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Restoration of Forest Riparian Buffer Strips on the Upper Reaches of the Qin River, Shanxi Province

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ABSTRACT

Forest riparian buffer strips have long been recognized for their important functions that include providing shade to reduce water temperature, enhancing deposition of sediments and other contaminants, reducing nutrient loads of streams, stabilizing stream banks with vegetation, reducing erosion caused by uncontrolled runoff, and providing habitats for riparian wildlife. To rehabilitate and reconstruct the riparian buffers at the source of the Qin River in Shanxi Province, China, a field survey and experiments were conducted to provide an example of forest riparian buffer construction in the region. An assessment index system was used to evaluate the Chishiqiao and Zihong rivers, both first-level tributaries of the Qin River. A comprehensive evaluation index system offered indicators of vegetation structural intactness and bank stability including vegetation continuity along the river channel, vegetation coverage and height, abundance of floristic components, associations among vegetation, rock, and soil types, bank structure, and soil erosion modulus. Results indicated that the Chishiqiao River was generally in good condition, and the condition of the Zihong River was average. Ratings for the abundance, arrangement, and coverage of riparian vegetation along the Zihong River were low due to the structural intactness subindex. To improve vegetation coverage, abundance, and collocation forms, we chose typical riparian vegetation zones, including grassland, shrub land, and shrub-grass land, and implemented different treatments, i.e. fencing the vegetation zones, planting grasses or shrubs, and covering with soil and turf. We found that soil hygroscopic coefficient, soil fertility, and total nitrogen content were strongly enhanced. Certain types of riparian buffer strips that would be suitable in this region are suggested.

Keywords: nonpoint source pollution, watershed management, sediment trapping efficiency

INTRODUCTION

Riparian zones are diverse mosaics of landforms, communities, and environments located within a larger landscape, and they serve as a framework for understanding the organization, diversity, and dynamics of communities associated with fluvial ecosystems (Naiman *et al*. 1997).

The riparian zone encompasses the stream channel between low and high water marks and the portion of the terrestrial landscape from the high water mark toward the upland where vegetation is influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman *et al*. 1988; exact definitions differ among researchers). The intermediate location of riparian zones gives these areas characteristics of both uplands and lowlands. Riparian vegetation is composed of species that are tolerant of a range of moisture conditions including dry and saturated conditions (Snyder *et al*. 1998). Riparian vegetation provides habitat and corridors for fish and wildlife, separations between agricultural activities and streams, and removal of sediment, nutrient, and chemical pollutants from upland surface runoff.

In recent years, there has been growing recognition of the importance of maintaining riparian areas that serve as buffer strips to control nonpoint source (NPS) pollution from agricultural fields (Lowrance *et al.* 1984; Peterjohn and Correll 1984; Jacobs and Gilliam 1985; Jordan *et al.* 1993). Buffers remove sediment from overland flow by decreasing flow velocity and allowing particles to settle. Buffer zones also increase water infiltration into the soil profile by decreasing the amount of runoff, thereby aiding in sediment interception (Yuan 2009). The chemical and biological processes that occur in riparian buffers transform the nutrients and chemicals entering riparian wetlands from upland sources into usable or less harmful forms (Welsch 1991). Therefore, riparian forest buffers are an important part of both nonpoint source pollution control and stream restoration strategies practiced in the U.S. and other countries. Riparian buffer systems have been adopted as best management practices in some nonpoint source pollution control programs (Gilliam *et al*. 1997). In 1991, the United States Department of Agriculture (USDA) adopted a multiple zone buffer system as the standard riparian buffer for both controlling NSP and protecting and restoring adjacent aquatic ecosystems. Specifications for the riparian forest buffer include a three zone riparian buffer system with each zone serving a particular main and a number of secondary purposes (Welsch 1991; NRCS 1995).

With the rapid increase in human population and the development of industry and agriculture, many riparian buffer systems have been severely disturbed by human activity. Therefore, extensive research has been conducted pertaining to the design and restoration of riparian buffer systems. Watershed models such as the USDA Annualized Agricultural Nonpoint Source Polluting model (AnnAGNPS) (Bingner *et al.* 2003), the Riparian Ecosystem Management Model (REMM) (Lowrance *et al.* 2000), and the Vegetative Filter Strip Modeling System (VFSMOD) (Muñoz-Carpena *et al.* 2007) have been developed to simulate the impact of riparian buffer systems on water quality. These models have proven to be effective tools for evaluating watershed management efforts. Numerous studies have been conducted to evaluate the factors affecting sediment trapping in riparian buffer strips and to determine the best design of

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buffer systems for maximum environmental benefits. Results generally show that the trapping efficiency of buffers depends primarily on buffer width, vegetation type, density, and spacing, sediment particle size, slope gradient and length, and flow convergence.

