Feasibility Study on Six Kinds of Plants in Long-Term Submergence Conditions

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***Abstract* - Artificial vegetation in hydro-fluctuation belt of reservoir is the key to protect the ecological environment of this zone. In order to protect the ecological environment of water-level-fluctuating zone in Pubugou Hydropower Station, the author of this paper simulates the growing situations of 6 kinds of plants under the condition of long-term submergence. These are: i) Eleusine indica, ii) Polygonum amphibium L, iii) Hemarthria altissima, iv) Bermuda grass, v) Alternanthera philoxeroide and vi) Vetiveria zizanioides. The growth adaptability of these plants is evaluated. The results showed: 1a. After 64 days of submergence, the survival rates of Eleusine indica and Polygonum amphibium L are 30% and 0% respectively, 1b. After 240 days of submergence, the survival rates of Vetiveria zizanioides, Hemarthria altissima, Bermuda grass and Alternanthera philoxeroide are 65%, 60%, 75% and 25% respectively. 2. When completely submerged, Polygonum amphibium L, Hemarthria altissima, Vetiveria zizanioides and Bermuda grass all grow slowly, while Alternanthera philoxeroide can stretch its shoots rapidly. When subjected to 32d, 150d, 180d, 180d and 180d of full submergence respectively, Polygonum amphibium L, Alternanthera philoxeroide, Hemarthria altissima, Bermuda grass and Vetiveria zizanioides will resume growth very well by increasing the foliage mass and its height in order to acquire light and increase contact area to enhance Photosynthesis. It shows that the above 5 kinds of plants belong to submergence tolerant herbs and can try to grow separately in the elevation higher than 848m, 842m, 837m, 837m and 837m above water level in the hydro-fluctuation belt of reservoir in Pubugou Hydropower Station. Therefore, this study provides a spatio-temporal scientific basis for the ecological environment management in the hydro-fluctuation belt of reservoir in Pubugou Hydropower Station.**

Keywords - Hydro-fluctuation belt; Vegetation restoration; Adaptability; Suitable elevation; Pubugou Hydropower Station.

-I. INTRODUCTION

Hydro-fluctuation belt, also known as the fluctuation zone, is the zonal region of rivers, lakes and reservoirs, which is submerged and exposed to be a piece of land due to periodic water level fluctuation. Riparian vegetation has important effects on the stability of riverbanks, soil and water conservation, biodiversity and ecological balance maintenance. Therefore, selecting plants that can survive in the riparian zone is the key to ecological management of riparian zone [1-3]. In recent years, foreign researches have mainly focused on the change of riparian vegetation after the completion of the dam and the competitive ability of local species and invasive species, while domestic researches tend to concentrate on the adaptive plants in the natural riparian zone along the Yangtze River [4-5]. However, researches on the ecological management of hydro-fluctuation belt of reservoir in Pubugou Hydropower Station are rather less. Besides, after the impounding of Pubugou Hydropower Station, it will form a hydro-fluctuation belt with a drop of 60 meters, thus bringing serious environmental problems such as water pollution, soil erosion, sediment deposition, geological disasters and so on. Therefore, it is necessary to carry out corresponding researches on the ecological management according to the characteristics of this zone.

The construction of reservoir changes the natural laws of flood and drought in the riparian zone, making the duration of submergence in elevation of different heights above water level become different[6], but usually less than 4 months. Vetiveria zizanioides, a perennial herb with a very developed root system, has a strong ability to hold water and soil [7]. Polygonum amphibium L grows naturally in the shallow waters located at the edge of the lakes, ditches and wetlands. Eleusine indica has spikes of flowers, which is favorable to improve the quality of landscapes in reservoir[8-9]. However, Hemarthria altissima[10] and Bermuda grass [11] are distributed in riverbanks of low elevation that is close to the river surface; Alternanthera philoxeroide can adapt to the fluctuation of water level in reservoir to a certain extent[12], therefore, they are likely to survive longer-term submergence after the construction of reservoir.

By studying the survival conditions, underwater growth and recovery growth of 6 kinds of plants in hydro-fluctuation belt under the condition of submergence at different time, this paper aims to provide a scientific basis for the ecological restoration of the hydro-fluctuation belt of reservoir in Pubugou Hydropower Station.

