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ORIGINAL ARTICLE

Eco-service value evaluation based on eco-economic functional regionalization in a typical basin of northwest arid area, China

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Abstract Ecosystem services are the basis of human living and development. Land use has significant effects on the ecosystem structure and functions, even its services. Using the remote sensing (RS), geographical information system and ecological economy theory, this paper analyzed land use changes of different eco-economic functional areas in Manas River Basin during the period 1958–2006 using different stage RS images. This paper selects the evaluation method obtained by Costanza et al. and Xie Gaodi, and the ecological sensitivity coefficient analysis, which analyzed the variation characteristics of eco-service values of different eco-economic functional areas. The results showed that the land use pattern has changed greatly from 1958 to 2006. The area of farmland and industrial area increased rapidly, while the forest area, grassland, water area and unutilized area decreased greatly. The total eco-service value of the river basin decreased from 3,529.64 US\$ $\times$ 10^6 in 1958 to 2,559.88 US\$ $\times$ 10^6 in 2006. There was 27.47 % net loss of 969.76 US\$ $\times$ 10^6. The eco-service values of various land use types in the study area were close to the regional real values and the results were credible. There existed apparent temporal and spatial changes in the eco-service values of different eco-economic functional areas, and this significant change in the eco-service values was driven by economic development. Consequently, in view of eco-economic characteristics and ecological issues of various eco-economic functional areas, relevant strategies of ecological conservation were proposed for enhancing the general eco-service value of the river basin and realizing the regional sustainable development. The ''yuan'' is Chinese money unit (¥), US\$1 = ¥6.27 (yuan).

Keywords Eco-economic functional regionalization · Eco-service value · Land use · Manas River Basin

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Introduction

Ecosystems generate a range of goods and services important for human well-being, collectively called ecosystem services. They contribute to human welfare directly or indirectly by the structure, function and ecological process of the ecosystem, including necessary ecological products in human life and ecological function guaranteeing human life quality (Costanza et al. 1997, 2007; Guo et al. 2001; Fisher et al. 2009). However, these services were considered with very little or no attention paid to the indirect value of the ecosystem in providing ecological services and functions such as biodiversity maintenance, reduced quantity and quality of fresh water, carbon storage, nutrient cycling, air and water filtration, and erosion control (Bai et al. 2012; Xu et al. 2012; Zhang et al. 2007b). Land is the crucial component of the terrestrial ecosystem; there exists the interactional relationship between land use structure and natural ecosystem service function, which influences ecosystem properties, processes and components, which are the basis for providing services (Zhao et al. 2004; Nelson et al. 2009). For this reason, it is significant to explore the ecosystem service value changes of different land use types in different periods. The economic valuation of ecosystem services is becoming increasingly important to understand the multiple benefits provided by ecosystems. The studies are presently one of the hot topics in the research field of ecosystem sustainability, which has achieved wide concerns of ecologists and economists (Kumar and Kumar 2008; Plummer 2009; Baskaran et al. 2010; Liu and Costanza 2010; Sagoff 2011; Fu et al. 2011). A large number of previous researches focused on the eco-service value evaluation on the national or regional scale (Zhang et al. 2010; Zhang and Lu 2010; Chang et al. 2011); however, the ecological economic value changes and induced ecological responses were rarely involved in the different eco-economic functional areas of the typical arid river basin in China. Consequently, much attention should be paid to the variation characteristics of eco-service values of different eco-economic functional areas, and further discussions about ecological issues and strategies of different sub areas by analyzing and quantifying the importance of ecosystems to human well-being. It may be used for regional planning to help the decision makers and environmental agencies in forecasting scenarios and regarding the sustainable use and management of ecosystem services.

Manas River Basin in Xinjiang, with its unique intrazonal landscapes, belongs to a typical area with dramatic exploitation and use of water and land resources in the arid area of northwestern China, and was chosen as a case study for ecosystem services research. Xie et al. (2003) formulated the equivalent value table of ecosystem services per unit area of Chinese terrestrial ecosystems; the system was based on questionnaires from 200 Chinese ecologists and referred to the value estimation method of Costanza et al. (1997), which became a basis of relative assessment. Previous studies on the regional ecosystem service values mainly took counties and cities or regions as the calculation units (Zhao et al. 2004; Yang et al. 2008; Li et al. 2010; Shi et al. 2010); however, it was incapable of judging the environmental qualities of various eco-economic functional areas. This paper studied the eco-service values of different eco-economic functional areas in different periods, and revealed the land use characters and reasons for ecosystem service value changes. This research is intended to provide scientific evidences for reasonable planning and ecological restoration of the river basin.

Study area

The Manas River Basin is situated between the northern slope of the Tianshan Mountains and the southern edge of the Junggar Basin, and covers about 3.35×10^4 km^2 (Fig. 1). Located in the heartland of Eurasia, Manas River Basin is recharged by five stream systems with the total surface runoff volume of 22.98×10^8 m^3 per annum from snow- and glacial-fed sources. Manas River is the longest river in southern Junggar Basin with the total length of 400 km and the annual runoff volume of 12.7×10^8 m^3. Geographically, its northern part is high and southern part is low; mountains cover the northern part; the oasis and desert covers the southern part. The basin holds varied geomorphological types including mountain, plains and desert. Therefore, it is characterized as a mountain-oasis-desert system, which is regarded as a very typical landscape in Northwest China and even Central Asia (Cheng et al. 2006; Fan et al. 2008; Liu et al. 2008).

Manas River Basin belongs to the continental arid climate zone, and there are relatively larger spatial and temporal differences in precipitation. The annual amount of precipitation is as low as 110–200 mm, while the annual evaporation reaches up to 1,500–2,100 mm, and the annual temperature is 6.6 °C (Zhang et al. 2002; Ling et al. 2013). Manas River Basin oasis is the largest artificial oasis in northern Tianshan Mountains of China with coordinated urban–rural development. It is the model of oasis exploitation and economic development in Xinjiang. The ecological environment has fragility in the watershed. In recent years, because of natural environment variation and population growth, the overall change of land use and land cover has taken place in the watershed, which has affected the oasis stability.

