Influence of diversion power stations on riparian plant communities along Dicun stream China

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Abstract: This article used three diversion power stations with different operating years along Dicun stream of the source of Jiulong River to study the riparian plant community and discussed the impact of power station development on riparian plants. The results showed that:(1)There were significant differences in the plant diversity of herbs, shrubs and trees among all sample plots in the study area ($P < 0.05$).(2) The species number of the second and third diversion power stations with longer operation time was larger than that of the fourth diversion power station with short operation time.(3) The water-borne plants were concentrated in the herb layer in the influence area of the diversion power station, and the Richness, Shannon- Wiener, Simpson and Pielou indexes of water-borne plants in the study area were significantly different ($P < 0.05$). (4) The appearance of diversion power station leaded to the change of environmental factors, and the river depth and flow rate had significant positive correlation with the diversity index of riparian plants and water water-borne plants ($P < 0.05$). In general, with the increase of the operation time of the power station, the surrounding riparian plant will form a new stable community.

Keywords: Diversion power station; Riparian plants; Water-borne plants; Environmental factors

1 Introduction

Small hydropower refers to hydropower stations with installed capacities of 25 MW and below, and most of their water resource development is concentrated in mountainous areas. Because of their small investments, short cycles and quick results, small hydropower can solve problems associated with electricity consumption in remote areas without electricity and or with scarce electricity. Moreover, due to the great differences in altitude that occur in mountainous areas and large river drops, the development mode of small hydropower is generally diversion power stations (Hussaina et al, 2019; Author et al, 2019). The water storage and drainage methods of a diversion power station cut the river in the affected section into 5 relatively independent units: the backwater section above the dam, the dewatering section below the dam, the upstream section of the drainage outlet, the downstream section of the drainage outlet, and the diversion channel section. The phenomena of water reduction, river drying and rapids in some river reaches, all of which threatens whole river ecosystems, and these changes are not conducive to the healthy development of rivers (Chen et al, 2020; Dorber et al, 2019).

While the development of diversion power stations brings economic and social benefits, it inevitably changes the surrounding riparian plant conditions (Tisserant et al, 2020). Riparian plants are an important component of riparian ecosystems and are one of the best indicators that reflect their regional ecological environment; they are expected to be good indicators of the ecological damage caused by the development of diversion power stations (Zhang et al, 2020a). Previous studies have shown that the small reservoirs formed in the upper reaches of dams submerge the habitats of plants under rivers (Fink et al, 2018), and the construction of dams hinders the exchanges of material and energy between the upstream and downstream regions, disrupts the longitudinal dispersion of water-borne plant propagules along rivers, changes the vegetation in riparian zones, and reduces the numbers and diversity of riparian plant species (Atkins et al, 2020). In addition, due to the succession of riparian plants, the short-term vegetation changes differ from the long-term responses, and cascade dams are more complex than single dams (Ouvang et al, 2010). However, most studies have mainly focused on the impacts of large-scale power stations on plants in the vicinity of dams. There are few studies on the impacts of small power stations on plants, especially in the slow-flowing water above dams, in the regions under dams, and at the hydropower stations caused by diversion power stations. There is still a lack of research on the effects of the reduced-water reaches upstream of hydropower station outlets and the rapid flows downstream of hydropower station outlets (Zhang et al, 2020b).

Changes in environmental factors in riparian zones will cause the establishment of new plant communities and the disappearance of some plant species; these effects will change the original community types (Bauer et al, 2018). Relevant studies have suggested that the characteristics of plant species and riparian hydrology and morphology jointly determine the aggregation of riparian plant communities (Van et al, 2014). With the development of diversion power stations, the hydrological conditions of riparian zones have become extremely unstable, seriously affecting the distributions (Deng et al, 2014). With the emergence of diversion power stations, the topographic features of some rivers are reshaped, which will eventually affect the growth of riparian plants (Louckova et al, 2012). According to research, in a study of plant communities approximately 50 years before and after the construction of the Shasta Dam, the trees on the riverbank gradually disappeared, and the floodplain of the riverbank turned to agricultural land. Although there was significant flow regulation, the riverbank mobility and erodibility increased by approximately 50%, increasing the vulnerability of the adjacent land to erosion (Micheli et al, 2010). The changes in riparian environmental factors caused by the river drying up due to the emergence of power stations have also greatly changed the riparian landscape, hydrology and overall river transport of sediments (Bianchi et al, 2015). However, changes in riparian plant communities come not only from the influence of diversion power stations but also from influences involving the land use, urbanization, agriculture, sand mining, and invasive species (Sun et al, 2020). The resilience of riparian communities may be more affected by the spatial diffusion of rivers and landscapes than by instantaneous diffusion in soils, but the flow regulation of dams will hinder the regeneration of riparian plants (Bourgeois et al, 2017). Therefore, it is very important to pay attention to the impacts of environmental factors caused by diversion power stations on riparian plants.

