Patterns of plant species richness along the drawdown zone of the Three Gorges Reservoir 5 years after submergence
Sun Rong, Liang Shaomin, Qiu Shike and Deng Wei

ABSTRACT
This study was conducted to understand the patterns of plant species richness in the Three Gorges Reservoir after 5 years after 175 m submergence. We hypothesized that hygrophyte and xerophyte species would show different species richness patterns, which was tested by collecting species composition and environmental variable data in 50 m long and 5 m wide transects in the drawdown zone from 145 m to 180 m. Xerophyte species richness (XSR) was highest in the middle of the drawdown zone, whereas hygrophyte species showed a continuous downward trend from 145 m to 180 m. Correlation analyses showed that the flooding period was significantly negatively correlated with the total species richness (TSR), XSR, and hygrophyte species richness (HSR). The TSR and XSR showed a significant positive correlation with soil type and a significant negative correlation with available K. HSR was significantly correlated with soil type and negatively correlated with ammonium N.

INTRODUCTION
A drawdown zone is the special lake-land ecotone caused by water level fluctuation due to reservoir operations, representing an important site for studying the mechanisms and driving factors of plant community succession (DeBerry & Perry 2008). Drawdown zones are important transitional regions for the exchange of substances, energy, and information between river ecological systems and terrestrial ecological systems, and have obvious marginal effects (Gregory et al. 1991). Drawdown zones have drawn much attention in the communities of scientists studying environmental science, soil science, and ecology (Minshall & Rugenski 2007).

The Three Gorges Project, at present the largest water conservancy project in the world, is a multi-purpose hydro-development project for flood control, power generation, and navigation improvement. These functions generate a remarkable drawdown zone in the Three Gorges Reservoir (TGR).

In November 2003, the water level of the TGR rose to nearly 139 m, which was maintained with slight fluctuations for 3 years until late September of 2006, when the TGR began the experimental impoundment of water at levels of up to 156 m above sea level. In 2008, the maximum water level exceeded 173 m for the first time. By October 2010, the dam’s water level had risen to 175 m, its full capacity. In addition, the water levels decreased by approximately 30 m during the flooding season. Flooding in the reservoir behind the Three Gorges Dam (TGD) extends up to 663 km upstream, almost to the city of Jiangjin in Chongqing Municipality. The reservoir has an amplitude of 30 m, with 348 km² of newly flooded drawdown zone with a littoral zone length of 4,900 km at the maximum reservoir height (Yuan et al. 2013). The construction of the TGD was expected to have a great influence on all ecosystems involved (Subklew et al. 2010) and its impact on the environment was expected to be immense (Kellogg & Zhou 2014). Drawdown zone vegetation is an important part of the drawdown ecosystems and has important ecological functions, including protecting biodiversity, protecting the shore and slowing sedimentation, improving partial microclimates, and suppressing non-point source pollution.

Drawdown zone vegetation has been a hot topic in research since the mid-1960s (Nilsson & Berggren 2000; Mitsch et al. 2008). The hydrology regime, including the depth, frequency, duration, and the predictability of flooding, is the decisive factor in drawdown vegetation succession and

Key words | drawdown zone, hygrophyte, plant community, species richness patterns, Three Gorges Reservoir, xerophyte

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distribution patterns. Of these, the duration and depth of flooding have been shown to be the most important factors influencing the structure and richness of riparian plants, and changes in the hydrology regime also change the soil’s physical and chemical properties (Aerts et al. 2003). Since the construction of the TGR began, the ecological environment has undergone tremendous changes, during which most of the plants disappeared. Compared to the pre-dam ecology, the vegetation biomass and species diversity decreased, trees and shrubs and other woody plants nearly disappeared, and annual and biennial herbs became the most common plants in the drawdown zone (Lu et al. 2010).

