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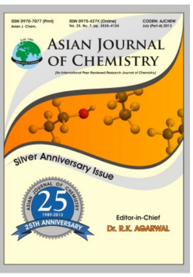

Is *Salvinia natans* (L.) a Water Quality Improver?

JINQI WANG[1], YOUFEI ZHENG[1,*] and GUOXIANG WANG[2]

[1]Nanjing University of Information Science & Technology, Nanjing 210044, P.R. China
[2]School of Geography Science, Nanjing Normal University Nanjing 210024, P.R. China

*Corresponding author: E-mail: zhengyf@nuist.edu.cn

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S. natans (L.) is a free-floating aquatic plant in freshwater bodies. The impact of *S. natans* (L.) on water quality is tested in natural waters. A natural water body is divided into some regions and two similar regions are used to experiment. *S. natans* (L.) is planted and the water quality is monitored regularly and analyzed. This showed that the water quality during the growing season is not only improved in planted *S. natans* (L.) significantly, but also the capacity of re-oxygenation is reduced remarkably because of *S. natans* (L.) covering the water surface. Thus dissolved oxygen content of the experiment water body is lower than the control water body and affecting the conversion of various elements in the experiment water body. When the plant coverage exceeds 80 %, *S. natans* (L.) will affect the re-oxygenation capacity significantly, photo permeability ability, result in the dissolved oxygen concentration reduction and affect other aquatic organisms activities, the nitrogen and phosphorus content is increased rapidly in water body, so lead the water quality to deterioration, but permanganate index is affected minor. The water quality indexes restores the similar level with the control until *Salvinia natans* (L.) died and subsided to the sediment. *Salvinia natans* (L.) may pollute the water body after death and decompose at a short-term if *Salvinia natans* (L.) grows a large-scale and absorbs many nutrients from the sky and water. So *Salvinia natans* (L.) can't improve the water quality at their live period, on the contrary conduces the water quality deterioration. The ecological restoration careful selects the *Salvinia natans* (L.) as purification species in eutrophic water, the growth trend of *Salvinia natans* (L.) is closely monitored, the *Salvinia natans* (L.) coverage must be controlled and must be reaped by period.

Key Words: *Salvinia natans* (L.), Anaerobium, Total nitrogen, Total phosphorus, Ecological restoration.

INTRODUCTION

Salvinia natans (L.) is a free-floating aquatic plant that has no true roots but probably has similar functions to true roots[1,2]. It grows fast and covers the water body quickly and benefits from increased temperature and increased nutrient loading owing to global warming and human activity[3], *S. natans* (L.) has a very high growth rate in nutrient-rich and stagnant waters[3-5] and can easily be harvested. *S. natans* (L.) can remove the nitrogen, phosphorus and other nutrients from the water and purify the polluted water. Some experiments show that *S. natans* (L.) can absorb the nutrients from the water and has an excellent purification on eutrophic water[6], some studies indicated that *S. natans* (L.) can absorb some heavy metal *i.e.*, Cu(II), Ni(II), Hg(II) significantly[7-9] cadmium and lead[10] effectively and uptake toxic metalloid such as As (V)[4,11]. *S. natans* (L.) has the potential to be used in constructed wetland systems for wastewater treatment, it has a very high growth rate in nutrient-rich and stagnant waters and as the produced biomass can easily be harvested[12,4].

The previous research is conducted in the artificial eutrophic water that no sediment, it is different with the natural ecosystem. Can *S. natans* (L.) absorb the nutrient from the natural water body obviously as the foregoing experiments? In this study, *S. natans* (L.) was planted in the natural water body and the water quality indexes are monitored regularly, the *S. natans* (L.) purification function in the natural water body is investigated.

