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Impacts of Human Disturbances on Riparian Herbaceous Communities in a Chinese Karst River

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ABSTRACT

Riparian zones suffer from increased human disturbances and the plant communities change unpredictably in response to altered conditions. It is important to understand the effects of human activities on plant communities for rational tourism development and ecological protection programs. We sampled 14 and 27 sites in nearly natural and human-influenced landscapes along the Lijiang River in southwest China, respectively, to detect human impacts on the ecosystem. We set three survey lines, based on a submersion gradient, at each site to determine whether herbaceous species richness increased with distance from the river, and we examined the effects of disturbance on herbaceous distribution. The landscapes shared 101 common species, and unique species in the human-influenced landscape were partly synanthropic. The species richness and diversity indices of the nearly natural landscape were significantly higher than those of the human-influenced landscape ($P < 0.01$). Species richness increased with distance from the river in the nearly natural landscape, and a significant difference was detected among the variances of survey lines ($P < 0.05$) in the human-influenced landscape. In the nearly natural landscape, species richness increased with fewer hydrological effects, and a stable community was maintained. However, human disturbances led to community variability and fragmented riparian habitats, resulting in species extinction and ecological degradation. We suggest that appropriate dam and reservoir regulations, prohibition of soil destructions, and a long-term research program for ecosystem protection may help in improving the monitoring of human influences and sustainable management in riparian zones of tourist rivers.

INTRODUCTION

People tend to live in areas adjacent to rivers to meet transportation, power production, food, and waste disposal needs (Naiman & Decamps 1997). Rivers and associated dependent territories, namely riparian zones, have increasingly suffered because of anthropogenic activities. Riparian zones sustain numerous plant and animal communities, maintain a range of ecosystem services (Coroi et al. 2004), and provide vital freshwater resources (Allan 1995). Riparian vegetation is currently rooted in the most vulnerable and threatened ecosystem in the world, and its conservation is thus of immense importance (Tockner & Stanford 2002). However, areas with riparian vegetation lack adequate protection, especially in third world countries that emphasize development. Plant communities are changing faster, and becoming more unpredictable in response to human disturbances and increased abiotic and biotic pressures (Parmesan & Yohe 2003, Root et al. 2003, Walther 2010). These changes have been particularly pronounced, as evidenced by shifts in composition and changes in diversity and distribution in forests at different elevations (Klanderud & Birks 2003, Lesica & McCune 2004, Pauli et al. 2007, Randin et al. 2009, Sproull et al. 2015) and in different watersheds (Méndez-Toribio et al. 2014, Pennington et al. 2010, Sunil et al. 2016).

Several studies that focused on forest composition and diversity only minimally addressed the herbaceous layer, probably because it comprises a minuscule proportion of the forest biomass. However, the herbaceous layer can contain greater than 90% of the plant species in a forest, and contributes up to 20% of the foliar litter on the forest floor (Gilliam 2007). Furthermore, the herbaceous layer can become intricately linked with canopy species by competing with tree seedlings for energy and nutrients (Graves et al. 2006, George & Bazzaz 2003, Lyon & Sharpe 2003), which mitigates the potential loss of nutrients that are essential to trees (Gilliam 2007). Karst landforms are generally characterized by extensive outcropping of soluble rocks and thin soil layers (Li et al. 2015), and frequent hydrological processes render the riparian ecosystem even more vulnerable, leading to the dominance of water-tolerant herbs. Therefore, herbaceous plants are crucial to the structure and function of riparian ecosystems. Moreover, knowledge of the composition and distribution of local natural vegetation is needed for improved restoration, because the most successful restoration methods mimic the processes of natural ecosystems (Fries et al. 1997). As water tolerance thresholds narrow, acclimation potential diminishes and productivity is limited to unsubmerged growing periods. These sensitivities provide unique circumstances for observations of the long-term effects of hydrology and the biotic interactions between herbaceous community processes and patterns. The Lijiang River riparian community is influenced by frequent hydrological fluctuations and consequent soil factors, and this influence decreases as distance from the river increases. Therefore, we hypothesized that, in a natural circumstance, herbaceous species richness and soil nutrient increase as the distance from the river increases (H1).

There are likely multiple drivers of change in the herbaceous layer (Sproull et al. 2015) and global warming, biotic interactions, and disturbances often work in concert, making it difficult to disentangle the contribution of each factor (Schweiger et al. 2010, Walther et al. 2009). Nevertheless, most short-term local changes are not caused by climate change but by land-use changes and natural fluctuations of species abundance and distribution (Parmesan & Yohe 2003). Site conditions affect local resource availability and can be important drivers of plant species diversity (Bartels & Chen 2010, Chipman & Johnson 2002, Roberts & Gilliam 1995). Although canopy tree species richness appears to be predominantly controlled by the availability of energy and climatic water, total plant species richness, which is primarily composed of understorey plants, is mainly controlled by soil conditions (Zhang et al. 2014). Other studies also found that local site conditions may have a stronger influence than regional climate on understorey plant species (Chipman & Johnson 2002, Oberle et al. 2009).

