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Dynamic evaluation of ecosystem service value of the riparian zone based on remote sensing from 1986 to 2012

B. L. Fu[1,2], Y. Li[1], B. Zhang[1], B. S. Yin[3], H. L. Zhu[1,2], and Z. F. Xing[1,2]

[1]Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, 4888 Shengbei Street, Changchun, Jilin 130102, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]Tangshan Normal University, 156 Jianshe Street, Tangshan 063000, China

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Correspondence to: Y. Li (liying_neigae@126.com)

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Abstract

In this paper, we calculated comparable and dynamic ecosystem service value per unit area in the riparian zone of Second Songhua River; then we also estimated changes in the value of ecosystem services resulting from land use changes; finally, we continuously evaluated the riparian ecosystem service value based on 520 basic evaluation units (BEUs) and explored the trend of the riparian ecosystem service value from 1986 to 2012. The results indicated that comparable economic values of per unit area food production of farmland ecosystems in 2012 almost increased three times more than that in 1986 from 154.83 to 382.45 $\$ \, ha^{-1}$; the people's willingness to pay for farmland ecosystem services increased from 0.24 in 1986 to 0.48 in 2012; the land areas supporting the environment and society generally declined, whereas areas of farmland significantly increased from 1986 to 2012; the riparian total ecosystem service value increased from 42.30 million $ in 1986 to 119.67 million $ in 2012, with an average increase rate of 4.06 $\% \, yr^{-1}$; the ecosystem service value of four reaches all have seen a sharp increase from 1986 to 2012; the average ecosystem service value of *a* reach was the smallest one in the four reaches, and the value of *c* and *d* reach was significantly more than other two reaches.

1 Introduction

A riparian zone is the interface between land and a river or stream. It is also an ecological transition zone of material, energy and information exchange between land and water ecosystems, which has the dual features of water and land (Zhang et al., 2010). Riparian zone is also the proper nomenclature for one of the fifteen terrestrial biomes of the earth. Riparian zones are significant in ecology, environmental management, and civil engineering because of their role in soil conservation, their habitat biodiversity, and the influence they have on fauna and aquatic ecosystems, including grassland, woodland, wetland or even non-vegetative. With the global climate change, urban sprawl, pollution aggravated and other human activities, riparian zone ecologic worsening, ecosystem destruction and other issues have become increasingly prominent (Jansen et al., 2005; González del Tánago et al., 2006; Gurung et al., 2009; Ivits et al., 2009; Magdaleno et al., 2010; Barquın et al., 2011). Ecosystem services can be defined as the conditions and processes through which natural ecosystems and the species that comprise them, sustain and fulfill human life (Daily, 1997), or the goods and services provided by ecosystem, which contribute to human welfare, either directly or indirectly (Costanza et al., 1997a, b). The provision of ecosystem services is directly related to the functionality of natural ecosystems upon which ecological processes and ecosystem structures depend (De Groot et al., 2002). Nevertheless, when human beings have tapped and utilized the riparian zone, they usually have emphasized its market value or the direct use value, ignoring its other ecological utility and ecological value. Excessive exploitation and utilization of riparian zone inevitable damages and weakens its ecosystem service function. In addition, land use has been the most direct form of human activity in the interaction between human being and nature, which plays a decisive role in the maintenance of ecosystem services function (Fernandes et al., 2011; Fernández et al., 2014).

Nowadays, some scholars have carried out the related researches about land use changes are coupled to ecosystem services (Metzger et al., 2006; Collard and Zammit, 2006; Yoshida et al., 2010) or how changes in the value of ecosystem services can be estimated (Chen et al., 2009; Li and Ren, 2008), estimating the value of ecosystem services of river mainly has concentrated on watershed or basin scale (Chen et al., 2012; Mendoza-González et al., 2012; Luisetti et al., 2014), and relatively little elaboration of the riparian zone's scale of ecosystem services has taken place. They usually used the value coefficient for single year to estimate the ecosystems service value based on time series ignoring the influence of economic factors (such as price level, consumption level and inflation) on the value coefficient.

In this paper, the main objectives of the present study were that: (1) we assigned equivalent weight factor per unit hectare of terrestrial ecosystem services in the riparian zone; (2) we calculated comparable and dynamic ecosystem service value per unit area in the riparian zone after comparable economic values of food production of farmland ecosystems and dynamic correction; (3) we estimate changes in the value of ecosystem services resulting from land use changes; (4) we continuously evaluated the riparian ecosystem service value based on 520 basic evaluation units (BEUs) and explored the trend of the riparian ecosystem service value from 1986 to 2012.

2 Study area and data source

2.1 Study area

This study was conducted on the riparian zone belonging to a part of the Second Songhua River from Fengman reservoir to Sancha estuary, the total length of 360 km. The Second Songhua River is the largest river in Jilin Province, Northeast China and flows through Jilin city, Dehui city, Songyuan city and other 11 cities and counties from the top-down (Fig. 1). The topography of the river basin mainly contains hills and plains. The climate is sub-humid receiving 700 mm annual rainfall. The 85 % of vegetative periods is from May to October.

A great change has taken place in the situation of land use from 1986 to 2012. The ecosystem of the riparian zone have done much damage by vegetation devastating forest for arable land, overgrazing, transportation infrastructure, urban sprawl, sand mining, tourism development, reclaimed wetland and other human activities. So the Chinese Ministry of Water Resources has decided to investigate and evaluate the ecological stability and integrality of the riparian zone from 2012.