EXPERIMENTAL

Experiment was conducted at the ecological restoration experimental pond in Nanjing Normal University (32.11 ºN, 118.91 ºE), the average depth of the pond is about 115 cm, the deepest depth is 215 cm, the major pollution sources comes from the surface runoff, the experimental district is located in the central part of the pond. There are no aquatic plants in the pond before the experiment. Some impervious materials, floating bodies divided the pond into some isolation zones (Fig. 1), some cement tubes press the impervious materials into the sediment to ensure every region separated from each other. The water is exchanged with the outside only through precipitation and evaporation. The experimental area is about 1500 m^2 and is divided into five isolated districts (A, B, C, D, E),

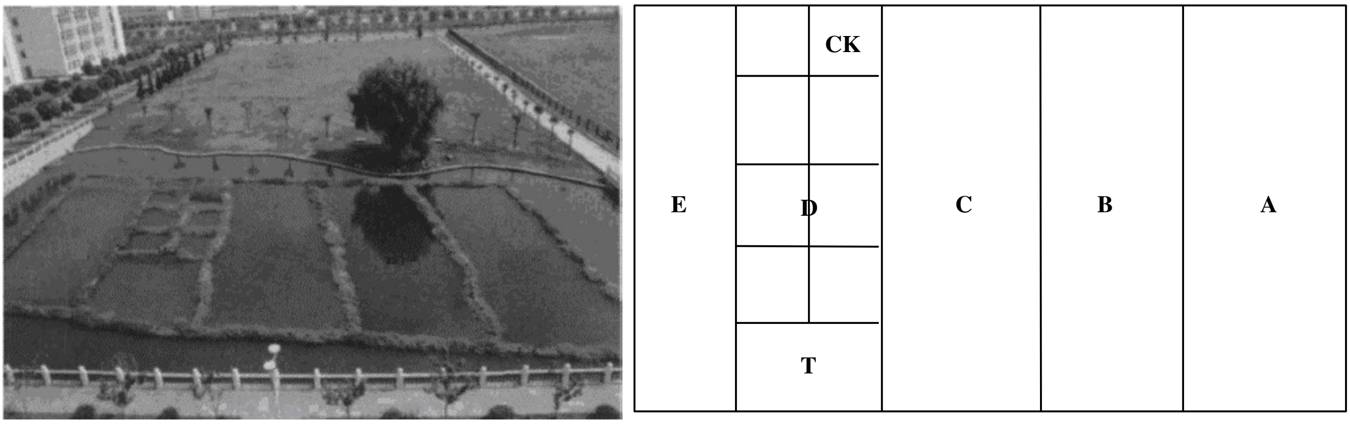


Fig. 1. Experimental area and the schematic diagram

the D district is divided into nine little districts, one district planting *S. natans* (L.) is marked as T, another region without any aquatic plants is marked CK, as a control water body, the two experimental zones have the same area (50 cm, 60 cm) and the water quality of indexes are little difference at the previous month (Table-1).

TABLE-1
WATER QUALITY INDEXES OF THE
TWO EXPERIMENTAL REGIONS

Parameter	CK	T
Dissolved oxygen (mg L^{-1})	2.640	2.670
Total nitrogen (mg L^{-1})	1.597	1.622
NH_4^+–N (mg L^{-1})	0.337	0.406
NO_2^-–N (mg L^{-1})	0.042	0.042
NO_3^-–N (mg L^{-1})	0.086	0.112
Total phosphorus (mg L^{-1})	0.172	0.162
I_{Mn} (mg L^{-1})	10.779	10.751

The propagules of *S. natans* (L.) were collected from Taihu Lake, the propagules were planted in the experimental zone on September 6th 2004 and grew naturally, the experiment was over on the following February 19th 2005, the experiment lasts 166 days.

The monitoring indicators have dissolved oxygen, total phosphorus, total nitrogen, ammonia nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), permanganate index (I_{Mn}). The dissolved oxygen content and the water temperature were monitored by the dissolved oxygen instrument (Model: YSI-55, made in USA) at 9 o'clock; I_{Mn} was measured by acidic potassium permanganate titration according to the water and wastewater monitoring method[15]. The water sample were pre-treated (5 % potassium sulfate solution, 121 ºC, 30 min), total nitrogen, NH_4^+-N, NO_3^--N, NO_2^--N and total phosphorus were measured by the water flow analyzer (SKALAR, made in Netherlands).