We suppose the following: (1) the development of a diversion power station will lead to changes in the species number and composition of the plant community in the affected area; (2) water-borne plants, especially water-borne trees and shrubs, are more sensitive to the development of diversion power stations, and these species will experience high mortality; (3) the development of diversion power stations changes the surrounding environmental factors, such as the river morphology and hydrology. Changes in environmental factors are the main reason for decreases in riparian plants. Through this research, we can determine the influence of diversion power stations on riparian plant species compositions and compositions of water-borne plants and provide a reference for the ecological restoration of riparian zones.

2 Methods and materials

2.1 Study area

Dicun stream was one of the streams at the source of Jiulong River, originated in the hawksbill mountain area between the southern Wuyi Mountains and Boping Mountains. The main river channel was 32 km long with an altitude range of 300-1200 m. It belonged to the upper paleozoic low mountain and hilly landform in southwest Fujian Province. The landform was complex and the drop was large, which creates conditions for hydropower development. There were eight cascade hydropower stations in the study area. This article taken Dicun stream second-level power station, third-level power station, and fourth-level power station as the main research area. The three power stations along the river from upstream to downstream were shown table 1and figure 1.

Table 1 Basic information of three power stations in Dicun stream

Power station	Year of completion	Installed capacity (kw)	Power drop (m)	Type
Second-level（SE）	1980 year	750	90m	Diversion
Third-level （TH）	2000 year	395	40m	Diversion
Fourth-level（FO）	2009 year	1120	90m	Diversion

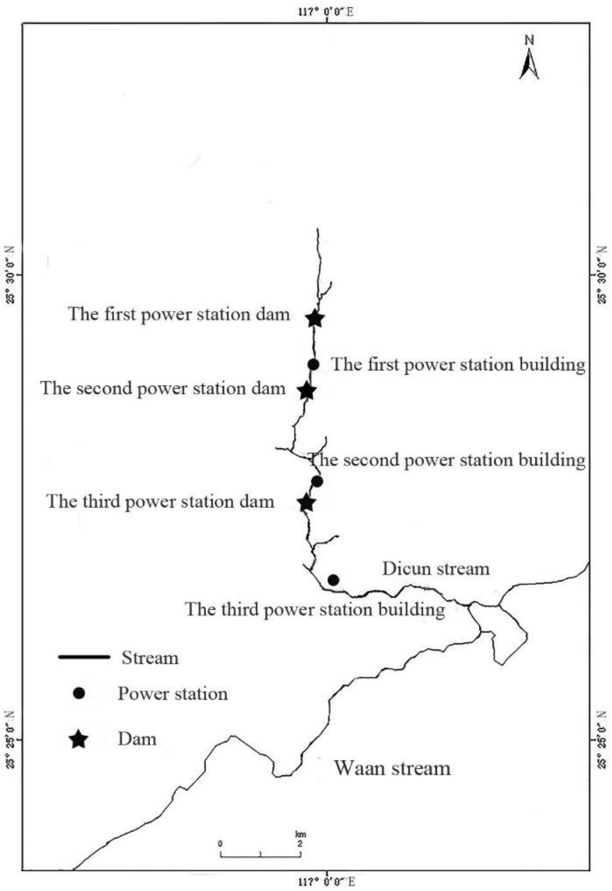


Fig. 1 Geographic location maps of power stations

2.2 Plant investigation

In April 2019，The plant species were investigated in the main affected areas of 50 m (DB) upstream of the dam, 50 m (DA) downstream of the dam, 50 m (HB) upstream of the discharge outlet of the hydropower station, and 50 m (HA) downstream of the drainage outlet of the hydropower station. A sample plot with a length of 100 m (parallel to the flow direction of the river) and a width between the highest and lowest water level of the river was set in each affected area. Set 3 tree plots of 10 m×10 m in each plot, 1 shrub plot of 5 m×5 m in each tree, and 2 herb samples of 1 m×1 m in each shrub. At the same time record the plant species type, coverage, number of plants, breast diameter and height were recorded at the same time. etc. According to *flora of China* (1991) and *flora of Fujian*(1982), the plants were identified and classified. Refer to Kew Royal Botanical garden seed database（ *http://data.kew.org/sid/* ）and related literature (Guo et al, 2017;Yu et al, 2019) to determine the species of water-borne plants.