1 II. MATERIALS AND METHODS

1.1 –A. Experimental Materials

TABLE I. EXPERIMENTAL MATERIALS

Chinese Name	Latin Name	Family	Genera	Category
Polygonum amphibium L [13]	*Polygonum amphibium L.*	Polygonaceae	Polygonum	Type I (naturally distributed in riverbanks of middle elevation)
Eleusine indica [14]	*Eleusine indica (L.) Gaertn*	Poaceae	Eleusine	
Vetiveria zizanioides [15]	*Vetiveria zizanioidesia zizanioides*	Poaceae	Vetiveria zizanioidesia	Type II(naturally distributed in riverbanks of low elevation)
Hemarthria altissima [16]	*Hemarthria altissima*	Poaceae	Vetiveria zizanioidesia	
Alternanthera philoxeroide [17]	*Alternanthera philoxeroide*	Amaranthaceae	Alternanthera	
Bermuda grass [18]	*Bermuda grass*	Poaceae	Cynodon	

1.2 –B. Experimental Design

(1)Research Objective: Study on the adaptability of 6 kinds of plants in the hydro-fluctuation belt of reservoir under the condition of long-term and full submergence.

(2)Research contents: Survival rate, plant height, average total length and average total number of branches (Average total length and average total number of branches of Type I plants are separately measured at T0 (the moment of coming out of the water), T1 (8 days after T0) and T2 (8 days after T1). Average total length and average total number of branches of Type II plants are separately measured at T0 (the moment of coming out of the water), T1 (10 days after T0) and T2 (20 days after T1)).

(3)Test time: Altogether 270 days from October 1, 2014 to June 28, 2015.

(4)Cultivation medium: humus soil: loam =1:4.

(5)Test place: Teaching and Research Base of Sichuan Agricultural University.

(6)Treatment methods (See Table 2).

TABLE 2 TREATMENT METHODS

Treatment Groups		Treatment Methods
Preparatory Phase	Experimental Group and Control Group	Seedlings of *Polygonum amphibium L* and *Eleusine indica* were collected from Pubugou reservoir in April, 2014. And eugenic suckering plants of similar size of *Polygonum amphibium L*, *Eleusine indica*, *Vetiveria zizanioides*, *Hemarthria altissima*, *Alternanthera philoxeroide* and *Bermuda grass* began to be cultivated in May of that year.
	Control group	Plants of control group were placed in the open space of experimental base, and were watered, weeded and managed routinely.
Experimental Phase	Experimental Group	Plants of submergence group were placed in a 2.5m high pool filled with water and were completely submerged. Among which, plants of type I were subjected to 16d, 32d, 48d and 64d submergence, while plants of type II were subjected to 30d, 60d, 90d, 120d, 150d, 180d, 210d and 240d submergence.

A part of tissue in plants under submergence will wither in the water, which is difficult to be collected. Therefore, the growth indexes of all plants studied in this paper are about the existing functional green tissue sections [19].

1.3 –C. Data Analysis

Experimental data, tables and figures in this paper are dealt with by SPSS 21.0, Matlab 2012a and Microsoft Excel 2010.

II. RESULTS AND DISCUSSION

A. Survival Rate

Survival rate is an important index to judge plants' ability of tolerance to submergence. And it is also an important criterion to judge the distribution of plants in the riparian zone. Besides, there is a significant correlation between the lowest water level for plants in riparian belt to distribute and their survival rates under the condition of submergence[20]. It could be caused by different intensity of submergence in different elevation of riparian zone in flood season. Results are showed in table 3 and table 4. According to table 3 and table 4, the survival rate of Polygonum amphibium L subjected to 16d and 32d submergence is higher; while Eleusine indica are all dead after 3 days of submergence. Vetiveria zizanioides, Hemarthria altissima and Bermuda grass have strong abilities of tolerance to submergence, so after 180 days of submergence, their survival rates have always remained above 80%; however, Alternanthera philoxeroide's ability of tolerance to submergence is relatively weak. After 90 days and 120 days of submergence, 2 out of 20 emersed plants are dead, and after 150 days of submergence, the survival rate drops to 60%.