The ecology of the TGR drawdown zone has attracted much attention. First, plants with suitable submergence tolerance have been researched. These include trees, such as Pterocarya stenoptera (Wang et al. 2013) and Pinus elliottii (Zhou et al. 2012), shrubs such as Morus alba (Zhang et al. 2012), Salix variegata (Chen et al. 2013), and Distylium chinense (Li et al. 2012a, 2012b), and herbs, such as Hemarthria compressa (Luo et al. 2012), Paspalum distichum (Liao et al. 2012), and Cynodon dactylon (Tan et al. 2010). Researchers have investigated morphological characteristics, photosynthesis, chlorophyll, fluorescence, non-structural carbohydrates, and clonal integration (Chen & Xie 2009; Li et al. 2011). Second, researchers have explored the relationship between the environment and drawdown vegetation diversity and spatial patterns after water-land change (Sun et al. 2011a; Guo et al. 2013; Ye & Zeng 2013). Third, researchers have explored the dynamic prediction of plant communities based on the analysis of natural vegetation in the fluctuation zone of the TGR and community succession theory (Wang et al. 2005). These studies include experimental simulations combined with laboratory analyses and field investigations, as well as theoretical speculation and survey-based studies of plant communities in the TGR drawdown zone after its formation.

However, by the end of 2014, 5 years after the 175 m line was submerged, what had occurred for the drawdown zone vegetation? Is the vegetation adapted to the alternating water/land habitats? The mechanisms of plant responses to environmental stress and how the composition of vegetation will change under these conditions should be explored. A clear understanding of these issues will not only enhance our knowledge of the ecological adaptability of plants in alternating water/land habitats but will also help in evaluating the ecological impacts of the TGR and the development of riparian vegetation.

In this study, we examined the vegetation in the drawdown zone of the Baijiaxi River, which is the second tributary of the Yangtze River, in Chongqing, China. This river flows into the Pengxihe River, the largest tributary in the TGR. The site experienced 5 complete years of flooding to 175 m above sea level, making it an ideal system for testing theories related to the patterns and processes of vegetation change after 5 years of submergence. The community studied was situated between the 145 m and the 180 m water levels. The main objectives of this study were to examine the drawdown vegetation in order to: (1) examine the species richness patterns of hygrophytes and xerophytes 5 years after submergence and (2) assess the role of various environmental factors in determining the species richness in the drawdown zone.

METHODS

Study areas

The Pengxihe River is 182.4 km long with a total catchment area of 5,173 km², of which a section 108 km in length is affected by the 175 m water-level submergence of the TGR. The total area of the zone of fluctuation is 55.47 km², accounting for 15.90% of the total area of the drawdown zone of the TGR, which is both typical and representative for a plant study in the TGR. Its climate is humid subtropical and subtropical, with a mean annual temperature of 18.5 °C and high temperature variation due to the large gradient differences and complicated landforms. The annual precipitation averages 1,100–1,500 mm. The river’s greatest discharge is 6,886 m³/s, while its smallest is 4.6 m³/s, with an average of 107.1 m³/s. The Baijiaxi River is located in the midstream of the Pengxihe River. It has a drawdown zone of more than 10,000 m² and a width at the 145 m to 175 m level of more than 100 m (Figure 1). When the TGR was constructed, the original trees and shrubs were removed from the potential drawdown zone.

This study did not involve human participants, specimens or tissue samples, or vertebrate animals, embryos or tissues; or endangered or protected species. The study area therefore did not require specific permission.

Field methods

Species richness

In July 2014, 27 study transects were established along the 135 m wide drawdown zone from the 145 m to the 180 m level (Figure 1). Each transect was 50 m long (parallel to the river flow) and 5 m wide, and community features
such as plant species and height were recorded. We recorded all rooting vascular plant species within each transect, and species richness values were calculated separately for each transect. Each species was categorized as a hygrophyte or xerophyte species based on its water demand.

The timing of these surveys may have missed some winter annual and spring ephemeral species, but logistical issues precluded additional surveys. Most plant species retain a vegetative presence after blooming, and few would have been entirely absent during the August sampling time.

