan counties) and plain land downstream (e.g. Jingyang County), deep soils and an arid climate ideally suited for grain crop, grass and forest production.

Population growth in the Jinghe watershed increased by 275% from 1949 to 2002, but per capita arable land decreased by 67% over the same period. More than 80 percent of the people in the area are involved in agricultural production. Land ownership is vested in the national government but the user rights of farmland were transferred from the collective, i.e. the brigade under the people's commune, to individual households under a system of contracts. This is the so called household contract responsibility system. Farmers can possess land usufruct rights through land contracts. The term of land contracting can be extended by another 30 years and a turnover mechanism for land-use rights has been established for the first time in history. The collectives may adjust land distribution and use according to the local situation. The sale, rent and transfer of land owned by the collectives is banned unless the government, at least at the county level, officially designates land for non-agricultural use. Arable land (43% of the total land area) and grassland (42%) are the two dominate land use types of the watershed. Farmers in the watershed mainly practise small-scale and subsistence agriculture and grow about ten different kinds of crops. Winter wheat, summer maize and potato are the principal crops. The rest of the land is allotted to the cultivation of vegetables (cabbage, chili, eggplant) and fruit (apples, pears). Land is owned collectively and per capita land area is 0.74 ha (Table 2) higher than the national average figure (0.09 ha).

Guyuan and Jingyuan counties located upstream and Jingyang County located downstream in the Jinghe watershed are selected as the study areas. We chose these areas to compare their consumption patterns and nutrient intake level from their consumption. Upstream, the population density was 29 persons km^{-2} in the early 1950s, exceeding the threshold of 7–20 persons km^{-2} defined for arid and semi-arid regions by the United Nations. The figure increased to 100 persons km^{-2} in 2006; in downstream Jingyang County. The population

Table 2 Social and economic conditions in study area.

Parameters	The watershed	Up-stream	Down-stream
Population density(person km^{-2})	136	100	644
Per capita land area (ha)	0.74	1	0.09
Per capita arable land area (ha)	0.31	0.32	0.09
Per capita water resource (m^3)	192	192	232
Per capita GDP (RMB)	3777	3840	7597
Proportion of land use (%)			
Arable land	43	32	58
Forest land	10	11	10
Grass land	42	53	5
Water body	1	1	8
Built-up land	2	2	17
Unused land	2	1	2
Livestock (head household^{-1})			
Cattle	0.1	1	0.7
Pig	0.5	0.4	1.3
Sheep	1.2	2	1.3
Poultry (chicken, duck)	3.4	3	18

Data source: Statistical Yearbook of Ningxia Hui Autonomous Region, and Gansu and Shaanxi provinces in 2001 and 2006.

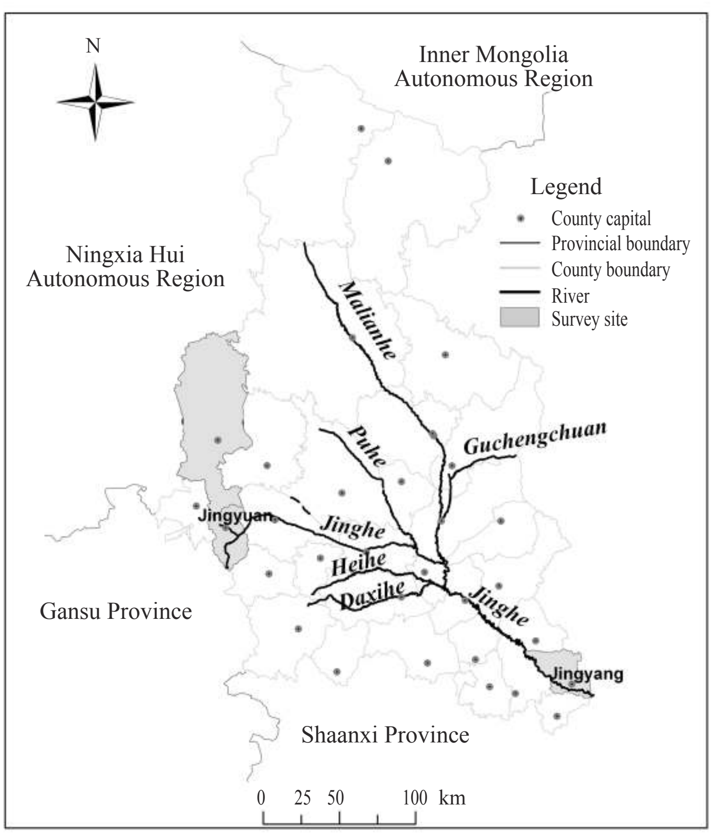

Fig. 3 Location of the Jinghe Watershed and of the study areas.

density is more than six times that for the upstream areas, putting high pressure on limited land resource. To cope with this pressure on land, over the past decades farmers upstream had expanded their production activities to the mountainous slope land that can no longer be used for agricultural purposes. Farmers downstream intensified their production activities through increased inputs such as irrigation and chemicals. Intensive land-use in the marginal land has led to land degradation and vegetation destruction in many parts and has also had adverse environmental impacts. Soil erosion, insufficient water supply, loss of forest and grassland and the increasing fragility of the eco-environment and natural resources have become increasingly serious problems in the area. Degradation of natural and environmental resources reduces productivity and longevity of these resources and ultimately adversely affects sustainability of the entire ecosystem.