The conditions at the Lijiang River site have changed in recent years because of increased tourism interest in its scenic karst landscape, and human disturbances have subtly differentiated riparian land use. Some researchers are concerned that ecological degradation has occurred in the human-influenced landscape, and that this may cause species extinction and decreased species diversity. However, other researchers suggested that intermediate disturbances result in high species diversity in these communities. For instance, they cite the intermediate disturbance hypothesis (IDH) (Connell 1978), which predicts that high disturbance frequencies lead to the dominance of disturbance-adapted pioneer species, low disturbance frequencies lead to low-diversity communities of competitive-dominant species, and intermediate disturbance frequencies result in a mixture of both the species groups, thus resulting in peak plant diversity via succession (Chen & Taylor 2012, Connell & Slatyer 1977, Taylor & Chen 2011). In consideration of the moderate disturbance frequencies and appropriate water and temperature condition of Lijiang River, we hypothesized that in the human-influenced landscape, the species diversity may remain at a level similar to that of the nearly natural landscape, but that featured species might exhibit greater variability in areas with human disturbance (H2).

This study evaluated human disturbances in riparian herbaceous communities in the riparian zone of the Lijiang River. Here, we compared herbaceous composition and soil conditions in nearly natural and human-influenced landscape to assess changes under anthropogenic disturbances. In our analysis, we examined discrepancies in species diversity and lateral herbaceous distribution. We also built longitudinal species richness patterns to measure the effect of human disturbance. Our study aimed to determine whether the ecosystem had degraded and to identify the most vulnerable zones under present anthropogenic disturbances. We addressed the two hypotheses by analysing the differences in the patterns of herbaceous species richness and soil nutrient with the decreased hydrological effects from the river, exploring the differences in species diversity, and detecting the variability of its featured species between the nearly natural and the human-influenced landscapes.

METHODS

Study Area

The Lijiang River refers to the upper reaches of a second-order stream that drains into Pearl River. It is located in the northeast part of the Guangxi Zhuang Autonomous Region which is characterized by average annual precipitation of 1500-2600 mm（Qin et al. 2017), of which 40% occurs during the summer. This region is a subtropical monsoon climate zone, and the low-latitude study area (24°46’N-25°38’N, 110°17’E-110°31’E, (Fig. 1) contains abundant energy and illumination as well as a warm average annual temperature of 17.8-19.1°C (Qin et al. 2017). The Lijiang River has been the focus of anthropogenic service activities, including orchard picking, local catering, modern infrastructure development, and riverbank protection measures that have been constructed for tourist convenience and safety. However, the riparian zone faces increasing disturbances because of the convenient activities that occur close to the water, and riparian vegetation has been forced to adapt to transforming local land conditions. However, there are two natural reserve areas, Qingshitan Reservoir Natural Reserve and Maoershan Natural Reserve, in the northern upper and middle reaches of the Lijiang River. In addition, with the obstruction of karst clustered mountains, some lower reaches also remain undeveloped. These artificially or naturally protected areas have few inhabitants, and with the exception of some human activities, the ecosystem exhibits original species succession and remains relatively unchanged. The changes in other lands provide special circumstances for the study of anthropogenic disturbance in riparian communities.

Canopy species are sparsely distributed in riparian zones, and the species differ between the nearly natural landscape and the human-influenced landscape. *Pterocarya stenoptera* C. DC. is the most dominant tree, and it occurs along the entire length of the Lijiang River. Furthermore, *Bambusa multiplex* (Lour.) Raeusch. ex Schult. & Schult. f. is common because it was planted within riparian communities during the middle of the last century because of its well-developed roots, which can aid dyke strengthening and prevent soil erosion along banks. Nevertheless, the nearly natural riparian communities share diverse dominant species, including *Cinnamomum camphora* (L.) J. Presl, *Triadica sebifera* (L.) Small, *Salix rosthornii* Seemen, and *P. stenoptera*. Forest belts occur close to the riparian zone, and these zones are intermittent because they have been replaced with other land use types (e.g., paddy fields, gardens, and urban infrastructures).

Strips of Riparian Zone

Regarding the condition of the site, the riparian zone can be divided into four strips that are influenced by hydrological fluctuations: floodplain (7-8 months of submersion), riverside slope (5-6 months of submersion), midslope terrace (3-4 months of submersion), and upland side slope (1-2 months of submersion). This division is based on a preliminary study similar to that of Zenner et al. (2013). The floodplain strip failed to grow vegetation, with the exception of sporadic aquatic plants, because the area is full of cobblestones. Furthermore, the floodplain strip contains few fine soil particles because of drastic scouring. However, from the riverside slope strip to the upland side slope strip, gravel with a relatively higher fine soil content nourishes several herbaceous plants. The aforementioned bank protection measures were constructed exactly midway between the riverside slope and the midslope terrace along the 'golden travel reach', which can be used as a waterside pavilion after the 3-4 month wet season.

Sampling

In total, 41 sites were sampled (Fig. 1), including 14 in nearly natural landscapes and 27 in human-influenced landscapes. We constrained the sites to those that could be reached by wading, including areas without steeps and

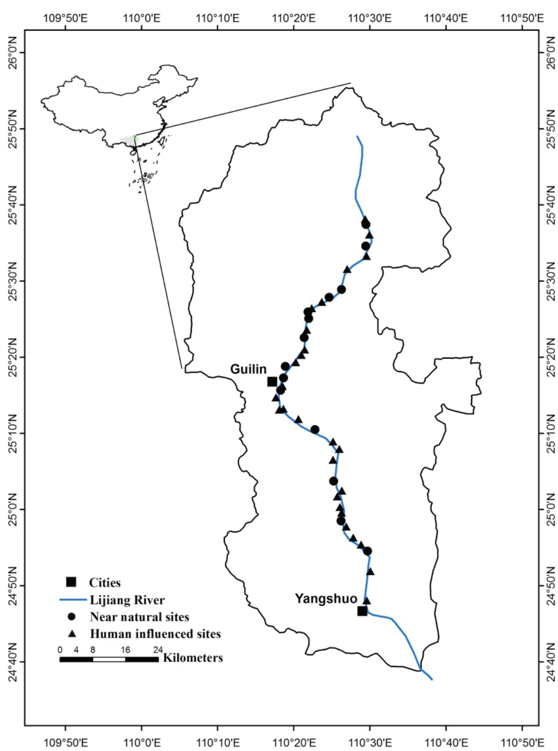

Fig. 1: Location of the study area and sampling sites.