2.3 Environmental factors investigation

During the investigation, the environmental factors of each plot were measured three times, and the average value was taken. The elevation was measured by GPS, and the slope was measured by compass. The sediment types were classified and assigned according to the grain size (1: coarse sand grain size 0.2 ~ 2.0 mm, 5: Gravel grain size 2.0 ~ 20.0 mm, 10: Pebble Grain Size 20.0 mm ~ 200.0 mm, 20: stone grain size > 200.0 mm). The width of the river was measured with a tape, the depth of the river was measured with a meter, and the velocity was measured with a current meter. The pH of soil factors were determined by potentiometric method, ammonia nitrogen by extraction indophenol blue colorimetry, nitrate nitrogen by ultraviolet spectrophotometry, available potassium by sodium tetraphenylborate turbidimetry, available phosphorus by molybdenum antimony colorimetry, and organic matter by potassium dichromate volumetric method. In view of the differences in the impacts of different types and disturbance intensities on the river ecosystem, in order to facilitate comparison, human disturbance intensities were classified and assigned (Zhu et al, 2014).

2.4 Diversity analysis of plants

According to the distribution characteristics of riparian plant community, the relative height and relative coverage were selected as herb indicators to measure riparian plant, and the species Richness index (R), Shannon-Wiener index (H), Simpson index(D) and Pielou index (E) are selected which was an indicator of riparian plant diversity. The specific calculation formula was as follows(Ren et al, 2020)：

Richness index：

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

Shannon-Wiener index：

$$H = -\sum P_i \, lnP_i \qquad (2)$$

Simpson index：

$$D = \sum {P_i}^2 \qquad (3)$$

Pielou index：

$$E = \frac{H}{lnS} \qquad (4)$$

Where P_i was the important value and S was the number of species.

2.5 Statistical analysis

One way ANOVA of plant species number and plant diversity data was completed by SPSS 25.0; The relationship between the number of plant species, plant diversity and various environmental factors was used for redundancy analysis (RDA) with Canoco 5.0, used Origin 9.0 software for drawing.

3 Results

3.1 Influence of power station development on riparian plants

3.1.1 Species composition and quantity change

From figure 2, a total of 399 species of plants belonging to 296 genera and 120 families were recorded. Angiosperms were the most, with 365 species, while pteridophytes and gymnosperms were less, with 30 and 4 species respectively. Among them, a total of 266 species of riparian plants were found in the second-level diversion power station, 226 species in the third-level diversion power station and 192 species in the fourth-level diversion power station. There was significant difference in the number of plant species among the three power stations ($P < 0.05$). The total species varied from 61 to 126 species, including 30 to 64 species of herbs, 16 to 45 species of shrubs and 10 to 29 species of trees. There were significant differences in the total species, herb species, shrub species and tree species in the four plots above and below the dam, upstream and downstream of the outlet ($P < 0.05$).

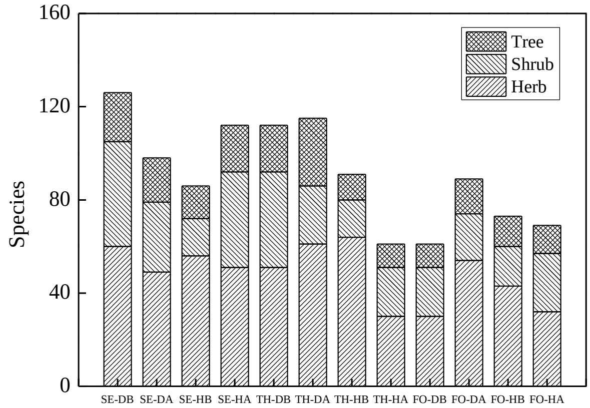


Fig. 2 Variation of species of riparian plants

3.1.2 Plant diversity

The Richness index of herb layer, shrub layer and tree layer in different habitats of diversion type hydropower station varied from 6 to 12, 4 to 22 and 5 to 10, respectively. The results of one-way ANOVA showed that the Richness index of herb layer and shrub layer of the second stage hydropower station, herb layer of the third stage hydropower station and shrub layer of the fourth stage hydropower station were significantly different ($P < 0.05$) (Figure 3-a).

