Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 2	pp. 605-613	2016

Original Research Paper

Plant Diversity and its Correlation with the Physicochemical Properties of Soil in Different Gradient Levels in the Riparian Zone of Lijiang River

Lu Yang and Wang Dongmei†
Key Laboratory of Soil and Water Conservation and Desertification Combating, Ministry of Education, School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
†Corresponding author: Wang Dongmei

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 15-02-2016
Accepted: 18-03-2016

Key Words:
Plant diversity
Physicochemical properties of soil
Riparian zone
Lijiang river

ABSTRACT

Riparian zones are the most diverse and complex biophysical habitats being threatened by anthropogenic activities. Degradation of riparian vegetation is a serious problem. This study conducted a field standard sample plot investigation and experiments to evaluate plant diversity and the physicochemical properties of soil in different gradient levels of a riparian zone. The distribution patterns of plants and their correlation with the physicochemical properties of soil were also analysed. This study provides a theoretical basis for ecological protection, vegetation recovery, and vegetation reconstruction in a riparian zone in Guangxi and in the whole karst region of southwestern China. Ten typical sample plots in the riparian zone of Lijiang River in Guilin City, Guangxi Province, were selected. Various parameters, including quantitative characteristics of the plots and physicochemical properties of soil, were analysed. Results revealed that species abundance, diversity, and richness, as well as evenness indexes of plant communities in the riparian zone increased with the increase in gradient zone variation. The species diversity, Shannon-Wiener index, and evenness indexes of the plants in the herbal zone did not significantly differ from those in the shrub zone. Species richness index also significantly increased. In addition, the species richness indexes in the shrub zone did not significantly differ from those in the arbor zone. Physicochemical analysis revealed that the soils in the gradient zones were primarily composed of neutral and slightly alkaline sand. Soil bulk density initially increased and then decreased with the increase in relative altitude. The organic matter contents in the soil also increased. Changes in total nitrogen, total potassium, quick-acting potassium, and total phosphorus were not significant. Multiple regression analysis indicated high fitting degrees of total biomass, diversity, and environmental elements. Moreover, the contribution of soil texture on diversity was higher than that of soil nutrients.

INTRODUCTION

River ecosystem, a significant component of natural ecosystems, is an open and dynamic system with various functions, such as material production, biological diversity maintenance, environmental purification, disaster regulation, leisure, and entertainment (Huang et al. 2013). River banks, such as riparian zone, play essential roles in river ecosystems (Forman 1997). However, ecological problems, accompanied by flood inundation in rainy season, wetland shrinking, and vegetation degradation, along the bank of Lijiang River have exacerbated because of economic development and excessive exploitation of tourism resources. Riparian zones also perform various functions, such as controlling sediment and nutrients in surface runoff, protecting water quality, providing habitat for land and river animals, and maintaining biological diversity of rivers (Rao et al. 2008). Hence, the distribution characteristics of vegetation, the relationship between plant community diversity and soil, and the major influencing factors of plant community diversity in the riparian zone should be understood to solve vegetation restoration problems in riparian zones, particularly in Lijiang River.

Vegetation composition is closely correlated with soil nutrients under different degrees of grazing disturbance (Wang 2014, Zhang et al. 2009, Han et al. 2008, An et al. 2011, Liu Jianli 2013, Hou et al. 2002, Yang et al. 2010, Chen et al. 2001). Different vegetation communities exhibit a strong inherent correlation with sandy soil in spaces during desertification (Yang et al. 2010, Chen et al. 2001). Vegetation composition is significantly correlated with soil nutrients during vegetation succession in a grassland ecosystem (Antonio et al. 2005, Wu et al. 2014, Qu et al. 2003). Soil physicochemical properties significantly differ under various mountain vegetation compositions (Zhang et al. 2014, Yu et al. 2014, Jiang et al. 2011, Li et al. 2006). However, the relationship between vegetation characteristics and soil physicochemical properties in different gradient levels of riparian zones has been rarely investigated. Hence, this study conducted a comparative correlation analysis between vegetation and soil in four different gradient zones, namely, gravel zone, herbal zone, shrub-grass zone, and arbor-shrub-grass zone, to determine the succession patterns of vegetation and to provide a scientific basis for the restoration of the degraded ecosystem in the riparian zone of Lijiang River.

MATERIALS AND METHODS

Study area and sample-plot selection: Lijiang River is the upper reach of Gui River in Xijiang River of the Pearl River System, which is located in northeast Guangxi. The main stream is of 214km with total drainage area being 12,285 km^2. The Lijiang River belongs to mid-subtropical humid monsoon climate zone with all-year-round sufficient sunshine, moderate climate, abundant rainfall, long frost-free season, long summer and short winter, four distinctive seasons and rain and heat basically being in the same season (Liu et al. 2003), its temperature is within 17.8~19.1°C, annual rainfall is within 1814~1941mm, annual evaporation capacity is within 1377~1857mm, and annual average relative humidity is 80%; annual runoff is quite abundant, but annual distribution is quite uneven, from March to August is its flood season, covering about 80% of annual runoff, and runoff from May to June covers 40% of annual runoff, from September to February in the year ensuing is its dry season, and January is the driest month, covering only 2% of annual runoff (Zhu et al. 2008, Lu et al. 2015). From Guilin-Yangshuo reach, except for artificial revetment, from water body to river bank in Riparian Zone of natural river reach presents obvious zone distribution from gravel zone, herbal zone, shrub zone to arbor zone. Commonly seen arbors are Chinese ash, *Cinnamomum burmanni*, *Cinnamomum camphora,* moso bamboo, etc., shrubs mainly have *Securinega suffruticosa*, thinleaf adina, five-leaved chaste tree, etc., and herbs mainly have *Bermuda grass*, *Persicaria hydropiper*, scandent hop, etc.