those without appreciable channel manipulation (Jackson et al. 2015) such as revetments constructed within two to three years. Hence, sites associated with each landscape type were randomly set at a variable distance on both sides of the river, depending on specific circumstances. At each of the sites, one survey line was set in the riverside slope, midslope terrace, and upland side slope strips. Survey lines were 45 m long, and 100 × 100 cm quadrats (five per line) were systematically located 10 m apart along each survey line. Therefore, 15 plots were surveyed for species composition, richness, and diversity at each site. All species (including herbs, lianas, and shrubs under 50 cm and woody saplings under 100 cm) rooted within the confines of the plot were recorded to determine richness and composition (Sproull 2015). Cover estimates (Biswas & Mallik 2010, Coroi et al. 2004, Rheault et al. 2015) were scored by the same observer looking down at a 1 m height, and plot species presence/absence counts were summed to determine the frequency. Soil samples were collected in every 100 × 100 cm quadrats and analysed in Key Laboratory of Soil and Water Conservation and Desertification Combating, Ministry of Education, Beijing Forestry University. Species accumulation curves were used to estimate the validity of the sample sizes (27 and 14 sample sites in nearly natural and human-impacted landscapes, respectively).

From March to May of 2015, the 41 sites were surveyed, and species with different life-history characteristics were accounted for each month. Most species were identified in the field, uncommon species were verified at the College of Life Science, Guangxi Normal University (Guilin, China), and a few species were unidentified.

Data Analyses

We calculated bootstrap and abundance cover estimator (ACE) values using the statistical software program Estimates (v8.2; http://viceroy.eeb.uconn.edu/estimates), and frequency data (percentage of plots per site in which each species was present) were used to accurately gauge our sampling efforts. ACE values are used to estimate richness with a focus on species abundance and rare species, whereas bootstrapping is a more traditional randomization-based estimation method (Sproull 2015). Bootstrap and ACE values were plotted alongside one another to compare species accumulation in each landscape based on the survey data.

To compare the herbaceous composition and to test species diversity differences between human-influenced and nearly natural regions, we examined landscape scales. We used importance values for riparian herbaceous species to describe the composition differences between the two landscape types. The importance value index (IVI) was calculated by summing the relative density, relative frequency, and relative cover, and the sum was then divided by three. To estimate species diversity, we used richness (number of species at each site), the Shannon-Wiener diversity index, the Simpson diversity index, and the evenness index (Magurran 2004). We also used regression analyses, following the River Continuum Concept (Vannote et al. 1980), to reveal the longitudinal richness distribution pattern, which could reflect riparian habitat availability and physical heterogeneity in different river reach types (more habitat availability should host more richness); then, we used a general linear model to measure the effect of human disturbance on riparian diversity.

To test the hypothesis that herbaceous species richness and soil nutrient increased as the distance from the river increased, we counted the species (number of species in each strip) and computed the average of soil data at the survey line scale, and then analysed the differences among the three strips that represented different distances. The standard deviation of species richness was calculated for each strip from the five plots. The standard deviations were then used to determine whether species richness exhibited greater variability in human-influenced landscapes that were subjected to various degrees of anthropogenic disturbance among the three strips. We used an analysis of variance (ANOVA) to examine the differences in the mean species richness standard deviations across the three riparian strips that were subjected to human disturbances. For further understanding of different kinds of human disturbance on soil condition, we also used an ANOVA to analyse the differences of soil data between nearly natural landscape and tourism, grazing, and sand mining landscapes which were most common disturbances in Lijiang River riparian zone.

A two-tailed *t*-test was used to compare species diversity indices for each categorized landscape, and a one-way ANOVA was used to compare soil data and species richness and its variability among strips. Fisher's least significant difference (LSD) and Tamhane's T2 significant difference (if equal variance not assumed) were calculated from the ANOVA results. All data analyses were conducted using Excel 2010 and IBM SPSS Statistics 20.

RESULTS

Bootstrap and ACE data exhibited saturation at the high end, indicating that almost all species present in each landscape were captured during this survey. The result confirmed that our sample sizes (n = 27 in human-influenced landscape; n = 14 in nearly natural landscape) were adequate (Fig. 2). Regarding the two landscapes, 175 species belonging to 55 families were recorded, and most genera were represented by a single species. Nearly natural landscapes harbored a