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2.2 Data source

2.2.1 Land-cover data and other data

The land-use cartographies (1 : 100 000 scale) used in this study is available under request to Resources and Environment Science Data Center, Chinese Academy of sciences (Table 1). These land-use datasets was developed in 1986, 1995, 2000, 2005 and 2010 to comply with Chinese Academy of sciences and constitutes a very detailed vegetation catalogue. The land-use dataset in 2012 were acquired by pretreating Landsat 8 OLI (Operational Land Imager) images in 2013, setting up interpretation keys of field work, referring to the land-use cartography dataset in 2010 and then interpreting the images. According to the field work, the interpretation precision was 87.47 %.

Other dataset mainly contain 1 : 500 000 geomorphic map compiled by Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 1980s 1 : 100 000 topographic map and SRTM 90m DEM. The range of riparian zone is obtained from the geomorphic map and topographic map.

2.2.2 Normalized difference vegetation index data

There are 28 Multi-spectral Landsat images (Landsat MSS, TM, ETM+, OLI), captured of the study area, from May to October in 1986, 1995, 2000, 2005, 2013. Path/row is 118/29, 119/29 (Table 2). The spatial resolution of Landsat TM, ETM+ and OLI Multi-spectral bands is 30 m. The spatial resolution of Landsat MSS Multi-spectral bands is 78 m. These Landsat images are currently available at http://glovis.usgs.gov/ from U. S. Geological Survey (USGS). We calculated the average value of Normalized difference vegetation index (NDVI) of the study area from May to October in every year using ENVI 5.0 software (Exelis Visual Information Solutions, 2012).

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2.2.3 Socio-economic data

Socio-economic data is collected from China Statistical Yearbook for 1986–2013 and China Agricultural Product Cost Benefit Compilation for 1986–2013 compiled by National Bureau of Statistics of China.

3 Methods

3.1 Basic evaluation units

To link land-cover and riparian ecosystem service, the study area was partitioned into four parts. Each part was divided into discrete units. These units were called "basic evaluation units" (BEUs). As BEUs were applied over homogeneous river reaches not longer than 600 m following the Chinese Ministry of Water Resources technical document (Rivers (Lake) Health Assessment Indicators, Standards and Methods V1.0), that the length was used as a splitting criterion. Hence, the river reach (retrieved as a single feature GIS polyline) was split again from mouth to source for the main channels using ArcGIS software (ESRI, 2012). Then, the polygon covering the riparian area was cut using lines perpendicular to the river centerlines. This resulted in almost 520 BEUs. The width between the river bank and the riparian area external boundary ranged from 296 to more than 4700 m, depending on valley morphology.

3.2 Determination of equivalent weight factor of ecosystem service functions

Because the same ecological community exist spatial heterogeneity and the cumulative effect of human activity on the study area, the coverage of forest land, shrub woodland and sparse woodland in the study area exist obvious difference. The ability of ecosystem service functions, provided by different woodland is also different. The situation of high- (vegetation fraction > 60 %), mid- (30 % < vegetation fraction ≤60 %) and low-coved (10 % < vegetation fraction ≤30 %) grassland is the same as the woodland. So we determined to calculate the equivalent factor of forest land, shrub woodland, sparse woodland, high-, mid- and low-coved grassland based on the equivalent factor table of terrestrial ecosystem service values in China and calibrated parameter of Jilin province in China proposed by Xie et al. (2008) (Table 3) using Eqs. (1)–(2).

$$\varpi = \frac{\mathrm{NDVI}_m}{\mathrm{NDVI}_n} \tag{1}$$

$$e_{ij} = \lambda_{ij} \times \varpi \tag{2}$$

Normalized difference vegetation index (NDVI) is the average value from May to October; m is the subtype of land use category (such as forest land, sparse woodland, shrub woodland and high-, mid- and low-coved grassland), n is the supertype of land use category (such as forest and grassland); i refer to ecosystem service function type, and j is the land use category; λ is the equivalent factor of forest area and grassland in the Table 3. We determined the equivalent factor in the Table 3 after correction as the equivalent factor of ecosystem service values in the riparian zone (Table 4).

3.3 Estimation of static ecosystem service values per unit area

3.3.1 Valuation of food production functions of farmland ecosystem

The one factor was equal to the economic value of 1/7 of the actual food production of cropland per hectare. The value of the food production functions of farmland ecosystems was calculated as previously reported by Xie et al. (2008).The value of food production function per unit farmland area is determined as

$$E_a = 1/7 \sum_{m=1}^{4} (P_i \times Q_i) m = 1 \ldots\ldots 4 \tag{3}$$

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Here, E_a is the economic value of food service per unit area provided by the farmland ecosystem (Yuan × ha); m is the crop type, including wheat, corn, sorghum, beans; P_m is the average price of crop i (Yuan × kg^{-1}); Q_m is the yield of crop per unit area (kg × ha^{-1}).