Researched area was the riverway from Guilin City to Yangsuo reach of the Lijiang River with overall length being 83km, and ten natural sampling points which had not been artificially interfered along the bank of the Lijiang River were selected. According to vegetation composition type and the distance from riverway centre, crosswise divided terrestrial-aquatic transverse zone of the Lijiang River into four gradient zones: gravel zone, grass zone, shrub zone and arbor zone, and each gradient zone was set with 3-5 major quadrates with their area being 10m×10m, herb, shrub and arbor investigations were conducted and topographical factors such as altitude, relative elevation difference, slope gradient, slope aspect and gravel content were recorded, five 1m×1m herbal small quadrates in each major quadrate were set, GPS was used to position each sample plot, longitudes and latitudes were recorded, and a cement column was used to mark each quadrat for long-term observation and data recording (Table 1).

Sample-plot investigation and sample collection: Conducted vegetation and soil investigations in ten selected natural points, and indexes of arbor measuring record are variety, number of plants, height, crown breadth, diameter at breast height, clear bole length; indexes of shrub collection are variety, number of plants, height, crown breadth, basal diameter, cover degree, biomass; indexes of herbal collection are variety, height, number of plants, cover degree, biomass. Whole-plant digging method was used for biomass collection in shrub zone, and quadrat sampling method was used for biomass collection in herbal zone. As soil layer was thin within terrestrial-aquatic transverse zone of the Lijiang River, soil profile was dug in each small herbal quadrat, and soil samples were taken according to three levers: 0~10 cm, 10~20 cm and 20~30 cm. Mixed them and took back to the room. After they were air dried, they were smashed. After fine roots were picked off, ran them respectively through 2mm and 0.5mm soil sieves, and conducted sealed storage for measuring indexes such as soil mechanical composition, organic matter, pH value, N, P and K.

Data processing and analysis: Diversity measurement indexes include:

(1) Species richness:

$$R = S \qquad ...(1)$$

(2) Shannon-Wiener diversity index

$$H = -\sum_{i=1}^{s}\left(\frac{N_i}{N}\right)\ln\left(\frac{N_i}{N}\right) \qquad ...(2)$$

(3) Pielou evenness index

$$E = \frac{H}{\ln S} \qquad ...(3)$$

(4) Simpson dominance index

$$D = 1-\sum_{i=1}^{S}P_i^2 \qquad ...(4)$$

In the equation, S = number of species within quadrat/quadrat area, p_i is the proportion of number of individual species *i* in total number of individuals in the community, namely $p_i = N_i/N$ is number of individuals of the i^{th} trees species, and N is total number of individuals in the quadrat.

Soil measurement indexes include: (1) soil mechanical composition, divided according to system standards of USDA, and measured by combination of screening and hydrometer methods, (2) pH value, adopted 2.5:1 water-soil ratio, measured with potentiometer method, (3) potassium dichromate oxidation method was adopted for measuring organic matter, (4) available phosphorus, measured by Mo-Sb colorimetric method with $NaHCO_3$ diges-

Table 1: Basic information of sample plots.

Number	Coordinate	Width (m)	Grade (°)	Elevation (m)	Quadrat	Elevation differences(m)
JingPingShan	N25°14'4.44"E110°18'45.30"	13	15	146	5 big quadrat,21 small quadrat	3.2
WeiJiaDu	N25°13'35.05"E110°19'29.02"	44	3	142	9 big quadrat,33 small quadrat	2.3
LongMenCun	N25°12'14.30"E110°20'50.37"	26	7	142	9 big quadrat,27 small quadrat	3.1
DaXu	N25°10'24.09"E110°25'32.42"	18	9	135	5 big quadrat,24 small quadrat	2.8
QianJingCun	N25° 7'5.65"E110°25'35.51"	87	8	134	12big quadrat,39 small quadrat	3.3
WuJiuTan	N25° 6'33.61"E110°25'11.45"	19	11	134	6 big quadrat,26 small quadrat	3.5
GuanYan	N25° 3'46.68"E110°25'58.95"	58	3	128	8 big quadrat,29 small quadrat	2.7
ShangTaoYuan	N25°01'39 "E110°27'44 "	67	4	127	9 big quadrat,28 small quadrat	3.8
YangDiXiang	N25°00'09 "E110°27' 41 "	43	5	126	8 big quadrat,26 small quadrat	3.7
LaoCunTou	N24°56 ' 48 "E110°28' 36 "	14	18	125	4 big quadrat,20 small quadrat	4.3

tion, (5) alkali- hydrolyzale nitrogen, diffusion method was used, boric acid was used to absorb ammonia, then it was titrated with standard acid, and hydrolytic nitrogen content was calculated, (6) total potassium, measured by perchloric acid digestion flamephotometer method with hydrofluoric acid, (7) quick-acting potassium, extracted by using neutral ammonium acetate, measured by flamephotometer method.

Excel 2007 was used to draw and process all data, and SPSS18.0 software was adopted to conduct variance analysis, correlation analysis and regression analysis.