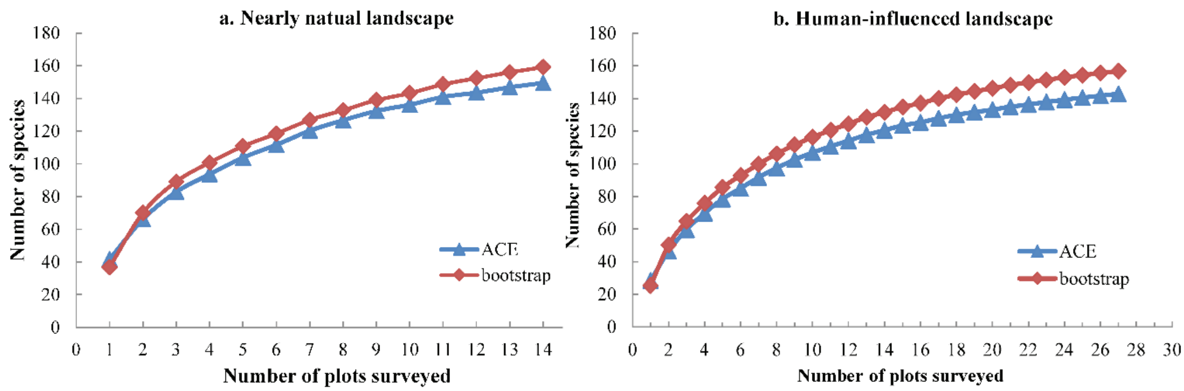

Fig. 2: Species accumulation curves illustrating bootstrap and ACE values calculated from the frequency survey data from the two landscapes. Frequency data were calculated as the percentage of plots per site in which a species was present.

higher number of species (144 species from 52 families) than that in the human-influenced landscape (132 species from 48 families). Furthermore, the mean species number for each site in the nearly natural landscape (35.07) was significantly higher ($P < 0.01$) than that of the human-influenced landscape (25.44). The two landscapes shared 101 common species, which accounted for 70.14% and 76.52% of species from the nearly natural and human-influenced landscapes, respectively (Table 1).

Table 1: Herbaceous characteristics in nearly natural and human-influenced landscapes.

Variables	Nearly natural landscape	Human-influenced landscape	Total
Species numbers	144	132	175
Genera numbers	123	106	130
Family numbers	52	48	55
Unique species	43	31	74
Mean number of species/site	35.07 ± 9.55a	25.44 ± 8.40b	-

Unidentified species were included in the species numbers of the two landscapes, but excluded from genera and family numbers. The mean species number per site (±standard deviation) was the average of the amount surveyed at each site, and different letters denote significant differences between landscapes (two-tailed *t*-test; $P < 0.01$).

The importance value index (IVI) indicated that all the dominant species belonged to the 101 most common species, and the IVI of the top 20 species accounted for 65.35 and 74.99 (100 total) in nearly natural and human-influenced landscapes, respectively. Furthermore, 14 of these top 20 species were common, indicating their dominance in the Lijiang River riparian zone (Table 2). The IVI ranges for unique species were 0.02-0.95 and 0.02-0.37 for nearly natural and human-influenced landscapes, respectively. Although the association seemed negligible, we identified the following synanthropic species that were highly associated with the human-influenced landscape: the planted fruits *Vitis vinifera* L., *Garcinia tetralata* C.Y. Wu ex Y.H. Li, and *Citrullus lanatus* (Thunb.) Matsum. & Nakai; the local delicacy *Colocasia esculenta* (L.) Schott; and greening and beautification plants *Styphnolobium japonicum* (L.) Schott, *Senna sophera* (L.) Roxb., and *Clerodendrum japonicum* (Thunb.) Sweet. However, unique species in the nearly natural landscape were not common, with the exception of *Impatiens macrovexilla* Y.L. Chen, which was cultivated and originated in Guilin.

The nearly natural landscape had higher and more significant Shannon-Weiner and Simpson indices than the human-influenced landscape (two-tailed *t*-test, $P < 0.01$), whereas the Pielou evenness indices from the two landscapes did not differ significantly. The high Simpson and evenness indices indicated high levels of sample diversity and low levels of species dominance in both the landscapes (Fig. 3).

In lateral herbaceous distribution, the mean species richness increased from the riverside slope to the upland side slope, and a significant difference between the means (Fisher's LSD, $P < 0.05$) was detected in the nearly natural landscape. However, the data resembled a hump-shaped pattern in the human-influenced landscape, and a significant difference was only detected between the riverside slope and the midslope terrace (Fisher's LSD, $P < 0.05$, Fig. 4). In longitudinal species richness patterns, Pearson correlation coefficients showed that mean plot-level species richness was strongly associated and increased with site distance (curve length along the river of each site to the northernmost site, the same below) in both the landscapes (0.893/0.673 in nearly natural and human-influenced landscapes, respectively, $P < 0.001$), and the slope of regression line was significantly higher in the nearly natural landscape than in the human-influenced landscape ($P < 0.01$). This discrepancy

Table 2: Importance value index (IVI) for some of the common species in the two landscapes.

