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Physical-Ecological Engineering for Purifying Water Quality in Algae-Type Eutrophic Lake ----Reconstruction of Macrophytes in Wulihu of Taihu Lake, China*

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Abstract *In the barren lake, algae-type eutrophication lake, fifteen aquatic vascular plants were introduced and vegetated in our enclosures of physical-ecological engineering. The area of each enclosure is 200 m^2, with length of 40m, width of 5m and depth of 1.8m. From 1995 to 1997, we had successfully vegetated 15 communities with the propagation techniques of pot-culture and sturdy seedling. The communities included floating, leave-floating and submerged macrophytes, such as* Alternanthera phyiloxeroides, Eichhornia crassipes, Trapa maximowiczii, Nymphoides peltata, Potamogeton maackianus, P. crispus, Myriophyllum spicatum, Hydrilla verticillata, Elodea nuttallii, *etc. These aquatic macrophytes not only adapted themselves to the environment but also purified the lake water.*
Keywords: *Aquatic macrophyte, Reconstruction, Algae-type eutrophication, Lake Taihu*

The shallow lakes numerously distributed along mid-lower reaches of the Changjiang River are great important to human life and economic development. However, due to the heavy exploitation for decades, many lakes have been changing to such an extent that the previous lush aquatic macrophytes were almost completely replaced by enormous planktonic organisms. This transmutation results in a great reduction of self-purification of the lake water. Many lakes face serious environmental problems and their function were minified. The reconstruction of aquatic macrophytes is very important to reintegrate the ecological balance of lake ecosystem.

Lake Taihu is located in the lower reaches of Changjiang River, China. It is one of the five largest freshwater lakes in China, with a watershed area of 36 500 km^2, a water surface area of 2338 km^2, and an average water depth of 1.9 m. There are six large cities and about 34.2 million people around the lake. Lake Taihu is very important for the people living and economic development. There were many kinds of aquatic macrophytes and they occupied

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most part of the lake before 1970s. The water was very clean. However, aquatic macrophytes have been replaced by phytoplankton since the 1970s. From 1980s, water quality of Lake Taihu has become worse and worse year by year. The algal-bloom occurs continually, recently. In this paper, we report some results of reconstruction of aquatic macrophytes in a Bay of Lake Taihu (Jin Xiangcan *et al*, 1990, Fan Chengxin, 1996).

1. Experiment material

According to the previous flora of aquatic vascular plant in Lake Taihu, fifteen macrophytes were introduced in our enclosures. All the population was assembled in terms of their ecological characteristics. The main ecological characteristics of 15 macrophytes are showed in Tab. 1. Some species of aquatic plants cultured in PEEN were shown in Fig. 1

Tab. 1 Main ecological characteristics of introduced macrophytes

No. and Species name	Growth period	Growth temperature	Modes of reproduction	Ecotype
1. *Eichhornia crassipes*	May to Nov.	20-35	Axillary bud	Floating
2. *Alternanthera philoxeroides*	Mar. to Dec.	20-30	Axillary bud	Floating
3. *Hydrocharis dubia*	June to Nov.	20-30	Creeper	Floating
4. *Trapa maximowiczii*	Apr. to Nov.	20-30	Seed	Leaves-floating
5. *T. Bicornis*	Apr. to Nov.	20-30	Seed	Leaves-floating
6. *Nymphoides peltata*	Apr. to Nov.	15-25	Rhizome	Leaves-floating
7. *N. Indica*	Apr. to Nov.	15-25	Rhizome	Leaves-floating
8. *Potamogeton maackinus*	Mar. to Nov.	20-30	Axillary bud	Submerged
9. *P. malaianus*	Apr. to Nov.	20-30	Rhizome	Submerged
10.*P. crispus*	Oct. to June	10-20	Winter bud	Submerged
11.*Myriophyllum spicatum*	Mar. to Nov.	15-30	Root tillering	Submerged
12.*Vallisneria spiralis*	Apr. to Nov.	20-30	Corm	Submerged
13.*Hydrilla verticillata*	May to Nov.	20-30	Scaly bud	Submerged
14.*Ctratophyllum demersum*	Apr. to Nov.	20-30	Winter bud	Submerged
15.*Elodea nuttallii*	Evergreen	15-30	Axillary bud	Submerged

2. Experiment methods

In enclosures of physical-ecological engineering, pot-culture and direct seeding with sturdy seedling were used to cultivate macrophytes. In order to avoid the frost damage, floating plants, such as *Eichhornia crassipes* and *Alternanthera philoxeroides*, were covered with plastic membrance before frost weather.