The Simpson index of herb layer, shrub layer and tree layer in different habitats of diversion hydropower station varied from 0.7265 to 0.8779, 0.7251 to 0.9196 and 0.6995 to 0.8838, respectively. The results of one-way ANOVA showed that there was no significant difference in the Simpson index of the fourth-level power station ($P>0.05$) (Figure 3-b).

The Shannon Wiener index of herb layer, shrub layer and tree layer in different habitats of diversion hydropower station ranged from 1.5063 to 2.2615, 1.4230 to 2.7659 and 1.4035 to 2.2222, respectively. The results of one-way ANOVA showed that there were significant differences in the Shannon-Wiener index between the herb layer and shrub layer of the second-level power station and the herb layer and shrub layer of the third-level power station ($P<0.05$). (Figure 3-c).

The Pielou index of herb layer, shrub layer and tree layer in different habitats of diversion hydropower station varied from 0.8428 to 0.9407, 0.8251 to 0.9532 and 0.8321 to 0.9665, respectively. The results of one-way ANOVA showed that there was no significant difference in Pielou index of riparian plants in different habitats (P > 0.05) (Figure 3-d).

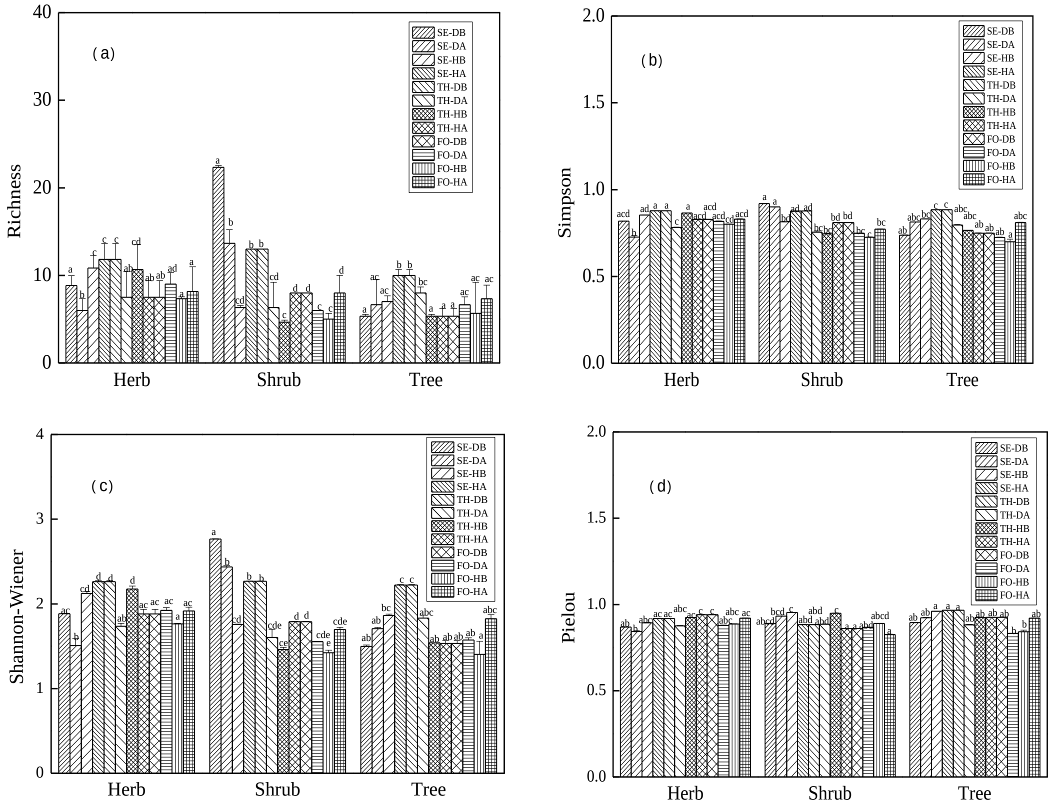


Fig. 3 Riparian plant diversity in power station habitats

3.2 Influence of power station development on water-borne plants

3.2.1 Species composition and quantity change

From figure 4, a total of 177 species of water-borne plants were recorded, belonging to 131 genera and 51 families，there were 169 species of angiosperms and 8 species of pteridophytes. Among them, a total of 112 species of water-borne plants were found in the second-level diversion power station, 107 species in the third-level diversion power station and 93 species in the fourth-level diversion power station. There was significant difference in the number of water-borne plant species among power stations (P < 0.05). In terms of lifestyle, the water-borne plants were concentrated in the herb layer, and the number of shrubs and trees with water-borne ability was less. There were 24~64 species, 20~55 species of herb, 1~7 species of shrub and 0~5 species of tree. There were significant differences in the total species, herbaceous species, shrub species and tree species in the four plots above and below the dam, upstream and downstream of the outlet (P < 0.05).