Generally, wide buffers are likely to be more efficient in trapping sediment than are narrow buffers. For example, Dillaha *et al.* (1989) and Magette *et al.* (1989) reported sediment trapping efficiencies of 70–80% for 4.6 m and 84–91% for 9.1 m wide grass filter strips (FS). However, the first 3–6 m of a buffer plays a dominant role in sediment removal. Robinson *et al.* (1996) found that sediment was reduced by 70 and 80% from plots with 7 and 12% slopes, respectively, within the first 3 m of the buffer.

Sediment trapping efficiency is also affected by slope, but the overall relationship is weak. Blanco-Canqui *et al.* (2004a, 2004b) and Gilley *et al.* (2000) found that for buffers about the same width (0.7 and 0.72 m), sediment trapping efficiency was lower in areas with greater slopes (5% vs. 8–16%). However, Dillaha *et al.* (1989), Robinson *et al.* (1996), and White *et al.* (2007) all observed that sediment trapping efficiency does not necessarily de-crease as slopes increase.

Both forested and grassy vegetation can filter sediment from upland runoff, and grass buffers and forest buffers have similar sediment trapping efficiencies. However, vegetation type differed significantly in their ability to remove total suspended solids (TSS), total P, and total N (Kyle *et al.* 2007). Indigenous species tend to be more suitable for buffer strips than are exotic species. For grass buffer strips, switchgrass appears to be more efficient in trapping sediment than an equal width of fescue (Rankins *et al.* 2001; Blanco-Canqui *et al.* 2004a) or cool season grasses (Lee *et al.* 1999). However, Rankins *et al.* (2001) found that big bluestem and eastern gamagrass were more efficient in trapping sediment than switchgrass.

Interest in restoring ecological, aesthetic, and recreational values to degraded stream channels has grown enormously in recent years (Williams 1990; NRC 1992), and stream protection efforts encompass a number of approaches. The goal of many restoration projects is to protect riparian zones with the fewest possible environmental impacts, using approaches such as planting riparian vegetation, using willow (*Salix* spp.) spilling (retaining walls constructed of willow stems woven together from which live willows sprout), installing willow wattles, using post and wire revetments with willow plantings, cabling dead trees along the eroding bank, and installing deflectors to direct currents away from the threatened bank (Gray and Leiser 1982; Gough 1991).

Although numerous research has investigated the management of riparian areas, information is lacking on how buffer zones should be designed to accommodate site-specific features, especially in China. Thus, the objective of this study was to develop an assessment system to evaluate riparian vegetation condition and to assess adaptive management approaches for the restoration of damaged buffers at the source of the Qin River in Shanxi Province. Field surveys and experiments were conducted to establish a method for reconstructing forest riparian buffers in this region.

MATERIALS AND METHODS

Site description

This study was conducted in Qinyuan, Shanxi Province (N36° 18′~36° 37', E111° 45′~112° 33'), along two first order tributaries of Qin Basin, namely the Chishiqiao and Zihong rivers. The catchment area belongs to a semiarid continental monsoon climate of the warm temperate zone. The mean annual temperature is 8.6°C, and the average annual rainfall is 662 mm. The Chishiqiao River is 39 km long with a drainage area of 415.63 km^2. The Zihong River is 50 km long with a drainage area of 394 km^2.

Assessment of riparian status

1. Field survey

Data information of the riparian was collected through the methods that combined with key-point investigation and general census. Lab-based data collection included accessing information on administrative map, vegetation distribution, hydrology, topography, vegetation, weather, and results of previous stream surveys. Real-time data in the field, the characters of vegetation and bank were collected by quadrat method and visual assessment.

The field survey was conducted from March to April, 2007. Nine transects near the source of the Chishiqiao River (1$^\#$–9$^\#$) (**Fig. 2**) and four transects near the source of the Zihong River (10$^\#$–13$^\#$) (**Fig. 3**) were surveyed. These transects were 30-50 m in width, and chosen random from one of the sections of the riparian.

