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Revegetation Strategies for Water-Level Fluctuation Zone of the Three Gorges Reservoir Region*

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Abstract: After the full functioning of the Three Gorges Dam (TGD), the hydrologic regime will be markedly changed and most of the pre-dam vegetation in the new Water-Level Fluctuation Zone (WLFZ) may fail to persist. How to revegetate WLFZ of the Three Gorges Reservoir Region (TGRR) has become a hot topic for the scientific community and the governments. Based on review of scientific literature and the findings of our research, we here bring forward a scheme addressing strategies for revegetation of WLFZ of TGRR. Firstly, monitor vegetation dynamics based on permanent plots along the Three Gorges upstream from TGD, potentially providing suitable plants for the future revegetation plans. Secondly, examine the potential of soil seed bank for revegetation of the above-ground vegetation, and evaluate self-regeneration of the post-dam vegetation. Based on these data, select suitable plants for revegetation that integrate desirable physiological and life-history traits. Specifically, wetland vegetation could be constructed with lotus (*Nelumbo nucifera*) and aquatic plants. For sites with gentle terrain and fairly hospitable soil conditions, vertical planting of trees, shrubs and grasses/forbs along the elevation gradient could be considered. To attain the sustainable vegetation cover, the newly artificial vegetation should be monitored for at least 5 years.

Key words: water-level fluctuation zone; rehabilitation; restoration ecology; Three Gorges Reservoir
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After the first stage impoundment of the TGR to 135 m (2003), the second stage impoundment to 156 m (2006), the experimental impoundment in 2008 (172.8 m) and 2009 (171.4 m), on October 26th of 2010 the water level behind the Three Gorges Dam (TGD hereafter) reached 175 m for the first time, indicating the full functioning of the Three Gorges Reservoir. The water level now fluctuates from 145 m (during the flood season) to 175 m (during the non-flood season), which has created a new Water-Level Fluctuation Zone (WLFZ hereafter) between the highest and lowest water level, with a difference in surface-water elevation of 30 m creating a total drawdown area of about 300 km^2[1].

There were fertile pre-dam cultivated fields and forest lands, or towns, docks and other populated areas, which have been changed into areas seasonally flooded. In artificial wetlands created after impoundment by the TGD, former terrestrial plants cannot persist due to their lack of adaptation to flooding. The WLFZ has become one of the most significant environmental concerns of both central and local governments because of its vast area and outstanding ecological and environmental issues, as well as its strong impacts on the long-term and normal functioning of the TGD, water quality of the Yangtze River, and the production and life of residents in the Three Gorges Reservoir Region (TGRR hereafter).

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Vegetation in the drawdown zones of reservoirs enhances the productivity of the riparian zone, provides physical structures and biological elements for wildlife habitats, and has aesthetic values[2]. Due to the flood-season reversal and prolonged duration of flooding, the new drawdown zone will dramatically change the environmental conditions of the riparian zone[3], which is expected to negatively influence biodiversity, water quality and human utilization of the area. Revegetation is one of the effective measures for improving the adaptation of drawdown zone ecosystems[4]. Conducting research on rehabilitation to protect the ecological environment of the TGRR is therefore significant. Based on review of scientific literature concerning revegetation of reservoir drawdown zones, we here bring forward rehabilitation strategies for the drawdown zone of the TGRR and provide theoretical support for revegetation projects in this area.

1 Revegetation Strategies for the WLFZ of TGRR

As important types of ecotones, WLFZ of reservoirs are markedly different from those of natural rivers. Vegetation inhabiting the littoral (riparian) zones of natural rivers has resulted from long periods of adaptation and evolution. How long it will take to revegetate the WLFZ of the TGRR remains unclear. Thus, we have developed an overall outline concerning rehabilitation of the WLFZ of the TGRR (Fig. 1).