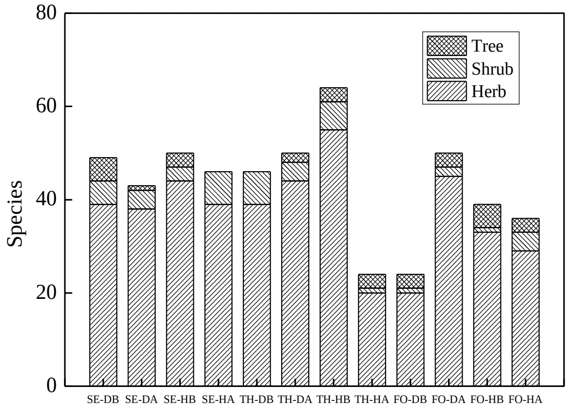
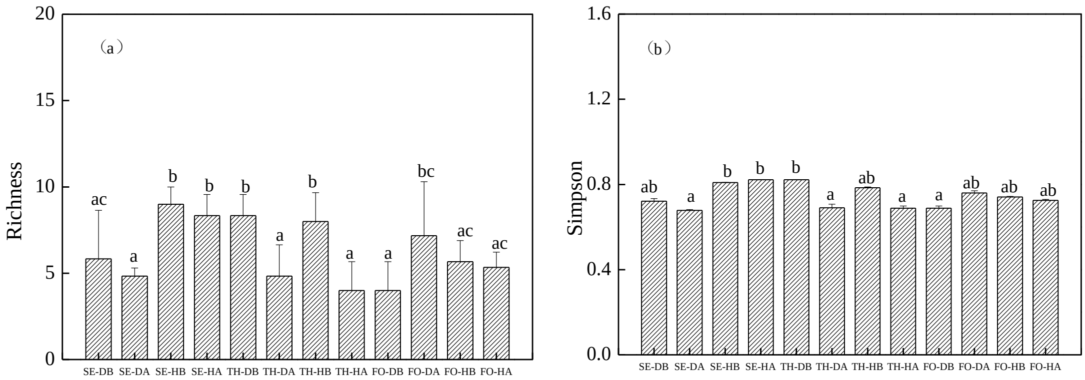


Fig. 4 Variation of the number of water-borne plant species

3.2.2 Plant diversity

The Richness index of herb layer hydrophytes in different habitats of diversion type hydropower station was the highest in SE-HB plot, which was 9, and the lowest in TH-HA and FO-DB plot which was 4 (Figure 5-a). The Simpson index was the highest in SE-HA and lower TH-DB plot, which was 0.8221, and the lowest in SE-DA plot, which was 0.6780 (Figure 5-b). The Shannon Wiener index was the highest in SE-HA and TH-DB plots, which was 1.8840, and the lowest was TH-HA and FO-DB plots, which was 1.2725(Figure 5-c). The Pielou index was the highest in SE-HA and TH-DB plots, which was 0.9113, and the lowest was SE-HB plots, which was 0.8285(Figure 5-d). The results of one-way ANOVA showed that the Richness index and Shannon Wiener index of water-borne plants were significantly different in different habitats above and below the dam of the third power station and the fourth power station ($P < 0.05$), and there were significant differences in the different habitats between the second-level power station and the third-level power station on the dam-downstream of the drainage outlet ($P<0.05$).