Nearly natural landscape species	IVI	Human-influenced landscape species	IVI
Arthraxon hispidus (Thunb.) Makino	7.60	*Arthraxon hispidus*	14.86
Oplismenus hirtellus (L.) P. Beauv. subsp. undulatifolius (Ard.) U. Scholz	7.20	*Murdannia triquetra*	7.21
Trachelospermum jasminoides(Lindl.) Lem.	4.69	*Cynodon dactylon*	5.48
Achyranthes aspera L.	4.58	*Oplismenus hirtellus* subsp. *undulatifolius*	5.29
Glechoma longituba (Nakai) Kuprian.	4.20	*Achyranthes aspera*	5.07
Murdannia triquetra (Wall. ex C.B. Clarke) G. Brükn.	4.03	*Glechoma longituba*	5.01
Persicaria hydropiper (L.) Spach	3.45	*Humulus japonicus*	3.74
Aster tataricus L. f.	3.17	*Persicaria hydropiper*	3.33
Persicaria barbata (L.) H. Hara	2.94	*Oxalis debilis* var. *corymbosa*	3.22
Humulus japonicus Siebold &Zucc.	2.71	*Clinopodium chinense*	2.59
Kalimeris indica (L.) Sch. Bip.	2.70	*Trachelospermum jasminoides*	2.49
Rubus rosifolius Sm.	2.70	*Persicaria barbata*	2.31
Cynodon dactylon (L.) Pers.	2.62	*Persicaria chinensis* (L.) H. Gross	2.26
Paederia foetida L.	2.38	*Aster tataricus*	2.24
Urena lobata L.	1.86	*Setaria plicata*	2.14
Salvia prionitis Hance	1.86	*Cyperus cyperoides* (L.) Kuntze	1.93
Ageratum conyzoides L.	1.85	*Perilla frutescens* (L.) Britton	1.81
Oxalis debilis Kunth var. *corymbosa* (DC.) Lourteig	1.78	*Kalimeris indica*	1.35
Setaria plicata (Lam.) T. Cooke	1.60	*Alternanthera philoxeroides* (Mart.) Griseb.	1.35
Clinopodium chinense (Benth.) Kuntze	1.45	*Bidens pilosa* L.	1.33
Total	65.35	Total	74.99

All dominant species were common species surveyed in the two landscapes. Only the top 20 are shown in descending order, and 14 of these species were common. The IVI values of other common species ranged from 0.03 to 1.24 in the nearly natural landscape and from 0.12 to 1.28 in the human-influenced landscape.

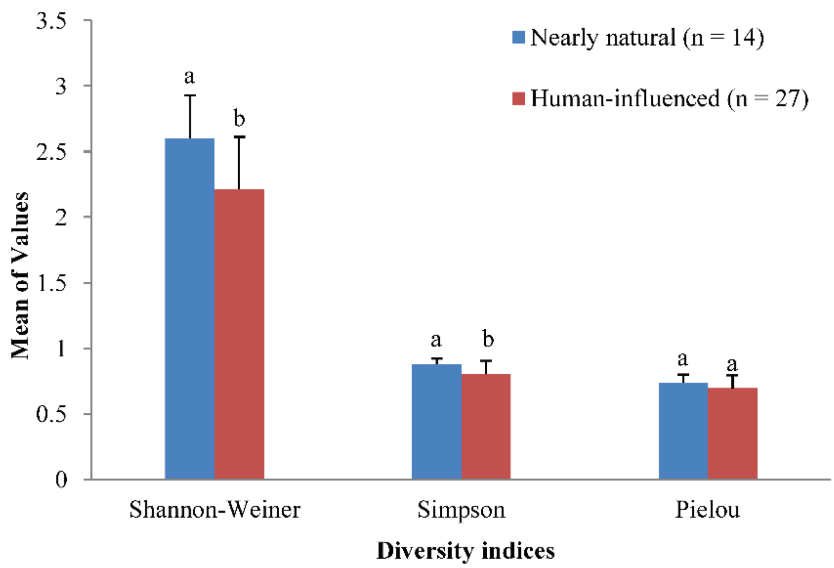

Fig. 3: Mean diversity indices between the two landscapes. Bars represent one standard deviation. Columns with a different letter are significantly different at the P < 0.01 level using a two-tailed t test.

indicates that human disturbance had a negative effect on riparian species richness (Fig. 5). Furthermore, the standard deviation of species richness within the survey lines ranged from 0.707 to 2.510 in the nearly natural landscape, and no significant difference was detected. However, the standard deviations of species richness were significantly different and much higher for the midslope terrace and the upland side slope than for the riverside slope in the human-influenced landscape (Fisher's LSD, $P < 0.05$). This result indicated greater variability associated with disturbance in the human-influenced landscape (Fig. 6).

Soil organic matter, available nitrogen, available phosphorus, and clay particle content increased from the riverside slope to the upland side slope in nearly natural landscape, however no significant difference showed in grazing and sand mining landscape except clay particle content in

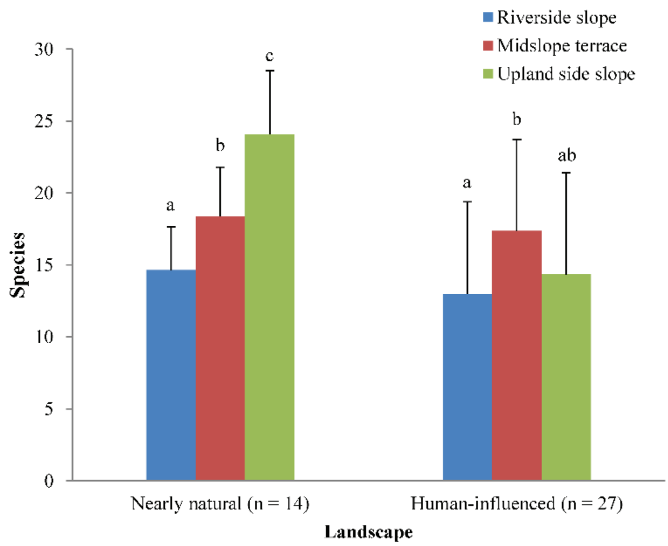

Fig. 4: Mean species richness among strips in the two landscapes. Bars represent one standard deviation. Columns sharing a common letter are not significantly different at the P < 0.05 level using Fisher's LSD.