3.3.2 Calculation of ecosystem service value per unit area in riparian zone

The economic value of ecosystem services per unit area in the riparian zone was determined using the equivalent factor of ecosystem services values in the riparian zone after calibration the weight factors (Table 4) and the economic value of food production of farmland ecosystem services in the study area.

$$u = \frac{\mathrm{NDVI}_1}{\mathrm{NDVI}_0} \tag{4}$$

$$E_{ij} = e_{ij} \times u \times E_a (i = 1,2\ldots\ldots 9; j = 1,2\ldots\ldots 10) \tag{5}$$

NDVI_0 is the average value of NDVI in the basin, and NDVI_1 is the average value of NDVI in the riparian zone calculated by Landsat images; i refer to ecosystem service function type, and j is the land use category; E_a is the economic value of food production of farmland ecosystem; e_{ij} is the equivalent factor of the ecosystem service function i of an ecosystem type j in the Table 4. E_{ij} is the value per unit area of ecosystem service function i of an ecosystem j.

3.4 Estimation of dynamic ecosystem service values per unit area

The realization of ecosystem service value needs to combine the local people's willingness to pay, and the willingness to pay is one of the basic concepts and theory for evaluating value of non-market goods and ecological services. Because people's understanding of ecological service value is a gradient of awareness. In the lower

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stage of economic development, the awareness of ecological value is also low, and this awareness level enhances relatively slowly; but after it have reached a well-off, the requirement for environmental comfort service will dramatically increase until it become saturated. This characteristics of process of cognition can be described Pearl Growth Curve. The ecosystem service value that human can accept is closely related to the willingness to pay and social-economic development level. In order to keep the comparability of data from 1986 to 2012, we need to calculate the comparable economic values to eliminate influence of price level, inflation and other economic factors. In addition, the willingness to buy ecosystem service value will change along with the economic development from 1986 to 2012. So we used the Pearl Growth Curve model to correct the static coefficients of ecosystem service values.

Comparable economic values of food production of farmland ecosystems.

$$E_{an}=E_{am} \bigg/ \frac{\phi n}{\phi m} \times \frac{\mathrm{GDP}_m}{\mathrm{GDP}_n} \times 100 \tag{6}$$

The equation is from China Statistical Yearbook compiled by National Bureau of Statistics of China. In this equation, both m and n are years, with m being the current year and n being the past year. E_{am} is the current the economic value of food service of farmland ecosystem in riparian zone for year m, E_{an} is calculated by the E_{am} value in year n during the study period. GDP is the Chinese Gross Domestic Product and Φ is the yearly GDP index.

Dynamic correction method based on Pearl Growth Curve model.

$$E=\frac{L}{1+a\times e^{-bt}} \times E_a \quad t=\frac{1}{En}-3 \tag{7}$$

Here, E is the ecosystem service value per unit in year m, t is the socio-economic development indicator, a, b and L are constants and set to 1, e is the natural logarithm, En is the Engel coefficient and E_a is the food production value of farmland ecosystems in the current year.

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3.5 Calculation of ecosystem service values in the riparian zone

$$\text{ESV} = \sum_{i=1}^{9} \sum_{j=1}^{10} S_j \times E_{ij} \quad (8)$$

Here, ESV is the total value of ecosystem services, S_j is the area of ecosystem type j, E_{ij} is the value per unit area of ecosystem services i of ecosystem type j, i is the type of ecosystem services and j is the type of ecosystem.

4 Results

4.1 Economic value per unit area of ecosystem services

The ratio between the average of Normalized difference vegetation index (NDVI) in the riparian zone and the average of NDVI in the basin was calculated to calibrate the value coefficient of ecosystem services per unit area transformed from basin scale to riparian zone scale. The regional socio-economic development data of the basin districts for 1986 to 2012 were provided by the State Statistics Bureau of China. First, the GDP index from the State Statistics Bureau of China was used to calculate comparable economic values of food production for lessening influence of price level, inflation and other economic factors and enhancing the comparability of ecosystem services value from 1986 to 2012. Second, these data were used to obtain the Engel coefficients and to calculate the dynamic correction parameters based on Pearl Growth Curve model for static ecosystem service values per unit area. Last, the value per unit area of every ecosystem service was obtained after a series of corrections using the parameters listed in Table 5, (1 US \$ = 6.21 Yuan (2014)).

The economic values per unit area of ecosystem services were calculated for the different ecosystems of the riparian zone in 1986, 1995, 2000, 2005 and 2012. As listed in Table 6 and Fig. 2a, the values per unit area of the different ecosystems in

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2012 was significantly more than the other four years. Meanwhile, the comparable economic values of per unit area food production of farmland ecosystems in 2012 almost increased three times more than that in 1986 from 154.83 to 61.59 $ ha^{-1}.

4.2 Estimation of ecosystem service values

The ecosystem service values of the riparian for the different years were obtained from the economic value per unit area of ecosystem services and the area of different ecosystems. The area of the different ecosystems can be seen from Table 7.