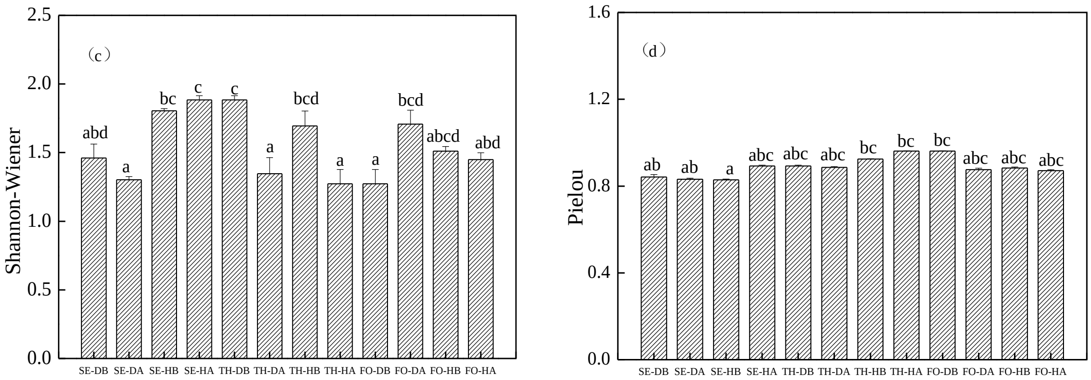


Fig. 5 Waterborne plant diversity

3.3 Relationships between plants and environmental factors

In the investigation of environmental factors, due to the small contribution rate of some environmental factors in the plot to plant diversity, the environmental factors with an explanatory value <0.1% were removed and re-analyzed to finally generate RDA ordination maps of riparian plant diversity and water-borne plant diversity. From figure 6a, environmental factors such as elevation, river water depth, and bamboo felling in different habitats of diversion-type power stations indicate that the three have a greater impact on the riparian plant diversity in this area. Herb Richness, Simpson, Shannon Wiener index and tree Richness, Simpson, Shannon Wiener, Pielou index were positively correlated with water depth, and negatively correlated with bamboo cutting. The Pielou index of herbs and shrubs was positively correlated with flow velocity, and negatively correlated with available phosphorus. Shrub richness, Simpson and Shannon Wiener index were positively correlated with altitude, and negatively correlated with bamboo cutting and available potassium. From figure 6b, the arrow axis of the environmental factors such as velocity, water depth and nitrate nitrogen in the influence area of diversion power station shows that the three factors have a great influence on the diversity of water transmission plants in the area. The Richness, Shannon-Wiener, and Simpson indexes of water-borne plants are positively correlated with river water depth and nitrate nitrogen, and negatively correlated with pH, river width, bamboo felling, and slope. The Pielou index of water-borne plants is positively correlated with river flow velocity.

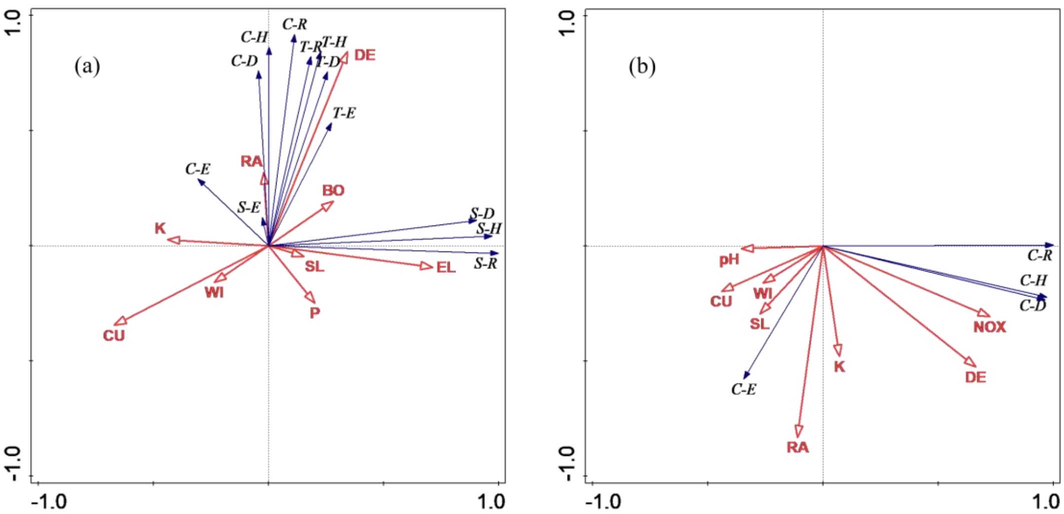


Fig.6 Sequence map of plant diversity and environmental factors. (a) Riparian plants; (b) Water-borne plants

Note: The abbreviations of plant indicators in the figure are: Richness index, Shannon-Wiener index, Simpson index and Pielou index herb layer are C-R, C-H, C-D, C-E, and shrub layer are S-R, S-H, S-D, S-E, tree layer are T-R, T-H, T-D, T-E. Environmental factors are referred to as elevation EL, slope SL, sediment type BO, river width WI, water depth DE, flow velocity RA, ammonium nitrogen NH_4, nitrate nitrogen NO_x, available potassium K, available phosphorus P, organic matter OM, bamboo felling CU, road construction RO, river garbage RU, house construction HO, sewage discharge SE, breeding BR, agricultural activities AG, hydropower development HY.