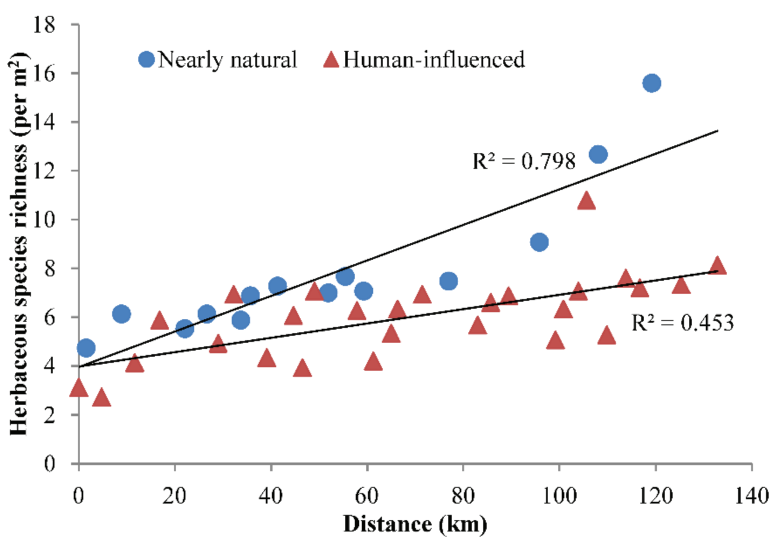

Fig. 5: Mean herbaceous species richness within the Lijiang River riparian zone, in relation to distance of 14/27 sites (nearly natural and human-influenced respectively). Distance represents the curve length along the river of each site to the northernmost site.

sand mining landscape. What's more, the soil indices in tourism landscape was significantly higher in midslope terrace and upland side slope than in riverside slope (Fig. 7).

DISCUSSION

Species Composition and Distribution

We found the plant species in the herbaceous community of Lijiang River riparian zone to have more competitive/ruderal strategies, thus providing greater ecosystem resilience (López et al. 2013). This is because the nearly natural landscape and human-influenced landscape shared a substantial proportion of species and exhibited no absolute predominant species (top 20 species with a total IVI of 65.35%/74.99%, respectively), which was confirmed by a high Pielou evenness index (Table 2, Fig. 3). Indeed, most of the common

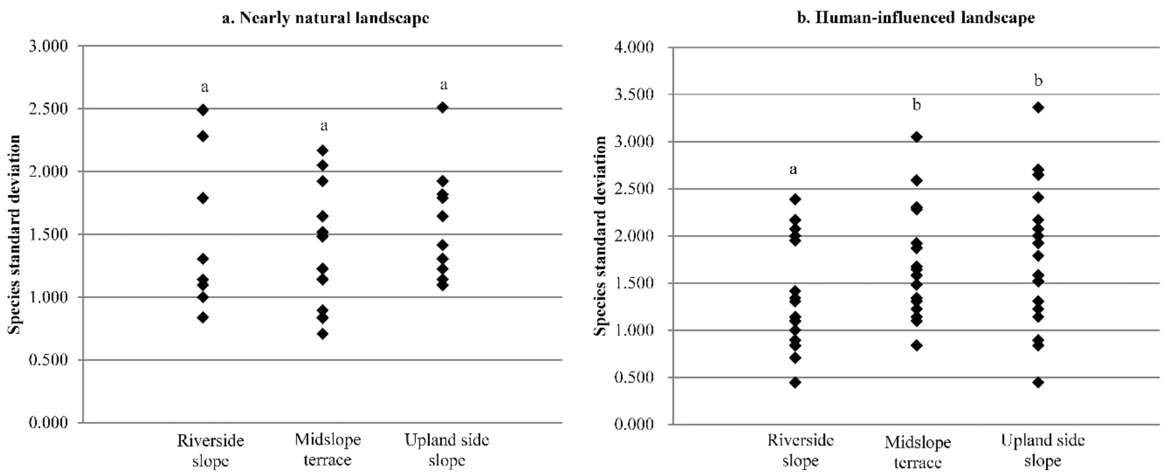

Fig. 6: Distribution of the standard deviation of species richness, by survey lines, for the two landscapes. Distributions that do not share a letter have different mean standard deviations of species richness according to Fisher's LDS at the P < 0.05 level.

