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STUDY ON THE RELATIONSHIP BETWEEN PHYSICAL STRUCTURAL INTEGRALITY AND ECOSYSTEM SERVICES VALUE IN THE RIPARIAN ZONE

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KEY WORDS: Riparian Zone, Physical Structural Integrality (PSI), Basic Evaluation Unit, Ecosystem Service Value (ESV), PSI and ESV Relationship

Abstract:

Riparian zone is crucial to the health of streams and their surrounding environment. A healthy riparian zone can provide food, habitats, protecting water quality and many other ecological functions and environmental benefits. Evaluating riparian quality is essential to achieve and maintain good stream health, as well as to guarantee the ecological functions that riparian areas provide. In this study, we addressed the consistency of characterizing integrality of ecosystem of a riparian zone in Northeast China with physical structural integrality (PSI) and ecosystem service value (ESV), and explored the relationship between the PSI and ESV. The procedures included (1) evaluation of PSI of the riparian zone based on remote sensing; (2) calculation of the riparian ESV based on basic evaluation units (BEUs); (3) exploration of statistical relationships between the PSI and the ESV by the performance of linear regression. The study concluded that the trend of PSI was the same as the ESV, and they were consistent in describing the quantitative trend of the riparian zone's ecosystem integrity. There was statistically significant correlation (R =0.66, P < 0.01 level) between PSI and ESV.

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1. INTRODUCTION

Riparian zones are ecosystems located along the bank of rivers, streams, or other water networks. Usually riparian zones are narrow strips of land that line the borders of water source, which are an ecological transition zone of material, energy and information exchange between land and water ecosystems (USDI Bureau of Land Management, 1998; Tang et al., 2014).When riparian zones are tapped and exploited, the market value or the direct use value is captured while other intangible ecological benefits ignored. Excessive exploitation and utilization of riparian zones will inevitably damage and weaken ecosystem service functions. Land use has been considered an indicator to evaluate riparian quality, which plays a decisive role in the maintenance of ecosystem services function (Fernandes et al., 2011; Miserendino et al., 2011; Fernández et al., 2014; Lu and He, 2014). Therefore land-use types and patterns in a riparian zone have been prone to affect the structure and function of the ecosystem. Quantification of ecosystem service value (ESV) of a riparian zone based on land use data has been considered an efficient approach to characterize its integrality of ecosystem (Li et al., 2008; Kindu et al., 2016; Li et al., 2016).

Several methodologies for assessing riparian quality and PSI existed and formed different evaluating indicator systems (Dixon et al., 2005; Munné et al., 2003; Jansen et al., 2005; Barquın et al., 2011; González et al., 2011). Riparian PSI and ESV both characterize the integrality of ecosystem, leading to two questions: (1) when riparian integrality of ecosystem is characterized by PSI and ESV, are their results consistent? (2) What is the statistical relationship between PSI and ESV?

To answer aforementioned questions, we did the followings: (1) used remote sensing method to evaluate the PSI of the riparian zone based on 520 basic evaluation units (BEUs); (2) calculated the coefficient of ESV per unit area and the ESV based on 520 BEUs in the riparian zone; (3) contrastively analyzed the trend of PSI and ESV in four measurement sections along the riparian zone; and (4) explored the statistical relationship between PSI and ESV, and further analyzed the ability of using PSI to model ESV by linear regression model.

2. STUDY AREA AND DATA SOURCE

2.1 Study area

This study focused on the 360 km riparian zone of the Second Songhua River from Fengman Reservoir to Sancha estuary. The Second Songhua River is the largest tributary and source of Songhua River, which originates in Changbai Mountain and flows through major cities and counties of the Jilin Province in Northeast China (Figure 1). The elevation of the river basin is between 54 to 2,667 meters above mean sea level. The climate of river basin is temperate continental climate with four clearly distinct seasons. The mean annual rainfall in the area is about 600-800mm.