Data resources

The remote sensing (RS) data of this paper were from aerial photographs from 1958, Landsat MSS images from 1976, Landsat TM images from 1987 to 1998, and China-Brazil Earth Resource Satellite (CBERS) images from 2006 (Table 1). These satellite images could not be compared directly because the coordinate reference system and resolution used in each image were not consistent. First, the atmospheric conditions of the image data were standardized; geometric rectifications used a pre-rectified image to confirm all the RS images in the same coordinating system (with root mean square (RMS) error < 1 pixel). Second, based on analyzing the characteristic of spectrum, the optimum combination of bands has been established. False color composite in bands 421 was applied to MSS images in 1976, and RS images in 1987, 1998 and 2006 were processed using false color composite in bands 432. Coordinates of pairs of points were identified with the 1998 TM image and the 1:100,000 topographic map. The same topographic map was used as the geo-referenced standard

Fig. 1 Sketch map showing the location of Manas River Basin

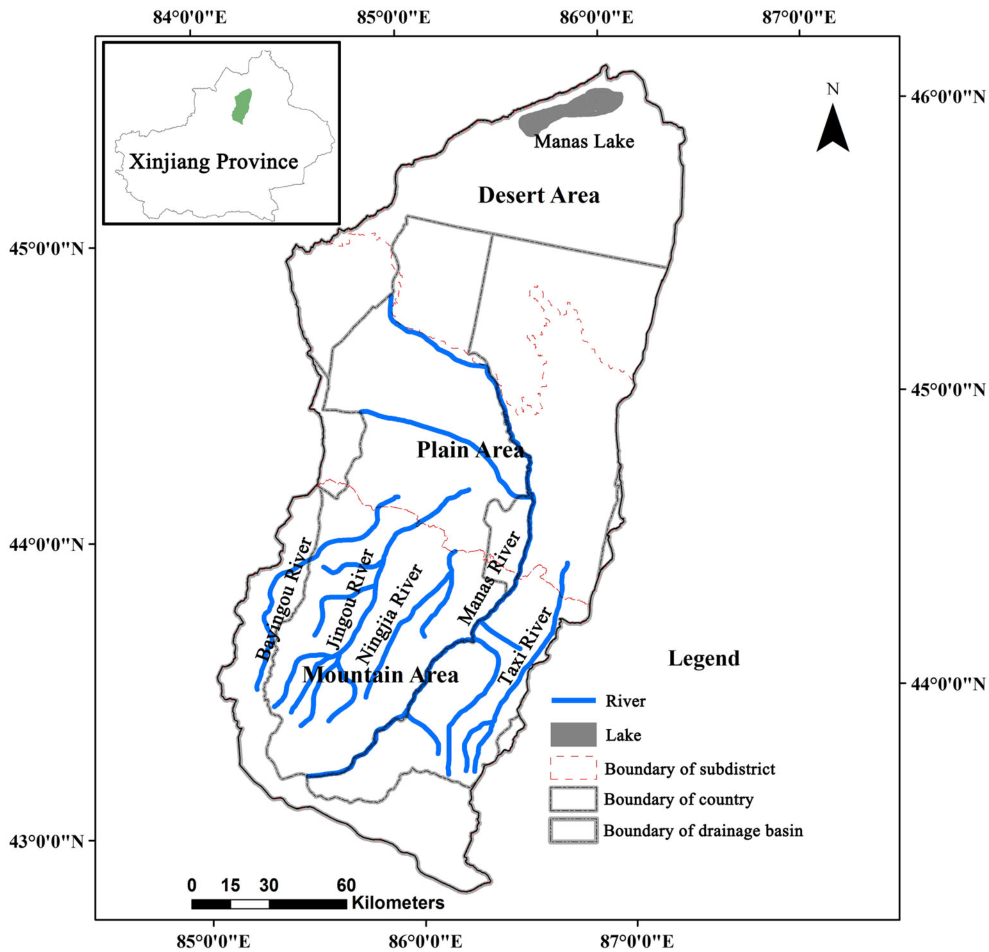

Table 1 Information on the data sources

Years	Data type	Spatial resolution	Remote sensing images (path/row, collection time)
1958	Topographic data	1:1,00000	Derived from aerial photography in 1958
1976	Multispectral Sensing System (MSS)	79 m × 79 m	155/29, 1976-07-15
1987	Landsat Thematic Mapper (TM)	30 m × 30 m	144/29, 1987-09-10; 143/29, 1987-01-26; 144/28, 1987-08-09; 144/30, 1987-09-10
1998	Landsat Thematic Mapper (TM)	30 m × 30 m	144/29, 1998-07-04; 144/28, 1998-07-04; 144/30, 1998-10-17
2006	China-Brazil Earth Resources Satellite (CBERS)	19.5 m × 19.5 m	35/49, 2006-08-24;35/50, 2006-07-29; 35/51, 2006-07-03; 34/48, 2006-07-06; 34/49, 2006-07-06; 34/50, 2006-07-06; 34/51, 2006-07-06; 33/49, 2006-07-09; 34/50, 2006-07-09; 34/51, 2006-06-13; 33/50, 2006-07-06

and the geo-rectified 1998 data as the master dataset; the 1976, 1987 and 2006 images were resampled and rectified. In the end, the RS images were geo-referenced to Universal Transverse Mercator (UTM) coordinate system. The image data were subsequently resampled to a pixel size of 30 m × 30 m. Average root mean square (RMS) error was < 0.5 pixels. All of them were managed within ArcGIS to form a comprehensive database. According to the spectral characteristics of each band for the MSS, TM, and CBERS, therefore, in the composite images of MSS, TM and CBERS, the vegetation, water, desert, and saline land were red, blue or black, light brown yellow, and clear white, respectively. The RS images were developed through visual interpretation, based on the spectral, radiation, and geometric characteristics of the surface features, and analyses of ground-truthed GPS points, and topological relation establishment based on the classification system of land use types. The classification accuracy of the RS data is assessed usually by the Kappa coefficient; the land use/cover data in 1976, 1987, 1998, and 2006 were 64.8, 81.3, 86.4, and 88.3 %, respectively. The classification result was validated using field investigation data, and thus the land use change chart and attribute data were obtained for further studies. These data showed that the classified images generally agree with actual land use. The main land use types of river basin are determined as 13 types. The most representative biome was used as a proxy for each land use category including: (1) farmland for irrigated land, dry land and newly reclaimed land; (2) forest land for economic forest, forested land, shrub land, open forest land, and sparse shrub land; (3) grassland for high coverage grassland, middle coverage grassland, and low coverage grassland; (4) water area for lake, reservoir, and flood land; (5) industrial area for urban settlement, rural residential land, and industrial and mining special use land; (6) unutilized land for glacier and permanent snow, semi-fixed sand dune, gobi, saline land, playa, and bare rock.

Research methods

Evaluation method of eco-service value

The variations of ecosystem service functions and benefits resulting from land use type changes are evaluated by the calculation of economic values. Costanza et al. (1997) put forward the principles and methods of ecosystem service evaluation, which only apply to the region with specific conditions. Xie et al. (2003) worked out China's ecosystem service value equivalent factor table, meaning the annual service value per unit area of each land use type according to the reality of China. In addition, correlational research has been testified of its feasibility in the northern Tianshan Mountains (Sun et al. 2010). Proceeding from the actual situation of the study area and the current research progress (Chen et al. 2010; Bian and Lu 2012), the Chinese ecosystem service value unit area of different ecosystem types were improved and supplemented (Table 2), thus determining ecological value coefficients of different land use types in Manas River Basin.