RESULTS

Vegetation Characteristics in Terrestrial-Aquatic Transverse Zone

Species composition: Our study revealed that the herbal layer of the riparian zone is relatively rich in vegetation species, with 30 families, 60 genera, and 67 species. Species composition in different gradient levels indicated that the dry-and-wet alternating scouring effects on the riparian zone are reduced and soil conditions are enhanced as relative elevation increased. Hence, the species composition of herbaceous plant species at the herbal layer roughly increases during transition from the gravel zone to the arbor zone. By comparison, the species composition at the herbal layer in the shrub zone (21 families, 34 genera, and 36 species) is slightly larger than that in the arbor zone (20 families, 32 genera, and 34 species). This difference is possible because an open forest land forms in the arbor zone and occupies large spatial resources; as a consequence, vegetation at the lower layer receive a low amount of light and nutrient supply. Thus, the superposition of ecological niche is strengthened at the herbal layer in the arbor zone, and competition between herbs in the arbor zone is stronger than that in the shrub zone (Table 2).

Our study also compared the species compositions at the shrub layers of the shrub zone and the arbor zone. We found

Table 2: The composition of species in different gradient zones.

Gradient zones	Family	Genus	Species
Gravel	8	15	17
Herb	14	27	28
Shrub herbage	21	34	36
Trees brushes grasses	20	32	34

that the shrub species (16 families, 18 genera, and 19 species) in the arbor zone are greater than those in the shrub zone (7 families, 7 genera and 7 species). The arbor zone is composed of a thick soil layer with stably rooted shrubs that can provide protection during flooding. Hence, many shrub species can survive during a long-term alternation of wetting and drying processes in the arbor zone. Vegetation, consisting of 12 families, 13 genera, and 13 species, at the arbor layer exists in the arbor zone. Arbor species do not gather in one family or genus; this phenomenon indicates that plant habitat diversity is high in the riparian zone of Lijiang River.

This study also examined the species diversity in the riparian zone of Lijiang River. Beach grass and Bermuda grass are the dominant species in the gravel zone. Bermuda grass, sedge, *Persicaria hydropiper*, and *Eremochloa ophiuroidides* Hack are the dominant species in the herbal zone. Chinese ash shrub, thin-leaf adina, five-leaf chaste tree, oleander, Bermuda grass, and *E. ophiuroidides* dominate the shrub zone. Chinese ash arbor, five-leaf chaste tree, *Securinega suffruticosa*, mulberry, *Salvia prionitis*, sedge, *Arthraxon hispidus* and *Oxalis rubra* are dominant species or edificators in the arbor zone.

Species diversity: Species diversity is an effective index that reflects community structure, functional characteristics, and ecosystem stability (Li et al. 2013). In Table 3, the diversity index presents a significantly increasing tendency during transition from the gravel zone to the arbor zone, from the gravel zone to the herbal zone, and from the shrub zone to

Table 3: Species in the vegetation community of the different gradient zones.