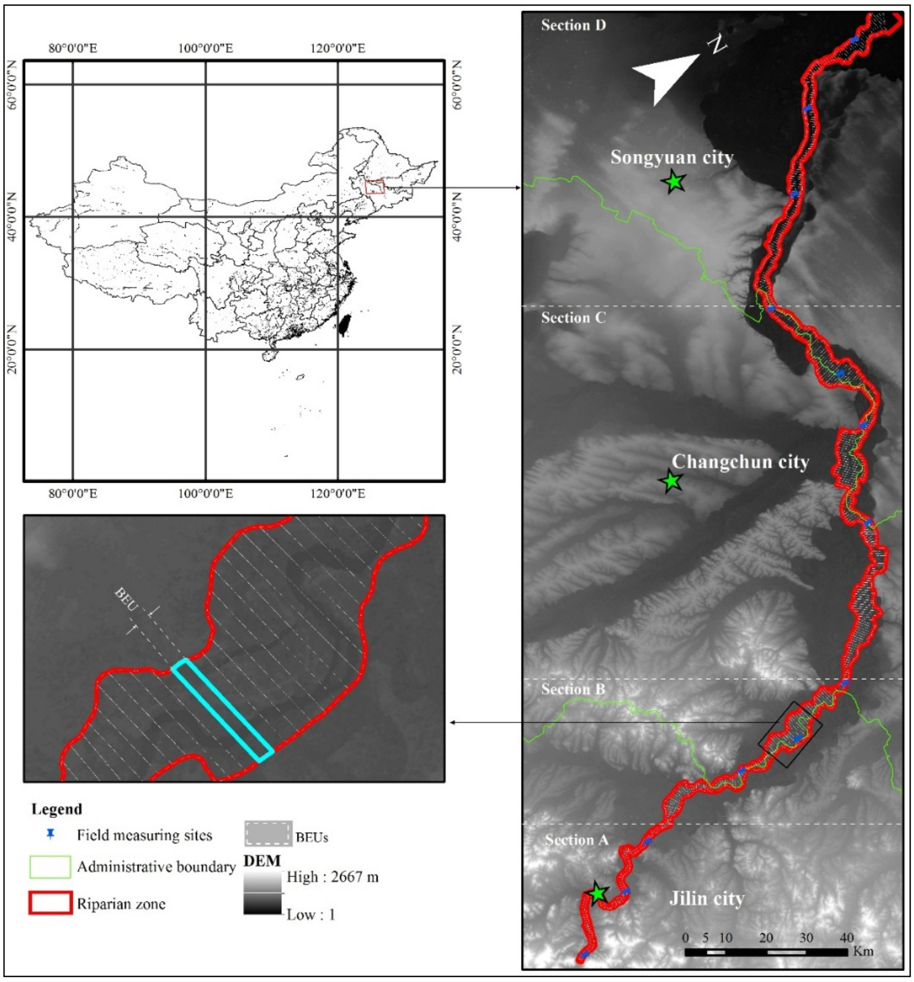

Figure 1. Location of study area and field measurement sites. Sections A, B, C and D represent the four measurement sections. Each section was partitioned into small serial units named basic evaluation units (BEUs).

2.2 Data source

2.2.1 Land cover data and other data

The land use dataset of 2012 derived from updating the land use map of 2010 with Landsat 8 Operational Land Imager (OLI) images acquired in 2013 according to the interpretation keys from field measurement sites (Figure 1 and Table 2). The 30m multi-spectral Landsat 8 OLI images covered the study area on 14 June and 12 October 2013, respectively, with path/row as 118/29 and 119/29.

Other datasets adopted including 1:500,000 geomorphic map and 1:100,000 topographic map developed by the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences; and Shuttle Radar Topographic Mission (SRTM) generated Digital Elevation Model data at 90 m spatial resolution. According to the definition of riparian zone, reference the 1:100,000 topographic map and 1:500,000 geomorphic map, the elevation range of the riparian zone was between 120 and 350 meters.Socio-economic data for 2012 derived from China Statistical Yearbook and China Agricultural Product Cost Benefit Compilation compiled by the National Bureau of Statistics of China, including the average price of main crop types of wheat, corn, sorghum and beans, yield of crop per unit area and the value of Engel coefficient. The positions of monitoring sites were obtained by global positioning system (GPS), and each monitoring point laid 10m×50m evaluation area. The slope angle and slope length was directly measured by a laser rangefinder, and used to calculate slope height. Vegetation coverage was measured by 1m×1m quadrat within the 10m×50m evaluation area.

3. METHODS

3.1 PSI and BEUs

The PSI is one of the important components in river health evaluation. The concrete evaluation indicators and weights are described in the Table 1.

The research area was divided into four measurement sections (Figure 1) and each section was partitioned into small serial units, named basic evaluation units (BEUs). The river was retrieved as a single feature GIS polygon and split from mouth to source for all the main channels. Then, the polygon covering the riparian zone was dissected using lines perpendicular to the river centerlines. This process generated 520 BEUs in the study area (Figure 1).