This paper discussed the eco-service values of Manas River Basin using the method of Costanza, the total value of ecosystem services in this study area for 1958, 1976, 1987, 1998 and 2006 was calculated as follows:

$$\mathrm{ESV} = \sum (\mathrm{A}_k \mathrm{VC}_k) \quad (1)$$

where ESV the estimated ecosystem services value is the eco-service value (US$ per year), A_k the area of land use type k in study area (km^2), and VC_k the eco-service function value coefficient for land use category k, which stands for the eco-service value per unit area [US$ (km^{-2} per year)].

The contribution rates of various land use types were calculated by:

$$\mathrm{ESVC}_i = \mathrm{ESV}_i / \mathrm{ESV} \quad (2)$$

where ESVC_i is the contribution rate of eco-service value of land use type i, and ESV_i the annual eco-service value of land use type i.

Sensitivity analysis method

To testify whether the research results of Costanza are appropriate for the eco-service function of every ecosystem in Manas River Basin, the Coefficient of Sensitivity (CS) was calculated according to the standard economic method

Table 2 Ecosystem services value unit area of different ecosystem types in Manas River Basin (US$ ha^{-1} year^{-1})

Land use type	Ecological value per unit area					
	Farmland	Forest land	Grassland	Water area	Industrial area	Unutilized land
Gas regulation	70.558	493.939	112.903	64.912	–	–
Climate control	125.598	381.037	127.018	64.912	–	–
Disturbance regulation	54.864	65.869	43.876	–	–	–
Water conservation	84.673	451.595	112.903	2,876.108	41.515	4.226
Soil formation and protection	206.045	550.383	275.199	1.404	–	2.823
Waste treatment	231.451	184.880	184.880	2,565.646	13.844	1.404
Biodiversity protection	100.191	460.064	153.828	351.404	–	47.974
Nutrient circulation	141.132	26.316	42.344	64.912	–	–
Bio-control	31.611	5.263	16.683	–	–	–
Food supply	141.132	14.115	42.344	14.115	13.174	1.404
Raw material	14.115	366.922	7.049	1.404	–	–
Entertainment and culture	1.404	180.638	5.646	612.472	13.174	1.404
Sum	1,202.775	3,181.021	1,124.673	6,617.289	81.707	59.234

to determine the effect of these coefficients on the estimated ecosystem values. The CS for ESV calculation indicates how much the ESV changes when the ESV coefficient changes by 1 %. Specifically, this paper adjusted the eco-service value coefficients of different land use types (Costanza et al. 1997) up and down by 50 % to determine the dependence of general eco-service value on eco-service value coefficients. The value of CS over one indicates that ESV is elastic relative to VC_k, and the total eco-service value change of the study area is relatively unstable to the eco-service function value coefficient. The value of CS < 1 indicates that ESV is lacking of elasticity. In addition, larger value of CS is more able to explain the critical effect of VC_k on the variation of ESV (Zhao et al. 2004; Bian and Lu 2012). Therefore, the variation of ESV is unstable relative to VC_k. The formula was calculated as follows:

$$\mathrm{CS} = \left| \frac{(\mathrm{ESV}_j - \mathrm{ESV}_i)/\mathrm{ESV}_i}{(\mathrm{VC}_{jk} - \mathrm{VC}_{ik})/\mathrm{VC}_{ik}} \right| \qquad (3)$$

where i and j refer to the coefficient values of the initial and adjusted ecosystem service value, respectively. CS is used to test the degree to which ESV is dependent on the ESV coefficient, to make sure that the coefficients are appropriate for the study area.

Results and analysis

Analysis on eco-service value sensitivities

The variation and sensitivity of total eco-service value of Manas River Basin were evaluated in accordance with the adjusted eco-service value coefficients (Table 3). The eco-service value sensitivity of the industrial area was minimum and close to 0.00, while the maximum (0.45–0.53) appeared in grassland. Consequently, the eco-service value sensitivities of various land use types in the river basin were all far less than ‘1’, while most of them were near zero with relatively small inter-decadal changes. The impact of the eco-service value coefficients on the total eco-service value changes was slighter, which also meant that the total eco-service value was relatively stable and short of elasticity. This further indicates that the study results in this paper are relatively reliable (Zhao et al. 2004; Bian and Lu 2012). When the eco-service value coefficient of farmland was adjusted upwardly by 50 %, the general eco-service value decreased on average by 0.77 % relative to the value before adjustment during 1958–2006. It showed that the eco-service value coefficient of farmland was close to the real value of ecological value coefficient of biomass summation in farmland. Other land use types had such features as well. Moreover, the above analysis revealed that the eco-service value coefficients presented by Costanza et al. (1997) and Xie et al. (2003) were feasible in eco-service value evaluation of Manas River Basin. Analyzing the transforms of land use types in different periods was the basis of eco-service value calculation.

Table 3 Ecological service sensitivity coefficients of different land use type in Manas River Basin in 1958, 1976, 1987, 1998 and 2006

Land use type	Ecological service sensitivity (CS)				
	1958	1976	1987	1998	2006
Farmland	0.09	0.12	0.18	0.25	0.31
Forest land	0.26	0.30	0.30	0.18	0.17
Grassland	0.47	0.53	0.47	0.48	0.45
Water area	0.18	0.03	0.04	0.08	0.05
Industrial area	0.00	0.00	0.00	0.00	0.00
Unutilized area	0.01	0.01	0.01	0.01	0.01

Analysis on land use changes

On the basis of land use data of Manas River Basin in 1958, 1976, 1987, 1998 and 2006 (Fig. 2), the change characters of various land use types were calculated (Table 4).