2.1 Pot-culture experiment

The submerged and leaves-floating macrophytes can not grow in eutrophication lake because of the low transparency. Therefore, we used the pot-culture technique to introduce macrophytes and made them adapt the poor environment step by step. The lake clay, collected from our experimental area, was put to 18 plastic pots. The thickness of lake clay in each pot was about 15 cm. Eighteen plastic pots were divided to three groups and suspended in different depth under water after seeding (Tab. 2). The pots of odd numbers were suspended in our enclosures and the others suspended in open lake area.

Tab. 2 Pot-culture experiment (Feb. to May, 1997)

	Propagules and amount	Number of pot	Depth of suspended, below water surface, cm
Trapa maximowczii	Seed, 20	1 and 2	30-40,
		3 and 4	80-90,
		5 and 6	110-130
Hydrilla verticillata	Scaly bud, 20	7 and 8	30-40
		9 and 10	80-90
		11 and 12	110-130
Vallisneria spiralis	Corm, 20	13 and 14	30-40
		15 and 16	80-90
		17 and 18	110-130

2.2 Direct seeding with sturdy seedling

The sturdy seedlings were selected from the blastochores of *Trapa bicornis, Vallisneria spiralis, Hydrilla verticillata* and *Potamogeton malaianus* at the beginning of April 1997. Eighty sturdy seedlings of each plant were directly seeded in each area both inside and outside of our enclosures.

2.3 Reconstruction of macrophyte community

According to the characteristics of the previous macrophyte communities and the ecological feature of each population, various plants were interplanted in our enclosures. Some mosaic communities were reconstructed.

2.4 Observation of macrophyte growth and monitoring of water quality

During the experimental period, the macrophyte growth was observed and some indexes of water quality were measured every month. These indexes include transparency, underwater luminous intensity, total nitrogen, total phosphorous, ammonia, etc.

3. Experimental results

3.1 Hibernation experiment of floating plants

The observation result shows that the frost comes in the last ten-days of November every year. The floating plant will be frozen to death soon after the frost comes. However, if the floating plants are covered with plastic membrane before the frost comes they can hibernate successfully and remain slow growth. The water temperature is about 6-15 ℃ and increases 3-10 ℃ comparing with the open water outside enclosures. The survival ratio of *Eichhornia crassipes* is about 30%. All plant of *Alternanthera philoxeroides* remains green.

3.2 Results of pot-culture experiment

In shallow eutrophic lake, the maximal distinction at different depth is the underwater luminance. Physical-ecological engineering improves the transparency of eutrophic water and underwater luminance effectively. The monitoring results of luminance and transparency show there is significant difference between inside and outside of enclosure. The transparency is about 95-110cm in enclosure and 30-50cm outside enclosure. The relative luminance is higher in shallow layer than deep layer and they also higher in enclosure than outside (Tab. 3).

Tab. 3 Main environmental factors of pot-culture (Feb. 11 to May 15, 1997)

Site	Day	t_w, ℃	SD, cm	Relative luminance, %		
				Lay1	Lay2	Lay3
In enclosure	32	10.5	100	26.4	10.8	4.2
	50	15.9	100	32.8	11.7	5.2
	62	18.6	95	33.8	12.1	5.5
	76	20.4	105	27.4	9.9	4.2
	92	26.3	110	28.4	10.6	4.7
Outside enclosure	32	10.5	30	7.2	0.2	0.1
	50	15.9	40	22.9	4.6	1.3
	62	18.6	40	14.5	2.9	0.9
	76	20.4	40	10.8	1.9	0.6
	92	26.3	50	16.4	4.3	0.3