3.2 Evaluated PSI of the riparian zone

Riparian zone's PSI was calculated and evaluated by indicators, including riparian stability, river connectivity and natural wetland conservation ratio, and within each indicator was composed by some sub-indicators (Table 1). We cross-checked the evaluating results based on remote sensing with field measurements. The results were assigned into one of the five existing quality classes following the technical protocol, i.e., *bad* (PSI=<0.2), *poor* (0.2<PSI=<0.4), *moderate* (0.4<PSI=<0.6), *good* (0.6<PSI=<0.8) and *better* (0.8<PSI=<1.0).

Indicators		Sub-indicators	
		Field measurement	Remote sensing
Riparian Stability (RST) (0.5)	Bank stability (BKS) (0.25)	Slope angle (SA) (0.2)	Water-level width ratio（WD）(1/3)
		Slope height (SH) (0.2)	
		Vegetation coverage rate (VC) (0.2)	Vegetation coverage rate (VC) (1/3)
		Soil types Erosion status (ES) (0.2)	Area of Riparian zone ratio (RA) (1/3)
	vegetation Coverage (BVC) (0.25)	Vegetation canopy cover	Vegetation coverage (BVC)
	human intervention intensity (RD) (0.25)	Human built structures, sand mining and other activities	Cropland, build up and other land cover types
River connectivity (RC) (0.25)		The numbers of dams and reservoirs	The numbers of dams and reservoirs
Natural wetland conservation ratio (NWC) (0.25)		Wetland area ratio in the evaluating year (A_C) and historical years (1978)（A_R）	Wetland area ratio in the evaluating year (A_C) and historical years(1978)（A_R）

Table 1. The evaluating indicators and weights of PSI

3.3 Estimation of ESV from land cover types

3.3.1 Calculation of ESV per BEUs

3.3.1.1 Valuation of food production functions of farmland ecosystem

The economic value of one equivalent weight factor, i.e., the value of the food production functions of farmland ecosystems including main crop types of wheat, corn, sorghum and beans, was calculated by the equation (1) following Xie et al. (2010).

$$E_a = 1/7\sum_{m=1}^{4}(P_i \times Q_i) \qquad m=1, 2\ldots4 \qquad (1)$$

Where, E_a is the economic value of food service per unit area provided by the farmland ecosystem (Chinese Yuan (CNY) · ha^{-1}; 1$ (USD) = 6.21Yuan (CNY) in 2014); *m* is the crop types; P_m is the average price of crop *I* (CNY · kg^{-1}); Q_m is the yield of crop per unit area (kg · ha^{-1}).

3.3.1.2 Correction the value coefficients based on Pearl Growth Curve model

The ESV that human can accept is closely related to the personal willingness to pay and social-economic development level. That is, the willingness to buy ESV will change along with the economic development. So the PGC model is used to modify the value coefficients of ESV.

$$E = \frac{1}{1+e^{-t}} \times E_a \qquad t = \frac{1}{En} - 3 \qquad (2)$$

Where, *E* is the economic value of food service per unit area after calibration with the PGC model, e is the natural logarithm, *t* is the socio-economic development indicator, *En* is the Engel coefficient and E_a is the economic value of food service per unit area.

3.3.1.3 Calculation of ESV per unit area

The ESV per unit area in the riparian zone was calculated by the equation (3), using the equivalent factor of ecosystem services values in Jilin Province and the economic value of food production of farmland ecosystem services after calibration.

$$E_{ij} = e_{ij} \times E \quad (i=1,2\cdots\cdots9;\ j=1,2\cdots\cdots7) \tag{3}$$

Where, *i* is ecological function types, *j* is the land cover types; *E* is the economic value of food production of farmland ecosystem after correction by the PGC model ($\$ \cdot ha^{-1}$); e_{ij} is the equivalent factor of the ecosystem service function *i* of a land cover type *j* in the Table 5. E_{ij} is the economic value per unit area of ecosystem service function *i* of an ecosystem *j*.

3.3.1.4 Calculation of ESV

$$ESV = \sum_{i=1}^{9}\sum_{j=1}^{7} S_j \times E_{ij} \tag{4}$$

Where, S_j is the area of land cover type *j* (ha), E_{ij} is the value per unit area of ecosystem services *i* of land cover type *j* ($\$ \cdot ha^{-1}$), *i* is the type of ecosystem services and *j* is the land cover type.