The land use types of Manas River Basin changed greatly on the time scale during the period 1958–2006; the area of farmland and industrial increased continually; while forest, grassland, water and unutilized areas decreased. It also reflected that the basin’s natural ecosystem was destroyed in the recent 50 years due to intensive human disturbance. Specifically, there showed the downtrend in forest land, grassland and water area of 1958–1976, in grassland and unutilized area of 1976–1987, in forest land, grassland and unutilized area of 1987–1998, and in forest land, grassland, water area and unutilized area of 1998–2006. Other land use types were on the rise in the corresponding periods. Among various land use types, farmland was on the successive increase in the recent 50 years. Especially, the increasing rates were largest during the period 1976–1987 (12,350 ha per year) and 1987–1998 (12,087 ha per year). The area of forest land showed a slight increase by 708 ha during the period 1976–1987 and decreased by 119,006 ha, particularly during the period 1987–1998. The area of grassland decreased continuously in four periods. Owning to over-grazing and excessive reclamation in mountain and plain grasslands, the decreasing rate of grassland reached up to 13,154 and 14,095 ha per year during the period 1976–1987 and 1998–2006. The area of water reduced by 79,140 ha during the period 1958–1976, which was because Manas Lake was starting to shrink and dry up during that period (Zhang et al. 2012). Thereafter, the water area expanded which was

Table 5 The value of different land use type in Manas River Basin (US$ × 10^6)

Land use type		Farmland	Forest land	Grassland	Water area	Industrial area	Unutilized area	Sum
1958	Value quantity	320.06	918.31	1,644.66	619.86	0.59	26.16	3,529.64
	Contribution rate	9.07	26.01	46.6	17.56	0.02	0.74	100
1976	Value quantity	354.15	871.83	1,552.93	96.35	1.63	34.85	2,911.74
	Contribution rate	12.16	29.94	53.33	3.31	0.06	1.2	100
1987	Value quantity	517.54	874.08	1,390.21	117.40	2.02	28.31	2,929.56
	Contribution rate	17.67	29.83	47.45	4.01	0.07	0.97	100
1998	Value quantity	677.46	495.52	1,286.00	213.22	2.23	26.19	2,700.62
	Contribution rate	25.09	18.35	47.61	7.9	0.08	0.97	100
2006	Value quantity	792.25	441.91	1,159.19	136.27	4.70	25.56	2,559.88
	Contribution rate	30.95	17.26	45.28	5.32	0.18	1.01	100

Table 4 The rate changes of land use in Manas River Basin from 1958 to 2006

Land use type	1958–1976		1976–1987		1987–1998		1998–2006	
	Variable quantity (ha)	Rate (ha $year^{-1}$)	Variable quantity (ha)	Rate (ha $year^{-1}$)	Variable quantity (ha)	Rate (ha $year^{-1}$)	Variable quantity (ha)	Rate (ha $year^{-1}$)
Farmland	28,332	1,574	135,854	12,350	132,954	12,087	95,434	11,929
Forest land	−14,612	−812	708	64	−119,006	−10,819	−16,854	−2,107
Grassland	−81,532	−4,530	−144,689	−13,154	−92,656	−8,423	−112,762	−14,095
Water area	−79,114	−4,395	3,181	289	14,482	1,317	−11,629	−1,454
Industrial area	12,631	702	4,818	438	2,530	230	30,228	3,778
Unutilized area	146,627	8,146	−110,334	−10,030	−35,829	−3,257	−10,604	−1,325

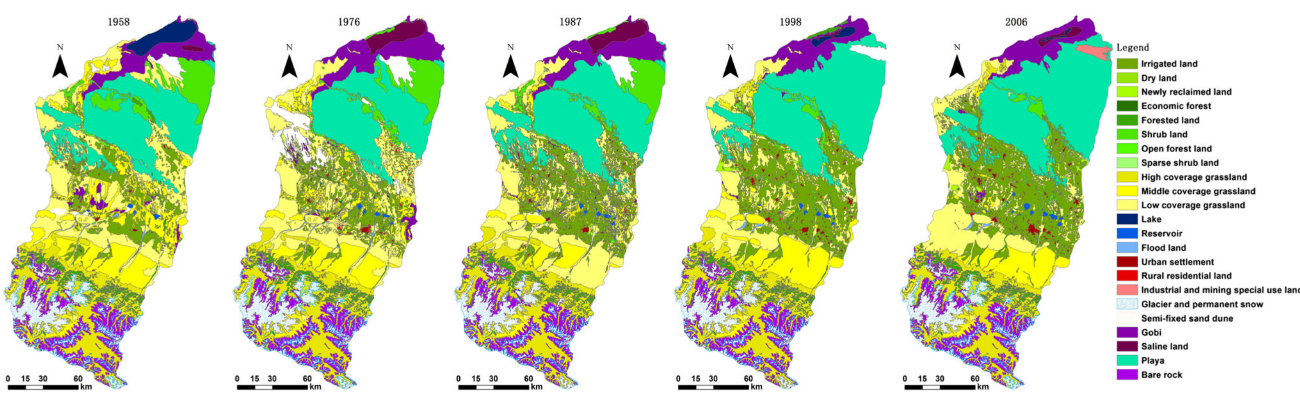

Fig. 2 Changes in land use and land cover from 1958 to 2006 in Manas River Basin

caused by the warming-wetting influences of the regional climate changes. However, impacted by population expansion and irrigation development, the area of water area reduced by 11,629 ha during the period 1998–2006; the industrial area showed a successive rise during 1958–2006, and had the largest increasing date of 3,778 ha per year during the period 1998–2006. During the period 1958–1976, the unutilized area expanded by 146,627.9 ha and subsequently remarkably decreased as a result of human activities and technological advance.

Eco-service value changes of Manas River Basin

The eco-service values of Manas River Basin were worked out by the formula (1), the benefits and intensities of ecosystem services relative to land use type changes in study area were thus put in quantitative analysis (Table 5 and Fig. 3).

The eco-service value of Manas River Basin decreased to 2,559.88 US$ × 10^6 in 2006 from 3,529.64 US$ × 10^6 in 1958 with the loss of 969.76 US$ × 10^6. Regional