Fanmily	Genus	Species	Importance Value			
			Gravel zone	Herb zone zone	Shrub-herbage	Trees-brushes-grasses
		Herb layer				
Cyperaceae	*Carex*	*Carex tristachya*	0.07	0.15	0.02	0.12
Umbelliferae	*Hydrocotyle*	*Hydrocotylesibthorpioides*	0.03	0.02	0.01	
Umbelliferae	*Centella*	*Centellaasiatica*		0.00	0.00	
Labiatae	*Salvia*	*Salvia officinalis*	0.06	0.01		
Labiatae	*Clinopodium*	*Clinopodiumchinense*				0.04
Labiatae	*perilla*	*Perillafrutescens*		0.00	0.00	0.01
Oxalidaceae	*Oxalis*	*Oxalis corniculata*		0.00	0.03	0.02
Oxalidaceae	*Oxalis*	*Oxalis corymbosa*			0.00	0.10
Malvaceae	*Urena*	*Urenalobata L.*		0.01	0.00	0.01
Malvaceae	*sida*	*Sida rhombifolia L.*				0.01
Amaranthaceae	*Celosia*	*Celosia argentea L.*	0.06	0.05	0.05	0.00
Amaranthaceae	*Alternanthera*	*Alternantheraphiloxeroides(Mart.)Griseb.*	0.06	0.01	0.04	0.00
Amaranthaceae	*Achyranthes*	*Achyranthesaspera*			0.02	0.04
Leguminosae	*Cercis*	*Cercis chinensis Bunge*		0.00		
Leguminosae	*Astragalus*	*Astragalussinicus*		0.01		
Leguminosae	*Lespedeza*	*Lespedeza cuneata (Dum.Cour.) G.Don*		0.00	0.02	
Polygonaceae	*Polygonum*	*Polygonumhydropiper*	0.03	0.13	0.04	0.08
Polygonaceae	*Polygonum*	*Polygonumlapathifolium*	0.01		0.00	
Polygonaceae	*Polygonum*	*Polygonumaviculare*	0.06	0.02		
Polygonaceae	*Polygonum*	*Polygonumchinense*				0.00
Asteraceae	*Ixeris*	*Ixerispolycephala*	0.01			
Asteraceae	*Ageratum*	*Ageratum conyzoides*	0.01		0.01	0.01
Asteraceae	*Dendranthema*	*Dendranthema morifolium*			0.01	
Asteraceae	*Xanthium*	*Xanthium sibiricum*		0.03	0.04	0.01
Asteraceae	*Artemisia*	*Artemisia argyi*			0.00	
Asteraceae	*Herba*	*HerbaBidentisPilosa*			0.01	
Asteraceae	*Kalimeris*	*Kalimerisindica*		0.03		
Euphorbiaceae	*Flueggea*	*Flueggeasuffruticosa*			0.00	
Euphorbiaceae	*Euphorbia*	*Euphorbia esula*				0.00
Solanaceae	*Solanum*	*Solanumnigrum*			0.01	
Solanaceae	*Solanum*	*Solanumaculeatissimum*				0.01
Gramineae	*Hemarthria*	*Hemarthriaaltissima*	0.01	0.02		
Gramineae	*Cynodondactylon*	*Cynodondactylon*	0.25	0.35	0.36	0.06
Gramineae	*Eleusine*	*Eleusineindica*	0.02			
Gramineae	*Digitaria*	*Digitariaischaemum*	0.01		0.01	0.01
Gramineae	*Paspalum*	*Paspalumdistichum*	0.02	0.01	0.01	
Gramineae	*Imperata*	*Imperatacylindrica*		0.01	0.03	0.04
Gramineae	*Eremochloa*	*Eremochloaophiuroides*		0.08	0.11	
Gramineae	*Miscanthus*	*Miscanthusfloridulus*		0.00		
Gramineae	*Arundinella*	*ArundinellaanomalaSteud*		0.01		
Gramineae	*Zoysia*	*Zoysia japonica Steud*			0.04	
Gramineae	*Apluda*	*Apludamutica*			0.01	
Gramineae	*Oplismenus*	*Oplismenusundulatifolius*				0.03
Gramineae	*Eragrostis*	*Eragrostisguangxiensis*				0.02
Gramineae	*Arthraxon*	*Arthraxonhispidus*				0.11
Gramineae	*Setaria*	*Setariaplicata*				0.01
Gramineae	*Roegneria*	*Roegneriakamoji*				0.00
Caryophyllaceae	*Myosoton*	*Myosotonaquaticum*	0.01			
Juglandaceae	*Pterocarya*	*Pterocaryastenoptera*		0.01		
rubiaceae	*Adina*	*Adina rubella*		0.01		0.00
Convolvulaceae	*Ipomoea nil*	*Ipomoea nil*		0.01	0.02	
Plantaginaceae	*Plantago*	*Plantagoasiatica*		0.00	0.00	
Ranunculaceae	*Ranunculus*	*Ranunculus chinensis*			0.01	
Violaceae	*Viola*	*Viola inconspicua*			0.01	0.01
Primulaceae	*Lysimachia*	*Lysimachiafortunei*			0.01	0.15

Table cont...

...cont table

Verbenaceae	*Vitex*	*Vitexnegundo Linn*			0.02	0.01
Commelinaceae	*Murdannia*	*Murdanniatriquetra*			0.05	0.05
Cruciferae	*Brassica*	*Brassica rapa var. chinensis*			0.00	
Moraceae	*Humulus*	*Humulusscandens*			0.01	
Chenopodiaceae	*Dysphania*	*Dysphaniaambrosioides*				0.00
Apocynaceae	*Nerium*	*Neriumindicum Mill*				0.01
liliaceae	*Ophiopogon*	*Ophiopogonbodinieri*				0.01
Lauraceae	*Cinnamomum*	*Cinnamomumburmannii*				0.01
Araceae	*Colocasia*	*Colocasiaesculenta*				0.00
Araceae	*Cryptocoryne*	*Cryptocorynesinensis*	0.30	0.02		
		Shrub-herbage layer				
Leguminosae	*Cassia*	*Cassia sophera Linn.*				0.07
Leguminosae	*Cladrastis*	*Cladrastisplatycarpa*				0.02
Apocynaceae	*Nerium*	*Neriumindicum Mill*			0.14	0.07
Euphorbiaceae	*Sapium*	*Sapiumsebiferum*			0.06	0.03
Euphorbiaceae	*Flueggea*	*Flueggeasuffruticosa*			0.07	0.13
Moraceae	*Morus alba*	*Morus alba*			0.05	0.10
Moraceae	*Broussonetia*	*Broussonetiapapyrifera*				0.01
Juglandaceae	*Pterocarya*	*Pterocaryastenoptera*			0.32	0.07
rhamnaceae	*Paliurus*	*Paliurusramosissimus*				0.03
Verbenaceae	*Vitex*	*Vitexnegundo Linn*			0.16	0.26
rubiaceae	*Adina*	*Adina rubella*			0.21	0.09
Urticaceae	*Boehmeria*	*Boehmerianivea*				0.02
rutaceae	*Citrus*	*Citrus reticulata*				0.01
Ulmaceae	*Celtis*	*Celtisbiondii*				0.03
meliaceae	*Melia*	*Meliaazedarach*				0.01
Rosaceae	*Rosa*	*Rosa multiflora var. carnea*				0.03
Bignoniaceae	*Jacaranda*	*Jacaranda mimosifolia*				0.01
Lauraceae	*Cinnamomum*	*Cinnamomumcamphora*				0.01
Lauraceae	*Cinnamomum*	*Cinnamomumburmannii*				0.02
		Trees-brushes-grasses				0
Juglandaceae	*Pterocarya*	*Pterocaryastenoptera*				0.47
Euphorbiaceae	*Flueggea*	*Flueggeasuffruticosa*				0.02
Euphorbiaceae	*Sapium*	*Sapiumsebiferum*				0.09
Rosaceae	*Rosa*	*Rosa multiflora var. carnea*				0.02
Ulmaceae	*Celtis*	*Celtisbiondii*				0.08
meliaceae	*Melia*	*Meliaazedarach*				0.07
Lauraceae	*Cinnamomum*	*Cinnamomumcamphora*				0.07
Cupressaceae	*Platycladus*	*Platycladusorientalis*				0.04
Leguminosae	*Cladrastis*	*Cladrastisplatycarpa*				0.04
Leguminosae	*Zenia*	*Zeniainsignis*				0.04
Aceraceae	*Acer*	*Acer buergerianum*				0.03
Moraceae	*Morus*	*Morus alba*				0.02
Taxodiaceae	*Metasequoia*	*Metasequoiaglyptostroboides*				0.03

