Three-Gorge Dam influences wetland macrophytes in middle and lower reaches of Yangtze*

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Abstract Dongting Lake, located in the middle and lower reaches of Yangtze, is regarded as a lake during the water swelling period and a continent in the ebbing period. The construction of the Three-Gorge Dam has influenced the water level of Dongting Lake and the growth of wetland macrophytes in the area. In this study, the growth of main species of wetland macrophytes, such as Carex and Phragmites at Dongting Lake, was observed, and the hydraulic gradient, one of the main factors dominating the abundance and distribution of wetland macrophytes, was also studied at six stations in Dongting Lake area and the effect of the Three-Gorge Dam construction on the growth of wetland macrophytes was observed.

Keywords: Three-Gorge Dam, Dongting Lake, wetland macrophytes, hydraulic gradient.

Dongting Lake, located in the central south of China, spans Hubei and Hunan provinces and lies in the middle and lower reaches of Yangtze River. It is an important natural reservoir of Yangtze, and its lakefront wetland is one of special freshwater wetlands in China. It is regarded as a lake during the swelling period and a continent in the ebbing period. Water level of Dongting Lake fluctuates from seasonal to daily, and it has changed with the operation of Three-Gorge Dam[1], along with the changes of its wetland macrophytes. Plant resource is one of the indicators for the state of the whole ecosystem[2], and water regime, as distinct from instantaneously measured water depth, has been implicated in affecting the distribution of macrophyte communities[3—5]. To study the impact of Three-Gorge Dam on the plants in middle and lower reaches of Yangtze, we observed the changes of hydraulic gradient affecting the abundance and distribution of wetland macrophytes in Dongting Lake area (Fig. 1) and these changes in dry and flood seasons were analyzed with the data of 2004.

1 Three-Gorge Dam Project

Yangtze River is the longest river in China and an impressing physical feature of Asia. It spans more than 6300 km from west to east and covers a total drainage area of 18×10^5 km^2 which is almost one fifth of the whole country. With many famous agricultural bases (e.g. the Jianghan plain, Dongting zone, the Yangtze delta, etc.) for rice, cotton and vegetable oil, the middle and lower reaches of the Yangtze River basin have been associated with rapid economic development. However, the frequent flooding events have been threatening the development of this region and even that of the whole China. Previously, the plains at the middle and lower reaches depended on various dikes to counteract flood. Unfortunately, this measure was not successful, and there have been many flood disasters associated with huge floodwater quantity and high-frequency occurrence and wide-area influences. In order to effectively counteract the flood disasters in this region, many researchers and experts have put forth various measures, including the construction of integrated water projects to combat flood radically and make full use of the water resources of the Yangtze River.

The Three-Gorge Dam Project is a well-known integrated water project lying at the Three-Gorge reach of the Yangtze River, which begins at Baidi