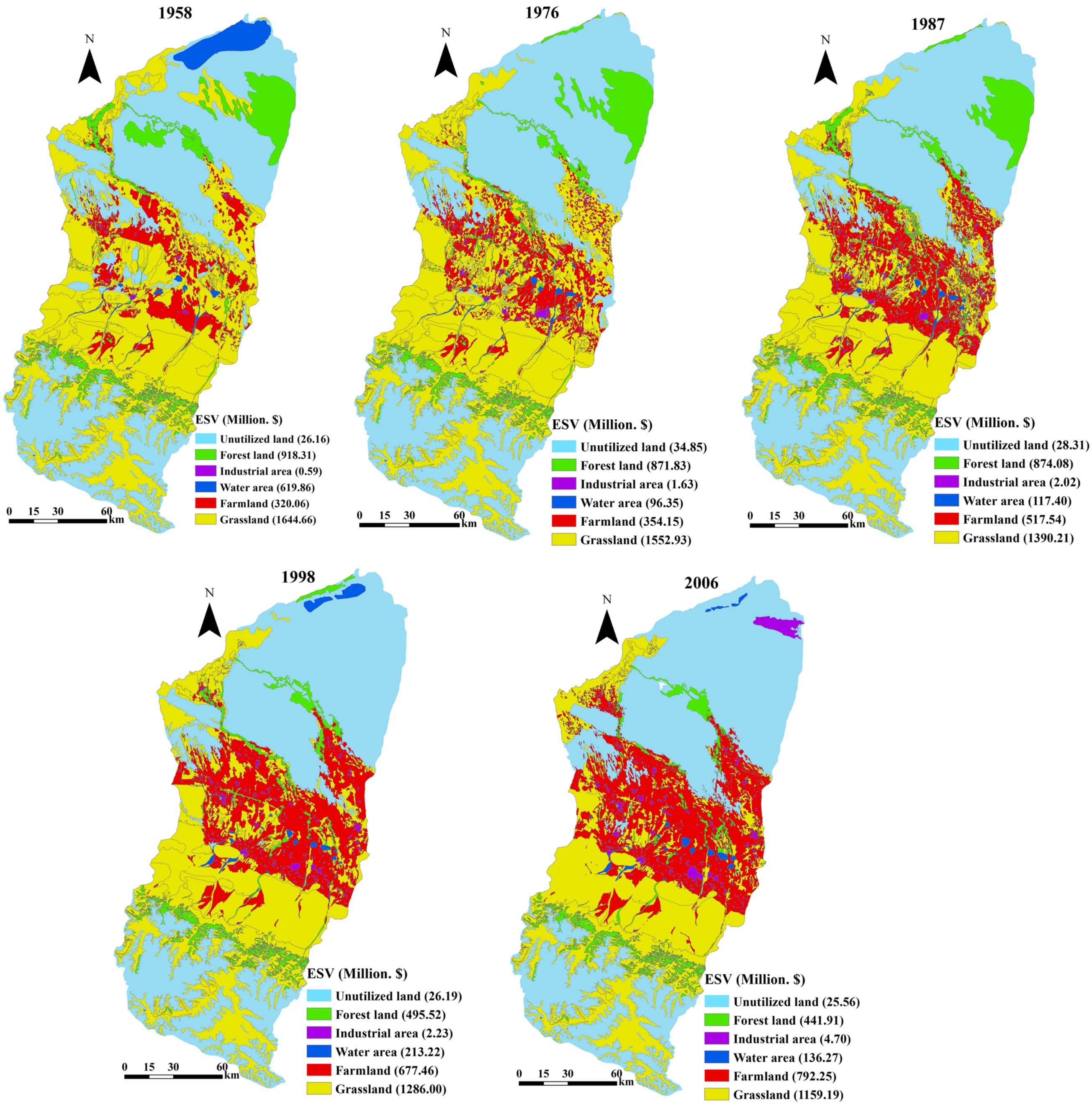

Fig. 3 Distribution of the ecosystem services value in Manas River Basin in 1958, 1976, 1987, 1998 and 2006

ecosystem service value quantities changed with the transforms of land use types, and ecological benefits were on a downtrend trend, whereas during the period 1976–1987, farmland, forest land and water area (eco-service value quantities per unit area of all were relatively large) were on the increase by the rate of 12,350, 64 and 289 ha per year, respectively. As a result, the eco-service value of the river basin rose by 17.83 US$ $\times$ 10^6 during that period. Before 1998, forest land and grassland accounted for relatively larger proportions of all land use types, which had relatively higher eco-service values per unit area, and the contribution rates were predominant. Forest land and grassland shrunk markedly and farmland expanded on a large scale since 1998, which gave rise to the contribution rate of farmland rising continuously. During the period 1958–1976, the values of farmland, industrial area and unutilized area rose by 34.08 US$ $\times$ 10^6, 1.03 US$ $\times$ 10^6 and 8.69 US$ $\times$ 10^6, respectively. However, the deduced eco-service value of water area was not offset by the former increments, and the eco-service value of river basin decreased during the period.

The eco-service values of farmland, water area, and industrial area increased during the period 1987–1998; however, the total eco-service value deduced by 228.95 US$ $\times$ 10^6. It was because the areas of forest land, grassland and unutilized area deduced by 378.56 US$ $\times$ 10^6, 104.21 US$ $\times$ 10^6 and 2.12 US$ $\times$ 10^6, respectively. Similar to the former three periods, the eco-service values of farmland and industrial area maintained the upward trend during 1998–2006. However, there presented decreasing trend in values of forest land, grassland, water area, and unutilized area, particularly, the eco-service values of grassland and water area decreased by 126.81 US$ $\times$ 10^6 and 76.95 US$ $\times$ 10^6. Accordingly, the total eco-service value of the river basin lost 140.74 US$ $\times$ 10^6 in this period.

Eco-economic functional regionalization of Manas River Basin

It was the first time to practice eco-economic functional regionalization in Manas River Basin. Exploring temporal-spatial changes of local ecological service values based on eco-economic functional regionalization, and understanding variation features of eco-service values of different eco-economic units and induced ecological responses. It may be used further for the local ecological restoration and optimization.

Based on the principles, indices and sub-area naming methods of eco-economic functional regionalization, and local geomorphic type (Cai et al. 2010; Fan et al. 2011), the Manas River Basin is discussed. This research adopts parts of previous research results (Zhang et al. 2012) that are from southern Tianshan Mountains to northern Gurbantunggut Desert; the river basin was divided into three first-grade areas that include nine second-grade areas (Fig. 4): (1) the southern part, forest, grazing and mining area in grassland-forest areas of Tianshan Mountains, which was subdivided into forest, grazing and runoff formation sub area in middle and high mountain areas of Eren Habirga Mountains (I1), and grazing, farming and soil–water conservation sub area in low mountain and broad valley areas of Taxi River-East bay-West Gobi (I2); (2) the central part, agriculture and town oasis area in Manas River plain, which was subdivided into three sub areas: agriculture and town oasis pollution prevention sub area in Manas-Shehezi-Shawan alluvial fan (II1), agricultural oasis salinization prevention sub area in Shihutan-Anjihai fan-fringing belt (II2), agricultural oasis sand fixation sub area in mainstream delta of Mosuowan (II3), agricultural oasis salinization and desertification prevention sub area in alluvial plain and mainstream delta of Xiayedi (II4); (3) the northern part, ecological conservation and sand industry area in Gurbantunggut Desert, the sub areas of which were: artificial restoration of desert vegetation and sand industry sub area on two sides of Mosuowan corridor (III1), natural restoration of desert vegetation and oil–gas exploitation and development sub area in northern Mosuowan (III2), and natural vegetation conservation and salt industry sub area in the lower reaches of Manas River and lake basin (III3).