2. Evaluation methodology

Existing approaches for reporting the condition of stream or streamside zones have been developed, including the Rapid Bioassessment Protocols (Barbour *et al.* 2009), Index of Stream Condition (Ladson *et al.* 1999), Geomorphic River Styles (Parsons *et al.* 2000), and the Riparian, Channel and Environmental Inventory (Robert *et al.* 1992). Building a comprehensive evaluation index to assess the condition of riparian vegetation is an important component of ecological restoration of riparian zones that not only provides a scientific reference for developing approaches to restore these systems to near-natural conditions but can also be used to measure the effectiveness of the restoration effort. Based on previous work on riparian assessment and considering the ecological status of riparian zones in China, an index system was created and applied to evaluate the condition of riparian vegetation at this study site. Additional restoration strategies were designed according to assessment results.

Selecting appropriate indicators from the information that have already collected is fundamental to the assessment. The indicators in this system were chosen based on the following principles: 1) The riparian zone is an open and comprehensive ecosystem whose condition is affected by a variety of factors. Therefore, indicators should be based on the ecology, hydrology, and soil mechanics that represent and reflect basic characteristics of the riparian zone. 2) The indicators can easily be measured and quantified.

The condition of the riparian zone can be described based on several indicators and subindices of the assessment system. Thus, the assessment system is hierarchical and includes an index of riparian vegetation condition, a subindex, and indicators. Therefore, the assessment of the condition of riparian vegetation is completed in two stages (**Fig. 1**). Scores for each subindex are summed up to provide the overall index score for the condition of the riparian vegetation. The subindex scores are determined by assessing and summing the scores of the indicators.

Recovery of riparian vegetation under different reclamation methods

The goal of restoring riparian buffers is to recover the structure and function of damaged vegetation. The design should be based on results of the assessment. In this study, plots encompassing degraded ecological conditions were selected along the reach of the riparian zone of the Qin catchment and included the following predominant vegetation types: (1) PG: pure natural grasses; (2) RI: riprap with sparse vegetation; and (3) PS: pure indigenous shrubs. The objective was to establish grass-shrub buffers. Kyle *et al.* (2007) observed that riparian buffers composed of grasses and shrubs reduce the amount of outflow runoff (>77%), sediment (>99%), total P (>85%), and total N (>85%). Reclamation methods included fencing, planting grass or indigenous shrubs, mulching, and turfing. By comparing the recovery of the plots under different artificial reclamation methods, the appropriate adaptive management strategy was obtained for each site-specific feature.

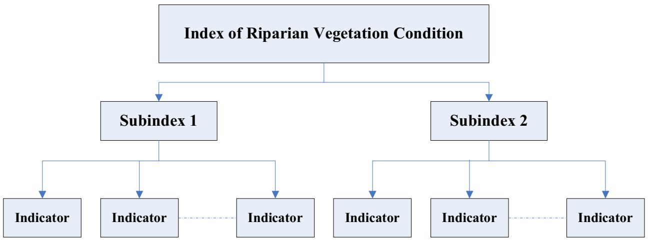

Fig. 1 Indicators, subindices, and the Index of Riparian Vegetation Condition.

Fig. 2 Photos of sections of the Chishiqiao River (Sections $1^{\#}$-$9^{\#}$).

RESULTS AND DISCUSSION

Establishing the assessment system

Bank stability and vegetation intactness are the primary characteristics of ecology riparian. To maintain normal ecosystem function, the bank structure must be stable. Once the bank collapses, the entire riparian ecosystem will be destroyed. Riparian ecological functions are achieved through the vegetation. Thus, the condition of riparian can be determined through a holistic appraisal of the structure of vegetation and the bank. Vegetation structure intactness and bank structure stability are the two subindices of the assessment, and both consist of various indicators.

1. Vegetation structure intactness subindex

Indicators include width, longitudinal continuity (a measure of the number and significance of gaps in streamside vegetation), proportion of indigenous species, abundance (number of species in the community), arrangement (collocation forms related to color, height, and area of the vegetation), and coverage (proportion of vegetation coverage in the area). These indicators were chosen because they are the factors that affect the filtration efficiency of buffers. Ratings for structural intactness are listed in **Table 1**.

Fig. 3 Photos of sections of the Zihong River (Sections $10^{\#}$-$13^{\#}$).