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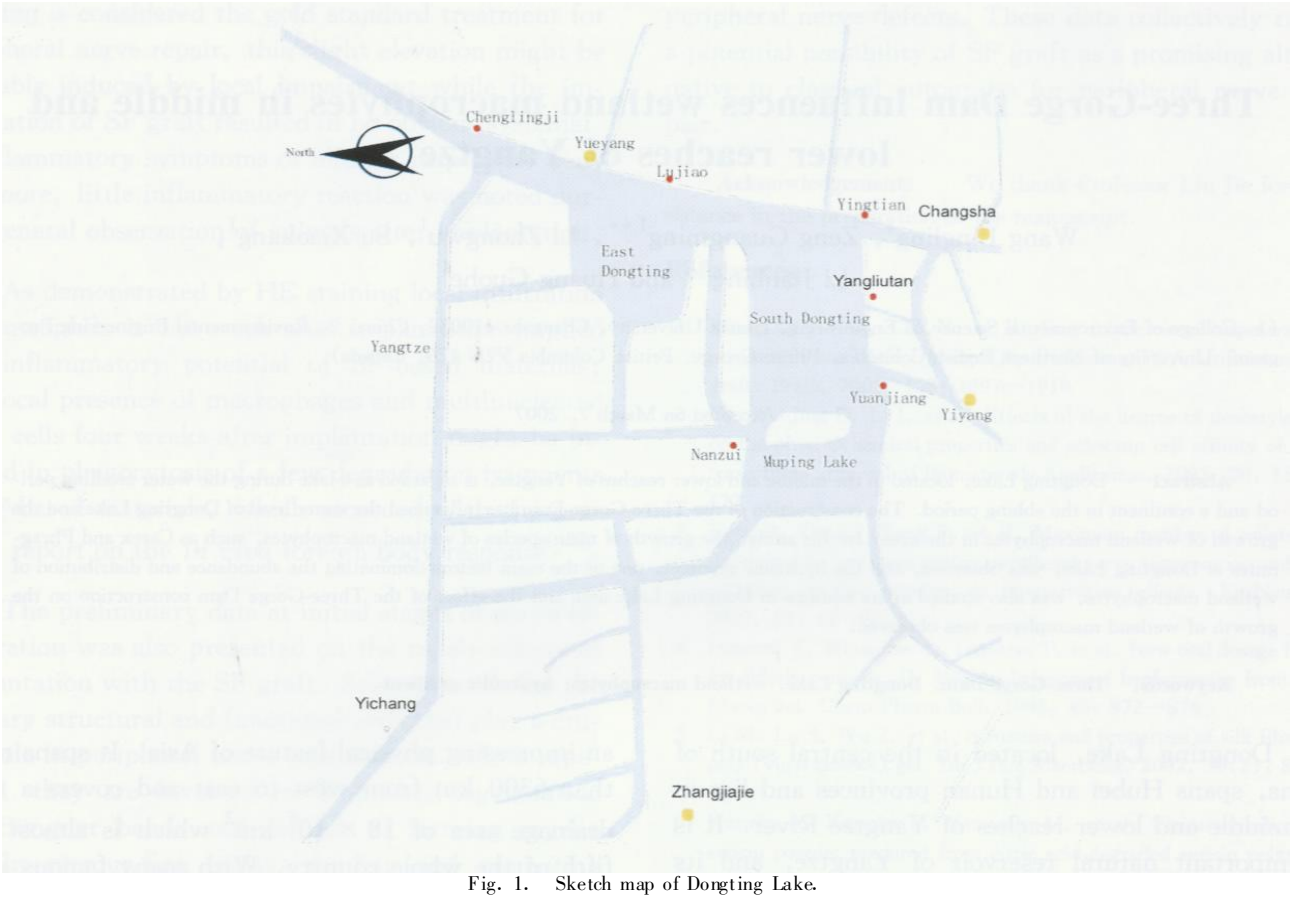

Fig. 1. Sketch map of Dongting Lake.

Town of Fengjie County in Sichuan Province and ends at Nanjin Guan of Yichang in Hubei Province and is about 200 km long. Because of its size and special location, the project is one of key determinants to control the social, environmental and economic development of the middle- and lower-reach regions of Yangtze basin. After the completion of the Yangtze Three-Gorge reservoir, its natural and limiting water levels to prevent flood will be 175 m and 145 m, respectively. Its lowest water level in dry reasons will be 155 m, and its design water level will be 175 m in order to combat the flood with a return period of 1000 year such as that in 1998.

2 Wetland macrophytes at Dongting Lake

Dongting Lake is located in the north of Hunan Province and the south reach of Jin River at the middle and lower reach of the Yangtze River. It consists of South Dongting Lake, East Dongting Lake and West Dongting Lake. It is a typical regulative and throughput lake, and its water level variation is smaller than that of a river. The lake is connected with a number of tributary streams, including Miluo River, Xinqiang River, Xiangyang River, and four other big streams such as Xiangjiang, Zijiang, Yuanshui and Lishui Rivers at its west, south and east, respectively. On the north side of Dongting Lake, there are three famous diversion openings which discharge Yangtze River water into the lake, named Songci, Ouchi and Taiping. There is only one diversion opening named Chenglingji which discharges the lake water into the Yangtze River. Dongting Lake contains about 1.78×10^{10} m^3 of water, covering a water area of 2700 km^2 and a total drainage area of 26.28×10^4 km^2 which is almost 14 percent of Yangtze basin[6].