the arbor zone. The difference in the diversity index between the herbal zone and the shrub zone is not significant. The richness index presents a significantly increasing tendency during transition from the gravel zone to the shrub zone. The richness index in the arbor zone slightly decreases compared with that in the shrub zone. Similar species composition is observed at the herbal layer in different gradient zones. The variation of the evenness index is similar to that of the dominance index. These parameters gradually increase from the gravel zone to the shrub zone. These two indexes in the shrub zone are slightly lower than those in the herbal zone. Conversely, these two indexes in the arbor zone are significantly higher than those in the three other gradient zones. The four indexes reflecting species diversity gradually increase during transition from the gravel zone to the arbor zone. This finding indicates that the stability of the community ecosystem increases in the four gradient zones. The four indexes reflecting species diversity in the gravel zone are low. This result indicates that ecosystem stability in the gravel zone is poor and is in an inferior phase during successive restoration, which may be related to unique habitats in the gravel zone. The soil cannot be reserved solidly through long-term and repeated scouring because the gravel zone has been in a wetting-and-drying alternation state for a long time with significant, frequent, and complicated water potential variation; as a result, plant growth is impeded.

Root cap ratio: Root cap ratio refers to the ratio of fresh weight/dry weight between the foot end and the aboveground part of plants. Therefore, the ratio can indicate the correlation between the foot end and the aboveground part of plants (Kang et al. 2010). In this study, the ratio between the biomass of foot end and the biomass of the aboveground part of plants at the herbal layer is considered as the root cap ratio. Table 3 shows that the underground biomass (T1) and the aboveground biomass (T2) of plants at the herbal layer increase during transition from the gravel zone into the arbor zone. This pattern is similar to the variation of species diversity in the four gradient zones. This pattern also indicates that the growth status of plants in the transverse zone is excellent and is not influenced by water flow as the relative elevation increases. In the gravel zone and the herbal zone, T1s are significantly greater than T2s, with values of 5.37 and 1.29, respectively. This finding reveals that the root cap ratio T1/T2 is>1. This result also suggests that the aboveground biomass is greater than the underground biomass in the gravel zone because of insufficient soil conditions for plant growth in the special habitat in the gravel zone. Plants need developed root systems to absorb moisture and nutrients essential for growth. The site condition of the herbal zone is superior; thus, the aboveground biomass slightly differs from the underground biomass. The root cap ratio in the shrub zone is similar to that in the arbor zone, with the respective values of 0.48 and 0.50. These findings indicate that T1s in both zones are significantly less than T2s. This result also demonstrates that the root cap ratio T1/T2 is<1. Although the root cap ratio at the herbal layer in the arbor zone is slightly greater than that in the shrub zone, the transition from the gravel zone to the arbor zone is not influenced, and the root cap ratio of the plants at the herbal layer significantly decreases.

Physicochemical Properties of Soil in Terrestrial-Aquatic Transverse Zone

Physicochemical properties of soil: ***Soil bulk density:*** Soil bulk density refers to the dry weight of soil within a unit volume and under a relatively natural state, where the amount of soil pores and soil solids plays leading quantifying roles. Soil bulk density can be considered an index to determine soil fertility. A relatively low soil bulk density accelerates the decomposition of soil organic matter at an abnormal speed. Consequently, plant root systems may not easily develop in soil; as such, plant dumping phenomena may occur. If the soil bulk density is relatively large, the soil density correspondingly increases. The free circulation of moisture and gases is inhibited and thus influences the rooting effect of plants and results in a decreasing redox potential within the soil. Toxic products, which are harmful to plant growth, will be produced in the soil. These products will impede the growth and development of plant root systems and plants. In summary, soil bulk density determines soil tightness and porosity; it also influences the permeability performance of the soil, flowing capacity of gases, and growth of plant root systems (Peng 1987).

Table 4: Herb layer plant root cap ratio.

Gradient zones	Underground biomass T1 (g)	Above-ground biomass T2 (g)	Root cap ratio (T1/T2)
Gravel zone	63.63	11.85	5.37
Herb zone	612.30	476.00	1.29
shrub-herbage	794.00	1666.00	0.48
trees-brushes-grasses	1571.00	3154.00	0.50

Table 5: Soil bulk density of different gradient zones.

Gradient zones	Vegetation type	Soil bulk density(g·cm-3)
Gravel zone	Herb	1.035a
Herb zone	Herb	1.331d
Shrub zone	Shrub, herbage	1.270bc
Arbor zone	Trees, shrub, herb	1.253b

Table 6: Soil mechanical composition of different gradient zones.