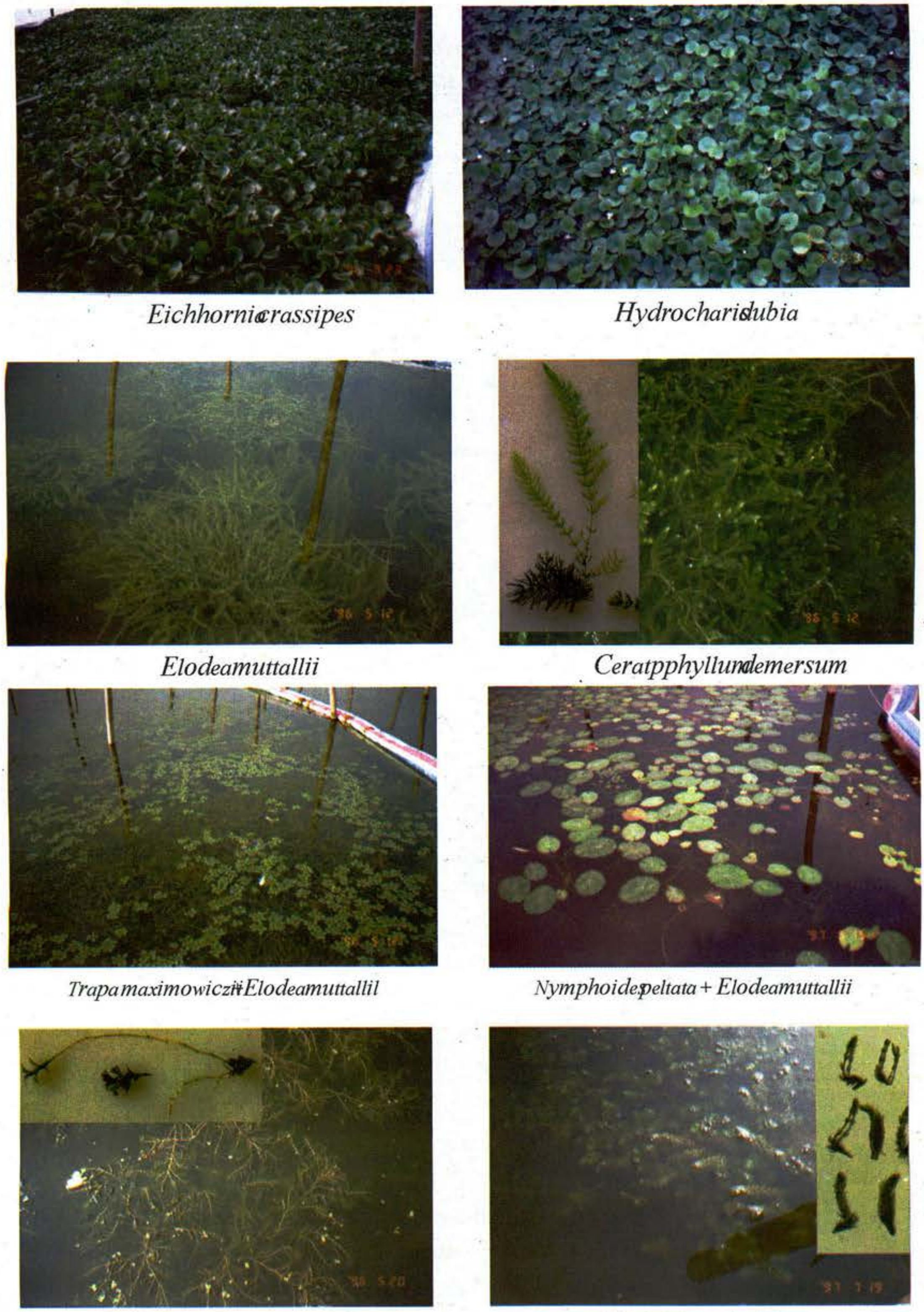
Note: Lay1, Lay2, Lay3 mean the depth of suspended pot, Lay1 30-40 cm, Lay2 80-90 cm, Lay3 110-130 cm, respectively.

Tab.4 The results of pot-culture of *Valliseria spiralis* (Feb. 11 to May 15, 1997)

Site	Day	Tillering ratio, %			Plant height, cm			Survival ratio, %		
		Lay1	Lay2	Lay3	Lay1	Lay2	Lay3	Lay1	Lay2	Lay3
Inside enclo-sure	32				1-2	1-2	1-2	80	75	65
	50				3-10	2-4	3-8	75	65	30
	62	10			10-15	4-10	8-17	60	50	10
	76	20			20-25	10-30	0	50	30	0
	92	30	5		30-36	25-53	0	40	20	0
Outside enclo-sure	32				2-3	1-3	2-3	90	85	75
	50				3-13	3-13	0	90	20	0
	62	20			10-17	8-15	0	80	10	0
	76	45			15-30	15	0	80	5	0
	92	60			25-35	36	0	80	5	0

Note: Lay1, Lay2, Lay3 mean the depth of suspended pot, Lay1 30-40 cm, Lay2 80-90 cm, Lay3 110-130 cm, respectively.