2.1 Communities of Dongting Lake wetland

The wetland aquatic vegetation plays an important role in maintaining ecological balance and restoring the ecosystem function. These plants provide and maintain habitats for aquatic animals and form an ecological buffer belt of the lakefront from water, which significantly alleviates water pollution from tributary streams. The sufficient lakefront plant coverage would change the lake flow pattern, resulting in various impacts on flood routing, purification of wetland and riverbed, and on the basin physiognomy.

There are four types of vegetation and 43 communities at the lakefront around Dongting Lake[7—9], including 6 communities of woody plant consisting of the flooding-tolerant communities, 13 paludified meadow communities consisting of flooding-tolerant and waterlogging-tolerant grass community and Carex community with strong bourgeoning ability[10], and 327 genuses of wetland plants with most of which being herbaceous[11—14], with about 254 genuses of seasonal flooding-tolerant paludose plants and hygrophyte plants, and with 18 genuses of mid-hygrophyte plants[15].

2.2 Distribution of wetland macrophytes

In 2000, the wetland area of Dongting Lake was about 1400 km^2, mainly consisting of the shoal of lake grass and the shoal of Phragmites (including *Miscanthus sinensis* and Phragmites community), which account for 883.6 km^2 and 678.8 km^2, respectively. The shoal of white mud is 30.96 km^2[15]. Horizontally, *Phragmites communis* exists mainly in the west Dongting Lake, and *Carex dispalata* is mostly occurring in the south and east Dongting Lake. Vertically, the white mud shoal is filled up below the low shoal by bedload; *Phragmites communis* exists near rivers and is significantly filled up below the high shoal by flood bedload. Most of the lake-grass shoals lay at above the low-middle shoal where the hypsography is rather low and even, while the shoal is not extremely filled up by bedload.

2.3 Growth characteristics of main wetland macrophytes

As mentioned above it is known that carex and phragmites are the main plants at the Dongting Lake, thus they were selected as study plants in this investigation. The carex is of four growing phases: (a) from the end of February to early March, these meadows begin to germinate; (b) during the following months, from March to April and even to the first ten days of May at east Dongting, the carex matures, flowers and turns into the procreating period; (c) the shoals are filled with water and the whole carex meadows are also flooded from the last ten days of April to the middle ten days of May, and (d) by the end of September or in early October, flood ebbs and these meadows are revealed and matured again[15].

Due to the effects of many factors (including different zones, climate, water quality, clay, etc.), the phragmites are associated with lots of regional variations and different wetland ecological variations[16, 17]. For example, the Yueyang phragmites, which normally is 3—4 m high, common at Dongting Lake[18]; such plants always live at high shoals which are above an altitude of 26 m, or at shallows of lake inside; their seeds germinate about in the middle ten days of February; the plant flowers during July to September, produce seeds in October and then begin to damp off and turn to be yellow[19].

2.4 Living hydrological conditions of wetland macrophytes

The wetland aquatic vegetations are often affected by hydrological conditions[20—22]. Water-level fluctuations are known to contribute to the abundance and distribution of aquatic vegetation in lake wetlands by keeping the wetlands in a perpetual state of disturbance, and preventing them from becoming dry fields or lean soil[23]. While in flood seasons their haulms will be broken off and even the root will be eroded. The productivity of hydrostatic wetland or consecutive deep-water wetland is very low, although the flowing condition may improve the primary productivity of wetland and promote the circulation and utilization of nutrient in some extent. However, rather low water level cannot guarantee the healthy growth of carex and phragmites, while some insect pests may often result in the degeneration of these emergent vegetations[2, 24]. The degeneration is significant in areas where hypsography is higher and is more easily influenced by the change of water quantity. The living stability of wetland macrophytes mainly depends on the stability of the water regime.