Changes of land use. From the Tables 7 and 8, we could see that the cropland comprised the largest portion of the total area, over 30 % of the total area for each year, and the next was wetland and shrub woodland. In contrast, the area of low-coved grassland, water body, build up and barren land was very small. The area of cropland was 29 885.45 ha in 1986 and 39 003.06 ha in 2012, increasing by 9117.61 ha, at an average increasing rate of 1.03 % yr^{-1}. The area of wetland increased 13829.36 ha from 8937.9 ha in 1986 to 22 767.26 ha in 1995, about 31.88 % of the total area. Then the area of wetland decreased by 12 582.7 ha from 22 767.26 ha in 1995 to 10 184.56 ha in 2012. The average annual decrease rate was 3.05 % yr^{-1}. The area of shrub woodland decreased by 9900.285 ha from 16 003.66 ha in 1995 to 6094.375 ha in 2012, the average annual decrease rate was 3.65 % yr^{-1}. The forest land and sparse woodland had small size in area, less than 4 % of the total area. The area of forest land decreased by 11.31 ha from 1986 to 2012, approximately 0.25 % yr^{-1}. The area of sparse woodland increased by 368.86 ha from 2332.49 ha in 1986 to 2701.35 ha in 2012, the average annual decrease rate was 0.57 % yr^{-1}. The three types of grassland also had small size in area, less than 10 % of the total area. The high-coved grassland increased in area from 2772.78 ha in 1986 to 3125.74 ha in 2012, with an average growth rate of 0.57 % yr^{-1}. The area of other grassland was with an average decrease rate of 2 ~ 3 % yr^{-1}.

Overall, cropland, woodland, grassland and wetland were the primary land use categories of the riparian zone, contributing to about 85 % of its total land use area. The area cropland and shrub woodland gradually increase from 1986 to 2012.

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Changes of ecosystem service values. From the Tables 9, 10 and Fig. 2b, the ecosystem service value of the wetland comprised the largest portion of the total values, over 30 % of the total value for each year from 1986 to 2012, and the next was cropland and shrub woodland, both more than 13 % of the total value for each year. The ecosystems, which comprised very small percent of the total value, less than 3 % of the total value, included low-coved grassland, water body, build up and barren land. The ecosystem service value of the wetland was 14.73 million $ in 1986 and 56.14 million $ in 1995, with an increase of 41.41 million $, and the average annual increasing rate was 14.31 % yr^{-1}. From 1995 to 2012, the ecosystem service value of the wetland decreased 2.90 million $, leaving only 53.25 million $ in 2012, 44.68 % of the total value. The average annual decrease rate was 0.2 % yr^{-1}. The primary reason for these was that this evaluation method considered both the area of ecosystem type and its ecosystem service function value per unit. The change trend of wetland is the same as its area change (Table 7). The ecosystem service value of the cropland was relatively large, 7.11 million $ in 1986 and increasing to 29.41 million $ in 2012, about 24.68 % of the total value. The average annual increase rate was 5.62 % yr^{-1}, a fact that was primarily because of the area of farmland having a significantly increase, with the average increasing rate of 1.03 % yr^{-1}. The ecosystem service value of the shrub woodland comprised 31.67 % percent of the total values in 1986 and decreasing to 13.57 %, and its ecosystem service value increased from 13.39 million $ to 16.18 million $, the average annual increase rate was 0.73 % yr^{-1}. The ecosystem service value of forest land and sparse woodland had small size in total value, less than 6 % of the total value. The value of forest land increased by 3.13 million $ from 1986 to 2012, approximately 4.28 % yr^{-1}. The value of sparse woodland increased by 4.56 million $ from 1.71 million $ in 1986 to 6.27 million $ in 2012, the average annual decrease rate was 5.13 % yr^{-1}.

In conclusion, the ecosystem service value of the wetland, cropland, woodland and grassland comprised 90 % of the total values. The total ecosystem service value in riparian increased from 42.30 million $ in 1986 to 119.17 million $ in 2012, with an average increase rate of 4.06 % yr^{-1}.

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4.3 Ecosystem service values based on BEUs

By utilizing the value coefficients (Table 6) and areas of different land use categories in the basic evaluation unit (BEU), the ecosystem service value of land use category *j*, value of ecosystem service function type *i* and the total ecosystem services value of riparian in 1986, 1995, 2000, 2005 and 2012 could then be obtained through programming in ArcGIS software following the Eq. (8). These results are shown in Figs. 3 and 4, Table 11.

The average ecosystem service value of *a* reach was the smallest one in the four reaches, and the average value of *c* and *d* reach was significantly more than other two reaches in each year. The average ecosystem service value of *d* reach was the largest one in all reaches. The primary reason for these was that the size of the *a* reach itself was the smallest among the four reaches, and the types of ecosystems in the *a* reach was mainly build up and cropland with a low ecosystem service value per unit; the size of *d* reach was relatively large, and its types of ecosystems was mainly wetland and grassland with a high ecosystem service value coefficient. There were fluctuations range of ecosystem service value in the end of *b*, *c* reach and the end of *d* reaches, especially a peak in *c* reach. The total trend of ecosystem service value in the *a* reach was steady in every year. The reason for these trend was that the structure of land use of the region changes in evidence from 1986 to 2012, and the rate of dynamic change of land use is very high (Table 8). The ecosystem service value of every reach in 2012 was the largest one in the five years.

The ecosystem service value of four reaches all have seen a sharp increase from 1986 to 2012. The average ecosystem service value of *a* reach was 0.02 million $ in 1986 and 0.06 million $ in 2012, with an increase of 0.04 million $. The average ecosystem service value of *d* reach was relatively large, 0.14 million $ in 1986 and increasing to 0.50 million $ in 2012.