The results of pot-culture show that germination ratio is nearly congruous in different depth. This result shows light has little influence on germination of macrophyte. However, light has significant influence on tillering ratio, plant height, survival ratio and biomass of macrophyte seedling (Tab. 4, 5, 6, 7).



Eichhornia crassipes

Hydrocharis dubia

Elodea muttallii

Ceratpphyllum demersum

Trapa maximowiczii+Elodea muttallil

Nymphoides peltata + Elodea muttallii

Potrmogeton crispus

Hydrilla varticillata

Fig. 1 Some species of aquatic plants cultured in PEEN for purifying water quality

Tab. 5 The results of pot-culture of *Trapa maximowiczii* (Feb. 11 to May 15, 1997)

Site	Day	Tillering ratio,%			Plant height, cm			Survival ratio, %		
		Lay1	Lay2	Lay3	Lay1	Lay2	Lay3	Lay1	Lay2	Lay3
	32				0	0	0			
Inside	50				2-3.5	2-3	1-3	95	90	95
enclo-	62				10-35	16-40	21-41	95	95	80
sure	76	25			36-62	26-75	25-73	90	95	70
	92	100	30		80-120	100-140	120-150	90	95	60
	32				0	0	0			
Outside	50				2-3	2-3.5	2-4	90	95	85
enclo-	62				18-35	15-37	20-39	95	85	70
sure	76	30			26-60	20-72	25-75	90	85	50
	92	90			63-125	90-120	110-145	90	85	50

Lay1, Lay2, Lay3 mean the depth of suspended pot, Lay1 30-40 cm, Lay2 80-90 cm, Lay3 110-130 cm, respectively.

Tab. 6 The results of pot-culture of *Hydrilla verticillata* (Feb. 11 to May 15, 1997)

Site	Day	Tillering ratio, %			Plant height, cm			Survival ratio, %		
		Lay1	Lay2	Lay3	Lay1	Lay2	Lay3	Lay1	Lay2	Lay3
	32				2-3.5	2-3	2-3.2	95	90	95
Inside	50				3.5-8	3-10	3-8	95	90	60
Enclo-	62	30			8-10	9-15	8-13	90	80	40
sure	76	40			10-24	15-37	13-35	90	70	10
	92	60	10		25-44	37-55	25-65	85	70	5
	32				2-6	1-8	2-4	95	90	85
Outside	50				10-20	8-20	6-25	90	45	10
enclo-	62	25			16-23	18-23	21	85	30	5
sure	76	35			20-45	19-40		80	20	0
	92	50			40-63	45-65		75	20	0

Lay1, Lay2, Lay3 mean the depth of suspended pot, Lay1 30-40 cm, Lay2 80-90 cm, Lay3 110-130 cm, respectively.

Tab. 7 Biomass of plant in pot-culture, 92d (May 15, 1997)

	Lay 1 (30-40 cm), g		Lay 2 (80-90 cm), g		Lay 3 (110-130cm), g	
	Inside	Outside	Inside	Outside	Inside	Outside
Trapa maximowiczii	3 240	3 820	3 610	2 910	2 600	1 800
Hydrilla verticillata	680	900	560	240	20	
Valliseria spiralis	160	480	80	30		

Three plants don't tiller below the underwater depth of 110-130 cm in enclosure and below 80 cm out enclosure. The survival ratio is higher in enclosure than outside enclosure. It is also higher in shallow layer than deep layer.

The variation of biomass is interesting (Tab. 7). At the shallow layer (30-40 cm), the biomass is lower in enclosure than outside. However, the biomass is higher inside than outside of our enclosure below 80 cm. This indicates that light play key role on the growth of macrophyte.