3.4 The statistical relationship between PSI and ESV

Because PSI and ESV were not dimensionally homogeneous, they measured at different scales that did not contribute equally to the analysis. In the study, variables were standardized by the equation (5) to make sure all variables contribute evenly to a scale.

$$\overline{X} = (X - X_{\min})/(X_{\max} - X_{\min}) \tag{5}$$

We modelled the ESV using linear regression. In the model, the standardized ESV (Z-ESV) was as a dependent variable, and the standardized PSI (Z-PSI) was as an independent variable. Before performing linear regression, the Z-PSI were arcsine-square root transformed. The same transformation was also applied to the dependent variable (Z-ESV) to achieve normal distribution and improve homoscedasticity. Then, we selected the five mathematical models (such as linear, logarithmic, quadratic, cubic, exponential) to carry out curve estimation referring to the scatter diagram.

4. RESULTS

4.1 Evaluating result of PSI

The evaluation result was shown in Figure 2. To check the accuracy of the result, we used the evaluation result based on field measurements (PSI_FM) to verify the result based on remote sensing observations (PSI_RS) (Figure 2(a)).

4.1.1 Evaluating results of 14 measurement sites

The evaluation results based on remote sensing was that there were a little differences in some measurement sites, and the differences concentrated on the section A and D. But these differences were within 0.2, and would not affect the evaluation of an entire sections. Field measurements of three sites in the section A were higher than that the remote sensing results. The results calculated by remote sensing were higher than that by field measurement in the rest of measurement sites (Figure 2(a)).

4.1.2 Evaluating results of four measurement sections

The evaluating results of four measurement sections based on two methods were that the result concentrated on 0.45 ~ 0.85; the section D was still the highest and the section A was the lowest; according to the quality classes following the technical protocol, the evaluating results of section A and B were both in *moderate* category (0.4 < PSI < 0.6), and the section C and D were both in *good* category (0.6 < PSI < 0.8). This result demonstrated that the trend of the evaluating result of PSI_RS was consistent with PSI_FM (Table 2).

Sections	PSI_FM	PSI_RS
A	0.54	0.45
B	0.52	0.57
C	0.62	0.64
D	0.74	0.81

Table 2. The evaluation result of four sections

4.1.3 Evaluating results of BEUs

The evaluating results of BEUs were different in four measurement sections. The evaluation values of BEUs in the

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section D were higher than that of other sections, and the results in the section A was the lowest in the four sections. Besides, there was an observed fluctuation in the section B (Figure 2(b) and 2(c)).