TABLE 3 THE SURVIVAL RATE OF PLANTS (I)

Vegetation	Days of Submergence/d			
	16	32	48	64
Eleusine indica	0%	0%	0%	0%
Polygonum amphibium L	100%	80%	60%	30%

TABLE 4 THE SURVIVAL RATE OF PLANTS (II)

Vegetation	Days of Submergence/d							
	30	60	90	120	150	180	210	240
Hemarthria altissima	100%	100%	100%	100%	90%	90%	75%	60%
Bermuda grass	100%	100%	100%	100%	100%	90%	80%	75%
Vetiveria zizanioidesia zizanioides	100%	100%	100%	100%	100%	85%	75%	65%
Alternanthera philoxeroide	100%	100%	90%	90%	60%	50%	40%	25%

2.2 –B. Growth Response under Submerged Conditions

The results are shown in figure 1.

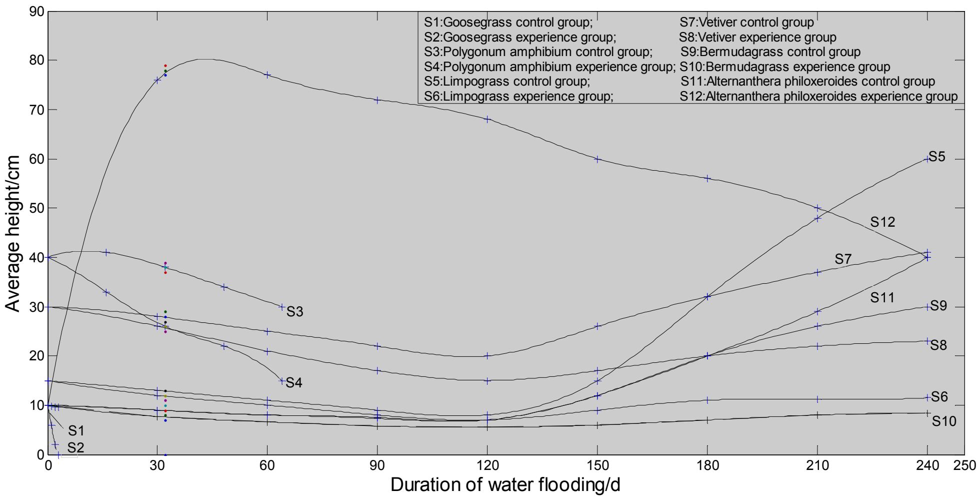


Fig. 1 The situation of growth

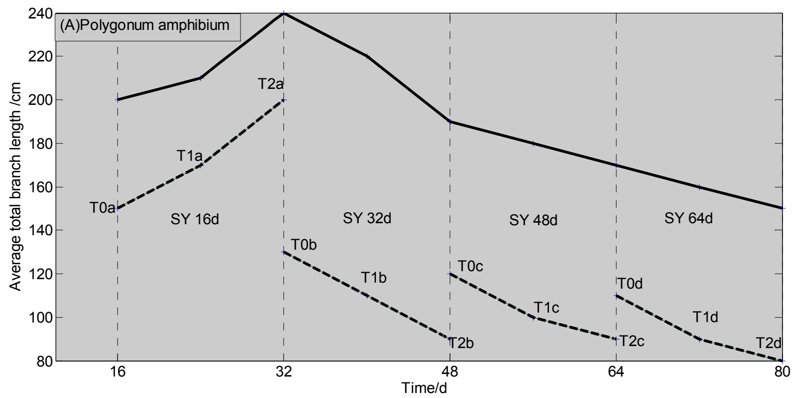
According to figure 1, for Polygonum amphibium L, the growth state of full submerged plants (S4) and control plants (S3) in the first 32 days is similar, while the negative growth rate of S4 is significantly higher than that of S3 after 32 to 64 days of submergence. Therefore, 32 days of submergence can be regarded as a critical point of growth condition. The height of Hemarthria altissima plants (S6) under submergence are lower than that of the control group (S5), the growth rate of S6 from 150d to 180d is positive, but always lower than that of control plants, so S6 began to recover but is lower than S5. At the same time, the height of S6 from 180d to 240d basically remains unchanged, but S5 grows rapidly. Therefore, 180 days of submergence can be regarded as a critical turning point in growth situation. When Vetiveria zizanioides is submerged from 150d to 180d, the growth rate of submerged plants (S8) may increase rapidly but they will grow slowly from 180d to 240d. But the control plants (S7) grows rapidly. And there is a significant difference between them. Therefore, 180 days of submergence can be regarded as a critical turning point in growth situation. However, there is little difference between negative growth rate of the submerged group (S10) and control group (S9) of Bermuda grass from 30 to 120 days. And the height of S10 gradually restores from 120d to 180d. S9 grows rapidly after 150 days of submergence (spring), but S10 grows relatively slow from 180d to 240d. Therefore, the critical turning point in growth situation is 180 days of submergence. Meanwhile, the elongation of Alternanthera philoxeroide experimental group (S12) grows rapidly from 0 to 30 days. What's more, their old leaves fall off rapidly and their new leaves grow quickly while the control group (S11) grows stably. During the period of 150d to 240d, the positive growth rate of S11 increases significantly, while the negative growth rate of S12 accelerates, so 150 days of submergence can be seen as a critical point in growth situation. S2 shows that Eleusine indica may not apply to the Hydro-fluctuation belt.