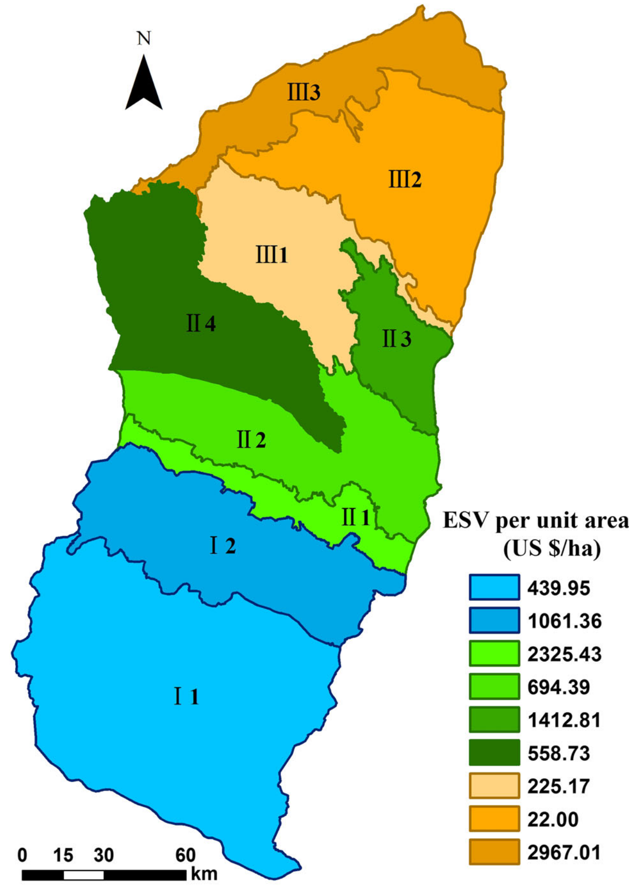

Fig. 4 Spatial varieties of ecosystem service values in different ecological and economic sub areas in the Manas River Basin

Eco-service value changes of different eco-economic functional areas on the temporal scale

In Manas River Basin, the eco-service values of different eco-economic functional areas are determined by the regional eco-economic characters and land use types. The eco-service value changes of different eco-economic functional areas in the study area were analyzed on the temporal scale (Table 6).

From Table 6, the eco-service value of Area I1 increased by 0.89 US$ $\times$ 10^6 during the period 1958–2006, which was because the eco-service values of forest land and grassland increased by 6.13 US$ $\times$ 10^6 and 20.93 US$ $\times$ 10^6, counteracting the reductions of other land use types. The eco-service values increased with the rates of 7.23 and 14.29 % in the periods 1958–1976 and

Table 6 Ecological services values of different eco-economic sub areas in Manas River Basin (US$ $\times$ 10^6)

Eco-economic sub area	Ecological service value				
	1958	1976	1987	1998	2006
I1	392.04	412.81	381.78	406.85	392.93
I2	415.93	414.71	413.79	445.09	440.29
II1	246.70	233.21	268.90	294.59	308.96
II2	369.90	358.42	329.53	305.71	248.70
II3	154.50	121.36	108.93	194.27	196.08
II4	336.99	344.82	315.99	285.47	252.12
III1	151.31	118.58	98.71	83.83	67.83
III2	356.75	264.60	211.48	13.18	9.73
III3	1,105.53	643.22	800.46	671.63	643.24

1987–1998, and decreased during other periods. The increase of eco-service values was chiefly attributed to the expansion of grassland and unutilized area during the period 1958–1976 and expansion of grassland and water area during the period 1987–1998. The reductions were due mainly to a decrease in grassland, water area, and unutilized area. The eco-service value of Area I2 was on the rise during 1958–2006 like Area I1. During the period 1987–1998, the eco-service value increments of farmland, forest land, and water area made up the losses of increment of 31.30 US$ $\times$ 10^6 during the same period. The eco-service values were on the reduction in other periods as a result of greatly reduced grassland, water area and unutilized area. The values of Area II1 decreased by 13.49 US$ $\times$ 10^6 during the period 1958–1976; this was because the decrements of water area and forest land were much larger than the increments of the other lands. The eco-service values of farmland, grassland and industrial area increased in the subsequent three periods; therefore, the regional eco-service value during the period 1958–2006 rose by 62.26 US$ $\times$ 10^6. The eco-service values of grassland in Area II2 reduced by 213.53 US$ $\times$ 10^6 during the period 1958–2006, offsetting the increments of other land use types. Thus, the regional eco-service value was continuously decreased. The eco-service value increment of Area II3 reached 41.58 US$ $\times$ 10^6 during the whole study period. Area II3 lies in the lower reaches of Manas River Basin. The phenomenon that farmland and industrial area take up a great deal of the forest land and grassland before the late 1980s, results in the reduction of regional eco-service value. Thereafter, the local departments strengthened ecological construction and restored forest land. The restoration of forest land, as well as the increase of farmland, made the regional eco-service value present an increasing trend during the period 1987–2006. The eco-service value of Area II4 has totally decreased by 84.87 US$ $\times$ 10^6 from 1958 to 2006. However, during the period 1958–1976, the values of farmland, grassland, water area and industrial area were more remarkable, counteracting the decrease of forest land and unutilized area. Accordingly, the regional eco-service value in this period rose by 7.83 US$ $\times$ 10^6. The eco-service value of Area III1 reduced by 83.48 US$ $\times$ 10^6 during 1958–2006. The main contributed land use types were forest land and grassland. Residents blocked dams, built reservoirs and reclaimed land in upstream Manas River Basin since the 1950s; it is the main leading cause of the death of sand-protecting forest and grassland (caused by water shortage) planted along the edge of desert. During the period 1958–2006, the value of Area III2 decreased by 347.01 US$ $\times$ 10^6. Area III2 is located in Gurbantunggut Desert with the fragile ecosystems. The oil exploitation in desert hinterland further accelerated environmental degradation; therefore, the values of forest land and grassland decreased considerably. The eco-service value decrement of Area III3 during the period 1958–2006 was 462.29 US$ $\times$ 10^6. Owing to the increase of farmland, the regional values rose by 157.23 US$ $\times$ 10^6 merely during the period 1976–1987; the other three periods were the decreasing periods. The cutoff of downstream Manas River and intermittent drying of lakes during the period 1958–1976 were the primary causes of eco-service value decrease in this period. The reduction of eco-service value during the period 1987–2006 was chiefly caused by the expansion of the desertification area. If the certain amount of ecological water discharge is ensured, the regional ecological security is enhanced.

Eco-service value changes of different eco-economic functional areas on the spatial scale

According to land use type map of Manas River Basin in 2006, the present spatial variation characteristics of eco-service values of various eco-economic functional areas were obtained after calculations (Fig. 4).

The sequences of eco-economic service values per square km of different eco-economic functional areas were: III3 > II1 > II3 > I2 > II2 > II4 > I1 > III1 > III2.