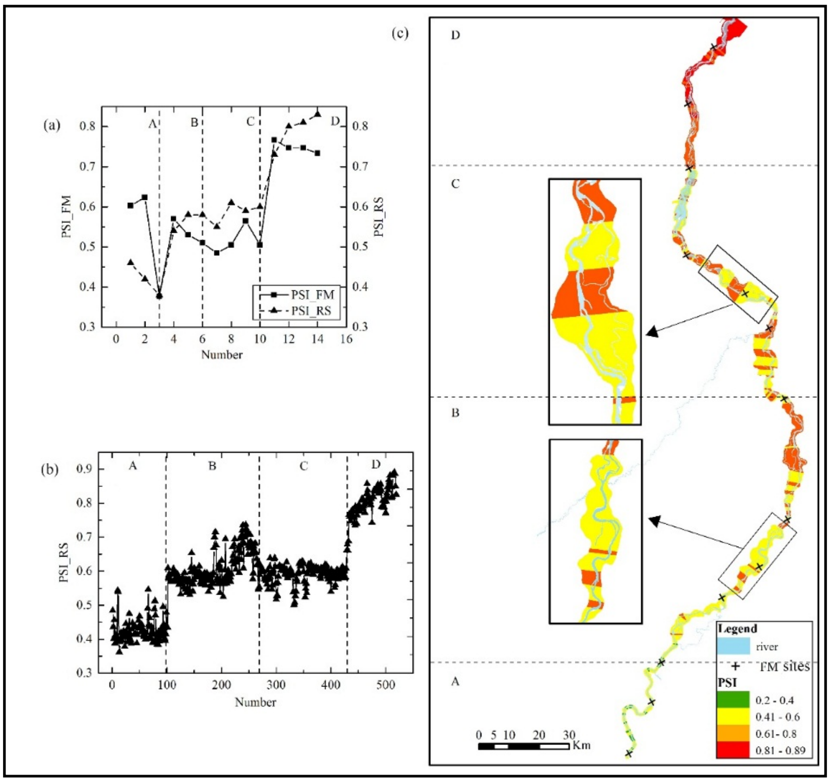

Figure 2. The evaluation result of PSI: (a) was the result of 14 measured sites; (b) and (c) were the result of 520 BEUs; (c) expressed the spatial distribution of result in the form of map. PSI_FM was the evaluating result of PSI calculated by the field measurement, and the PSI_RS was the result calculated based on remote sensing. FM sites was the field measured sites. A, B, C and D were the four measurement sections.

	Forest	Grassland	Cropland	Wetland	Water	Unused land
Food	32.93	42.91	99.79	35.93	52.89	2.00
Raw material	297.38	35.93	38.92	23.95	34.93	3.99
Gas regulation	431.10	149.69	71.85	240.50	50.89	5.99
Climate regulation	406.15	155.68	96.80	1352.18	205.57	12.97
Water regulation	408.15	151.68	76.84	1341.20	1873.10	6.99
Waste treatment	171.64	131.73	138.71	1437.00	1481.91	25.95
Soil retention	401.16	223.53	146.69	198.59	40.91	16.96
Biodiversity protection	450.06	186.61	101.79	368.23	342.29	39.92
Entertainment	207.57	86.82	16.96	468.02	443.08	23.95
Total	2806.15	1164.57	788.36	5465.61	4525.57	138.71

Note: 1$ (USD) = 6.21Yuan (CNY) in 2014

Table 3. The coefficients of ESV to each land cover types per unit area ($ · ha^{-1}).

4.2 Calculation ESV based on BEUs

4.2.1 The coefficients of ESV per unit area

The coefficients of ESV per unit area were calculated by the Equation (1) ~ (3). The value coefficients and area of different land cover types was shown in Table 3.

4.2.2 ESV based on BEUs

In order to be convenient for the next to explore the relationship between the PSI and ESV, we calculated the ESV for each individual unit of the 520 BEUs (Figure 3 (b) and 3 (c)), and selected 14 BEUs (Figure 3 (a)) from 520 BEUs, which had consistent one-to-one match the 14 measurement sites in the Table 1.

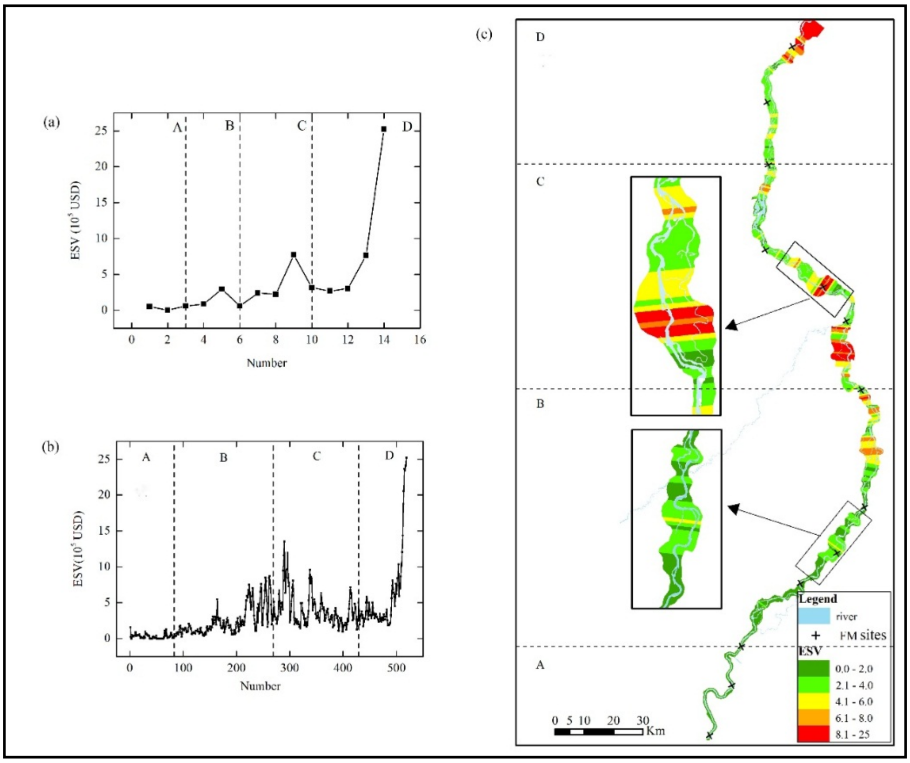

Figure 3. ESV based on 520 BEUs: (a) was ESV of 14 measuring sites; (b) and (c) were both the ESV of 520 BEUs; A, B, C and D were the measurement sections.