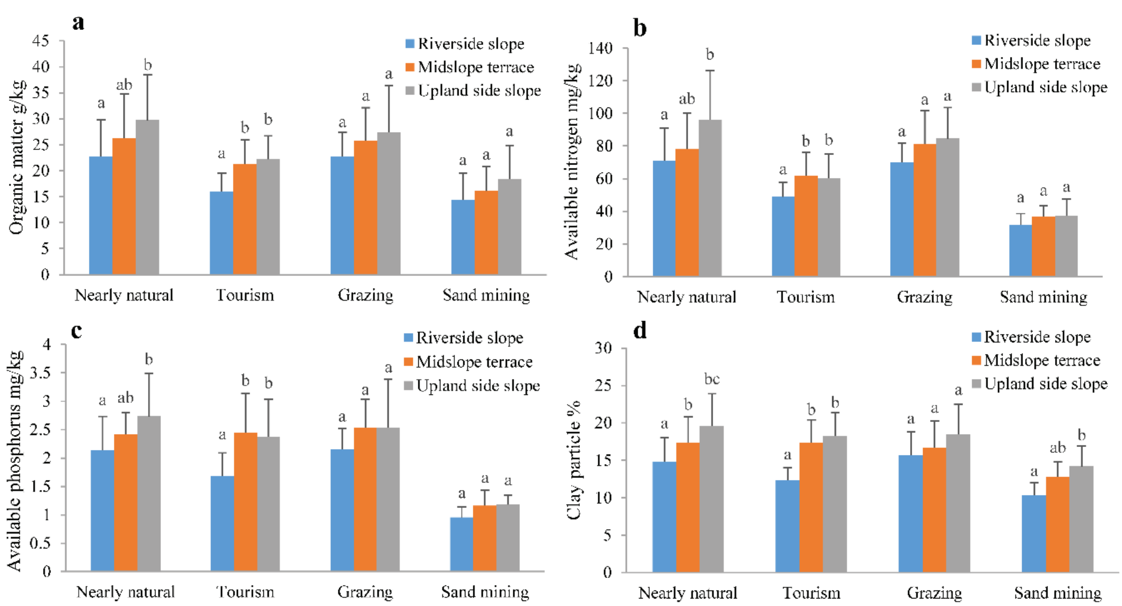

Fig. 7: Mean soil organic matter, available nitrogen, available phosphorus, and clay particle content among strips in the nearly natural landscape and tourism-influence, grazing-influenced, and sand-mining-influenced landscapes. Bars represent one standard deviation. Columns sharing a common letter are not significantly different at the P < 0.05 level.

species were perennials with a branched rhizome or exhibited higher relative cover, which implied an elevated leaf canopy and capacity for extensive spread, i.e., competitive strategies (Grime 1974). In contrast, although the 3-4 month wet season had disastrous floods, the abundant energy, illumination, and precipitation as well as the warm temperature of the Lijiang River provided appropriate growing conditions for annuals or short-lived perennials that had a characteristic of rapid growth, i.e. ruderal strategies (Grime 1974). The unique species showed the same strategies in the nearly natural landscape but exhibited more human-related sapling shrubs or trees in the human-influenced landscape, which reflects the impacts of human activity on herbaceous composition. In the human-influenced landscape, picking orchards, featured restaurants, and greening and beautification projects exist to attract tourists. Many fruits (e.g., *Vitis vinifera* and *Garcinia tetralata*), vegetables (e.g., *Colocasia esculenta*), flowers, and trees (e.g., *Styphnolobium japonicum*, *Senna sophera* and *Clerodendrum japonicum*) were planted in gardens, and these species might disperse to adjacent lands (Moran 1984), including riparian zones used for human activities (e.g., picnics or barbecues in the wild with fresh fruits and vegetables). In fact, exotic species could easily end up in undisturbed areas without human activities within 2-4 years (Gomes et al. 2014). Thus, these synanthropic species might change the species composition of Lijiang Riparian zone by intruding to other human-influenced and even natural landscapes under further tourism.

Our results confirmed the hypothesis (H1) that herbaceous species richness increased with distance from the river (Fig. 4). This result contradicted that of Coroi et al. (2004) in that the restrictive factors in their study area were light, water and soil nutrients, which declined in the farther streamside forest, thus leading to lower species richness. In our study area, the vegetation of riparian zones was frequently removed or covered with alluvia following floods, and the terrain left after water withdrawal was subsequently colonized by pioneer species, as is typical (Coroi et al. 2014). Thus, the nearly natural landscape species were mainly affected by hydrological factors and consequent soil factors, because the canopy species are sparsely distributed in riparian zones and other factors were not restricted (e.g., abundant energy, sufficient illumination, and a warm average annual temperature in the study area). As the water tolerance thresholds declined, reduced scour in the upper riparian zones retained fine soil particles that provided a better environment for growth. Herbaceous species richness also increased from the upper reaches to the lower reaches because of more complex natural conditions. In natural riparian zones, reaches with higher riparian habitat availability and physical heterogeneity are thought to support greater species richness (Bruno et al. 2014). Our data showed a monotonically increasing species richness pattern from upper reaches to lower reaches in both the landscapes; this implies a natural higher riparian habitat availability and physical heterogeneity in the lower reaches of Lijiang River because of its more peculiar pinnacles in 'golden travel reach', which may lead to a wider range of illumination and temperature. Under these conditions, optimum illumination or temperature will occur for a larger number of species.

Effects on Herbaceous Community

Although the herbaceous composition and distribution are highly structured by hydrological processes and habitat availability under natural circumstances, the land-use variables can be more important for explaining riparian vegetation patterns under anthropogenic pressure (Tabacchi et al. 1996, Ferreira & Moreira 1999). Sand mining observed in the riverside slope of the landscape might pose a threat to native species because it can obstruct the flow of surface water (Sunil et al. 2016, Nagler et al. 2008), leaving pits that are always full of rainwater, and make the clay particle be washed away easier (Fig. 7), therefore, the germination and establishment ability of species would be diminished. Defecation behavior by grazing animals seemed to be beneficial to nutrition, but the study did not reveal a significant increase in nutrients associated with restored floodplain dynamics and inundations, which have been documented for other rivers (Schaich et al. 2010). Furthermore, grazing can also play a vital role in influencing the vegetation and topsoil structure, including the preference and trampling of specific herbs by cattle. Therefore, grazing can change the habitat fitness (Sagar et al. 2003) and influence competitive interactions between species, and the destruction of the topsoil structure can also lead to low-nutrient conditions under strong hydrological effects that promote the colonization of a few stress-tolerant species (Gomes & Asaeda 2009, Doležal et al. 2013). Traditional revetments are generally constructed with concrete and have extremely low conductivity (Li et al. 2015), which obstructs the substance and energy exchange between the riverside slope strip and upper strips. On the one hand, when lacking supplements from upper lands, species in lower lands may face an inferior growing environment (Fig. 7). On the other hand, the interception of nutrients or pollutants makes upper lands uncertain for nourishing plants. Tourism activities add additional complication factors to riparian zones, and these factors may have positive or negative effects on species diversity. However, uncontrolled tourism activities can exert immense pressure on the riparian zones, leading to declines of typical riparian species, and consequently affecting the biodiversity of a river (Sunil et al. 2016).