5 Discussion

Riparian zones present sharp gradients in environmental factors, ecological processes and biological communities (Gregory et al., 1991). The conservation of riparian areas in good quality is crucial for maintaining many important ecological functions in rivers, including many services provided to society (Hruby, 2009; NRC, 2002). Despite this, riparian areas are commonly under huge anthropogenic pressure due to land-use transformation and fragile environments (Fernández et al., 2014). The importance of finding a balance between socio-economic development and fluvial ecosystem preservation is reflected in the increasing number of studies relating riparian buffer width with riparian functions (e.g. Hawes and Smith, 2005). Studies of the ecosystem service values of riparian zone and their changes could provide data for evaluating ecological system scarcity. Furthermore, comparing changes in the ecosystem service values of different years could help to provide specific regulatory strategies and create a theoretical basis for ecological security and sustainable social and economic development. Specifically, the introduction of basic evaluation unit can provide novel insights for calculating ecosystem service value.

Ecosystem services are supplied at various spatial and temporal scales, which has a strong impact on the value different stakeholders attach to the services (Millennium Ecosystem Assessment, 2003; Turner et al., 2003; Hein et al., 2006). With respect to spatial scale, we calibrate parameters of equivalent weight factor and value coefficients using the Normalized difference vegetation index. As for the dynamic ecosystems and the developing economy and the growing population, the local people's willingness to pay for the ecosystem functions would also be changing. This study utilized the concept of ecological economics and recommends the use of the economic development level factor (GDP and GDP index) to calculate the comparable ecosystem services value. The introduction of comparable economic values and dynamic correction method can realize estimation of dynamic ecosystem service value based on the time series. Some researcher used the value coefficient for single year to estimate and compare

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the ecosystems service value based on time series ignoring the influence of economic factors (such as price level, consumption level and inflation) on the value coefficient.

Estimation ecosystem service value based on basic evaluation unit, applied within homogeneous river reaches not longer than 600 m, linked riparian ecosystem service and assessing riparian zone quality. However, critical items in riparian management, such as flood risk assessment or riverine species conservation, cannot be understood without a continuous evaluation of the riparian corridor (González del Tánago and García de Jalón, 2011; Fernández et al., 2014). Estimation ecosystem service value based on basic evaluation unit could continuously monitor and evaluate riparian ecological status over time. In addition, this method used remote sensing technology for estimation ecosystem service value have many advantages including frequent acquisition, repeat coverage for monitoring changing conditions, and low image cost in comparison to field work.

Land use has been used as a proxy measure of ecosystem services and as an indicator of riparian quality. However, the biomes used as proxies for the land use categories are clearly not perfect matches in every case (Kreuter et al., 2001). In addition, the accuracy of the average value coefficients is in doubt because of ecosystem heterogeneity. Despite some methodological shortcomings, some products derived from remote sensing are nowadays easy to obtain. In particular, some remote-sensing derived land-cover data are nowadays available over large areas. As they also include periodical updates, they potentially constitute a good data resource for ecosystem service valuation over time.

6 Conclusions

After calculation value coefficient of ecosystem service in the riparian zone, comparable economic values and dynamic correction, this paper dynamic estimate ecosystem service value of riparian zone by multiplying the area of a given land use category by the corresponding value coefficient. By analyzing and discussing the changes of

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ecosystem service value based on land use in riparian zone from 1986 to 2012, we finally came to the conclusions as follows: (1) the values per unit area of the different ecological systems in 2012 was significantly more than the other four years; (2) the total ecosystem service value in riparian increased from 42.30 million $ in 1986 to 119.17 million $ in 2012, with an average increase rate of 4.06 % yr^{-1}; (3) The ecosystem service value of four reaches all have seen a sharp increase from 1986 to 2012. This study could contiguously estimate ecosystem service value of the riparian zone for different years after a series of calibration, especially comparable value and Pearl Growth Curve model. The method based on basic evaluation unit can monitor ecosystem integrity of the entire riparian zone based on time series, which is useful to help in the establishment of guidelines for riparian management and conservation.

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Table 1. 1 : 100 000 Land-use categories in the riparian zone.

First categories	Second categories and number
Forest area	forest land (21),sparse woodland (22), shrub woodland (23)
Grassland	High-coved grassland (31), mid-coved grassland (32), low-coved grassland (33)
Cropland	paddy field (11), glebe field (12)
Wetland	Riverine Wetlands (63)
Water body	rivers (41), reservoirs fishery (43) and lakes (42)
Barren land	lands unused or difficult for using (61), saline-alkaline land (62)
Build up	industrial and commercial (52), residential (51), transportation ends (53)

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Table 2. Multi-temporal landsat images.

Year	Path/Row		Sensors
	118/29	119/29	
	18 May 1987	6 May 1986	MSS
1986	2 Jun 1986	1 Jun 1986	
	20 Sep 1986	19 Sep 1986	
	11 Jun 1996	2 Jun 1996	MSS
1995	18 Jul 1995	11 Jul 1995	TM
	29 Sep 1995	20 Sep 1995	
	25 Jun 2001	11 Aug 2001	
	12 Aug 2001		
2001	7 Oct 2001		
		24 Jun 2001	ETM+
		28 Sep 2001	
	10 Oct 2005	29 May 2006	TM
		17 Aug 2006	
2005		17 Oct 2005	
	30 May 2006		ETM+
	18 Aug 2006		
2012	25 May 2013	1 Jun 2013	OLI
	16 Oct 2014	7 Oct 2014	

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Table 3. Equivalent weight factor per unit hectare of terrestrial ecosystem services in Jilin province.