3 Hydraulic gradient

A number of papers have been published that document the effect of hydraulic gradient on nutrition transfer and water balance in ecosystem[25, 26]. However, investigators have rarely accounted for the direct and indirect effects of hydraulic gradient on abundance and distribution of aquatic vegetation in lake wetlands. In wetland habitat, the water condition, including the depth and fluctuation of water level, is one leading factor affecting the composition and distribution of wetland macrophytes[27]. Since these plants adapt to the special environment chronically, their responses to the hydraulic gradient are of differ-

ent characteristics[28]. In this study the hydraulic gradient is selected to analyze the effect of the Three-Gorge Dam project on the wetland macrophytes of Dongting Lake.

The hydraulic gradient describes the changes of water level at two spots, and is expressed by the following function:

$$i = \frac{\Delta h}{l} \tag{1}$$

where i is the hydraulic gradient without any unit, Δh the hydraulic head difference between two specific spots, l the distance between them, and the unit of Δh and l is in meter.

So far only a few papers have reported the relationships between macrophytes and the hydraulic gradient. The effect of hydrological condition (mainly characterized by hydraulic gradient) on wetland macrophytes of Dongting Lake before and after operation of the Three-Gorge Dam Project, is discussed here. Based on Eq. (1), it is known that higher dispersion of water levels at two spots would result in higher hydraulic gradient. Since higher or lower water level does harm to the plant growth, the greater change of hydraulic gradient is also harmful. Thus such changes should be controlled in a proper range.

4 Effect of the Three-Gorge Dam on wetland macrophytes at Dongting Lake

4.1 Change of hydraulic gradient at Dongting Lake after operation of the Three-Gorge Dam

Among the spots around Dongting Lake, Chenglingji is the nearest to the Three Gorge reservoir. It is affected by the reservoir most quickly, and is a reference point to study the effect of the Three-Gorge Dam on Dongting Lake. Thus it is selected as the base spot here.

$$i_k = \frac{\Delta h_k}{l_k} = \frac{h_k - h_0}{l_k} \tag{2}$$

where i_k is the hydraulic gradient of spot i, Δh_k the hydraulic head difference between spot k and Chenglingji spot, l_k the distance of spot k from Chenglingji spot and is a constant, h_k the water level of spot k, h_0 the water level of Chenglingji spot, and the unit of Δh_k, l_k and h_k is in meter. We recorded the water level of all spots before and after the operation of the Three-Gorge Dam in 2004. The daily means of water level were calculated for monthly databases which are shown in Table 1. According to Eq. (2), the data of their hydraulic gradients are plotted against time as shown in Figs. 2 to 6.

Table 1. Water level at each site during lower and higher water seasons before and after the operation of the Three-Gorge Dam in 2004 *

			Spot					
			Lujiao	Yingtian	Yangliutan	Yuanjiang	Nanzui	Chenglingji
Water level in dry seasons (m)	Nov	Before	27.70	26.11	25.75	27.79	27.60	24.16
		After	27.69	26.10	25.74	27.78	27.59	24.03
	Dec	Before	25.31	23.47	23.28	25.77	25.41	21.56
		Ater	25.31	23.47	23.28	25.77	25.41	21.56
	Jan	Before	24.01	22.04	21.94	24.67	24.21	20.15
		Ater	24.09	22.11	21.96	24.69	24.25	20.22
	Feb	Before	23.66	21.65	21.58	24.38	23.89	19.77
		Ater	23.89	21.87	21.62	24.44	23.99	19.87
	Mar	Before	25.23	23.38	23.20	25.70	25.33	21.47
		Ater	25.37	23.52	23.23	25.74	25.39	21.57
	Apr	Before	24.76	22.86	22.71	25.30	24.90	20.96
		Ater	24.74	22.84	22.70	25.29	24.89	22.98
	May	Before	29.59	28.21	27.71	29.39	29.34	26.22
		Ater	29.64	28.64	27.98	29.60	29.62	26.75