3.3 Results of direct seeding with sturdy seedling

In our enclosure, one month after direct seeding, water caltrop (*Trapa bicornis*) grows up to water surface. *Hydrilla verticillata* and *P. malanianus* spend one and half month reaching water surface. *Vallisneria spiralis* takes two months to approach water surface. However, outside enclosure all plants die except water caltrop. Water caltrop can grow inside and outside of enclosure, but even so, the survival ratio, plant height and biomass are higher inside than outside (Tab. 8).

Tab. 8 The results of direct seeding (April 2 to June 1, 1997)

		Trapa bicornis		*Hydrilla verticillata*		*P. malanianus*		*Vallisneria spiralis*	
		Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Survival	0 d	100	100	100	100	100	100	100	100
ratio, %	60 d	80	5	20	0	30	0	10	0
Plant height,	0 d	1.5	2.5	5	4.5	3	2.5	4	4
cm	60 d	240	220	130	0	180	0	110	0
Biomass, g	60 d	6400	420	400	0	1080	0	100	0

Tab. 9 The main characteristics of 15 macrophyte communities

Symbol of community*	Growth period	Cover degree,%	Biomass, kg/m^2	Auxiliary species*	Water depth, cm	SD, cm
Ec	May to Nov. (1996-1997)	95	10.5			200
Ap	Nov.1996 to Dec. 1997	75-95	13.2	Ms, Hv, Cd, En		210
Hd	May to Nov. (1997)	95	8.37			150
Tm	Apr. 1995 to Nov.1997	85-100	10.2	Tb, Cd, En	140-280	140-230
Tb	May 1996 to Dec.1997	95	12.66	Tm, Ms, Cd, En	130-260	130-210
Np	Nov. 1996 to Feb. 1998	65-80	1.2	Ms, Hv, En	140-220	140
En	Sept. To June (1995-1997)	85	7.82	Ms, Hv, Cd	130-160	130-160
Pc	Oct. to June (1995-1997)	60	5.24	Tm, Cd, En	130-160	130
Hv	Nov. 1996 to Dec. 1997	50	4.82	Hd, Ni, Cd	130-210	130-210
Ms	Nov. 1996 to July 1997	55	5.10	Tm, Cd	130-180	130-160
Cd	Dec. 1995 to Dec. 1997	45	3.96	Hv, Ed	140-280	60
Tm-En	Nov. 1995 to Nov. 1996	90	8.62(Tm) 8.82(En)	Cd, Hv, Pc	140-310	140-210
Tm-Ms	Nov. 1996 to July 1997	95	5.90(Tm) 3.84(Ms)	Hd, Cd, En	140-210	140-200
Np-En	Nov. 1996 to Dec. 1997	100	0.86(Np), 4.70(En)		140-210	140-165
Tm-En-Pc	Nov. 1995 to Aug. 1996	75	4.96(Tm) , 6.00(En), 1.54(Pc)		140-300	140-200

*Note: Ap: *Alternanthera philoxeroides,* Cd: *Ctratophyllum demersum,* Ec: *Eichhornia crassipes,* En: *Elodea nuttallii,* Hd: *Hydrocharis dubia,* Hv: *Hydrilla verticillata,* Ms: *Myriophyllum spicatum,* Ni: *N. indica,* Np: *Nymphoides peltata,* Pa: *Potamogeton maackinus,* Pc: *P. crispus,* Pm: *P. malaianus,* Tb: *T. bicornis,* Tm: *Trapa maximowiczii,* Vs: *Vallisneria spiralis*

3.4 Results of reconstruction of macrophyte community

From 1995 to 1997, we have successfully reconstruct 15 macrophyte communities in our enclosures of physical-ecological engineering (PEEN) (Tab. 9). The alternative growth of these communities makes the PEEN remain green at all times and play important role on purifying eutrophic water.

The succession of reconstructed community is realized with artificial regulation and control. In the end of November, the community of *Trapa bicornis* develops into the community of *Potamogeton crispus*. The latter becomes the dominant of the ecosystem from December to June of next year. From May, *Potamogeton crispus* is replaced by *Trapa* spp. step by step. *Trapa* spp. becomes dominant again. It similarly from May replaces the community of *Elodea nuttallii*.