5.1 Research methods

We conducted our study from a bottom-up perspective using household surveys and available local data. Primary information was collected through household surveys, focus-group discussions, interviews with key informants, and field observations. The field survey sites are shown in Figure 3. More details of our study are presented by Zhen *et al*. (2008). We also selected two villages (one each in Guyuan and Jingyuan counties) for the upstream area of the watershed and one village at the downstream end of the watershed, and used simple random sampling to select households in each village for our survey. Fieldwork was carried out from June to August 2006 in the upstream areas and in July 2007 in the downstream area, for a total of 128 and 150 households, respectively. Data were analyzed using version 10.0 of the SPSS software (SPSS Inc., Chicago, IL), with significance defined at $p < 0.05$. Additional analysis was done using version 7.3.0 of the Matlab software (The Mathworks, Natick, MA).

5.2 Household consumption of basic items

Table 3 lists the ecosystem services directly consumed by the respondents based on the results of our survey. These services are important to local people to provide a comfortable lifestyle, and none of the services is easily substituted. The major consumption category, in both the upstream and the downstream areas, was grains (502 and 198 kg person^{-1} y^{-1}, respectively), followed by vegetable consumption (17 and 68 kg person^{-1} y^{-1}) and eggs and milk (1.81 and 11.25 kg person^{-1} y^{-1}). Meat was also consumed in both areas, but the amount was only slightly higher than eggs and milk in the upstream areas and considerably lower in downstream areas, with average annual per capita consumptions of 2.05 and 5.85 kg, respectively. Those figures show that there is large difference in consumption patterns between upstream and downstream respondents, with food consumption in downstream areas more diversified than in upstream areas and revealing a relatively high consumption of vegetables, fruits, meat, eggs, and milk.

Different combinations of consumption result in different nutrient intake amounts. Table 4 shows the standard coefficient of nutrients (Li 2007) and the amount of the nutrient intake. By comparing the nutrient intake between upstream and downstream areas, we noticed that the upstream respondents have sufficient energy and protein intake when compared with the standard value, but an insufficient amount of fat, whereas the downstream respondents were deficient in the intake of all three kinds of nutrients. By tracing the sources of the nutrients, we found that the larger proportion of nutrients came from plant products, mostly grains (per capita 502 kg y^{-1}), in upstream areas compared to downstream areas (per capita198 kg y^{-1}). For instance, the proportion of animal protein was only 1.5% of the protein intake in the upstream whereas it is 10.7% in downstream areas. Both the upstream and the downstream respondents were extremely deficient in fat intake due to insufficient nutrients from

Table 3 Basic consumption of food items, water, and fuel reported by the survey respondents.

Category	Items	Quantity			
		Upstream		Downstream	
		Mean	S.D.	Mean	S.D.
Food items					
Grains	Wheat	314	213	163	68
(kg person^{-1} y^{-1})	Rice	na	na	7	7
	Maize	20	132	22	28
	Potato	168	138	6	7
	Total	502	349	198	79
Vegetables and fruits	Vegetables	17	42	68	56
(kg person^{-1} y^{-1})	Fruits	na	na	30	40
	Total	17	42	98	82
Meat	Beef	0.84	2.36	0.27	1.16
(kg person^{-1} y^{-1})	Mutton	0.72	3.24	0.16	0.68
	Pork	0.49	4.38	5.02	5.12
	Poultry	na	na	0.4	1.33
	Total	2.05	8.27	5.85	6.37
Eggs and milk	Eggs	1.81	0.91	7.61	6.49
(kg person^{-1} y^{-1})	Milk	na	na	3.64	11.55
	Total	1.81	0.91	11.25	15.08
Water					
Water	Drinking	7.3	4.2	18.3	12.8
(m^3 household^{-1} y^{-1})	Animal	36.5	59.8	47.5	82.7
	Irrigation	na	na	890	391
Fuel					
Fuel	Firewood	1115	1535	579	567
(kg household^{-1} y^{-1})	Straw	1094	931	1487	2737
	Hay	499	447	na	na
	Dung	1115	1338	na	na
	Coal	na	na	1951	1045
	Natural gas	na	na	54	50

na: not available.

Table 4 Nutrient intake and average nutrient coefficients used to assess the nutritional characteristics of the foods consumed by residents of the study area*.