4 Discussion

4.1 Impact of diversion power stations on riparian plants

The emergence of diversion power stations has changed the depth and flooding frequency of rivers, resulting in different, new riverbank conditions in different river sections (Xie et al, 2015). Carles (2018) also proved that a whole riparian ecosystem was in an adjustment sequence before and after the construction of a hydropower station, the morphological changes were connected in a series, and finally, riparian stability was achieved with the observed changes. It is also proven in this study that the numbers of species in the areas of the second and third power stations with longer operation lives were larger than that of the fourth power station with fewer operation years. With the increase in the operation time of a power station, the surrounding riparian plants form new, stable communities. However, it was also found that the number of species near the second-level power station that had with a short operation time was greater than that of the third-level power station with a long operation time. This was because the third-level power station was located downstream of the second-level power station, and the impact of the cascading power stations was cumulative (Hou et al, 2011). Studies have found many negative eco-environmental problems caused by the construction and operation of cascade dams to be more complex than those caused by single hydropower stations (Zhang et al, 2019). Moreover, the fourth-level power station analyzed in this study directly used the tail water of the third-level power station to generate electricity, which aggravated the influence of the downstream area of the third-level power station on the surrounding plants.

There were significant differences in the observed changes in herbs, shrubs, and trees among all sample plots in the study area ($P<0.05$), indicating that the emergence of diversion power stations had an impact on riverside plants. In addition, the numbers of riparian plants in the affected areas were different in different operation years, indicating that the short-term vegetation changes and long-term responses were different in the riparian plant community successions among the studied areas (Ouvang et al, 2010). Studies have shown that the emergence of a dam has a positive local impact on the number of plant species near the dam (Bombinoet al, 2009). We found that the number of shrub species on a dam was greater than that in other affected areas. This is because the backwater surface formed on the dam was not enough to submerge the habitats of shrubs. The width of the river was wider at the dam than at other river sections, the water flow was slow, and the sedimentation material was dense, which improved the wet conditions of the river section and was suitable for the growth of shrubs. In contrast, the water level below the dam was reduced, and the exposed surfaces of river bottom rocks increased, which was not conducive to the regeneration of riparian shrub species (Azami et al, 2004; Bombino et al, 2014). The emergence of diversion power stations caused some river sections to be cut off and was not conducive to plant growth, which means that the completion of the renovation of ecological discharge facilities can effectively solve the problems of water reduction and drainage caused by hydropower development (Wang et al, 2018).

4.2 Impact of diversion power stations on water borne plants

Water-borne plants play an important ecological role in the composition of riparian plant communities. Studies have shown that differences in the species diversity of water-borne plants were related to adjustments of the river channel that occurred after the development of diversion power stations (Zhang et al, 2012). The discontinuity of river environments caused by dams induces morphological adjustments, which change the water depth and flooding frequency of the corresponding river section, intercept sediments and affect the river topography. Such changes in hydrology and topography can reduce the transport of sediments and nutrients and hinder water transport. Migration paths for the spread of plant species have serious impacts on vegetation species and communities (such as plant proliferation and reproduction) and habitat fragmentation in riparian areas (Kui et al, 2012; Wintle et al, 2007). The area below a dam was found to contain more deciduous deposits than naturally flowing stream sites, greatly increasing the coverage of some weeds (such as *Miscanthus*) and changing the original community (Elderd et al, 2003). The species diversity of a plant community directly or indirectly reflects the community structure type, stability degree and habitat difference, which can be used as an index to judge changes in the community structure and stability of an ecosystem (Li et al, 2020).