2. Streambank structure stability subindex

Indicators were chosen to assess rock type, bank stability (based on structure, slope, and height), bank structure (level of distribution of material in the bank), mean annual precipitation, influence of artificial barriers, and soil erosion. Ratings for structural stability are listed in **Table 2**.

Most indicators were assigned a numerical value or rating based on a four-point scale that provided a comparison with ideal conditions. Therefore, the overall condition of the riparian vegetation was divided into four grades by summing the two subindices as shown in **Table 3**.

Assessment results

Values of the index suggest that the Chishiqiao River was generally in good condition, and the condition of the Zihong River was average (**Table 4**). Values for the abundance, arrangement, and coverage of riparian vegetation in the Zihong River were low due to the structural intactness subindex. This assessment system could be used as the basis for designing effective riparian buffers in this region, and these results guided the following restoration study.

Recovery effectiveness

This study was conducted from April 2007 to 2009. Each plot measured 5×10 m, and the status of the plots prior to the start of the project and the specific measures made at each plot are as follows:

PG: This area was dominated by perennial grasses (>80%) including *Pennisetum flaccidum* Griseb and *Carex rigescens*. The reclamation methods included: 1) planting eight Willow (*Salix matsudana*, an indigenous shrub) seedlings; and 2) installing a 1.5-m high fence around the treatment plot (1#) to exclude livestock and people, which was paired with a control plot (2#) without a fence.

RI: The ground cover was composed of riprap with sparse vegetation. Vegetation is difficult to regenerate in such plots, which are common in riparian areas of the Qin River. The two types of reclamation methods included: 1) overlaying with 15 cm of soil, turfing (*Pennisetum flaccidum Griseb*, *Carex rigescens*), and fencing with a 1.5-m high fence; and 2) applying soil to a depth of 15 cm to treatment plots (1# and 2#) paired with an untreated control plot (3#).

Table 1 Ratings of indicators for the structural intactness subindex.

Width	Longitudinal continuity	Proportion of indigenous species	Abundance	Arrangement	Coverage	Scoring	Rating
>10	<10	>75	Dense		>95%	7.5-10	4
5-10	10-50	50-75	Fine		50-95%	5-7.5	3
1-5	50-100	25-50	Normal		25-50%	2.5-7.5	2
<1	>100	<25	Sparse		<25%	0-2.5	1

Table 2 Evaluation of indicators of structural stability.

Rock Type	Bank structure	Bank height (m)	Slope gradient(°)	Mean annual precipitation (mm)	Extent of artificial influence	Soil erosion (t/(km^2·a))	Scoring	Rating
Hard rock with good cementation (HR)	Even	<5	<15	<150	Slight	<500	7.5-10	4
Semi-hard rock with good cementation (SHR)	Uneven	5-15	15-30	150-250	Limited	500-900	5-7.5	3
Soft rock (SR)	Layered	15-30	30-45	250-400	Moderate	1000-1500	2.5-7.5	2
Loose soil (LS)	Fragment or Loose	>30	>45	>400	Severely	>1500	0-2.5	1

Table 3 Four grades of index measurements.

Category	Meaning
Essentially ideal	Structure is integrated and stable, play a strong function
Near ideal	Structure is near integrated and stable, play some function
Moderate modification from ideal	Structure is not so integrated and stable, just play a little basic function, but can be repaired in some situation
Highly modified from ideal	Structure is not integrated and stable at all, can not play basic function, hard to be repaired

Table 4 Results of riparian zone investigation.

	Width (m)	Longitudinal continuity	Abundance	Proportion of indigenous species (%)	Arrangement	Coverage (%)	Rock type	Bank structure	Height	Slope gradient (°)	Mean annual precipitation (mm)	Soil erosion
Chishiqiao River												
1#	>10	10	Dense	85	Good	88	HR	Uneven	0.8	Plat	657.7	800
2#	>10	4	Dense	80	Normal	86	HR	Fragment or Loose	0.6	Plat	657.7	800
3#	>10	8	Sparse	70	Normal	80	HR	Layered	0.6	Plat	657.7	800
4#	>10	6	Dense	80	Good	87	HR	Layered	0.9	Plat	657.7	800
5#	>10	0	Dense	80	Normal	90	HR	Uneven	0.4	Plat	657.7	800
6#	>10	25	Sparse	85	Normal	84	HR	Fragment or Loose	0.2	Plat	657.7	800
7#	>10	3	Dense	85	Good	88	HR	Fragment or Loose	0.4	Plat	657.7	800
8#	>10	0	Dense	85	Normal	88	HR	Even	0.6	Plat	657.7	800
9#	>10	3	Dense	85	Good	85	HR	Even	0.7	Plat	657.7	800
Zihong River												
1#	>10	0	Dense	85	Normal	87	HR	Even	0.3	Plat	680.7	2200
2#	1-5	20	Sparse	50	Normal	70	HR	Fragment or Loose	0.6	Plat	680.7	2200
3#	1-5	30	Sparse	50	Normal	50	HR	Layered	0.5	Plat	680.7	2200
4#	>10	15	Dense	75	Normal	89	HR	Even	0.9	Plat	680.7	2200