C. Recovery Growth

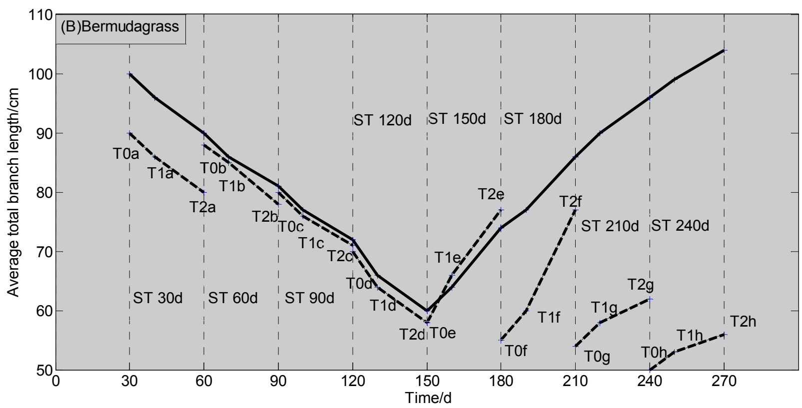
Due to the death of Eleusine indica after 3 days of submergence, the author only studies the recovery growth of Polygonum amphibium L, Bermuda grass, Alternanthera philoxeroide, Hemarthria altissima and Vetiveria zizanioides. At the same time, during the period between T0 and T2, if the recovery growth rate of submerged plants (the average total branch length or the slope of the curve of average total number) is greater than or equal to the control plants, the submerged plants are considered to recover well.

C.1 The Average Total Branch Length

The results are shown in figure 2. SY 16d, Recovery of submerged 16d (By analogy: SY xxd, Recovery of submerged xx d); T0、T1 and T2, The same meaning as the 1.2 experimental design; Similarly hereinafter.



(a)