Environmental factors

To explore possible correlations between species richness and site characteristics, eight environmental variables were recorded: flooding time (FT), bank substrate type (ST), bank substrate heterogeneity (SH), available P (AP), ammonium N (AN), available K (AK), organic matter (OM), and total salt content (SC).

FT was the length of time the area was submerged from July 2013 to June 2014, which was determined using the daily water level issued by the Three Gorges Corporation. Following Wright et al. (1984), a value for the ST was determined, weighted by the percentage composition of the bank substrate and based on the visual estimation of seven Ø values (log2-transformation of the size classification): clay (9.0), silt (6.5), sand (2.0), gravel (−2.0), pebbles (−4.5), cobbles (−6.5), and boulders (−9.0). To enable a collective treatment of all ST and all banks, two additional types, peat and bedrock, were arbitrarily given the respective Ø values of 12 and −12, i.e., they were placed marginal to clay and boulders, respectively. These values ranked the substrates in terms of water-holding capacity from high to low. The SH was measured as the number of different ST, irrespective of their relative abundance, within each study site. These types were also distinguished when the ST were mixed at the same site.

Data analysis

To test for variation in species richness by location, a polynomial regression using a stepwise multiple regression

Figure 1 | Location of sampling sites in the littoral zones of the Pengxihe River of the TGR.
analysis was performed. Correlations among the values of species richness and the eight environmental variables were also analyzed via the Spearman method.

**RESULTS**

Total species richness (TSR) \((R^2 = 0.899, P = 0.000, Figure 2(a))\), hygrophyte species richness (HSR) \((R^2 = 0.887, P = 0.000, Figure 2(b))\) and xerophyte species richness (XSR) \((R^2 = 0.889, P = 0.000, Figure 2(c))\) all showed a significant quadratic relationship with distance to the channel.

The correlation matrix (Table 1) indicates that TSR, HSR, and XSR were significantly positively correlated with FT. Furthermore, TSR was significantly positively correlated with ST and SH and negatively correlated with AK. XSR was significantly positively correlated with ST and significantly negatively correlated with AK. HSR was significantly positively correlated with ST and significantly negatively correlated with AN.

**DISCUSSION**

The drawdown zone of the TGR was in the earlier stages of succession, with a wet-dry cycling environment and a harsh, fragile and changeable habitat, which led to a simple structure and the appearance of rare species in the riparian vegetation communities (Wang & Gao 2010). Based on the field observations, the more time under water, the more occasional species, such as *Brassica campestris*, *Cucurbita moschata*, *Citrullus lanatus*, and *Lagenaria siceraria* appeared, but only in the 1st, 2nd, and 3rd transects. In the middle of the drawdown zone (from the 4th to the 12th transects), there were typical *Cynodon dactylon* communities with coverage of almost 100%, and only a few accidental species, such as *Calystegia sepium* and *Cuscuta chinensis*. In the upper part of the drawdown zone, because of the shorter FT, the distance to the channel, and the increased altitude, some shrub species appeared, such as *Lycium barbarum* and *Morus alba*. When the height exceeded 170 m, there were typical xerophyte species, with *Imperata cylindrica* communities distributed at approximately 175 m, similar to previous research (Sun et al. 2011).

Different plants require different environments. Water factors are critical in determining the distribution of species, leading to a variety of species in this drawdown zone (Figure 2(a)). First, the farther from the river, the fewer hygrophytes and more typical xerophytes (Figure 2(b) and 2(c)). The results showed that the TGR had a significant screening effect on the drawdown zone vegetation. On one hand, it screened and inhibited the plant propagation and community development at low water elevations, while on the other hand it facilitated seed dispersal and diffusion. After the water levels fell, regions away from the river gradually dried, and xerophytes with good dispersal ability may have reached the low elevation transects and temporarily survived (such as *Pterocarya stenoptera*, *Boehmeria nivea*, and *Vitex negundo*, which were found in the 1st, 2nd, and 3rd transects and other low-elevation sites). In the low altitude transects, the drawdown zone was affected not only by the TGR but also by seasonal, occasional floods and waves created by boats. Due to the flood damage and screening, it was difficult to achieve dispersal and rapid recovery of the casual species at low elevation. In sum, because of floods and the filtering effects of the TGR, species with complex roots and multiple seeds easily occupied these sites, while it is difficult for ordinary terrestrial plants to move in.