Gradient zones	Sand (%)	Silt (%)	Caly (%)
Gravel	86.65%	6.68%	6.67%
Herb	80.55%	10.77%	8.68%
Shrub herbage	77.63%	12.47%	9.90%
Trees brushes grasses	73.41%	14.69%	11.90%

In Table 5, soil bulk density in the gravel zone, herbal zone, shrub zone, and arbor zone of the study area is 1.035, 1.331, 1.270, and 1.253 g/cm^3, respectively. Among these findings, the soil bulk density in the gravel zone is the smallest and the soil bulk density in the herbal zone is the largest. As the elevation of the inundation zone increases, the soil bulk density initially increases and then decreases.

Soil mechanical composition: Soil mechanical composition is implicated in soil moisture storage capacity and fertilizer solidifying capacity. It is also used as a significant indicator of soil permeability performance and dominant evaluation factor of soil physical properties and quality. Plasma-like soil powder clay is beneficial for granular structure formation and plant growth (Jia et al. 1997).

In Table 6, sandy soil mass fractions in different zones are within 73.40%-86.66%. The mass fractions of particles are within 6.69%-14.68%. Clay mass fractions are within 6.66%-11.91%. Sandy soil content is greater than the mass fraction of powder clay. The sand contents in the four inun-

Table 7: Soil chemical properties of different inundation zone.

Gradient zones	pH	Organic matter	Total nitrogen	Alkaline-N	Total K	Available K	Total P	Available P
Gravel zone	7.268a	12.613a	0.919a	73.886a	23.125a	61.318a	0.499a	33.194a
Herb zone	7.089a	18.235b	1.040a	94.088b	22.366a	70.354a	0.527a	29.838ab
Shrub-herbage	6.939a	18.810bc	1.034a	89.840ab	21.317a	76.091a	0.478a	25.858b
Trees-brushes-grasses	7.054a	22.804c	1.214a	104.147b	22.069a	72.929a	0.527a	29.393ab

Table 8: The correlation of soil chemical properties in different inundation zone.

	Total nitrogen	Organic matter	Alkaline N	Available P	Available K	Total P	Total K	pH
Total nitrogen	1							
Organic matter	0.797**							
Alkaline N	0.743**	0.810**	1					
Available P	0.053	0.095	0.051	1				
available K	0.247*	0.222	0.148	0.402**	1			
Total P	0.403**	0.561**	0.468**	0.696**	0.435**	1		
Total K	-0.117	0.021	-0.029	0.460**	0.240*	0.541**	1	
pH	0.019	-0.159	-0.117	-0.038	-0.124	-0.217	-0.425**	1

dation zones are 6.68, 4.25, 3.53, and 2.72 times of the mass fraction of powder clay in this inundation zone, respectively. This finding indicates that the soil in the riparian zone of Lijiang River are mainly composed of sand.

The mass fractions of the different kinds of soil in the four zones, namely, serious inundation zone, medium inundation zone, mild inundation zone and slight inundation zone are as follows. For the sand, the mass fractions are 86.66%, 80.54%, 77.62%, and 73.40%, respectively. For the particles, the mass fractions are 6.69%, 10.76%, 12.48%, and 14.66%, respectively. For clay, the mass fractions are 6.66%, 8.69%, 9.91%, and 11.91%, respectively. The mechanical compositions in four zones indicate that sand content decreases as the relative elevation increases. By contrast, particle and clay contents increased. Soil particle composition is greatly influenced by the variation in water levels during wet and dry seasons. With the current scouring and bank erosion, large amounts of plasma-like particles and clays in soil are eroded, and the zone (gravel zone) approaching the riverway is greatly affected. As a result, the powder clay content decreases and the sand content increases. As the relative elevation increases, species diversities in the shrub zone and the herbal zone increase and plant community structures become more complicated. With these phenomena, the mechanical compositions of soil are significantly improved and the soil particle and clay contents are significantly increased. This conclusion is similar to that described in previous studies (Yang et al. 2009, Liu Xia et al. 2005).

Chemical properties of soil: In Table 7, the differences in soil pH, total nitrogen, total potassium, quick-acting potassium, and total phosphorus among the four zones are not significant. The organic matter contents of soil are 12.613, 18.235, 18.810, and 22.804 mg/kg, respectively. Organic matter contents increase as the relative elevation increases. Available nitrogen contents are high in the arbor zone and the herbal zone. By contrast, the available nitrogen contents are relatively low in the herbal zone. The contents of quick-acting phosphorus are 33.194, 29.838, 25.858, and 29.393 mg/kg, respectively, which are relatively higher in the gravel zone but relatively lower in the shrub zone.

In terms of the pH of the karst environment, soil pH is neutral and slightly alkaline, and its difference in the four zones is not significant. pH variability in a relatively smaller space is also not significant. The organic matter content of soil increases as the relative elevation increases. This phenomenon is related to the increasing vegetation community diversities and the reducing hydrological interference effect. Both vegetation diversity index and coverage degree increase, resulting in relatively more litters and root system biomasses. High-density vegetations are also beneficial for nutrient reservation. Thus, organic matter contents increase. Soil nitrogen mainly exists in organic matter in the form of organic nitrogen; as such, changes in available nitrogen content are similar to those observed in the organic matter content of the soil. In contrast to the soil nitrogen content, the potassium contents are greatly influenced by soil parent materials. Conversely, soil parent materials in the riparian zone of Lijiang River are identical. Hence, differences in total potassium and quick-acting potassium are not significant (Méndez-Toribio et al. 2014).