In riparian ecosystems, water transmission is generally considered to be the main carrier of many riparian species. Water-borne plants can affect riparian vegetation by promoting downstream community composition and diversity (Nilsson et al, 2010). Studies have found that water-borne plants were concentrated in herbaceous layers in the areas affected by diversion power stations, and the number of shrubs and trees capable of water-borne transmission was small, indicating that the structure of water-borne species in the affected areas was singular and the ecosystem was vulnerable. Although the herb layer is only a subordinate layer of the community and cannot be used to completely determine the structure and function of the community, in the process of community evolution, the herb layer plays an important role in improving the surrounding environment of the community (Wang et al, 2020). We also found that the richness, Shannon-Wiener, Simpson, and Pielou indices of herbs were significantly different among the various plots in the study area ($P<0.05$), indicating that the diversion power stations had impacts on the diversity of water-borne plants. Previous studies have found that diversion power stations destroy the propagation and colonization of water-borne plants. First, the hydrological conditions of a river can be affected by reductions in the peak flow and changes to the flow time; second, dams act as barriers to reduce the numbers of propagators moving downstream; and finally, dams reduce the downstream sediment transport and the areas of suitable habitats for propagules to germinate (Cubley et al, 2016), affecting the diversity of water-borne plants. In this study, the richness, Shannon-Wiener, Simpson, and Pielou indices of the herbs were significantly different among the various plots in the study area. This shows that the construction of dams has destroyed the continuity of the studied river, affected the continuous distribution of the riverbank vegetation, and changed the habitats, compositions and diversity of the riverbank plants downstream of the dams (Sun et al, 2014).

4.3 Relationships between environmental factors and plants in the affected areas of diversion power stations

Riparian plant species are selective to their growth sites, and the formation of plant communities is closely related to the surrounding environment. Riparian plants are also very sensitive to changes in the surrounding environmental factors, such as changes to the flood frequency and duration, soil type and microtopography and altitudinal changes of several meters or even several centimeters (Woo et al, 2018; Zhang et al, 2018). Relevant studies have proven that after the construction of a diversion power station, the annual runoff of the whole studied river section was reduced by 30% on average. In the reach downstream of a dam, the magnitude and frequency of the peak discharge are reduced by 30%. However, with increasing downstream distance, the peak flow returns to its natural value (Bejarano et al, 2013). Mature riparian vegetation will be formed after several decades if there is no large environmental impact (Ravot et al, 2019). However, riparian plants are affected not only by water diversion power stations but also by natural environmental factors and man-made environmental factors other than dams, which are difficult to separate (Rajbongsh et al, 2018; Słowik et al, 2018), and their combined influences often lead to the degradation of riparian plants (Musole et al, 2019).

According to the correlation analysis and RDA sequence diagram, the water depth of a river can promote plant diversity; an increase in water depth can improve the humidity of the surrounding environment, which is more suitable for plant growth. Generally, in mountainous rivers, a shallow water level will lead to an increase in the exposed surface of the rock bottom material. In addition, the accumulation of river garbage in the study area made it difficult for plant species to spread (Van et al, 2005). In this study, the Pielou index of water-spreading plants was significantly positively correlated with the flow rate ($P < 0.01$). The accumulation of more fine-grained soils in the calm river section than in the flowing river section lowers the hydraulic conductivity and makes plants near the water body enter the anoxic state more easily. In flowing river sections, the water turnover rate in highlands can serve to maintain optimal oxygenation of plant roots and reduce the negative effects associated with the oxygen content (Renofalt et al, 2007). Plant diversity in the study area was significantly negatively correlated with bamboo felling ($P<0.05$) because the local bamboo is felled directly along the mountain, which causes a decrease in the number and diversity of plant species (Li et al, 2012).

5 Conclusion

This study initially revealed the impacts of diversion power stations on the species composition, quantity changes and water-borne plant diversity of riparian plants. The main conclusions are as follows.

(1) There were significant differences observed in the changes in the herb, shrub and tree layers among all the plots in the study area ($P < 0.05$), indicating that the emergence of diversion power stations has an impact on riparian plants.

(2) The numbers of riparian plants differ among the areas affected by diversion power stations with varying numbers of operational years, and the species numbers of second-level and third-level power stations with longer operational years are larger than that of fourth-level power stations with shorter operational years, indicating that the short-term vegetation changes and long-term responses differ in the various riparian plant community successions.

(3) Water-borne plants were concentrated in the herb layer in the areas influenced the diversion power stations, indicating that the water-borne species community structure in the affected areas were singular, and the richness, Shannon Wiener, Simpson and Pielou indices of the herb layers in the study area were significantly different among different studied plots ($P < 0.05$), indicating that the diversion power stations had impacts on the diversity of water-borne plants.

(4) The emergence of diversion-type power stations has caused changes in environmental factors

in some river sections, among which the river depth and flow rate have great impacts on plant diversity.

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Data Availability Statement:

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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