To be continued

Continued

			Spot					
			Lujiao	Yingtian	Yangliutan	Yuanjiang	Nanzui	Chenglingji
Water level in flood seasons (m)	Jun	Before	30.62	29.36	28.78	30.27	30.29	27.35
		After	30.63	29.37	28.79	30.28	30.30	27.38
	Jul	Before	32.03	30.92	30.25	31.47	31.59	28.89
		After	32.02	30.91	30.24	31.46	31.58	28.85
	Aug	Before	32.31	31.22	30.52	31.70	31.84	29.18
		After	32.08	31.03	30.40	31.69	31.72	28.97
	Sept	Before	33.69	32.75	31.96	32.87	33.11	30.69
		After	33.68	32.74	31.95	32.86	33.10	30.65
	Oct	Before	29.94	28.59	28.07	29.69	29.66	26.60
		After	28.53	27.41	27.37	29.10	28.91	26.47

* The distances from Yingtian, Yangliutan, Yuanjiang and Nanzui to Chenglingji are 43000 m, 160000 m, 117000 m, 143000 m and 173000 m, respectively.

It can be seen that the change of hydraulic gradient of all these spots is less than that before the operation of the Three-Gorge Dam. The variation range of hydraulic gradient at Lujiao is from 0.00006977 to 0.00009047, which is the biggest among all the observed spots. The hydraulic gradients of other spots, including Yuanjing, Nanzui, Yangliutan and Yingtian, are from 0.00001145 to 0.00002944.

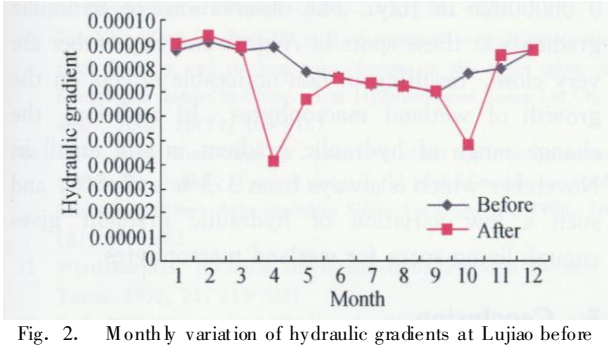

Fig. 2. Monthly variation of hydraulic gradients at Lujiao before and after operation of the Three-Gorge Dam.

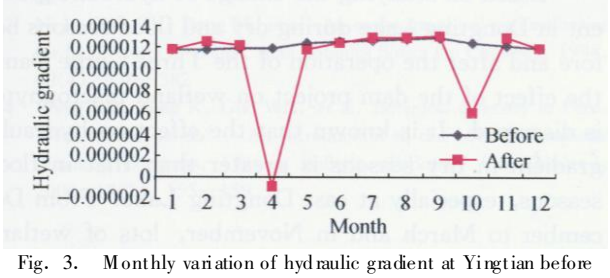

Fig. 3. Monthly variation of hydraulic gradient at Yingtian before and after operation of the Three-Gorge Dam.

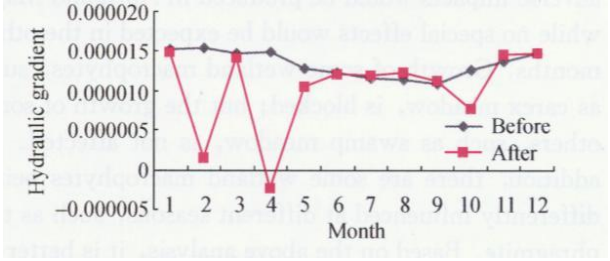

Fig. 4. Monthly variation of hydraulic gradient at Yangliutan before and after operation of the Three-Gorge Dam.