The eco-service value per unit area of Area III2 was the lowest among different eco-economic functional areas. The reason was that the area was mainly fixed and semi-fixed dunes with the dry climate, and vegetation coverage was relatively lower. The eco-service value per unit area of Area III1 was merely larger than that of Area III2, and the eco-service values of forest land and grassland contributed most. Area III1 had small eco-service value, the reason was that desert vegetation destruction was more intensive near regiments, and the protection forest on the edge of the desert was near to dearth. Therefore, there were even 50 % of semi-dunes activated in some areas. Area I1 was located in the headstream mountain areas with bare rock as the main land use type; therefore, the local eco-service value per unit area was small as well. The eco-service value per unit area of Area II4 was below the middle level among all functional areas. The contribution rates of forest land and grassland were largest among different land use types. The value of Area II4 was lower because of high underwater level, severe salinization and intensive desertification. The eco-service value per unit area of Area II2 increased by 135.73 US$ ha^{-1} more than Area II4, lying in the middle level of all functional areas. The salinized farmland area still accounted for 52 % of the total area though soil improvement had been implemented for many years. In addition, the economic structure of Area II2 was simple and dominated by agriculture; therefore, the regional output value per unit land area was low. Compared to Area II2, the eco-service value per unit area of Area I2 increased more by 366.83 US$ ha^{-1}, which was mainly contributed by farmland, grassland, and water area. Area I2 belonged to desert steppe and low vegetation coverage, and many intermontane valleys were reclaimed, which made Area I2 turn into the farming-pastoral region. The eco-service value per unit area of Area II3 was more than Area I2 and < Area II1. Area II3 was located in the downstream delta of Hutubi River and surrounded by desert on three sides. Area II3 was the major ecological restoration area in the river basin, and was mainly contributed by farmland and forest land. The eco-service value per unit area of Area II1 was only less than that of Area III3, and was mainly contributed by the expansion of farmland, grassland and water area. Area II1 was the region with the fastest urbanized and industrialized growth in the river basin; the regional population had been 60 % of the basin population, and the regional total output value has occupied 70 %. However, environmental pollution will be more serious with accelerated urbanized and industrialized growth. Simultaneously, owing to the municipal water utilization dependency on underground water, the regional groundwater has been lowering with the speed of 0.2–0.5 m per year. The eco-service value per unit area of Area III3 increased by 2,950.56 US$ ha^{-1} more than that of Area III2, and was the maximum of all functional areas. Natural vegetation grows well; however, the dry up of Manas Lake intermittently caused some damage to surrounding vegetation.

Strategies and suggestions

From the above discussions, the eco-service values of Manas River Basin represent a downtrend overall with the spatial differences, based on the historical documents, monitoring data from field surveys. Consequently, there are several solutions for enhancing the eco-service value of every eco-economic functional area in the river basin.

(1) Area III2 is the major oil development base in Manas River Basin. Natural close hillsides and grazing prohibition should be implemented for vegetation restoration. The extensive mode of production at the expense of environmental destruction is resolutely discarded, and forest distributed from Karamay to Manas Lake oilfield is regarded as the major protected object. Petroleum exploration and development should pay more attention to the environment, dispose wastes in time and emphasize vegetation protection in oil–gas exploration and development.

(2) To improve the eco-service value of Area III1, correspondence with natural features of the three geographic zones should be established for sand fixation. The first is the enclosed dune vegetation from human disturbance; the second is set up along the outskirts of regiments, and large-scale sand-protecting backbone forest composed of drought-resisting species are in artificial field planting, with the reasonable allocation of trees, shrubs and grass. The third is established for the protection and field planting of agricultural protection forest, and artificial watering for bare dunes. The drought-resistance and sand-fixation functions of species were selected. The well-filling and expelling measures should be carried out for those who dig wells and reclaim wasteland in the forest without authorization.

(3) Water resource regulation and optimal operation should be enhanced in Area I1. Under the mechanism, the felling of forest areas is forbidden. Local forestry authorities need to enhance artificial afforestation to restore the original forestland, and carry out rotational and light grazing patterns for sustainable growth of pasture.

(4) In the region with high ground water of level Area II4, shaft irrigation and drainage is selected to lower water table and improve salina fields. To fix bare dunes that distribute sporadically in farmland, *Haloxylon ammodendron* is planted by means of trickle irrigation (Zhang et al. 2007a). Local departments advance farmland development through implementing land integration (land replacement, assignment and contract, and new-type agricultural economic cooperation organization establishment), with the purpose of improving water-saving irrigation and agricultural intensification levels.

(5) Shaft irrigation and drainage are preceded in Area II2 to realize soil desalting. Drip irrigation under plastic film conducted in the areas without thorough

improvement, makes soil desalinization impossible. Therefore, it is necessary to implement the salt-leaching process in every interval of 2–3 years.

(6) Grazing prohibition is put into practice in desert steppe of Area I2; local departments should migrate part of herdsmen to oasis, and strengthen the combination of farming and grazing.

(7) Area II3 suffers from severe wind-sand disasters so that relevant departments should strengthen the construction of agricultural protection forest, implement forest belt contract system (determine the rights of contractor and guarantee low water price). Under natural conditions, the shallow groundwater is not appropriate for irrigation (high degree of mineralization), and the water table will also be influenced markedly. Therefore, the exploitation of underground water on the superficial layer is undesirable. In addition, deep groundwater is the nonrenewable water resource and exploitable only in irrigation peak seasons and extreme low water years.

(8) Rational use of surface water and cut down of the exploitation of underground water in Area II1. The wastewater is discharged after disposing and reaching the standard. Reclaimed water reuse is an approach to solve the water shortage crisis.

(9) In order not to make Manas Lake in Area III3 be the source of salt dust, relevant departments should

(10) discharge enough ecological water into Area III3 from the upper reaches in the Manas River.

Conclusions

This paper estimated eco-service values of Manas River Basin and different eco-economic functional areas by calculating eco-service value quantities, which contributed to the optimized allocation of basin land resources. The conclusions were attained as follows.

(1) During the period 1958–2006, the land use type changes showed as the expansions of farmland and industrial area, and the deductions of forest land, grassland, water area, and unutilized area. The regional natural ecosystems were destroyed severely due to human activities, and the ESVs decreased progressively over time. Forest land and grassland ecosystems were of great significance for stabilizing the regional ESV level and maintaining the overall functions of regional ecosystem.

(2) Ecosystem service values were distributed unevenly in space; the sequences of ESVs per square meter of different eco-economic functional areas were: III3 > II1 > II3 > I2 > II2 > II4 > I1 > III1 > III2. However, from the spatial variation aspect, ESV decreased in areas spread mostly in the northern desert land (Area III1, III2 and III3), ESV remained constant or changed only slightly in Area I1 and I2, Area II1 and II3 had inconspicuous rises of ESVs, Area II2 and II4 had inconspicuous falls of ESVs.

(3) To enhance the general eco-service value and realize the coordinated growth of the economy and environment, a series of ecological recovery strategies were proposed according to different eco-economic features and problems of different eco-economic functional areas. Therefore, the regional eco-economic functional areas need to be regarded as the research unit in analyzing eco-service values, which will make for improving the environmental qualities of eco-economic sub areas, and restoring the regional environment conditions.