The human disturbances associated with these land-use practices existing in the riparian zone of Lijiang River could easily cause habitat fragmentation, which could drive species to local extinction (Gilliam 2007). For example, the unique species and non-dominant common species appeared negligible with little importance, but these sparsely distributed species played a crucial role along the riparian zone. The absence of these species resulted from fragmentation that could lead to the decline of native species over time (Tabarelli et al. 1999). Although there is often a lag time before inevitable extinction occurs (Gilliam 2007), we believe that these human-induced factors have already combined to induce ecological degradation in the human-influenced landscape even it is not as optimistic as our H2, because the species richness and diversity of the nearly natural landscape were significantly higher than those of the human-influenced landscape (Table 1, Fig. 3). The results also showed a significant higher slope for the regression line in the nearly natural landscape and a higher standard deviation of richness among strips in the human-influenced landscape (Figs. 5 & 6), thus confirming that human disturbances had caused negative effects on the riparian diversity and made the midslope terrace and upland side slope strips more variable. However, the average Simpson diversity of the human-influenced landscape remained high (0.804). This result is attributed to greater ecosystem resilience and implies that the human-influenced riparian zone encountered relatively low or moderate disturbance intensities at the present stage. The theory of "intermediate disturbance" suggests that in some ecosystems with low or moderate disturbance intensities, a species diversity increase might occur (López et al. 2013). Additionally, the increased standard deviation of species richness in the human-influenced landscape was similar to that in former studies, which showed an increased standard deviation of structure variables between transects under intensive grazing near water sources; these results also agreed with the theory of "intermediate disturbance" (Adler et al. 2001, Cingolani et al. 2005).

Implications

Generally, an equilibrium steady state ecosystem is elastic and resistant to disturbance factors, and high-resilience communities may initially have minimal change (Morecroft et al. 2016). However, with higher climate or human disturbance, once a tipping point or critical threshold is reached, there may be a sudden change in community which is associated with a loss of ecosystem functional integrity (López et al. 2013, Morecroft et al. 2016). In this study, although a significant decrease of diversity was found in the human-influenced landscape, the diversity remained high, and a substantial proportion of species remained the same as in the nearly natural landscape. Preventing the crossing of a tipping point or critical threshold is crucial for sustainable management. As the vegetation distribution is highly structured by hydrological factors and consequent soil factors, and changing these environmental conditions can drastically alter community richness (Looy et al. 2016), we suggest the prevention of extensive intervention on water level and direct damage on soil. For example, dam and reservoir regulations should put an emphasis on flood peak cutting so as to not cooperate in deepening of the waterbed to better serve sightseeing boats during the dry season, which may lower the water level and intensify the competitive interactions. Sand mining should be forbidden as it directly destroys the structure of thin surface soils that are easily washed away by frequent hydrological process, consequently leading to difficulties associated with vegetation nourishment. A long-term research program is also needed to thoroughly evaluate community organization and stability and to explore mechanisms and how confounding human-induced factors influence the species community in the Lijiang River riparian zones. By analysing the changes in riparian community composition during the long-term research program, we can also infer community assembly mechanisms of resilience (Looy et al. 2016). Such information might help in the prevention of crossing a tipping point or critical threshold and be used for sustainable management of tourist rivers.

CONCLUSIONS

In the Lijiang River riparian zones, the nearly natural landscape and the human-influenced landscape shared a substantial proportion of herbaceous layer species, but human activities are changing the species composition by dispersing synanthropic species. These human activities affect biodiversity in various forms and have led to decreased species diversity, especially in the upper riparian sides. The herbaceous community is highly structured by the hydrological process and habitat availability in the natural riparian zone of the Lijiang River, but human activities have altered the natural species distributions and fragmented riparian habitats. The differentiated riparian land-use practices may have driven species to local extinction, and might have led to a more variable community. Our hypotheses were mostly supported by our study, although the significantly different diversity between nearly natural landscape and human-influenced landscape did not support H2. The disturbances to the riparian zone are not lethal at the present stage, and we found the greater ecosystem resilience maintained a high level of Simpson diversity in human-influenced landscape because of the competitive/ruderal strategies of herbaceous community. To prevent crossing a tipping point or critical threshold which may drastically decrease community richness, we suggest appropriate dams and reservoirs regulations, prohibition of soil destructions, and a long-term research program for better understanding of mechanisms in plant community to human disturbances.

In this study, we started by analysing the species composition, i.e., the stability of the community itself, for which less attention has been paid and few empirical studies exist. We revealed the species distribution mechanism, and then pointed out the most vulnerable district of the riparian zone and proposed protection strategies. This information may improve the monitoring of human influences on riparian zones of tourist rivers, especially in developing countries, which are keen on benefits that may limit ecological protections. Our findings can also be used as a reference to reconcile conflicts between tourism development and ecosystem stability for sustainable management.

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