The coverage was surveyed by the sample basket (20 × 20 cm), the coverage was identified and calculated with the area ratio method.

The sampling and measuring operation were all operated outside experimental region by a small boat in order to prevent mixing the water column and influencing the measurement indicators. The sampling frequency is approximately 7-10 days. The water temperature and dissolved oxygen were measured at 5 cm from the surface, the water samples were collected at 5 cm from the surface.

RESULTS AND DISCUSSION

A small amount of propagule of *S. natans* (L.) were scattered into the pond at the experimental beginning, *S. natans* (L.) began to grow after a week, the coverage was about 5 % after 20 day, the coverage was about 20 % after 30 day, 50 % after 40 day, 85 % after 51st day and 95 % after 72 day and covered the total water surface from 79 to 86 day. The leaves of *S. natans* (L.) began yellow and decayed after 116 day, *S. natans* (L.) had been completely decayed but cover the water surface approximately 90 % at the 137 day, the plant residues completely sank to the bottom at 166th day.

Temperature and dissolved oxygen: The water temperature has been in a downward trend (Fig. 2), the water temperature is around 25 ºC at the beginning, around 5 ºC at the end, 24.8 ºC in September, 19.1ºC in October, 15.7ºC in November, 8.6 ºC in December, 5.3 ºC in January. Its downward has an impact on dissolved oxygen and the microbial activities in the water and sediments.

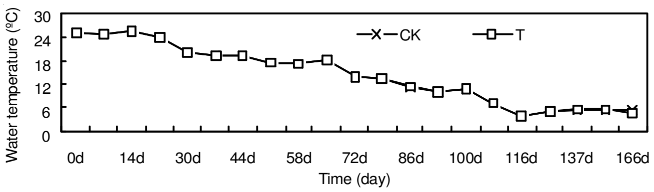


Fig. 2. Water temperature

The dissolved oxygen content of CK and T is the same variation during the entire experiment (Fig. 3). The dissolved oxygen content rises along with the water temperature decreasing. The dissolved oxygen variation trend of the two water bodies is similar same from the 0 day to 51th day, the dissolved oxygen average content of CK is 6.04 mg/L before 51th day, the dissolved oxygen average content of T is 5.92 mg/L, the dissolved oxygen content of the two water bodies is not significantly different ($P > 0.05$). The coverage of T exceeds by 85 % after 51st day, the dissolved oxygen average content of CK is 8.54 mg/L, while the T is only 5.59 mg/L, the dissolved oxygen average content of T is 52.8 % lower than CK, but the difference is not very significant ($P > 0.05$).

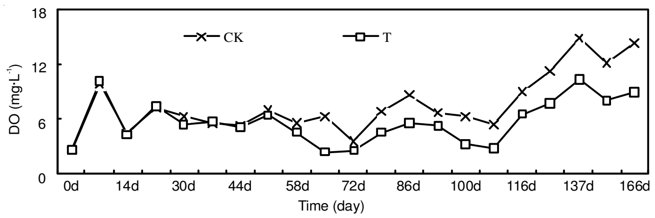


Fig. 3. Dissolved oxygen variation of the water bodies

Figs. 2 and 3 give the relation of dissolved oxygen and water temperature. The water bodies can exchange the oxygen through the water-air interface, when the coverage of T is less than 85 %, the dissolved oxygen content of the two water bodies are roughly equal, when the coverage of T is more than 85 %, the exchange of atmospheric oxygen and re-oxygenation of the water body of CK can continues through the air-water interface, the T hindered re-oxygenation through the air-water interface because of the T covering a large area of water body and the algae photosynthesis reduced during the day and weakened the ability of releasing oxygen. The dissolved oxygen content of the T significantly reduced compared with the no plants water body.