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References

Bai Y, Zheng H, Ouyang ZY, Zhuang CW, Jiang B (2012) Modeling hydrological ecosystem services and tradeoffs: a case study in Baiyangdian watershed, China. Environ Earth Sci 1–10. doi:10.1007/s12665-012-2154-5

Baskaran R, Cullen R, Colombo S (2010) Testing different types of benefit transfer in valuation of ecosystem services: new Zealand winegrowing case studies. Ecol Econ 69(5):1010–1022

Bian ZF, Lu QQ (2012) Ecological effects analysis of land use change in coal mining area based on the ecosystem service valuing: a case study in Jiawang. Environ Earth Sci 68:1619–1630. doi:10.1007/s12665-012-1855-0

Cai JL, Yi H, Huang Y (2010) Ecological function regionalization: a review. Acta Ecol Sinica 30(11):3018–3027 (in Chinese)

Chang J, Wu X, Liu AQ, Wang Y, Xu B, Yang W, Meyerson LA, Gu BJ, Peng CH, Ge Y (2011) Assessment of net ecosystem services of plastic greenhouse vegetable cultivation in China. Ecol Econ 70(4):740–748

Chen ZS, Che YN, Li WH, Chen YP (2010) Evaluating effect of land use change on environment in Ili valley based on ecosystem service value analysis. J Des Res 30(4):870–877 (in Chinese)

Cheng WM, Zhou CH, Liu HJ, Zhang Y, Jiang Y, Zhang YC, Yao YH (2006) The oasis expansion and eco-environment change over the last 50 years in Manas River Valley, Xinjiang. Science in China (Series D) Sci China SER D 49(2):163–175

Costanza R, d'Arge R, Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, Van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387(6630):253–260

Costanza R, Fisher B, Mulder K, Liu S, Christopher T (2007) Biodiversity and ecosystem services: a multi-scale empirical study of the relationship between species richness and net primary production. Ecol Econ 61(2–3):478–491

Fan H, Pan XD, Li YY, Fu C, Zhang FH (2008) Evaluation of soil environment after saline soil reclamation of Xinjiang oasis. China. Agron J 100(3):471–476

Fan ZL, Ye M, Xu HL, Qiao M, Zhang QQ, Zhang P (2011) Research on sub-divided ecological functional region on Manas River basin of Xinjiang. Arid Land Geography 33(4):493–501

Fisher B, Turner RK, Morling P (2009) Defining and classifying ecosystem services for decision making. Ecol Econ 68(3): 643–653

Fu BJ, Su CH, Wei YP, Willett lan R, Lue YH, Liu GH (2011) Double counting in ecosystem services valuation: causes and countermeasures. Ecol Res 26(1):1–14

Guo Z, Xiao X, Gan Y, Zheng Y (2001) Ecosystem functions, services and their values-a case study in Xingshan County of China. Ecol Econ 38(1):141–154

Kumar M, Kumar P (2008) Valuation of the ecosystem services: a psycho-cultural perspective. Ecol Econ 64(4):808–819

Li TH, Li WK, Qian ZH (2010) Variations in ecosystem service value in response to land use changes in Shenzhen. Ecol Econ 69(7): 1427–1435

Ling HB, Xu HL, Fu JY, Fan ZL, Xu XW (2013) Suitable oasis scale in a typical continental river basin in an arid region of china: a case study of the manas river basin. Quatern Int 286:116–125

Liu SA, Costanza R (2010) Ecosystem services valuation in China. Ecol Econ 69(7):1387–1388

Liu HY, Ji ZK, Tian J (2008) Reconstruction of former halophilous desert vegetation at present cropland sites using soil characteristics. Folia Geobot 43(1):35–47

Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron DR, Chan KMA, Daily GC, Goldstein J, Kareiva PM, Lonsdorf E, Naidoo R, Ricketts TH, Shaw MR (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front Ecol Environ 7(1):4–11

Plummer ML (2009) Assessing benefit transfer for the valuation of ecosystem services. Front Ecol Environ 7(1):38–45

Sagoff M (2011) The quantification and valuation of ecosystem services. Ecol Econ 70(3):497–502

Shi LY, Cui SH, Yin K, Liu J (2010) The impact of land use/cover change on ecosystem service in Xiamen. Acta Geogra Sinica 65(6):708–714

Sun HL, Li WH, Chen YP, Xu CC (2010) Response of ecological services value to land use change in the Ili River Basin, Xinjiang, China. Acta Ecol Sinica 30(4):887–894 (in Chinese, with English abstract)

Xie GD, Lu CX, Leng YF, Zheng D, Li SC (2003) Ecological assets valuation of the Tibetan Plateau. J Nat Resour 18(2):189–196 (in Chinese)

Xu XG, Cui CW, Xu LF, Ma LY (2012) Method study on relative assessment for ecosystem service: a case of green space in Beijing. China. Environ Earth Sci. doi:10.1007/s12665-012-1879-5

Yang W, Chang J, Xu B, Peng CH, Ge Y (2008) Ecosystem service value assessment for constructed wetlands: a case study in Hangzhou, China. Ecol Econ 68(1–2):116–125

Zhang XY, Lu XG (2010) Multiple criteria evaluation of ecosystem services for the Ruoergai Plateau Marshes in southwest China. Ecol Econ 69(7):1463–1470

Zhang BP, Yao YH, Cheng WM, Zhou CH, Lu Z, Chen XD (2002) Human-induced changes to biodiversity and alpine pastureland in the Bayanbulak region of east Tianshan Mountains. Mt Res Dev 22(4):1–7

Zhang JC, Zhao M, Liao KT, Xu YS, Zhang YC (2007a) Experimental research on desert vegetation restoration by drip irrigation at Minqin oasis edge. J Desert Res 27(1):94–98 (in Chinese)

Zhang WG, Hu YM, Zhang J, Liu M, Yang ZP (2007b) Assessment of land use change and potential eco-service value in the upper reaches of Minjiang River, China. J Forestry Res 18(2):97–102

Zhang BA, Li WH, Xie GD (2010) Ecosystem services research in China: progress and perspective. Ecol Econ 69(7):1389–1395

Zhang QQ, Xu HL, Li Y, Fan ZL, Zhang P, Yu PJ, Ling HB (2012) Oasis evolution and water resource utilization of a typical area in the inland river basin of an arid area: a case study of the Manas River valley. Environ Earth Sci 66(2):683–692

Zhao B, Kreuter U, Li B, Ma ZJ, Chen JK, Nakagoshi N (2004) An ecosystem service value assessment of land-use change on Chongming Island, China. Land Use Policy 21(2):139–148