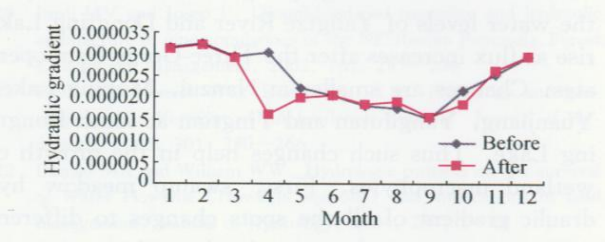

Fig. 5. Monthly variation of hydraulic gradient at Yuanjiang before and after operation of the Three-Gorge Dam.

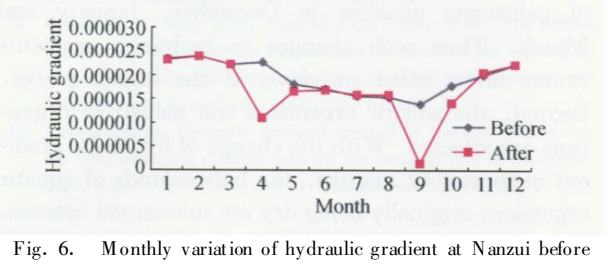

Fig. 6. Monthly variation of hydraulic gradient at Nanzui before and after operation of the Three-Gorge Dam.

According to the blueprint, after the operation of the Three-Gorge Dam, the increased fluxes at these six spots are -700 m^3/s, 110 m^3/s, 1170 m^3/s, 1760 m^3/s, 1480 m^3/s, and -360 m^3/s in dry season, and 376 m^3/s, 470 m^3/s, -520 m^3/s, -2170 m^3/s, -270 m^3/s and -7890 m^3/s in flood season, respectively. The effect of the Three-Gorge Dam Project on the hydraulic gradient of Dongting Lake in dry season is greater than that in flood season. The operation of the Three-Gorge Dam reduces hydraulic gradient of all the spots with different extents. The trends of hydraulic gradients variations after the operation of the dam, particularly those of Yuanjiang, Nanzui and Yingtian, are similar, which show two smallest numbers in April and October. The hydraulic gradient variation at Lujiao after the operation of the dam is the most distinct, in which there are significant changes in April and October, while the changes in

other months are stable. As a whole, it is indicated that the effect of the dam project on the hydraulic gradient of Dongting Lake is most significant in April and October, while the hydraulic gradients of Yingtian and Yangliutan after dam operation are even negative.

4.2 Effect on wetland macrophytes at Dongting Lake

As shown in Figs. 2—6, the change of hydraulic gradient at Lujiao lying at east Dongting Lake is the biggest of the six spots during dry season (including December and following spring), and this is because the water levels of Yangtze River and Dongting Lake rise as flux increases after the Three-Gorge Dam operates. Changes are smaller at Nanzui, Muping Lake, Yuanjiang, Yangliutan and Yingtian at south Dongting Lake. Thus such changes help in the growth of wetland macrophytes. First, swamp meadow hydraulic gradient of all the spots changes to different extents, however, the water levels at these spots are still lower than the grass meadow at the lowest local of palustrine meadow in December, January and March. Thus such changes in hydraulic gradients cannot affect other meadows at the higher places. Second, the aquatic organisms and palustrine organisms are affected. With the change of hydraulic gradient in these four months, the bottomlands of aquatic organisms originally being dry are submerged into water ahead of time, then the living plants are conserved and the seeds would burgeon quickly.