	Forest	Grassland	Cropland	Wetland	Water body	Barren land
Food	0.32	0.41	0.96	0.35	0.51	0.02
Raw material	2.86	0.35	0.37	0.23	0.34	0.04
Gas regulation	4.15	1.44	0.69	2.31	0.49	0.06
Climate regulation	3.91	1.50	0.93	13.01	1.98	0.12
Water regulation	3.93	1.46	0.74	12.90	18.02	0.07
Waste treatment	1.65	1.27	1.33	13.82	14.26	0.25
Soil retention	3.86	2.15	1.41	1.91	0.39	0.16
Biodiversity protection	4.33	1.80	0.98	3.54	3.29	0.38
Entertainment	2.00	0.84	0.16	4.50	4.26	0.23

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Table 4. Equivalent weight factor per unit hectare of terrestrial ecosystem services in riparian zone.

	1	2	3	4	5	6	7	8	9	10
Food	0.36	0.34	0.30	0.46	0.43	0.42	1.00	0.36	0.53	0.02
Raw material	3.25	3.07	2.68	0.39	0.36	0.35	0.39	0.24	0.35	0.04
Gas regulation	4.71	4.45	3.89	1.61	1.50	1.46	0.72	2.41	0.51	0.06
Climate regulation	4.44	4.19	3.66	1.67	1.56	1.51	0.97	13.55	2.06	0.13
Water regulation	4.46	4.21	3.68	1.63	1.52	1.47	0.77	13.44	18.77	0.07
Waste treatment	1.87	1.77	1.55	1.41	1.32	1.28	1.39	14.40	14.85	0.26
Soil retention	4.38	4.14	3.62	2.40	2.24	2.17	1.47	1.99	0.41	0.17
Biodiversity protection	4.92	4.65	4.06	2.00	1.87	1.81	1.02	3.69	3.43	0.40
Recreation	2.27	2.14	1.87	0.93	0.87	0.84	0.17	4.69	4.44	0.24

1, forest land; 2, shrub woodland; 3, sparse woodland; 4, high-coved grassland; 5, mid-coved grassland; 6, low-coved grassland; 7, cropland; 8, wetland; 9, water body; 10, barren land.

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Table 5. The calibrated parameters of economic value per unit area of ecosystem services.

Year	μ	Comparable value ($\$ \times ha^{-1}$)	Dynamic correction
1986	0.81	154.83	0.24
1995	0.63	297.78	0.24
2000	0.69	189.63	0.35
2005	0.61	255.59	0.39
2012	0.52	382.45	0.48

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Table 6. The of economic value per unit area of ecosystem services ($\$ \times ha^{-1}$).

Ecosystems	1986	1995	2000	2005	2012
1	885.67	1324.85	1347.53	1789.18	2808.89
2	836.92	1251.92	1273.36	1690.69	2654.27
3	731.29	1093.91	1112.64	1477.30	2319.27
4	360.82	539.73	548.98	728.90	1144.32
5	337.21	504.42	513.06	681.21	1069.46
6	327.10	489.29	497.67	660.78	1037.38
7	237.79	355.70	361.79	480.36	754.14
8	1648.56	2466.02	2508.24	3330.29	5228.35
9	1365.02	2041.88	2076.85	2757.51	4329.12
10	41.84	62.58	63.66	84.52	132.69

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Table 7. The area of different ecosystems in the riparian zone.

Ecosystems	1986		1995		2000		2005		2012	
	area(ha)	%	area(ha)	%	area(ha)	%	area(ha)	%	area(ha)	%
1	1788.199	2.552	1952.322	2.734	1784.722	2.481	1793.668	2.561	1676.885	2.527
2	16003.66	22.843	9888.919	13.847	9506.253	13.215	9737.214	13.902	6094.375	9.183
3	2332.492	3.329	1168.363	1.636	1268.793	1.764	1292.106	1.845	2701.35	4.071
4	2772.778	3.958	5112.287	7.158	6492.977	9.026	3293.859	4.703	3125.741	4.710
5	4456.944	6.362	2727.7	3.819	5160.99	7.175	3867.239	5.521	2085.792	3.143
6	762.6478	1.089	593.9916	0.832	1046.596	1.455	389.7336	0.556	461.2597	0.695
7	29885.45	42.658	26344.2	36.887	28625.18	39.794	31743.68	45.321	39003.06	58.773
8	8937.9	12.758	22767.26	31.879	17191.29	23.899	16915.04	24.150	10184.56	15.347
9	673.7293	0.962	397.3772	0.556	362.2801	0.504	725.6283	1.036	698.6185	1.053
10	2444.926	3.490	465.4029	0.652	494.7631	0.688	283.1492	0.404	330.8646	0.499
11	3874.208	5.240	3606.661	4.807	3872.193	5.108	4057.472	5.476	4953.713	6.946

1, forest land; 2, shrub woodland; 3, sparse woodland; 4, high-coved grassland; 5, mid-coved grassland; 6, low-coved grassland; 7, cropland; 8, wetland; 9, water body; 10, barren land; 11, build up.

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Table 8. Land use rate of change in the riparian zone.

Ecosystems	Land use rate of change per year (%)				
	1986–1995	1995–2000	2000–2005	2005–2012	1986–2012
1	0.88	−1.78	0.1	−0.96	−0.25
2	−4.7	−0.79	0.48	−6.47	−3.65
3	−6.68	1.66	0.36	11.11	0.57
4	6.31	4.9	−12.69	−0.75	0.46
5	−4.79	13.6	−5.61	−8.44	−2.88
6	−2.47	12	−17.93	2.44	−1.92
7	−1.25	1.67	2.09	2.99	1.03
8	9.8	−5.46	−0.32	−6.99	0.5
9	−5.14	−1.83	14.9	−0.54	0.14
10	0.88	−1.78	0.1	−0.96	−0.25
11	−0.71	1.43	0.94	2.89	0.95

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Table 9. The ecosystem services value (ESV) of different ecosystems (10^6 \$).