3.5 Changes of illumination and nutrient inside/outside of PEEN enclosure

In our enclosures of physical-ecological engineering, water transparency is improved signally (Fig. 2). Therefore, the intensity of illumination is higher inside than outside of enclosures (Fig. 3). It provides a suitable environment for submerged and leave-floating macrophyte. The growth of these aquatic plants decreases the concentrations of nitrogen and phosphorus and controls algae growth. As a result, the concentrations of nutrients and chlorophyll (Chl*a*) get down inside enclosure obviously (Tab. 10).

Table 10 Change of concentration of main nutriments ($mg \cdot L^{-1}$) and chlorophyll*a* ($mg \cdot m^{-3}$)

	TN	NH_4^+-N	NO_3^--N	TP	PO_4^{3-}-P	Chl*a*
Outside enclosure	6.621	3.859	1.326	0.167	0.022	64.93
Inside enclosure	1.662	0.388	0.651	0.074	0.017	33.92

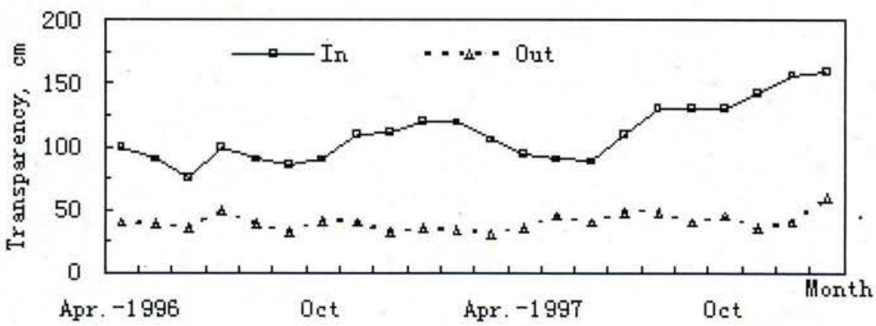


Fig. 2 Lake water transparency inside and outside of enclosure during April 1996 to January 1998

4. Conclusion

1) In shallow phytoplankton type eutrophic lake, macrophytes can be restored with the enclosures of physical-ecological engineering. The reconstructed communities may successfully realize annual successions. It is the key point that the populations and their spatial distribution should be reasonably collocated.

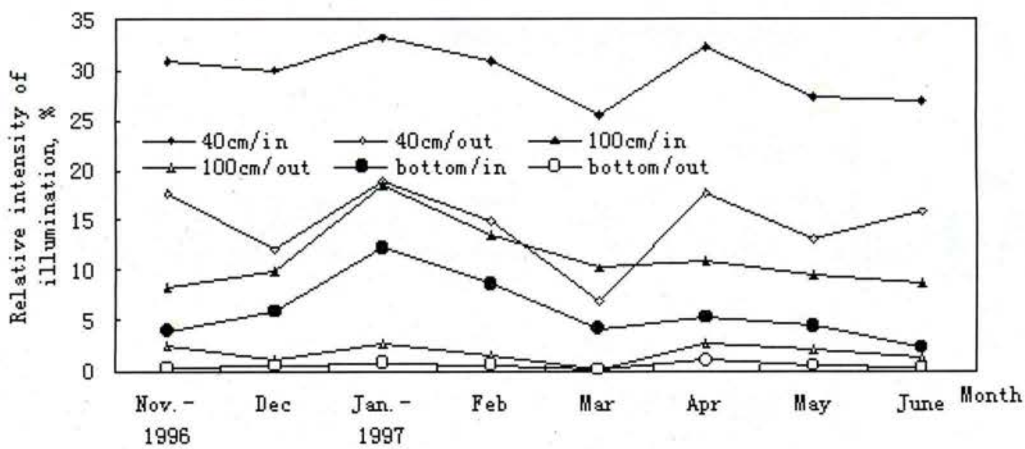


Fig. 3 The relative intensity of underwater illumination inside and outside of PEEN enclosure

2) The reconstructed communities can effectively inhibit algae growth and enhance water transparency. Specially, the enhancement of water transparency makes submerged macrophytes grow well. Sequentially, the succession between different ecotype populations may realize.

3) The reconstructed communities are able to purify eutrophic water and promote the benign recycle of aquatic ecosystem. The monitoring results show that macrophytes can effectively decrease nutrients and other pollutants in water. The healthy growth and annual succession of macrophytes not only make the eutrophic water become clean but also promote the restoration and benign recycle of aquatic ecosystem.

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