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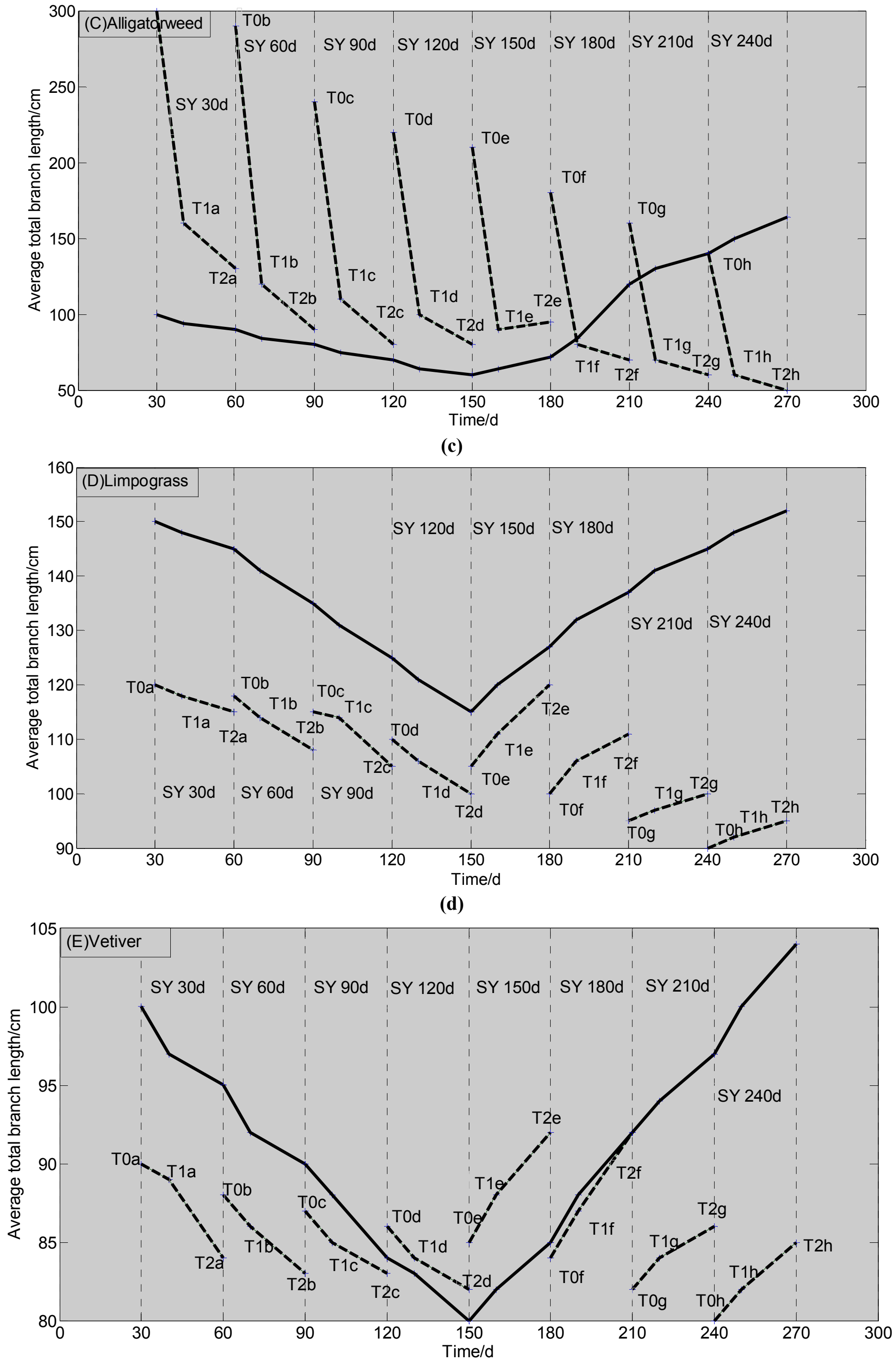


(c)

(d)

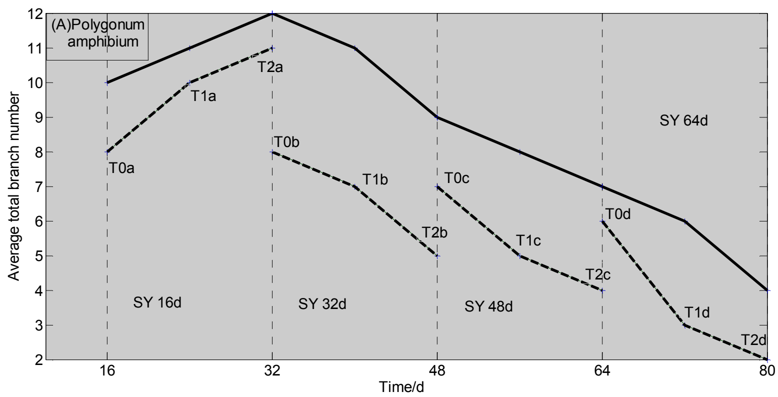
(e)

Fig.2 The average total branch length of five kinds of plants（—Control group、----Full submerged group）