4.3 The relationship between PSI and ESV

4.3.1 The trend between PSI and ESV

The ecological integrality of the riparian zone can be characterized by both PSI and ESV. To compare their performance at the coincidence of characterized ecosystem, we compared the trend of Z-PSI and Z-ESV based on the 14 BEUs corresponding to 14 measurement sites and 520 BEUs, respectively. The comparison showed that section D both had the highest Z-PSI and Z-ESV while section A had the lowest Z-ESV and Z-PSI (Figure 4); whatever Z-ESV and Z_PSI based on 14 BEUs and 520 BEUs, the trend of Z-PSI and Z-ESV was coincident, which demonstrated that they were consistent in the quantitative description trend of ecosystem integrality.

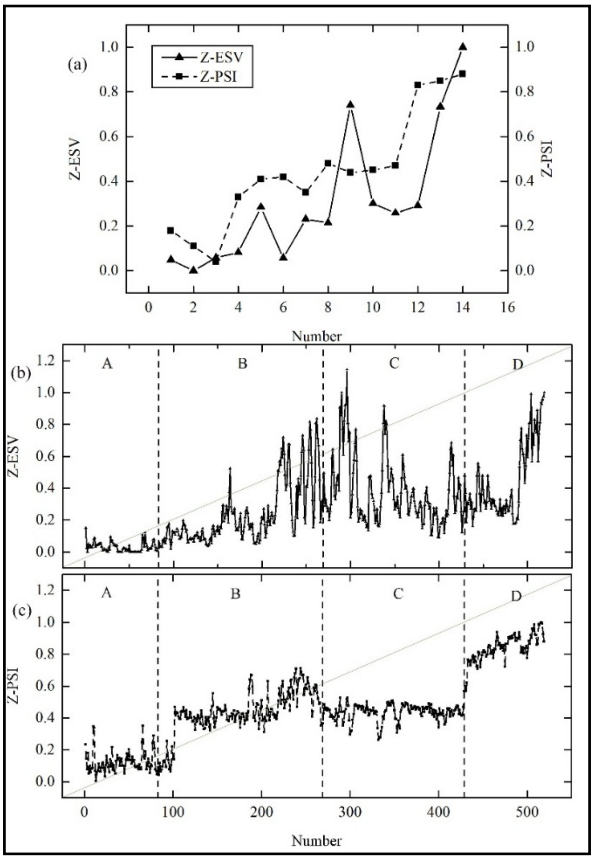

Figure 4. The trend of Z-ESV and Z-PSI: (a) was the trend of Z-PSI and Z-ESV based on the 14 BEUs corresponding to 14 measured sites; (b) and (c) was trend of Z-ESV and Z-PSI based on 520 BEUs, respectively; A, B C and D was the four measurement sections.

4.3.2 The statistical relationship between PSI and ESV

In order to further explore the statistical relationship between PSI and ESV, we tested five types of mathematical models, including linear, logarithmic, quadratic, cubic and exponential. Each of these models was utilized to carry out curve estimation referring to the scatter diagram. In the models, the dependent variable (Z-ESV) and the independent variable (Z-PSI) were both arcsine-square root transformed. The models performed better in revealing the relationship were linear, Quadratic and cubic curve models. The value of R^2 did not appear to be much different between those three models (Table 4).

After curve estimation, the linear model was selected to model Z-ESV with Z-PSI. The model was established with the one sample by linear regression analysis. The model was y=0.745*x-0.022 (R^2=0.435), in which y was Z-ESV and x was Z-PSI and the standard error of the parameters was less than 1. The other sample performed a leave-one-out cross-validation.