In Table 8, soil nutrients are positively correlated with the other soil chemical indexes. Soil pH in a karst environment is positively correlated with total nitrogen but is negatively correlated with the other soil chemical indexes. pH is also significantly negatively correlated with total potassium. In the zones with high pH, the contents of other nutrients are relatively low because of the combined effect of multiple factors. Hydrological influence is greater in the zones with a relatively high soil pH, such as gravel zone, than in the zones with a relatively low soil pH. As a consequence, poor vegetation conditions are observed. The feedback effect of vegetation on soil nutrients is weak and the soil nutrient contents are low. In the zones with a relatively low pH, such as shrub zone and arbor zone, and at relatively high elevations, the following phenomena are observed (Table 7): hydrological influence is low; vegetation diversity, coverage degree, and biomass are relatively high; the feedback effect of vegetations on soil is significant; and the nutrient contents are high.

The Relationship Between Plants and Soil in Terrestrial-Aquatic Transverse Zone

Total biomass and diversity is closely related to environmental elements such as soil nutrients and textures in terrestrial-aquatic transverse zone of the Lijiang River. Standard processing is conducted on total biomass, diversity and environmental elements, and SPSS is used to establish multiple regression formula as follows:

Total biomass = 0.808-0.147 total nitrogen-0.219 organic matters+0.123 available nitrogen-0.435 Oslen P+0.224 quick-acting potassium+0.457 total phosphorus-0.086 total potassium-0.292 pH-0.554 sands+0.406 particles-0.619 clays-0.055 gravels

$F = 7.303$, $P < 0.001$; $R^2 = 0.594$ ...(5)

Diversity = 0.699-0.109 total nitrogen+0.065organic matters-0.008 available nitrogen-0.116 OslenP+0.063quick-acting potassium+0.065 total phosphorus-0.132 total potassium-0.070 pH-0.170 sands+ 0.340 particles-0.052 clays-0.212 gravels

$F = 17.054$, $P < 0.001$; $R^2 = 0.773$ ...(6)

Multiple regression equation fitting degrees between total biomass and diversity and environmental elements are high, respectively $R^2 = 0.594$, 0.773. In terms of proportion of factor coefficient, contribution rate of soil nutrient element to total biomass is 54.81%, and that of soil texture to biomass is 45.19%. Contributions rates of total phosphorus and Oslen P in nutrients to total biomass are high, respectively 12.65% and 12.02%; contribution rates of clays and particles are high, respectively 17.13% and 15.30%. In terms of diversity in terrestrial-aquatic transverse zone, contribution rate of soil texture is higher than that of soil nutrients, respectively 55.19% and 44.81%. Contribution rates of particles and gravels in elements to diversity are high, respectively 24.25% and 15.11%.

CONCLUSIONS

Degradation of riparian vegetation has worsened in recent years because of frequent anthropogenic activities. The problems in restoration of riparian vegetation demand for prompt solution. In this study, we examined the plant diversity and physicochemical properties of soil in different gradient levels to reveal succession rules of vegetation in the riparian zone of Lijiang River. With increasing relative elevation, herbal species compositions in gradient levels roughly displayed an ascending tendency, and species diversity showed an obviously increasing tendency with the transition from gravel zone to arbor zone; however, the difference between the herbal zone and the shrub zone is not significant. In the transition from gravel zone to arbor zone, both the underground and aboveground biomass of plants in the herbal layer displayed a considerable increasing tendency. In addition, root cap ratio in the herbal layer later displayed an overall descending tendency from the gravel zone to shrub zone, and root cap ratio in the herbal layer in arbor zone was slightly larger than that in the shrub zone. Soils in the gradient zones mainly consist of sands; with increasing relative elevation, sand content demonstrated a decreasing tendency, whereas particle and clay contents showed an increasing tendency. Moreover, soil bulk density initially displayed an increasing and then a decreasing tendency; soil organic matter content displays an ascending tendency, whereas the contents of total nitrogen, total potassium, quick-acting potassium, and total phosphorus show no obvious variation. The degree of multiple regression equation fitting between total biomass and diversity and environmental elements are high. Furthermore, soil texture highly influenced species diversity. Future studies should focus on understanding vegetation configuration modes, particularly in Lijiang River, to provide a scientific basis for the restoration of degraded ecosystem in the riparian zone.

ACKNOWLEDGEMENTS

This study was supported by the “Twelfth Five-year” National Science and Technology Support Program (2012BAC16B03) of China.

REFERENCES

Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology Evolution & Systematics, 35(1): 257-84.

An, H., Yang, X.G., Liu, B.R., Li, X.B., He, X.Z. and Song, N.P. 2011.

Changes of plant community biomass and soil nutrients during the vegetation succession on abandoned cultivated land in desert steppe region. Chinese Journal of Applied Ecology, 22(12): 3145-3149.

Antonio, R. R., Juan, L. M., Carmen, A. and Bordon, J. 2005. Plant succession and soil degradation in desertfield areas (Fuerteventura, Canary Islands, Spain). Catena, 59(2): 117-131.

Chen, Y. F. and Dong, M. 2001. Spatial pattern and correlation of vegetation characteristics and soil properties in the Mu Us sandy desert. Acta Phytoecologica Sinica, 25(3): 265-269.