According to figure 2 (the slope of T0 to T1 and T1 to T2 indicates the recovery growth rate of average total branch length (the same below)), when Polygonum amphibium L (Fig.2 A) withdraws from 32 days of submergence, the growth situation of experimental group is similar to that of control group; When Polygonum amphibium L is in the period from 48d to 80d, the negative effects of long-term submergence on it gradually increase. Therefore, 32 days of submergence can be regarded as a critical turning point in this recovery situation. After 150 days and 180 days of full submergence, Bermuda grass' s (Fig. 2 B) recovery growth rate of the average total length of branches is significantly higher than that of the control plants, and grows even faster than the control group. After 210 days and 240 days of full submergence, the recovery growth rate of the submerged group decreases gradually and is remarkably lower than the normal growth rate of the control group, which means that 180 days of submergence can be seen as a critical turning point in this recovery situation. Most of the average total branch length of submerged Alternanthera philoxeroide (Fig. 2 C) decreases in a remarkable way from the time of T0 to that of T2. This is mainly because the newly formed branch of plants under water can not adapt to the aerobic environment and a large number of them dies when coming out. However, the recovery growth rate of the plants submerged for 150 days from T1 to T2 is higher than that of the control plants, which shows that the Alternanthera philoxeroide can start to resume growth quickly. But after long-term submergence of 180d, 210d and 240d, the negative recovery growth rates of the average total branch length of Alternanthera philoxeroide all increase. Therefore, 150 days of submergence is a critical turning point in this recovery situation. After 150 days and 180 days of submergence, the relative recovery growth rate of the average total branch length of Hemarthria altissima (Fig.2 D) is higher than that of the control group. But the negative impacts of prolonged wet stress (after 210 days and 240 days of submergence) on the recovery growth of Hemarthria altissima gradually become significant. Therefore, 180 days of submergence can be regarded as a critical point in recovery. The recovery situation of Vetiveria zizanioides (Fig. 2 E) is even better that that of the control group 180 days after withdrawing from submergence. When the recovery rate of the submerged group after 210 days of submergence is compared with that after 240 days of submergence, 180 days of submergence can be seen as a critical turning point of the recovery situation.

C.2 The Average Total Branch Number

The results are shown in figure 3.



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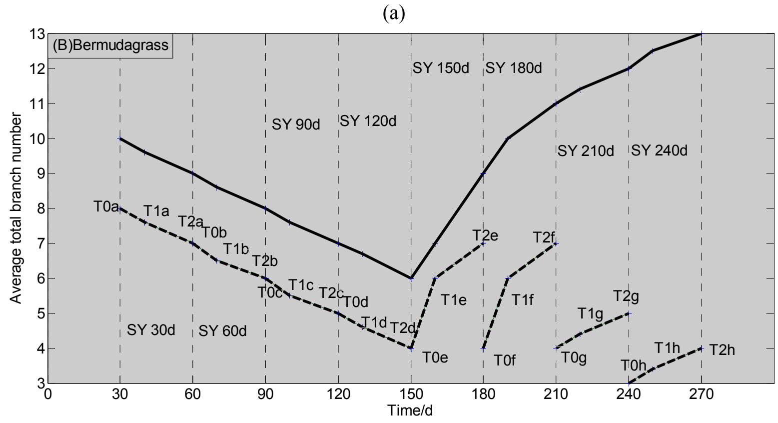

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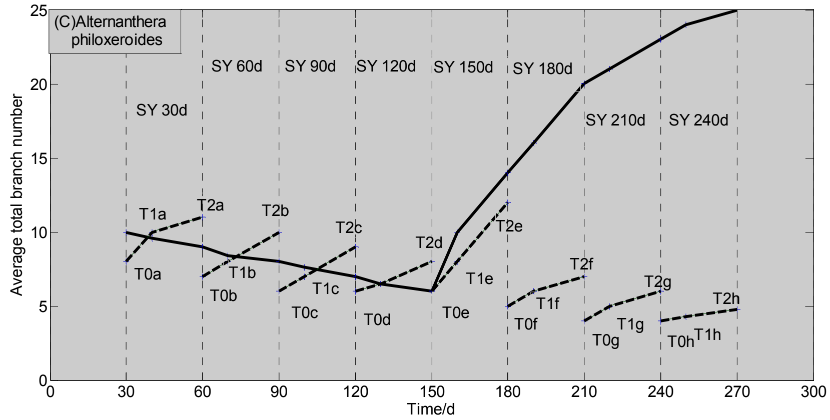

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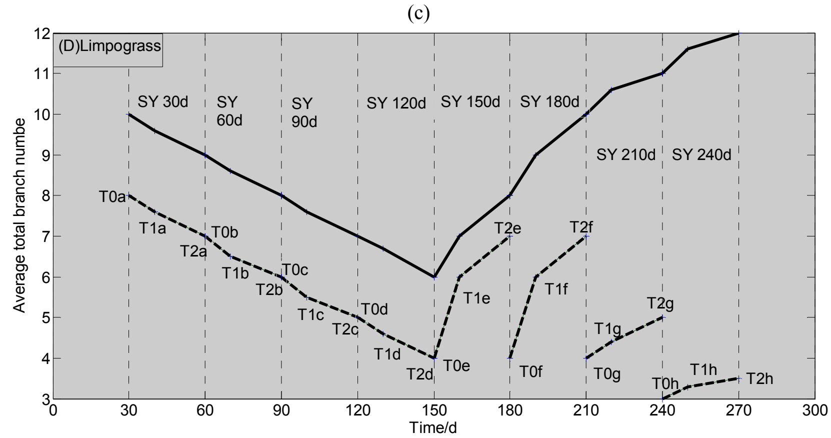