Ecosystems	1986		1995		2000		2005		2012	
	ESV	%	ESV	%	ESV	%	ESV	%	ESV	%
1	1.58	3.74	2.59	2.97	2.40	3.13	3.21	3.19	4.71	3.95
2	13.39	31.67	12.38	14.23	12.10	15.74	16.46	16.38	16.18	13.57
3	1.71	4.03	1.28	1.47	1.41	1.84	1.91	1.90	6.27	5.26
4	1.00	2.37	2.76	3.17	3.56	4.63	2.40	2.39	3.58	3.00
5	1.50	3.56	1.38	1.58	2.65	3.44	2.63	2.62	2.23	1.87
6	0.25	0.59	0.29	0.33	0.52	0.68	0.26	0.26	0.48	0.40
7	7.11	16.80	9.37	10.77	10.36	13.47	15.25	15.18	29.41	24.68
8	14.73	34.83	56.14	64.51	43.12	56.06	56.33	56.06	53.25	44.68
9	0.92	2.17	0.81	0.93	0.75	0.98	2.00	1.99	3.02	2.54
10	0.10	0.24	0.03	0.03	0.03	0.04	0.02	0.02	0.04	0.04
Total	42.30	100	87.03	100	76.91	100	100.48	100	119.17	100

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Table 10. The ecosystem services value (ESV) rate of change in different years.

Ecosystems	ESV rate of change per year (%)				
	1986–1995	1995–2000	2000–2005	2005–2012	1986–2012
1	5.03	−1.45	5.94	5.63	4.28
2	−0.78	−0.45	6.34	−0.25	0.73
3	−2.85	2.01	6.22	18.51	5.13
4	10.68	5.25	−7.6	5.86	5.02
5	−0.88	13.99	−0.1	−2.35	1.53
6	1.54	12.38	−13.14	9.25	2.54
7	2.8	2.02	8.04	9.84	5.62
8	14.31	−5.14	5.49	−0.8	5.07
9	−1.24	−1.5	21.61	6.08	4.69
10	−11.8	1.58	−5.34	9.05	−3.2
Total	7.48	−2.44	5.49	2.47	4.06

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Table 11. The average ecosystem services value in different reaches (10^5 \$).

Reaches	1986	1995	2000	2005	2012
a	0.21	0.32	0.29	0.47	0.57
b	0.67	1.53	1.12	1.64	2.84
c	1.00	2.32	2.00	2.72	3.82
d	1.35	2.48	2.45	2.76	4.96

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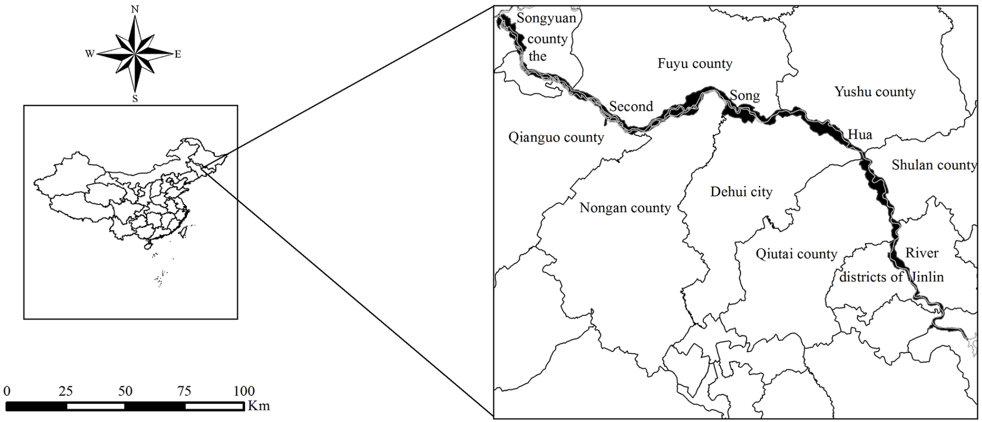

Figure 1. Location of study area.

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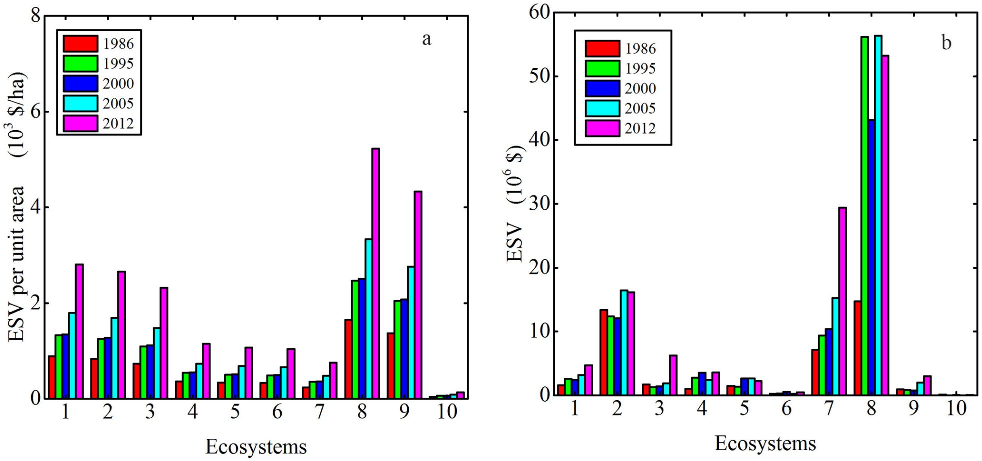

