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Short communication

The effect of winter impoundment of the Three Gorges Dam: The degradation and convergence of pre-upland vegetation

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ABSTRACT

It has been nearly five years since the Three Gorges Dam (TGD) became fully operational. After the large area of the water-level drawdown zone (WLDZ) created by the dam construction, several studies have investigated the effects of its impoundment on vegetation in this zone, but few have investigated any long-term changes in the WLDZ vegetation. In this study, we investigated changes in the vegetation in the WLDZ of 12 sites over a three year period following the dam's full start-up. We found that the number of plant species decreased significantly soon after the initial impoundment, with a similar trend in total cover of plant species. After one and three years of the dam being operational, the vegetation was found to contain many more species at higher occurrences at the 12 sites than those measured in pre-damming vegetation. Vegetation showed higher inter-site species similarities after three years than after one year, with a similar increase in similarities after one year compared to year zero.

1. Introduction

The regulation of river flow by building dams for hydroelectric power generation, irrigation and flood control has been a common phenomenon worldwide for centuries, but it has been intensified most in the last century (Mallik and Richardson, 2009). There are over 45,000 dams greater than 15-m high and more than 300 dams defined as "giant" according to one of three criteria on height (>150 m), dam volume (>15 million m^3) or reservoir storage (>25 km^3). The construction of dams has drastically changed water level regimes of the riverbank, with a dramatic impact on riparian vegetation. A number of studies have investigated the effects of dam-building on riparian vegetation (Nilsson et al., 1997; Shafroth et al., 2002; Uowolo et al., 2005), where flood duration and flood timings have been shown to be important factors affecting reservoir shoreline vegetation (Noble and Murphy, 1975; Nilsson and Keddy, 1988; Jansson et al., 2000).

The Three Gorges Dam (TGD) (111°00′14″E, 30°49′22″) on the Yangtze River is the largest "giant" dam built in China (Wu et al., 2004), being 181-m high and controlling over 660 km of the river's reach. The TGD impoundment is timed to occur over the winter period but lasts more than six months a year (Su et al., 2012). This type of submergence has been investigated in a few studies (New and Xie, 2008). Years after the TGD became operational, the reservoir shoreline vegetation appeared to be as lush as ever. However, the question remained as to whether the riparian vegetation was affected by the dam and indeed whether it might be undergoing non-visible degradation under such extreme episodes of winter submergence.

Although several studies have reported the short-term effects of the TGD on its shoreline vegetation (Wang et al., 2005; Sun et al., 2011; Wang et al., 2012), they did not explore longer term trends. We investigated three year period changes in vegetation along the reservoir shoreline to better understand the susceptibility of such vegetation to impoundment and to provide a baseline for riparian plant conservation and further studies.

2. Material and methods

Following the construction of the TGD, pre-upland vegetation along the riverbank was submerged as a result of substantial rises in the water level. Since 2006, annual impoundment of the Three

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Gorges Reservoir (TGR) has caused the water level to rise from 145 m ASL (above sea level, dead water level) in September to 156 m ASL (full bank water level) in November. This 156 m level is maintained for three months before returning to 145 m ASL again each May. This whole cycle was repeated annually till 2008, when the full bank water level was raised further to 173 m ASL in November and lowered to 145 m ASL in next May. Consequently, a water-level drawdown zone (WLDZ) spanning about 348 km^2, which is submerged for more than six months, exists along the reservoir bank. From September 2006 to September 2009, the reservoir shoreline was submerged up to 156–173 m ASL for one year and 145–156 m ASL for three years.

Our study was conducted at twelve sites located upstream of the TGD, which spanned from Wushan (109°52′E, 31°04′) to Fengdu County (107°43′E, 29°51′, Fig. 1). To ensure the comparability of the study sites, the survey was conducted on the same elevation intervals at these sites, namely in the 156–167 m ASL in October 2008, and 145–156 m ASL and 156–167 m ASL in September 2009, before the impoundment of the TGD. We re-visited exactly the same sites and transects in each investigation. Thus, we obtained baseline data for the terrestrial vegetation (156–167 m ASL transect, 2008, termed Year 0 in this study) along with data for the first and third year of submergence (156–167 m ASL transect and 145–156 m ASL transect, 2009, termed Year 1 and Year 3). We divided each transect into two equal sub-transects to facilitate the investigation. In each sub-transect, four 10 m × 10 m quadrats were set along a contour in each sub-transect with 30 m intervals for Year 0, where vegetation was dominated by woody species. Ten 3 m × 3 m quadrats were set along a contour in each sub-transect with 10 m intervals for Year 1 and Year 3, where vegetation was dominated by dwarf shrubs and grasses. In each quadrat, we recorded the name and estimated foliage projective cover of all individuals of each plant species except for moss. At the same time, we also recorded the life history stages of all species in each site.