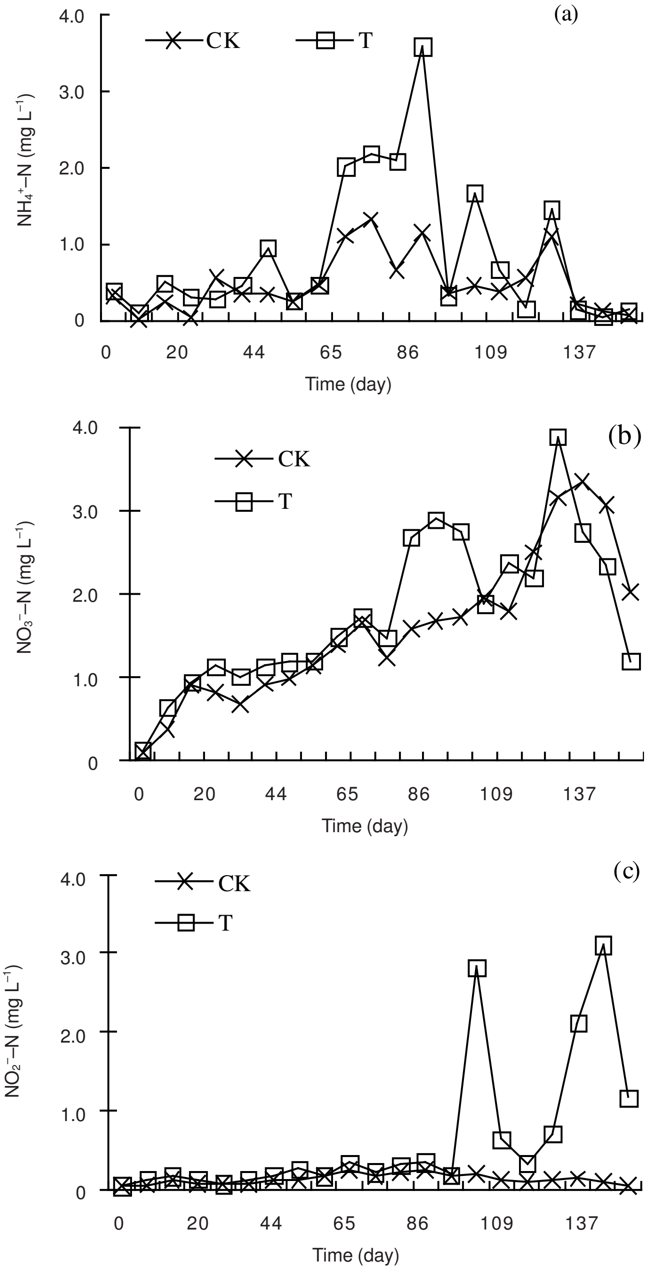
Nitrogen: Fig. 4(a) gives the NH_4^+-N concentration result, the coverage of the *S. natans* (L.) gradually increased from the experiment beginning to 58th day, the NH_4^+-N concentration of T is slightly higher than CK, the average concentration of T is 0.43 mg/L,the average concentration of CK is 0.30 mg/L, the former is 42.7 % higher than the latter. The average concentration of T is significantly higher than CK when the *S. natans* (L.) coverage exceeds 85 % from the 58th day to the 126th day and the average concentration of CK is 7.25 mg/L and the average concentration of the T is 14.31 mg/L, the latter is 97.4 % higher than the former. The *S. natans* (L.) quickly change yellow, sedimentation and death, decay, after the 137th day, the NH_4^+-N average concentration of T is 1.86 mg/L, the CK is 1.57 mg/L, the former is 18.5 % higher than the latter, the difference is very small.