Figure 2. The ecosystem services value (ESV) of different ecosystems: 1, forest land; 2, shrub woodland; 3, sparse woodland; 4, high-coved grassland; 5, mid-coved grassland; 6, low-coved grassland; 7, cropland; 8, wetland; 9, water body; 10, barren land. **(a)** is the per unit area of ecosystem services value from 1986 to 2012; **(b)** is the total ecosystem services calculated by multiply the area by the per unit area of ecosystem services value.

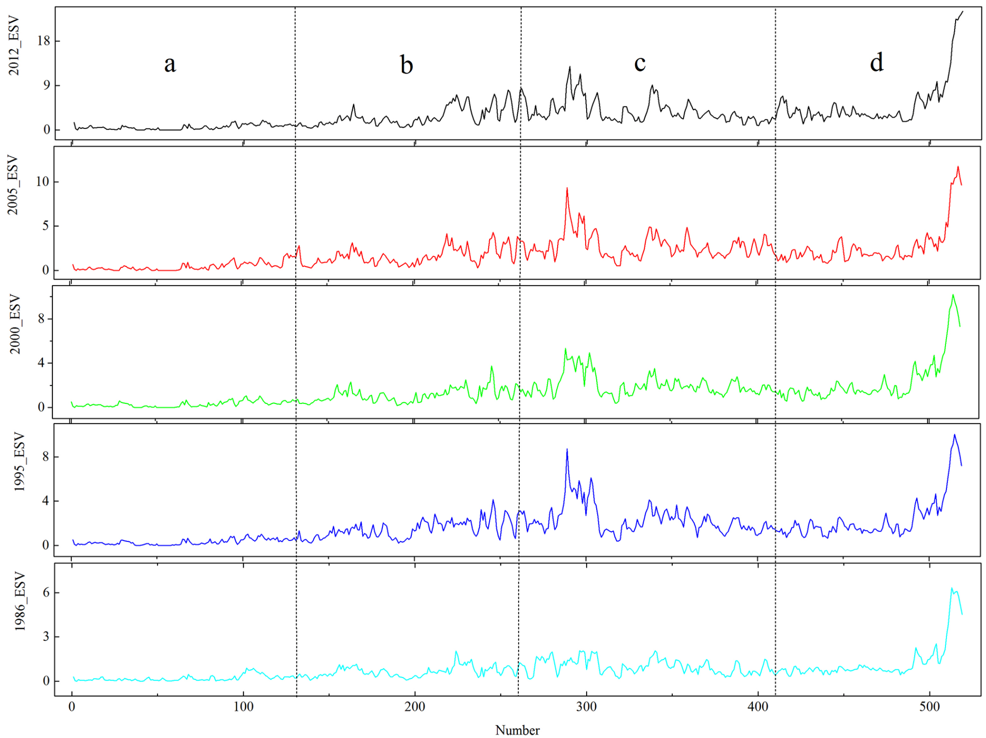

Figure 3. The ecosystem services value of different years in the 520 BEUs (10^5 $).

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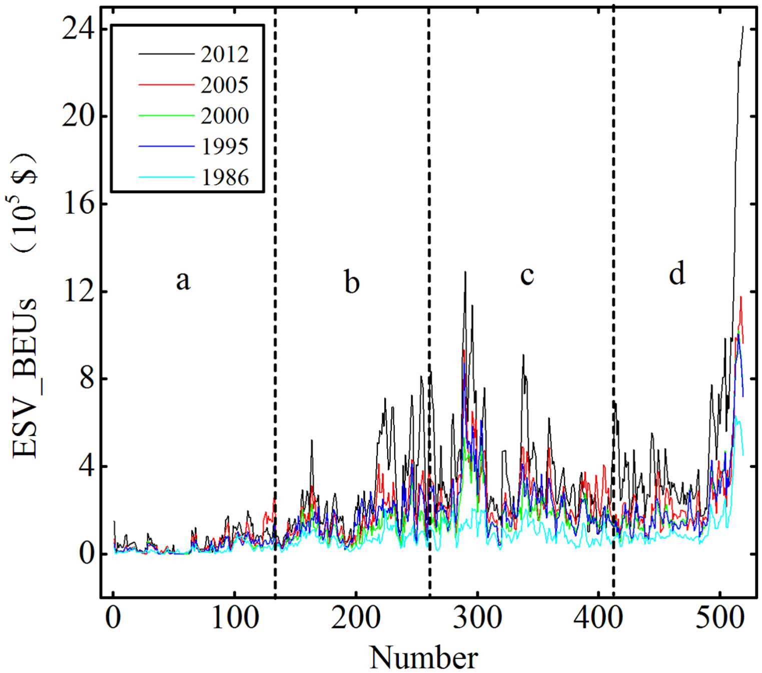

Figure 4. The average ecosystem services value in different reaches (10^5 $).