We classified the recorded plant species into two life form groups, each covering a specific trait: (1) morphology: trees + shrubs, forbs + ferns and graminoids (2) life history: perennials, annuals + biennials. The total number of species and total cover (sum of all species' foliage projective cover in each quadrat) at each site were calculated. We also calculated the percentage cover for different groups of species (foliage projective cover of each group divided by total cover) at each investigated site. The analysis of between-year variations of vegetation was performed as follows: We compared mean number of species and mean total cover at each site (Mann–Whitney U test) and compared differences in the number (Bonferroni test) and percentage cover of each species group per site (Mann–Whitney U test) between years. Then, we tested differences in the Shannon–Wiener index between years ($H' = -\Sigma Pi \times \ln Pi$, Pi = abundance of the ith species divided by abundance of all species in each site, paired-samples t test). In addition, species that occurred in more than nine sites were listed. The presence and absence of species with >0.1% of the total cover at each site were used to describe the floristic similarity between years by using the detrended correspondence analysis (DCA) ordination. We used SPSS 13.0 for all statistical analyses except for the DCA by Canoco 4.5. The Shannon–Wiener index was calculated with R 3.0.0. All figures were made using Origin 8.0.

Table 1
Comparison of number of plant species and coverage of entire flora of each species group and Shannon-Wiener index at Year 0, 1 and 3.

	Year of submergence		
	Year 0	Year 1	Year 3
Number of species			
Total number of species	51 ± 2.91a	52.7 ± 3.48a	32.1 ± 3.12b
Morphology			
Trees + shrubs	22.7 ± 1.92a	10.8 ± 1.99b	3.6 ± 1.03c
Forbs + ferns	19.7 ± 1.90a	32.1 ± 2.21b	19.4 ± 2.33a
Graminoids	8.7 ± 1.05 ns	9.8 ± 1.00 ns	9.1 ± 0.81 ns
Life history			
Annuals + biennials	9.7 ± 1.58a	22.7 ± 1.59b	17.7 ± 0.99c
Perennials	41.3 ± 3.14a	30 ± 2.93b	14.4 ± 2.40c
Cover			
Total cover	202.6 ± 23.02a	101.7 ± 10.64b	72.0 ± 5.0c
Percentage cover %			
Morphology			
Trees + shrubs	51.5 ± 5.02a	14.2 ± 4.76b	3.4 ± 1.94c
Forbs + ferns	19.7 ± 4.11a	64.2 ± 3.39b	44.3 ± 4.98c
Graminoids	28.8 ± 3.23a	21.5 ± 3.50a	52.3 ± 4.93b
Life history			
Annuals + biennials	11.3 ± 2.02a	65.1 ± 4.85b	67.6 ± 5.56b
Perennials	88.7 ± 2.02a	34.9 ± 4.85b	32.4 ± 5.56b
Shannon–Wiener index	2.9 ± 0.14a	2.7 ± 0.13a	2.1 ± 0.10b

Note: Different letters in each row indicate significant differences, $P = 0.05$.

3. Results

The number of species and total cover per site decreased significantly ($P < 0.05$, Table 1) in the three years following the dam start-up. The number and percentage cover of tree and shrub

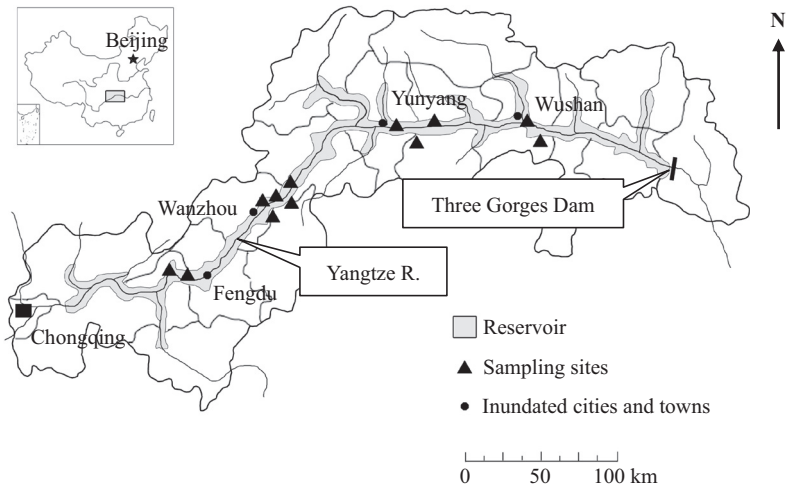

Fig. 1. Location of sampling sites in the Three Gorges Reservoir, China.