	Model Summary					Parameter Estimates			
	R^2	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.435	185.146	1	240	0.00	-0.022	0.745		
Quadratic	0.447	96.657	2	239	0.00	-0.197	1..243	-0.311	
Cubic	0.453	65.723	3	238	0.00	-0.452	2.497	-2.062	0.720

Table 4. Model Summary and Parameter Estimates

5. CONCLUSION AND DISCUSSION

The evaluation results concluded that the ecosystem of section A and B were both in *moderate* condition (0.4 < PSI < 0.6), and the ecosystem of section C and D were both in *good* condition (0.6 < PSI < 0.8). The ESV of riparian zone was calculated for each individual unit of the 520 BEUs. The ESV of the studied riparian zone was calculated to be $164.4 million. An average ESV of individual BEUs was $0.31 million. Comparison of the BEUs-based results between PSI and ESV found that the PSI and ESV were consistent in the quantitative description trend of integrality.

The PSI of the riparian zone of the Second Songhua River was evaluated with remote sensing and field measurements. The PSI values derived from remote sensing were consistent with field measurements at the section scale. The agreement between field and remote sensing evaluations demonstrates that the PSI of riparian zone calculated with remote sensing at the BEU scale is efficient, reliable and comparable.

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REFERENCES

Benayas, J. M. R., Newton, A. C., Diaz, A., & Bullock, J. M. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science, 325(5944), 1121-1124.

Chen, Q., Liu, J., Ho, K. C., & Yang, Z. 2012. Development of a relative risk model for evaluating ecological risk of water environment in the Haihe River Basin estuary area. Science of the Total Environment 420, 79-89.

Dixon I.H., Douglas, M.M., Dowe, J.L., et al., 2005. A Rapid Method for Assessing the Condition of Riparian Zones in the Wet/Dry Tropics of Northern Australia. In Proceedings of the Fourth Australian Stream Management Conference: Linking Rivers to Landscapes. Department of Primary Industries, Water and Environment, Hobart, Tazmania pp. 178-193.

Douglas M, Dowe J, Burrows D. 2006. Tropical Rapid Appraisal of Riparian Condition [M]. Land & Water Australia.

Fernandes, M. R., Aguiar, F. C., & Ferreira, M. T. 2011. Assessing riparian vegetation structure and the influence of land use using landscape metrics and geostatistical tools. Landscape and Urban Planning 99(2), 166-177.

Kindu, M., Schneider, T., Teketay, D. and Knoke, T., 2016. Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. Science of The Total Environment, 547, pp.137-147.

Li, T. H., Li, W.K., & Qian, Z.H., 2010. Variations in ecosystem service value in response to land use changes in Shenzhen. Ecological economics, 69(7), 1427-1435.

Li, G., Fang, C. and Wang, S., 2016. Exploring spatiotemporal changes in ecosystem-service values and hotspots in China. Science of The Total Environment, 545, pp.609-620.

Luisetti T, Turner R K, Jickells T, et al. 2014. Coastal Zone Ecosystem Services: From science to values and decision making; a case study [J]. Science of The Total Environment 493: 682-693.

Lu, Y. and He, T., 2014. Assessing the effects of regional payment for watershed services program on water quality using an intervention analysis model. Science of The Total Environment, 493, pp.1056-1064.

Mendoza-González, G., Martínez, M. L., Lithgow, D., et al., 2012.Land use change and its effects on the value of ecosystem services along the coast of the Gulf of Mexico. Ecological Economics 82, 23-32.

Miserendino, M.L., Casaux, R., Archangelsky, M., Di Prinzio, C.Y., Brand, C. and Kutschker, A.M., 2011. Assessing land-use effects on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. Science of the Total Environment, 409(3), pp.612-624.

Sánchez-Canales, M., Benito, A.L., Passuello, A., Terrado, M., Ziv, G., Acuña, V., Schuhmacher, M. and Elorza, F.J., 2012. Sensitivity analysis of ecosystem service valuation in a Mediterranean watershed. Science of the total environment, 440, pp.140-153.

Tang, Q., Bao, Y., He, X., Zhou, H., Cao, Z., Gao, P., Zhong, R., Hu, Y. and Zhang, X., 2014. Sedimentation and associated trace metal enrichment in the riparian zone of the Three Gorges Reservoir, China. Science of the Total Environment, 479, pp.258-266.

USDI Bureau of Land Management. 1998. Riparian Area Management: A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lotic Areas. Technical Reference TR 1737-15. pp, 4-7.

Xie, G.D., Zhen, L., Lu, C.X., Yu. X., Li, W.H., 2010. Applying value transfer method for eco-service valuation in China. Journal of Resources and Ecology, 1(1): 51-59.