Fig. 4(b) shows the NO_3^--N average concentration result, the *S. natans* (L.) covered the total water body from the experimental beginning to 72nd day. The NO_3^--N average concentration of T is slightly higher than CK, the rate is 18.4 %. The *S. natans* (L.) coverage reaches 100 % from the 79th day to the 93rd day, the NO_3^--N average concentration of T is 67.3 % higher than CK. The NO_3^--N concentration of the two water bodies has fluctuated since the 100th day to the 126th day. The *S. natans* (L.) decomposed and sank to the underwater from 137th day to 166th day, the NO_3^--N average concentration of T is lower than CK.

The NO_2^--N average concentration of T is slightly higher than CK during the experimental period (Fig. 4c). The NO_2^--N average concentration of CK is 0.13 mg/L,T is 0.18 mg/L from the the experimental beginning to the 93th day, T is 42.5 % higher than CK, is 0.06 mg/L.CK is 0.11 mg/L, T is 1.55 mg/L from the 100t day to the end, T is 1.44 mg/L higher than CK, the rate is 1291.2 %, the difference is very significant than before 93 days.

The total nitrogen average concentration of T is evidently higher than CK during the experimental period. The coverage of T is less than 85 % from the experimental beginning to the 58th day; the total nitrogen average concentration of T is slightly higher than CK. The total nitrogen average concentration of T is 2.11 mg/L, CK is 2.49 mg/L and the high rate is 18.1 %. The total nitrogen average concentration of T is much higher than CK from the 65th day to the 137th day, T is 6.76 mg/L, CK is 4.51 mg/L, the former is higher than the later, the high rate is 49.8 %. The total nitrogen content in the two water bodies is roughly equal after 137th day, their difference are very little. The two water bodies of total nitrogen data are done *t*-test from the 65th day to the 137th day, $P = 0.00163$ (< 0.01), the difference is not significant in the remaining period, the single tail *t*-test test result $P = 0.25611$ (> 0.01).

Due the quantities of aminate bacteria, nitrifying bacteria, denitrifying bacteria and some anaerobic bacteria and the ammonification, nitrification are affected by dissolved oxygen concentration, temperature, pH[13,14]. Water Aerobic-anaerobic state of T changes with the coverage variation of the *S. natans* (L.) and affecting the activities of nitrogen bacteria and the



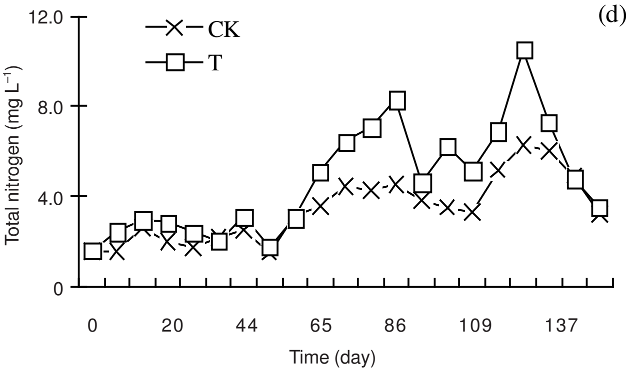


Fig. 4. Nitrogen variation of the water bodies

physical exchange in water and the water body sediment. The *S. natans* (L.) do not fully cover the entire surface of the water before the 58th day. The water bodies T and CK can exchange oxygen at the air-water interface, therefore, the dissolved oxygen concentration of the two water bodies have little difference. The ammonification bacteria, nitrifying bacteria and other aerobic microorganisms in the water and sediments all can operate normally. The categories, quantities, vitality of bacteria in T has little diversity compared with CK and the water temperature is quite high, the vitality of various types of bacteria is not affected, therefore, total nitrogen, NH_4^+-N, NO_3^--N, NO_2^--N content of the two water body are not much different. The multi-form nitrogen content of CK changes slightly after 58th days later compared with the former 37 days, but the variational amplitude is not significant comparing with T. T reaeration ability gradually weakened with the coverage increasing of the *S. natans* (L.). Thus, the dissolved oxygen concentration is less than T. The aerobic bacteria quantity in T reduced more than CK, anaerobic bacteria quantity increased, nitrification rate is inferior to CK[15], nitrite began accumulation[16], microorganisms release more nitrogen elements from the sediment to the water body than CK under the action of anaerobic, resulting in total nitrogen content significantly increases. *S. natans* (L.) completely decomposed and sank to the underwater after 137th day, the two water bodies restores normal re-oxygenation function, the total nitrogen content of the two water bodies tends consistent. NH_4^+-N, NO_3^--N, NO_2^--N content affected by the water temperature, the activity of nitrite bacteria is higher than nitrifying bacteria, when the experiment conducted to the 93th day, the water temperature dropped to below 10 ºC, the nitrite bacteria in the water body still ongoing activities, while weakening the activities of nitrifying bacteria, the rapid accumulation of nitrite in water, resulting in an increase in water content of NO_2^--N.