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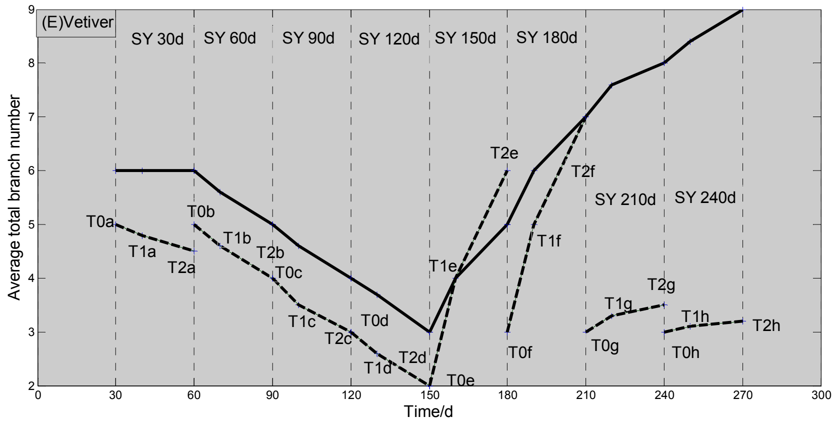

(e)

Fig.3 The average total branch number of five kinds of plants（—Control group、----Full submerged group）

According to figure 3, the recovery growth rate of the average total branch number of Polygonum amphibium L (Fig.3 A) is similar to that of the control plants at the moment of 16 days and 32 days of submergence. The negative growth rate of the average total branch number for the submerged group is higher than that of the control plants after 48 days and 64 days of submergence. So it's bad for the growth of Polygonum amphibium L to be completely submerged for 48 days and 64 days. There are no significant differences between the positive growth rate of the average total branch number of submerged Bermuda grass(Fig. 3 B) and that of the control group after 150 days and 180 days of submergence. Meantime, it can be observed in the experimental process that submerged plants of Bermuda grass can grow leaves rapidly when coming out of water, and the growth rate is even higher than that of the control plants but is lower than that of the control plants after a long-term submergence (210d and 240d).

From the moment of T0 (just out of the water) to T2, the average total number of branches and leaves of submerged Alternanthera philoxeroide (Fig. 3 C) shows a significant increasing trend. It has enhanced photosynthesis in order to compensate the consuming organics when plants grow rapidly under water. The recovery growth rate of the average total number of branches of the submerged plants is even higher than that of the control plants after being submerged from 30 days to 150 days, but is relatively lower than that of the control plants after 180d, 210d and 240d of submergence. The relative recovery growth rate of the average total number of branches of Hemarthria altissima (Fig.3 D) is significantly higher than that of the control plants after 150 days and 180 days of submergence, but gradually becomes lower than that of the control group after 210 days and 240 days of submergence. Meanwhile, the average total branch length and average total branch number of the submerged Hemarthria altissima plants are significantly lower than those of the control group at the moment of coming out of water (T0) but decrease gradually at the moment of all previous T0. The relative recovery growth rate of the submerged Vetiveria zizanioides (Fig. 3 F) is higher than that of the control plants after 150 days and 180 days of submergence, and is positive when the plants were submerged for 210 days and 240 days, but lower than that of control plants. Besides, the rate of reduction is accelerated with the extension of submerging time.

What's more, when plants are submerged, the floating mud, the dissolved substances and the phytoplankton in the water all play an important role in reducing the light penetration into the water. Besides, the whole submerging treatment will lower the water temperature, thus leading to the decrease of photosynthetic rate and plants' nutritional reserves. In summary, the longest underwater ideal time of Polygonum amphibium L, Alternanthera philoxeroide, Bermuda grass, Vetiveria zizanioides and Hemarthria altissima are 32d, 150d, 180d, 180d and 180d respectively.