Both internal and external factors affect the development and maintenance of plant communities (Casanova & Brock 2000; Bruno et al. 2014). Internal factors include the biological and ecological characteristics of the species, while external differences include the small scale of the biotope and habitat heterogeneity (Wang et al. 2001). From the internal perspective, species with strong reproducibility, large ecological amplitude, a high tolerance for drought and poor soils, and the ability to adapt to wetting-dry habitats were dominant. Large quantities of seed of species such as *Cynodon dactylon* and *Cyperus iria* accumulated in the drawdown zone, giving them an advantage in succession. When the drawdown zone experiences flooding, perennial herbs have stronger survivability and more developed root systems than annual herbs or pioneer species. However, in terms of the seed bank, the former was much smaller than the latter, and the number of species and the coverage of perennial herbs increased more slowly than that of annuals, which could not be the dominant position in the drawdown zone of the TGR. Under the environmental screening, external factors such as flooding had a stronger influence than the internal environment. At different elevations in the drawdown zone of the TGR with water logging times varying from 20 days to 120 days as a typical external filter criterion, the species adapted to this annual variation in water level could survive.

For small-scale plant communities, diversity may come largely from habitat differences. However, when there were great differences in habitats, succession of plant communities followed different paths, with differing
Figure 2 | Patterns of plant species richness in the littoral zone in the Penghohe River of the TGR.
community structures, functions, and dynamics (Liu et al. 2015). Because of the operation of the TGR, a vertical amplitude of approximately 50 m formed along both sides of the TGR with different FT, from 20 days in plot 26 to 120 days in plot 1, which led to significant differences in the habitats and plant communities. Chambers et al. (1991) observed that differences in the effects of micro-topography and soil conditions caused differences in the species compositions of soil seed banks, which directly affects the species composition and diversity of the vegetation. Coupled with the complex pattern of micro-topography and soil properties that determines the regional differences in the spatial distribution of vegetation, water level fluctuations and other disturbances also affect the process of vegetation development and the formation, distribution, transmission, and deposition of seeds, causing differences in the composition of the plant communities in different transects. In this study, micro-topography, such as low-lying puddles and terraced slopes, significantly improved the richness of the species in a site. For example, in a small puddle in plot 5 (no more than 5 cm in depth and 2 m² in area) a Sagittaria sagittifolia community and a Cyperus iria community emerged from within the uniform Cynodon dactylon community. On the terraced slopes diverse xeric plant species, such as Abutilon indicum, Conyza canadensis, and Centella asiatica, appeared.

The Intermediate Disturbance Hypothesis indicates that the maximum species richness occurs at medium levels of disturbance. Numerous studies have shown that the number of species is highest in the middle region of the riparian zone (Nilsson et al. 1989). This study found that, with a reduction in FT and increased altitude and distance to the riverbed, the TSR and XSR showed opposite successional trends. The HSR decreased from long to short FT (Figure 2(b)), which differs from the previous study of Sun et al. (2011b). Several factors played a significant role in this outcome. First, the seed sources of the drawdown vegetation were important. Nearer to the riverbed there were more seed sources and greater amounts of seed dispersed by water, such as those of the typical non-riparian species Citrullus lanatus and Cucurbita moschata. Seeds spread by birds or other animals, as well as those of native species, such as Cyperus iria, came from the soil seed bank and from higher regions of origin. In the field work, we found that Cyperus rotundus typically propagated from rhizomes. The second factor was more complex interference. The drawdown zone experienced flooding from the TGR, seasonal flooding, natural flooding pulses, and flooding pulses from boats. Wang & Gao (2010) found that in the drawdown zone of the TGR many species could not complete their life cycles due to hydrological changes, and the proportion of plants that could not complete propagation was positively correlated with flooding disturbances. Based on these reasons, more accidental species appeared in the 1st transect (1–5 m) than in the 3rd transect (10–15 m). Third, the combined effects of life history and water level fluctuations also affected the communities. In general, annual and biennial plants reproduced mainly by seed and had short life histories. They completed their life cycles before the water of the TGR rose. These plants, such as Xanthium sibiricum