Total phosphorus: The total phosphorus content of T is slightly higher to than CK before 14th day. The total phosphorus content of T is 7.60 % higher than CK. From the 14th day to the 126th day, the total phosphorus content of CK is 0.21 mg/L, the total phosphorus content of T is 0.32 mg/L during the rapid growth of the *S. natans* (L.), the high rate is 50.8 %. The *S. natans* (L.) rapidly decomposed and sunk to the underwater after the 126th day, total phosphorus content of the T is basically the same to CK, the total phosphorus content of the T only 0.59 % higher than the without plants. The total phosphorus content of T and CK don't basically change from the experimental beginning to the end, total phosphorus data of the two water bodies from 14 to 126th day is to do *t*-test, single tail test $P = 0.00131$ (< 0.01), the difference was highly significant and the remaining time to do *t*-test, single tail test, $P = 0.28570$ (> 0.01), the difference is not significant (Fig. 5).

The variation of dissolved oxygen in water bodies and sediments influences the activities of phosphate-accumulating bacteria, phosphorus is required for the synthesis of cell material-nucleic acids and a total phosphorus in bacterial growth time, when the water body is in the aerobic condition, the phosphate-accumulating bacteria in water body sorbs excessive phosphorus beyond their physiological need, stores some polyphosphoric acid particles in the bacteria cell[17]. In the anaerobic state, the poly-phosphate accumulating bacteria decomposes the organic phosphorus of the body, or polyphosphate and releases the soluble phosphate into the water[18,19]. The dissolved oxygen content of the water body also affected that the metal ions convert the water-sediment, in the rich-oxygen environment, water-sediment are in the oxidized state, some metal ions such as Fe^{3+} or Ca^{2+} can be combined with the phosphorus, the formation of phosphate deposits. Thus, the sediment adsorb ion of phosphate from the overlying water in the aerobic or anoxic environment, in dissolvable substance such as $Fe(OH)_3$, $Ca_3(PO_4)_2$ convert into soluble material $Fe(OH)_2$, $CaHPO_4$, therefore it is conducive to release the phosphate from the sediments. The phosphorus ions that combined with the iron, calcium ions released into the waterbody[20,21]. It shows in Fig. 5 that on comparing the T with CK, the dissolved oxygen content in the waterbody decreased with the increasing of the coverage of *S. natans* (L.). The water body gradually transform from aerobic to the anoxic state with the increasing of *S. natans* (L.) coverage, water gradually from aerobic to the anoxic state of the state change. When the *S. natans* (L.) population completely covered the water body, anaerobic state of the water body reaches the maximum, so the progress that the phosphate accumulating organisms releasing soluble phosphate in water body also reached a maximum, it rose to the highest total phosphorus.