Table 5 Condition of restored riparian zones with different reclamation methods.

Plots	April			August			
	Vegetation type	Coverage (%)	Height (cm)		Vegetation Type	Coverage (%)	Height (cm)
PG	Grass: *Pennisetum flaccidum Griseb*, *Carex rigescens*	80	5-10	1#	Grass: *Pennisetum flaccidum Griseb*, *Carex rigescens* Shrub: *Salix matsudana*	80 20	30-60 20-45
				2#	Grass: *Pennisetum flaccidum Griseb*, *Carex rigescens*	80	20-35
RI	Grass: *Pennisetum flaccidum Griseb*, *Carex rigescens*, wormwood	5	5-8	1#	Grass: *Pennisetum flaccidum Griseb, Carex rigescens*, wormwood Shrub: *Salix matsudana*	85 5	40-130 25-35
	Shrub: *Salix matsudana*	5	15-25	2#	Grass: *Pennisetum flaccidum Griseb, Carex rigescens,* wormwood Shrub: *Salix matsudana*	60 5	20-70 25-35
				3#	Grass: Pennisetum flaccidum Griseb, *Carex rigescens*, wormwood Shrub: *Salix matsudana*	5 5	10-40 20-30
PS	Grass: *Pennisetum flaccidum Griseb*, *Carex rigescens*, wormwood	10	5-10	1#	Grass: *Pennisetum flaccidum Griseb*, *Carex rigescens*, wormwood Shrub: *Salix matsudana*	10 40	30-90 25-50
	Shrub: *Salix matsudana*	30	15-40	2#	Grass: *Pennisetum flaccidum Griseb, Carex rigescens,* wormwood Shrub: *Salix matsudana*	10 30	15-25 20-40

Fig. 4 Pre- and post-project comparison in the PG plot.

Fig. 5 Pre- and post-project comparison in the RI plot.

Fig. 6 Pre- and post-project comparison in the PS plot.

PS: About 30% of vegetation consisted of shrubs (*Salix matsudana*), and about 10% were grasses (*Pennisetum flaccidum Griseb*, *Carex rigescens*, wormwood). The reclamation methods included: 1) planting 15 willow (*Salix matsudana*) seedlings; and 2) installing a 1.5-m high fence to exclude livestock and people.

The effect of these reclamation methods on improving vegetation condition was determined by comparing the values of assessment indicators prior to and after the measures were applied. The results are shown in **Table 5**.

PG: *Salix matsudana* survived about 15 days after planting. The height and density of vegetation in the treatment plot (1#) were significantly higher than those in the control plot (2#) (**Fig. 4**).

RI: Growth of vegetation in 1# was the greatest of the three plots. Both fencing and turfing effectively improved the condition of the vegetation, and mulching also had a small effect. Vegetation height and density were greater in 1# and 2# than in the control plot (3#) (**Fig. 5**).

PS: *Salix matsudana* survived approximately 15 days after planting. Vegetation height and density in the treatment plot (1#) were significantly greater than that in the control plot (2#) (**Fig. 6**).

Restoring a riparian buffer is effective at preventing non-point pollution and protecting aquatic ecosystems from degradation. A successful restoration design is based on a comprehensive assessment of the overall condition of riparian vegetation, and selecting proper indicators and building a rating system are critical for this assessment. This pilot study shows that fencing, planting grass or indigenous shrubs, mulching, and turfing are effective reclamation methods for restoring the structure and function of riparian vegetation. Although the assessment system and reclamation methods in this study are not yet mature, we look forward to providing a reference pattern for riparian buffer restoration in similar regions of China.

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