### Table 1 | Correlation matrix for all characteristics of the drawdown zone of the Penguuhe River, northern Chongqing, China

<table>
<thead>
<tr>
<th>TSR</th>
<th>XSR</th>
<th>HSR</th>
<th>FT</th>
<th>ST</th>
<th>SH</th>
<th>AP</th>
<th>AN</th>
<th>AK</th>
<th>OM</th>
<th>SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSR</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XSR</td>
<td>0.896**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSR</td>
<td>-0.404*</td>
<td>-0.768**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FT</td>
<td>0.885**</td>
<td>0.485*</td>
<td>0.895**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.631**</td>
<td>0.457*</td>
<td>0.688*</td>
<td>-0.556*</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH</td>
<td>0.556*</td>
<td>0.389</td>
<td>0.459</td>
<td>-0.46*</td>
<td>0.390</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>-0.362</td>
<td>-0.331</td>
<td>0.486*</td>
<td>-0.665*</td>
<td>0.0226</td>
<td>0.0758**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>-0.332</td>
<td>-0.356</td>
<td>-0.558*</td>
<td>-0.356</td>
<td>-0.272</td>
<td>-0.489*</td>
<td>0.335</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AK</td>
<td>-0.634**</td>
<td>-0.446*</td>
<td>-0.337</td>
<td>-0.432</td>
<td>0.245</td>
<td>-0.054</td>
<td>0.175</td>
<td>0.118</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>OM</td>
<td>-0.199</td>
<td>-0.211</td>
<td>-0.356</td>
<td>-0.358</td>
<td>-0.060</td>
<td>-0.252</td>
<td>0.179</td>
<td>0.432</td>
<td>0.107</td>
<td>1.000</td>
</tr>
<tr>
<td>SC</td>
<td>-0.295</td>
<td>-0.299</td>
<td>-0.434</td>
<td>-0.442</td>
<td>-0.142</td>
<td>-0.3560</td>
<td>0.145</td>
<td>0.632**</td>
<td>0.193</td>
<td>0.602**</td>
</tr>
</tbody>
</table>

Notes: Values are Spearman’s, *P < 0.05, **P < 0.01.
TSR (total species richness); XSR (xerophyte species richness); HSR (hygrophyte species richness); FT (flooding time); ST (substrate type); SH (substrate heterogeneity); AP (available P); AN (ammonium N); AK (available K); OM (organic matter); SC (total salt content).
* + "means positive and " - " is negative.
and *Abutilon indicum*, produced a large number of seeds that were then stored in the soil for later germination. Perennial plants have long life histories. They propagated through vegetative reproduction, and although they formed seeds, the number was small, and it was thus difficult for such plants to regenerate via the soil seed bank. *Satake et al. (2001)* indicated that the timing of severe disturbances can determine whether some annual species would follow a conservative strategy and finish blossoming and bearing fruit before the disturbed periods, even when the individual is not fully grown. The field investigation showed that *Xanthium sibiricum* previously completed the process of blossoming and fruiting in July and August but now does so in May or June. Fourth is the presence of a mono-dominant community. Communities composed only of *Cynodon dactylon*, *Cyperus iria*, or *Echinochloa crusgalli* var. *mitis*, with matted growth, high coverage and strong competitive ability, outcompeted other species for nutrition and living space, resulting in low species richness. We also considered that the edge effect hypothesis (Leopold 1933) might explain these differences, which suggests that the ecotone provides more habitat and nutrients, resulting in a higher species abundance and richness in the ecotone system than the nearby ecosystem. Indeed, the edge ecosystem could provide abundant matter, energy and resources; on the other hand, the edge habitat contained more fierce competition and more frequent natural disasters (severe material and energy changes). As is well known, the TGR is a typical ecotone with extreme material and energy movement. In the 135 m wide study area, from the river to the highland, the ecosystem changed from river to areas with a long FT, an intermediate FT, and a short FT and land, which exhibited characteristics of the lateral edge effect (Xia et al. 2020). The results (Figure 2(a) and 2(c)) showed a similar species richness trend. The HSR (Figure 2(b)) could be controlled more by water than other factors; with increasing distance to the river and altitude, the FT gradually shortened and eventually became nonexistent (175–180 m).