April is the spring growing season of carex meadow in swamp. After the Three-Gorge Dam is operated, the water level at each spot is lower, and the corresponding hydraulic gradient also decreases. Lujiao, lying at the east Dongting Lake, is the spot having the most obvious changes with even a variation ratio of 53.6%. Higher variation ratio of hydraulic gradient does harm to the growth of carex, with most of which growing at the east Dongting Lake. The hydraulic gradient at each spot is different in October, but the variation is small in the plant growing season after the dam project operation. Lower water level may facilitate lower shoals come out ahead of schedule, which promotes the abundance of plants on lower weed meadow and carex meadow. The abundance of phragmites has been stable and changes of hydraulic gradient have little effect on its yield.

After the first vale of hydraulic gradient in April, the flux increases to the highest, and the hydraulic gradient at each spot changes greatly in May according to Figs 2—6. This month is the proper time for growth and accumulation of phragmites. At the west Dongting Lake, there is plenty of phragmites and the change rate is higher here, then the abundance of this plant is reduced. In this month, most of wetland macrophytes at Dongting Lake grow more slowly with the increase of hydraulic gradient after the operation of the Three-Gorge Dam.

The hydraulic gradient at Dongting Lake changes slightly with flood increase of the Three-Gorge Dam from June to September. As we know, small change of hydraulic gradient has little effect on wetland during flood seasons. With decreasing flux of flood of the Three-Gorge Dam, hydraulic gradient at Dongting Lake has small but stable change. The hydraulic gradient at east Dongting Lake increases 0.0000007 for Lujiao, 0.00000021 for Yuanjiang, 0.00000017 for Nanzui, respectively, and at south Dongting Lake increases from 0.00000021 to 0.00000026 in July. The observations of hydraulic gradients at these spots in August and September are very close, resulting in non-noticeable effects on the growth of wetland macrophytes. In addition, the change range of hydraulic gradient is still small in November which is always from 3.3% to 7.5%, and such a low variation of hydraulic gradient gives enough living space for wetland macrophytes.

5 Conclusion

Based on studying the change of hydraulic gradient at Dongting Lake during dry and flood seasons before and after the operation of the Three-Gorge Dam, the effect of the dam project on wetland macrophytes is discussed. It is known that the effect on hydraulic gradient in dry seasons is greater than that in flood seasons, especially at east Dongting Lake. From December to March and in November, lots of wetland macrophytes at Dongting would benefit from the construction of the Three-Gorge Dam. However, some adverse impacts would be produced in April and May, while no special effects would be expected in the other months. Growth of some wetland macrophytes, such as carex meadow, is blocked; but the growth of some others, such as swamp meadow, is not affected. In addition, there are some wetland macrophytes being differently influenced at different seasons, such as the phragmite. Based on the above analysis, it is better to pay more attention to carex at dry seasons to protect

the balance of wetland ecosystem and to maintain the vegetation abundance at Dongting Lake.

References

1 Yan Z, Kutikova LA and Minoru S. *Notholca dongtingensis* (Rotifera: Monogononta: Brachionidae), a new species from Dongting Lake, China. Hydrobiologia, 1998, 386: 37—40

2 Rudi S, Rainer B and Vero B. Wildlife habitat analysis—a multidimensional habitat management model. Journal of Nature Conservation, 2003, 10: 253—268

3 Rea N and Ganf GG. The role of sexual reproduction and water regime in shaping the distribution patterns of clonal emergent aquatic plants. Aust J Mar, Freshwater Res, 1994, 45: 1469—1479

4 Blanch SJ, Granf GG and Walker KF. Tolerance of riverine plants to flooding and exposure indicated by water regime. Reg River, 1996, 15: 43—62

5 Boar RR. Responses of a fringing *Cyperes papyrus* L. swamp to changes in water level. Aquatic Botany, 2006, 84: 85—92

6 Jin XC. China Lake Environment (in Chinese). Beijing: Ocean Press, 1995

7 Peng DC and Yuan ZK. Fenny vegetation in Dongting Lake. Chinese Journal of Ecology (in Chinese), 1986, 5(2): 28—32

8 Zhuang DC. The characteristics of the biological resources and the evaluation of the welt and ecosystem in Dongting Lake area. Tropical Geography (in Chinese), 2000, 20(4): 261—264