Nutrient intake	Nutrient category	Upstream	Downstream
(Ratio to standard intake)	Energy (kcal)	3036 (1.31)	1766 (0.76)
(per person per day)	Protein (g)	97 (1.30)	62 (0.82)
	Fat (g)	22 (0.34)	21 (0.32)
Average nutrient coefficients			
Food category	Energy (kcal kg^{-1})	Protein (g kg^{-1})	Fat (g kg^{-1})
Grains (potato excluded)	3221	110.8	24.16
Vegetables and fruits	638	16.65	3.41
Meat, eggs and milk	2356	141.1	188.4
Potato	925	15.41	2.02
Intake standard (per person per day)	2320	75	65

* Nutrient coefficients data are from Li (2007), where the conversion coefficient from raw grain to processed grain is 86.7%; Nutrient intake standard refers to General Office of the State Council (2002).

animal sources.

Water consumption consists mainly of domestic consumption (drinking and consumption by animals), and the amount consumed for this purpose was comparable in the two areas. However, in contrast to the upstream areas, a large amount of water was used for irrigation of farmland in the downstream region, with an annual per household water use of 890 m^3. The major source of irrigation water is the Jinghe River.

Fuel consumption depended primarily on locally available resources. Due to the existence of vast plantations of trees and large areas of grasses in the upstream area, and the availability of shrubs, the main sources of fuel were firewood (1115 kg $household^{-1}$ y^{-1}), animal dung (1115 kg $household^{-1}$ y^{-1}), straw from crop production (1094 kg $household^{-1}$ y^{-1}), and hay (499 kg $household^{-1}$ y^{-1}). In contrast, downstream areas, where households engaged in intensive farming activities, used coal (1951 kg $household^{-1}$ y^{-1}) and straw (1487 kg $household^{-1}$ y^{-1}) as the major sources of fuel, supplemented by firewood (579 kg kg $household^{-1}$ y^{-1}) and natural gas (54 kg $household^{-1}$ y^{-1}).

6 Conclusions and future agenda

We have defined ecosystem consumption as human consumption and utilization of goods and services provided by the ecosystem, including those that are needed to sustain their livelihood (e.g. occupation of land to build residences). By focusing on human consumption, we constructed a conceptual framework for explaining the components of consumption and their interactions within a watershed system, and classified human consumption of ecosystem services within the study area into direct and indirect consumption. Of the many methods that can be used to directly and indirectly measure consumption, we chose physical measurements for the consumption of three major food groups and monetary measurements for WTP and WTA.

Our case study in a remote part of rural China demonstrated that in economically undeveloped rural areas, major consumption patterns are dominated by the basic items that are locally available to meet the physical demands of the people. Changing the local people's culturally and socially defined consumption preferences (demand) is not currently possible. Direct consumption of ecosystem services includes three basic food items like grains, vegetables and fruits, and meat, eggs and milk; water, and fuels required for survival.

As a developing field of research, the study of consumption of ecosystem services will require substantial additional research, both ecological and socioeconomic, as well as policy analysis and public education, before it becomes a truly useful tool for guiding the management of ecosystem resources. None of these challenges is unimportant. There are several additional concerns that must be resolved in future studies of human consumption of ecosystem services:

(1) It is necessary to identify the multiplicity of goods and services provided by ecosystems, so that these goods and services can have values assigned or can be otherwise ranked. The goods and services related most closely to human consumption are especially important because they must be prioritized and linked to both policy and market mechanisms. For example, in our studies we examined only a limited set of consumption categories, and did not rigorously examine their interactions other than through the calculation of preferences and utilities. A more detailed study would expand the categories of consumption to include more ecosystem services, and would also focus on their interactions.

(2) It will be necessary to provide more details of the mechanisms that govern consumption and consumer behavior, such as the cultural and other factors that determine preferences and choices. In the present study, we focused on formulating ecosystem services, but additional research should explore the impacts of human consumption on both human welfare and ecosystems and should explore the factors that underlie consumption choices.

(3) In-depth and site-specific study will also be required to identify the natural and human factors that affect the

consumption of ecosystem services in different study areas within a region.

(4) It will be necessary to describe and analyze the processes and causes that lead to expansion or shrinkage of consumption, and the stimulatory and inhibitory roles of policy in determining the consumption of ecological services, as well as the role of government policy in guaranteeing access to consumption of basic ecosystem services in a sustainable manner.

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生态系统服务消耗：概念框架与中国西部案例

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摘要: 由于人为因素和自然因素的共同作用，全球生态系统正经历着巨大的变化。而这些驱动因素中，只有人为因素可进行调控。本文以人类对生态系统服务的消耗为着眼点，分析人类在获取舒适生活的过程中与生态系统形成的相互作用。研究从回顾生态系统服务消耗研究入手，建立了将生态系统服务、生态系统服务消耗和生态系统管理三者相联系的概念框架，并构建了生态系统服务消耗研究模型。同时，进一步以中国泾河流域为案例，对模型在生态系统服务直接消耗模式研究中的应用进行了实证研究和探讨。

关键词: 生态系统服务消耗；概念框架；效用函数；中国泾河流域