Forman, R.T.T. 1997. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge: Cambridge University Press, 213-246.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B.H., Willms, W. and Wang, M. 2008. Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. Agriculture Ecosystems & Environment, 125(1): 21-32.

Hou, F., Nan, Z., Xiao, J. and Chang, S. 2002. Characteristics of vegetation, soil, and their coupling of degraded grasslands. Chinese Journal of Applied Ecology, 13(8): 915-922.

Huang, Y., Que, X. X. and Li, C.Y. 2013. Study on landscape ecological restoration technology of land/inland water ecotones along Li River. Journal of Southern Agriculture, 44(10): 1700-1704.

Jia, S.C. and Xu, Y.W. 1997. Feature and distribution law of soil mechanical composition. Environmental Monitoring in China, 13(3): 24-26.

Jiang, H.M., Li, M.Z., Wang, Q. and Liu, X.X. 2011. Dynamics of soil nutrients under different vegetation types in the Eastern Qilian Mountains. Research of Soil and Water Conservation, 18(5): 166-170.

Kang, B., Liu, S.R. and Cai, D.X. et al. 2010. Model of soil physical and chemical properties under different vegetation restoration in south subtropics. Chinese Journal of Applied Ecology, 21(10): 2479-2486.

Li, J.L. and Zhang, J.T. 2006. Plant species diversity in the middle part of the Taihang Mountain. Chinese Journal of Applied & Environmental Biology, 12(6): 766-771.

Li, Y., Wang, D.M. and Xin, Z.H.B. 2013. Spatial distribution of vegetation and soil in aquatic-terrestrial ecotone, Li River. Transactions of the Chinese Society of Agricultural Engineering, 29(6): 121-128.

Liu, J.L. 2013. Study on impact of mowing and grazing on vegetation and soil of typical steppe in Xilingol, Inner Mongolia. PhD Dissertation, The Chinese Academy of Agricultural Sciences, Beijing, P. R. China.

Liu, J.R., Feng, H. and Yu, X.L. et al. 2003. Preliminary discussion on the historic change of the name of the Lijiang River system. Carsologica Sinica, 22(1): 77-83.

Liu, X., Wang, L., Zhang, G.C., Liu, X.R. and Liang, H. 2005. Structural property of soil from. Different forest types on rocky mountainous area in middle of Shandong Province. Journal of Soil Water Conservation, 12(6): 49-52.

Lu, Y. and Wang, D.M. 2015. Diversity of plants on the alluvial islands of Lijiang River basin and the physicochemical properties of pheir soil. Nature Environment and Pollution Technology, 14(3): 533-540.

Méndez-Toribio, M., Zermeño-Hernández, I. and Ibarra-Manríquez, G. 2014. Effect of land use on the structure and diversity of riparian vegetation in the Duero River Watershed in Michoacán, Mexico. Plant Ecology, 215(3): 285-296.

Peng, S.L. 1987. Ecological dominance of the subtropical forest communities in Guangdong. Acta Ecologica Sinica, 7(1): 37-42.

Qu, G.H. and Guo, J. 2003. The Relationship between Different plant communities and soil characteristics in Songnen grassland. Acta Pratacultural Science, 12(1): 18-22.

Rao, L.Y. and Cui, J.G. 2008. Research advances on the eco-hydrological functions of riparian buffer. Science of Soil and Water Conservation, 6(4): 121-128.

Wang, X. 2014. The Influence of Grazing Disturbance to Spatial Pattern of Soil and Vegetation in Shrubland-Grassland Systems. M.Ag dissertation, The Western Ecological Research Center, Ningxia University, Yinchuan, P.R. China.

Wu, Y.N., Luo, W.T., Huo, G.W. , Li, H. and Hu, G. 2014. Spatial heterogeneity dynamics of soil carbon and nitrogen in the mini-patches during degeneration succession of grassland communities. Acta Ecologica Sinica, 34(19): 5549-5557.

Yang, H.L., Gao, P., Wang, H.W., Fujun, D. and Wugang, D. 2009. Characteristics of soil particles fractal dimension under different forest stands of the ecological restoration area in Dahei Mountain area. Science of Soil and Water Conservation, 7(5): 52-57.

Yang, M.H., Zhimei, Z., Mingming, C., ChunJie, W. and Yan, X. 2010. Study on the correlation of soil-vegetation in different desertification stages on the southeastern edge of Mu Us sandy land. Journal of Northwest A & F University (Natural Science Edition), 38(5): 182-187.

Yu, Y., Zou, L. and Sun, T.T. et al. 2014. Relationship between vegetation diversity and soil functional diversity in native pine forests. Pratacultural Science, 31(7): 1241-1247.

Zhang, G.S., Deng, H.J., Yu, W., Lin, Y., Ma, R., Wang, D., Wu, C. and Hong, W. 2014. Vertical gradient analysis of soil environmental factors and vegetation community in mountain areas of frequent debris flow: A case study in the Xiaojiang watershed, Yunnan. Chinese Journal of Applied and Environmental Biology, 20(4): 646-654.

Zhang, Z.C., Yan, Y. CH. and Shao, Z. Y. 2009. Study on the correlation between steppe vegetation and soil as well as the difference in response to disturbance. Journal of Arid Land Resources and Environment, 23 (5): 121-127.

Zhu, X.M. and Su, W.B. 2008. Study on the present status and countermeasures of biodiversity in Li river valley scenic spot. Ecological Economy, 4,153-157.