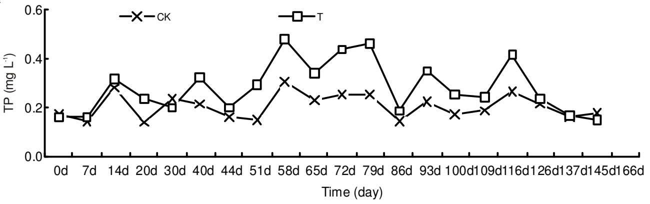


Fig. 5. Total phosphorus variation of the water bodies

Permanganate index: I_{Mn} in the water body is 10.78 mg/L at the beginning of the experimen, for T the I_{Mn} is 10.75 mg/L. For the two water bodies I_{Mn} is basically the same. There is no obvious change in I_{Mn} of CK and T rules throughout the experimental stage. The average I_{Mn} content of CK during the entire experiment is 10.85 mg/L and for T, IMn is 11.40 mg/L. The difference is not significant, the average I_{Mn} of CK is 11.32 mg/L from the experimental beginning to the 100th day, T is 11.92 mg/L, the difference is small. Only after the experiment after 100th day, a large number *S. natans*(L.) is decayed, the average I_{Mn} content of T is higher than CK. The average I_{Mn} content of CK is 9.74 mg/L by the 4 measure times, the average I_{Mn} value of the T is 10.18 mg/L and the higher value is no significant upward trend than before. The two water bodies do *t*-test all the experiment time, single tail test P = 0.11546 (> 0.05), the difference is not significant.

Permanganate index indicates the content of certain organic and reducing inorganic pollutants in water. It can be shown in Fig. 6 that the experimental water body is a natural pond in the campus, water supply primarily come from the natural precipitation, not exposed to industrial pollution. The organic and reducing inorganic in the water-sediment interchange little; therefore I_{Mn} did not change significantly during the entire experiment. Only after 100 days, *Salvinia* decomposes and releases some organic matter that uptake in growth period in the short term. Therefore I_{Mn} rises slightly higher than the control water body. Therefore, this experiment cannot decide whether the *S. natans* affect the permanganate index in other water body.

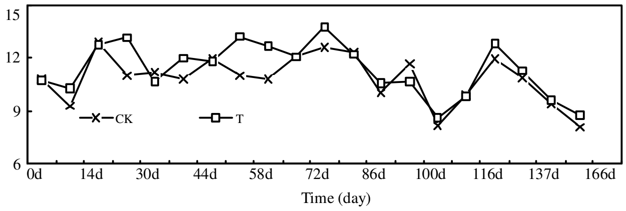


Fig. 6. I_{Mn} of the water bodies

During the *S. natans*(L.) growth period, dissolved oxygen content is falling with the growth of *S. natans*(L.), total nitrogen, total phosphorus and other major water qualities indicators is not only decreased, but increased in compared with the control water body, the water quality indexes of the experiment water body is roughly equal to the control after the experiment end, *S. natans* (L.) takes no significant role in improving water quality. When the *S. natans* (L.) coverage surpass 85 %, the *S. natans* (L.) population can significantly reduce the reaeration capacity of the water body and leads to the anaerobic state in compared with the control, the light transmission ability and the normal re-algae photosynthesis, that in turn, affects the various elements conversion in the water body, the sediment releases a lot of nitrogen and phosphate to the water, induces the total nitrogen, total phosphorus content increasing. Because of the experimental water zone is relatively small, the *S. natans* (L.) decomposes in a short time and do not impact the water quality, if the *S. natans* (L.) grows in a large water, it can absorb and fix some elements from the water body and the atmosphere and it rapidly decomposes in a short period of time, it will cause secondary pollution of water bodies.

Therefore, the ecological restoration selects the *Salvinia* as purification species in eutrophic water. The growth trend of *Salvinia* is closely monitored. The *Salvinia* coverage must be controlled by 80 % or less, it will seriously affect the reaeration capacity of the water body once the coverage beyond the threshold, affecting all kinds of organisms living in water. It can be selectively recovered by artificial means, on the one hand the Salvinia's coverage can be controlled, on the other hand the nitrogen, phosphorus and other elements fixed by *Salvinia* can be removed from the water. These measures can satisfies the control aim of the eutrophication of the water.

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