2 Vegetation Dynamics in WLFZ of TGRR

Research on impacts of the hydrological regime on the drawdown zone vegetation of reservoirs has a long history since successful revegetation needs understanding of the influences of water level fluctuation on local vegetation, diversity, and function[5]. With this information, specific technical notes can be integrated and developed for reservoir managers[4]. As for the TGRR itself, impacts of impoundment on local plants and vegetation in the WLFZ were first studied by Chen et al[6], and Jiang et al[7] examined the patterns of riparian vegetation in relation to elevation. Wang et al[8-9] and Bai et al[10] predicted the vegetation below 175m elevation after the creation of the TGD based on existing natural WLFZ vegetation. However, there will be a markedly different WLFZ after the TGD has become fully functional.

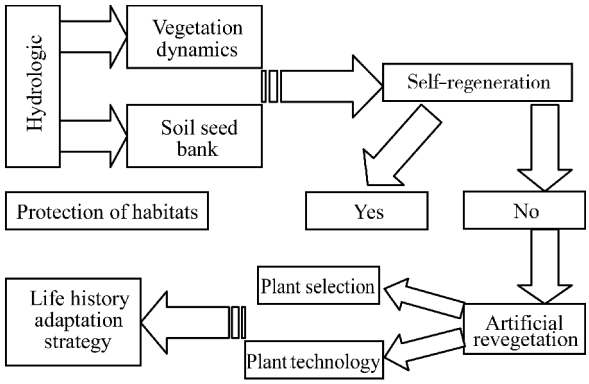

Fig. 1 Revegetation strategies of Water-Level Fluctuation Zone of Three Gorges Reservoir Region

Topography, species composition, and anthropogenic disturbance should be considered when examining vegetation dynamics[11]. Judging from data collected from 12 monitoring sites we established along the main channel of the Yangtze River from Banan to Zigui upstream of TGD, impoundment has significantly changed species composition and diversity of the pre-dam drawdown zone vegetation, but has had no significant influence on annual plant richness and biomass of the herbaceous layer[12]. Vegetation below 175m will be dominated by annuals, which has been confirmed by the findings of Wang et al[13], Sun et al[14], Liu et al[15] and Wang et al[16].

There is a distinct differentiation of vegetation along the Three Gorges section of the river valley, featuring a change in the longitudinal gradient at Fengjie as well variation in community composition with elevation. However, regarding the drawdown zone vegetation in the TGRR, there was no significant difference either on the longitudinal gradient of the gorges or the elevation gradient (145 ~ 156 m, 156 ~ 165 m, 165 ~ 175 m) [12].

When selecting suitable plants for rehabilitation of the reservoir WLFZ, plant physiology, morphology, and especially life history adaptation strategies should be considered. Persistent grasses/forbs and shrubs at elevations lower than 156 m can be used as optional plants for rehabilitation of WLFZ of TGRR[12].

3 Natural Recovery Potential of draw-Down Zone Vegetation in TGRR

The soil seed bank is an important source of propagules for natural revegetation and may play an important role during the course of rehabilitation of WLFZ in TGRR. To evaluate the potential of the soil seed bank to develop standing vegetation, we collected 45 soil samples from four sites (Changshou, Zhongxian, Wushan and Zigui) along the main channel of the Yangtze River upstream from the TGD and found the soil seed bank was dominated by annuals which had low similarity to the above-ground vegetation, indicating it is difficult for some non-annual plants to regenerate via the soil seed bank[17]. This was confirmed by the findings of Wang et al[18]. However, the soil seed bank should still be taken into account with regard to vegetation management in TGRR.

4 Plant Selection for Drawdown Zone Revegetation of TGRR

4.1 Physiological adaptation

Selecting plants that are adapted to long-term, complete and deep submergence is the first strategy for plant selection for WLFZ revegetation in TGRR. Ecophysiology is the main field of interest at present, such as studying photosynthesis during submergence[21], and high content of non-structural carbohydrates[22]. Simulating flooding effects on common perennials (*Paspalum distichum*, *Cynodon dactylon and Hemarthria altissima*) revealed their strong submergence resistance and suitability for WLFZ revegetation, while also showing that they got over the long-term and complete submergence by means of different strategies[23].