*Nilsson et al. (1989)* found that riparian species richness was greater at moderate levels of disturbance than under mild and severe disturbance. We also found that plots with an intermediate flooding period and moderate levels of conductivity and pH had lower species richness and the flooding period determined the species richness. OM, total nitrogen, and total phosphorus were higher in low elevation transects, indicating an increase in species richness as soil nutrients increased. In general, the Baijiaxi River is located in the central region of the TGR and the FT was the most important factor in species richness, while the soil salinity (conductivity) was the most important factor among the soil richness factors. As the duration of submergence to the 175 m line increased, the soil conductivity decreased, the nutrient content increased, and the soil physical and chemical properties improved. The pattern and strength of human activities also increased with time, causing species richness to fluctuate. A combination of several environmental factors and human activities determined the community composition. This reflected the effect of changing environments on the successional process, which may explain successional species diversity and dominant species formation.

Studies have shown that community stability is closely related to species diversity (Pennington et al. 2010). In general cases, as the successional process proceeds, diversity increases. However, in many communities, diversity decreases slightly after it reaches its peak. We considered that the effect of light strength decreased as water depth increased due to the water-rich sediment and FT, suggesting that the riparian vegetation under long-term flooding not only faced adversity but also faced matt adversity under long-term flooding, which apparently affected the germination, growth, and reproduction of the riparian vegetation (Li et al. 2012a, 2012b) (Figure 2(a)–2(c)). This result further demonstrated that community stability has wider implications, not merely that the diversity level might be the result of the simultaneous effects of various factors and mechanisms, and that species diversity is merely the foundation for a stable community foundation or a necessary condition.

Due to the joint influences of climate, hydrology, soil, and vegetation in the drawdown zone of the TGR at different spatial and temporal scales, the drawdown ecosystem showed unique characteristics. There was a unique pattern of riparian vegetation, which was affected not only by the biological characteristics of the plants but also closely related to the outside hydrology, soil, and other biological factors. The correlation analysis showed that there were different relationships between species richness and environmental factors. The strongest correlation was between the FT (hydrological factors) and TSR, and HSR had a higher correlation with the FT than other species richness factors (Table 1), which meant that FT was the most important factor. This result is consistent with the findings of Junk et al. (1989), which showed that flooding pulses and water were the most important interference factors in riparian vegetation.