9 Jian YX, Wang JB, He GQ, et al. A comparative study on aquatic plant diversity and its long-term changes in the three lakes of Dongtinghu district in China. Acta Hydrobiologica Sinica (in Chinese), 2002, 26(2): 160—167

10 Yu D, Kang H and Chen YY. Lake bend effect and its influence on the specific diversity of aquaic plants in the lakes of middle basins of Changjiang River. Acta Ecologica Sinica (in Chinese), 1996, 16(5): 476—483

11 Whittaker RH. Evolution and measurement of species diversity. Taxon, 1972, 21: 213—251

12 Soule ME. Conservation Biology: the Science of Scarcity and Diversity. Sunder and Massachusettes: Sinauer Associated, 1986, 584

13 Ni J, Chen ZX, Dong M, et al. An ecogeographical regionalization for biodiversity in China. Acta Botanica Sinica (in Chinese), 1998, 40(4): 370—382

14 Wang RQ, Song K, Guo WH, et al. Botanical diversity in Peril: What should we do? —An introduction to the 16th International Botanical Congress. Chinese Bulletin of Botany (in Chinese), 2000, 17(2): 155—159

15 Committee of Politics Consult, Economy, Science and Technology of Hunan Province. Relation Research of Three-Gorge Project and Dongting Lake (in Chinese). Changsha: Hunan Science & Technology Press, 2002

16 Zhao JG, Yang Q, Chen ZH, et al. Studies on root system biomass of the plans in several kinds of wetland. China Environmental Science (in Chinese), 2003, 23(3): 290—294

17 Deegan BD, Whiter SD and Ganf GG. The influence of water level fluctuation on the growth of four emergent macrophytes species. Aquatic Boany, available online 21 November 2006

18 Lang HQ. Wetland Vegetation of China (in Chinese). Beijing: Science Press, 1999

19 Li JG, Li GB, Liu F, et al. Reed resource and its ecological function and utilization in Baiyangdian Lake. South-to-North Water Transfers and Water Science & Technology (in Chinese), 2004, 35(3): 1672—1683

20 Jordi MV and Josep P. Drought-induced mortality and hydraulic architecture in pine populations of the NE Iberian Peninsula. Forest Ecology and Management, 2002, 161: 247—256

21 Paula JM, Hession WC, Rizzo DM, et al. Hydrology and geostatistics of a Vermont, USA kettlehole peatland. Journal of Hydrology, 2005, 301: 250—266

22 Donald M R and William WW. Hydrologic controls on the survival of Water Howellia (Howellia aquatilis) and implications of land management. Journal of Hydrology, 2004, 287: 1—18

23 Patricia CF. Ecosystem response to changes in water level of Lake Ontario marshes: lessons from the restoration of Cootes Paradise Marsh. Hydrobiologia, 2005, 539: 189—204

24 Gilber JC, Gowing DJG, Higginbottom PRG, et al. The habitat creation model: a decision support system to assess the viability of converting arable land into semi-natural habitat. Computers and Electronics in Agriculture, 2000, 28: 67—85

25 Heuperman A. Hydraulic gradient reversal by trees in shallow water table areas and repercussions for the sustainability of tree-growing system. Agricultural Water Management, 1999, 39(2—3): 153—167

26 Soares JV and Almeida AC. Modeling the water balance and soil water fluxes in a fast growing Eucalyptus plantation in Brazil. Journal of Hydrology, 2001, 253(1—4): 130—147

27 Van der Valk AG. Water-level fluctuations in North American prairie wetlands. Hydrobiologia, 2005, 539: 171—188

28 Han G and Zhang GF. On the feed-aimed potentialities and further development of phragmites communis and miscanthus sacchariflorus in the region of Dongting Lake. Resources and Environment in the Yangtze Basin (in Chinese), 1998, 7(3): 232—236