D. Suitable Elevation of Plants

Seasonal fluctuation of water level is often the limiting factor to limit the growth of plants in hydro-fluctuation belt. The water level of hydro-fluctuation belt in reservoir rises sharply in October. Therefore, the study on plants' ability of tolerance to submergence and the duration of submergence in this zone should start from October [21]. And it is practical to use the survival rate, growth response and recovery growth of plants to explore the longest survival time and suitable elevation. The suitable height range of plants (See table 6) can be estimated by using the vertical distribution of soil in Pubugou Hydropower Station (See table 5) and the variation of water level in Pubugou reservoir (Fig.4)

TABLE 5 VERTICAL DISTRIBUTION OF SOIL IN PUBUGOU HYDROPOWER STATION（TAKING THE WET YEAR FOR EXAMPLE)

Elevation	>850m	845～850m	841～845m	835～841m	821～835m	790～821m
Land existing way	L	W	W	W	W	W
Submerged time	0	Nov-Jan	Oct - Jan	Jun-Jan	Jun-Mar	Jun-Apr
Land time	1～12 month	2～10 month	2～9 month	2～5 month	4～5 month	1 month
Available time	360d	270d	240d	120d	80d	<60d

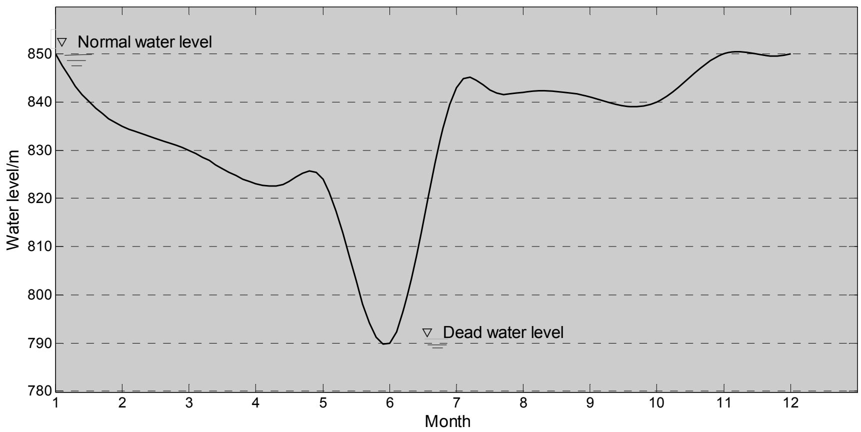

Fig.4 Water-head change of the high flow year in Pubugou reservoir

TABLE 6. THE SURVIVAL TIME AND SUITABLE ELEVATION OF PLANTS

Vegetation	Longest underwater time/d	Suitable elevation range/m
Polygonum amphibium L	32	>848
Alternanthera philoxeroide	150	>842
Bermuda grass	180	>837
Hemarthria altissima	180	>837
Vetiveria zizanioides	180	>837

III. CONCLUSIONS

(1) Survival rate is an important index to judge plants' ability of tolerance to submergence. This paper confirms that Eleusine indica is not suitable to grow in the hydro-fluctuation belt; Survival rate of Polygonum amphibium L submerged for 32 days is 80%, and survival rate of Alternanthera philoxeroide submerged for 150 days is as high as 90%; The survival rates of Vetiveria zizanioides, Hemarthria altissima and Bermuda grass submerged for up to 180 days are 85%, 90% and 100% respectively, which means that they have strong abilities of tolerance to submergence.

(2)Alternanthera philoxeroide gets rid of submergence quickly by stretching its shoots rapidly with a consumption of large amounts of nutrients; but Bermuda grass, Hemarthria altissima, Polygonum amphibium L and Vetiveria zizanioides stay in "stagnation" in order to preserve nutrients to maintain survival. And when coming out of water, they increase their branches and leaves to speed up photosynthesis to restore growth. The recovery effects of Polygonum amphibium L, Alternanthera philoxeroide, Bermuda grass, Hemarthria altissima and Vetiveria zizanioides are good within the submergence period of 32d, 150d, 180d, 180d and 180d respectively.

(3) This study shows that Polygonum amphibium L, Alternanthera philoxeroide, Bermuda grass, Vetiveria zizanioides and Hemarthria altissima can try to survive at the elevation higher than 848m, 842 m, 837m, 837m and 837m respectively in hydro-fluctuation belt of reservoir in Pubugou Hydropower Station. This conclusion provides a spatio-temporal scientific basis for the ecological environment management in the hydro-fluctuation belt of reservoir in Pubugou Hydropower Station.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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