Based on the results, three aspects of FT affect plant species in drawdown zones. First, the water status and soil nutrient status were derived from the flooding. Wetland and aquatic plants such as *Sagittaria sagittifolia* and *Cyperus*...
*iria* are found only in low-lying puddles with high water saturation. The second aspect is plant physiological tolerance and adaptability. The third aspect of FT is its effects on inter-specific competition under water constraints. *Cynodon dactylon* and *Echinochloa crusgalli* var. *mitis* had well developed root systems and strong adaptability to submergence, which was a competitive advantage in the mid-drawdown zone. It is well known that different plant species have different adaptabilities to habitat change, especially habitats that shift from water to land, leading to cycles of wet and dry soils in the drawdown zone of the TGR. This shows that plants in the Cyperaceae, Poaceae and Asteraceae families had greater adaptability, while woody plants (trees and shrubs) had poor adaptability. As a unique land and water ecosystem, the composition, structure, and pattern of drawdown vegetation were affected not only by the inundation but also by the specific environmental factors, especially the physical and chemical properties of the soil. This study found that there was a positive correlation between species richness and ST and SH (Table 1), which is consistent with the Intermediate Disturbance Hypothesis, and that at intermediate particle sizes and moderate levels of SH the species richness was the highest. The relationship between vegetation and soil chemical factors has been widely discussed, and many studies have shown that soil chemical factors play a key role in the pattern of the wetland vegetation distribution (Kulmatiski et al. 2008). Soil OM is an important indicator of soil quality and an important component of soil nutrients. This study found that there was a significant and positive correlation between TSR and XSR and soil OM, while HSR had a lower correlation, possibly because the moisture and water conditions had stronger effects on hygrophytes (Table 1). There was a significant negative correlation between species richness and the total SC, as in the Yellow River Delta (Ma et al. 2012). Gough and Shaltout found similar results for the coast of the Mediterranean and the Nile Delta, respectively (Gough et al. 1994; Shaltout et al. 1995).

Based on the site investigation, the study area was an isolated island when the TGR was filled to the 175 m level, (with the highest level at 184.5 m) and formally hosted bamboo forest above 175 m. Under these circumstances, there were no inputs of fertilization, with the 175 m level water erosion from the TGR, the soil nutrients decreased year by year. There was a significant correlation between HSR and AP, or AN, which was likely affected by the moisture gradient. Thus, the higher the altitude, the rarer the wetland plants (Figure 2(b)), and as a result of erosion over the years, soil nutrients showed an increase as the elevation gradient decreased. TSR and XSR showed no significant correlation with AP, or AN.

**CONCLUSION**

To some extent, there was a weak correlation between plant diversity in the drawdown zone and soil chemistry, which was different from the findings of previous studies. FT was the main limiting factor for plant species since the periods of submergence were long, and limited the effect of other factors. With long-term flooding, the content of soil nutrients in the drawdown zone was insufficient to significantly affect the spatial distribution of riparian vegetation.

**Recommendations**

In subsequent studies, the understanding of seed sources in the drawdown zone should be enhanced. The proportion of seed sources and the high-land species, soil seed bank, hydrochor, and animal transport should be defined, thus providing the basis for riparian vegetation in recovery. Further study should be focused on vegetation succession in the lower areas of the drawdown zone in the TGR under specific water level fluctuations. Based on a 10-year study, the authors found that the phenophase in the drawdown zone changed, which significantly advanced and reduced the mean germination time. Some species completed their entire life cycle of germination, growth, flowering, and seed bearing in a short time during the recession flow of the TGR. *Xanthium sibiricum*, *Cynodon dactylon*, and *Abutilon indicum* were representative of this phenomenon. *Xanthium sibiricum* completed its entire life cycle, growing to only 20 cm high. The flowering and seed bearing of *Cynodon dactylon* advanced from July to May. Further, small-scale study of the correlation between micro-topography and plant diversity should be enhanced. In this study, micro-topography significantly affected species diversity. Even very small (1 m²) changes produced completely different species. Fourth, the slopes of drawdown terraces should also receive more attention. Little research has addressed the effect of slope on diversity. However, in the field investigations, whenever elevation transitions occurred, even if the slope was a high 1 m, the diversity was also much higher than on adjacent terraces. Future studies should pay more attention to the plant diversity on slopes, exploring its formation and development mechanisms, which could help maintain and recover slope diversity and support soil and water conservation. Finally,
studies of low-altitude (<155 m) species diversity should be increased. The significance of this study was that these locations are affected by long-term flooding (inundated more than 80 days annually) of the TGR, seasonal flooding (more than three times every year), and sailing wave pulses, which significantly affected formation and succession mechanisms under different types and intensities of disturbance.

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