4.2 Life history strategy

There have been fewer studies of plant selection based on life history than those concerning physiology and morphology, and the potential of annuals that can complete their life cycle between drawdown and re-impoundment has been underestimated[12]. Nevertheless, Little and Jones[24] suggested herbaceous plants be used in drawdown zone revegetation. According to germination performance under storage and submergence conditions, plants suitable to revegetate WLFZ of TGRR are *Echinochloa crusgalli*, *Xanthium sibiricum*, *Amaranthus paniculatus*, *Aeschynomene indica*, *Amaranthus* sp., *Artemisia annua*, *Eclipta prostrata*, *Bidens bipinnata*, *Polygonum hydropiper*, and *Amaranthus viridis*[25-28].

5 Artificial Revegetation of WLFZ of TGRR

In a study of the WLFZ of Kinbasket Reservoir, Carr and Moody[29] found that the limiting factor for revegetation was not water level fluctuation but the initial plants which can be established through artificial planting. Successful species selections for revegetation have been realized in Oregon (USA) reservoirs, Upper Arrow and Ontojfirvi lake, and some reservoirs of B. C. Hydro in Canada. Bald cypress, Salix and Carex had the best performance indicating their adaptation to habitats that are strongly disturbed by water level fluctuation. The revegetation plan has to last at least 5 yr to facilitate the self-sustaining restoration of vegetation cover. To select suitable plants and planting model for revegetation of WLFZ of TGRR, we have established the artificial rehabilitation experiment and demonstration base in Zhong County, Chongqing, China.

5.1 Structuring wetland vegetation with aquatic plants

Before the impoundment of the TGR, there were a lot of paddy fields in the potential drawdown zone. After pre-treatments, it is feasible to establish wetland vegetation with aquatic plants in this region. The phenology of *Nelumbo nucifera* (lotus) is consistent with the hydrological regime of TGRR, and its root acts as a storage organ. Water lily grows sufficiently in the summer, flowering, fruiting, beautifying the landscape, accomplishing its life history and then gets over the winter with high water level with storage root stocks. Furthermore, it can protect water and soil, deplete soil nutrition and decrease the release of nutrition elements to the reservoir. Lotus seed also has economical benefits and can bring profits to local farmers. This model can be applied to establish wetland vegetation in WLFZ of TGRR[30-31].

5.2 Vertical planting with trees, shrubs and herbs to revegetate the drawdown zone

Bao et al[32] suggested enhancing the ecological function of the drawdown zone and protecting water and soil by using self-locking concrete modules in which *H.*

altissima, *C. dactylon* and *F. tikoua* can be planted. However, at lower elevation with, woody plants may not survive the flooding while at higher elevation, the aim of water and soil protection cannot be well attained by growing herbs. Thus, we put forward a planting model with plants having different growth form, life history, and adaptation strategies along the elevation gradient; a vertical settlement pattern to rehabilitate the drawdown zone of TGRR.

We proposed a model consisting of three annuals: *Setaria viridis*, *Digitaria ciliaris* and *Leptochloa chinensis*; three perennials: *C. dactylon*, *H. altissima*, *P. distichum*; three shrubs: *Araucaria cunninghamii*, *Morus alba* and *Salix variegata*; and three trees: *Salix chaenomeloides*, *Taxodium ascenden* and *Taxodium distichum* as planting materials. Along the elevation gradient, from lower to higher (145 to 175 m), in turn, there will be annuals, perennials, shrubs and trees[33].

6 Future Directions

Revegetation of the drawdown zone of TGRR is a formidable and challenging job. Research groups from universities, scientific institutions and governments have launched rehabilitation projects along the main channel and tributaries. However, most of the research effort has so far been short-term, and long-term (at least 5 year) on-site monitoring on the artificial vegetation needs to be carried out to evaluate the feasibility of plant species and planting model selections. During the course of evaluation, besides ecological and social benefits, economic benefits also need to be taken into account for achieving the goals of sustainable development.

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