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COMPARISON OF SINGLE AND MIXED PLANT ARTIFICIAL FLOATING ISLANDS FOR DOMESTIC SEWAGE TREATMENT

Comparación de islas flotantes artificiales de una sola planta y mixtas para el tratamiento de aguas residuales domésticas

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Key words: mixed plants, water purification, sewage treatment, removal rate

ABSTRACT

The artificial floating island is an ecological restoration technology of water environment based on the principle of ecological hydraulics aiming at solving the problem of eutrophic water by degrading chemical oxygen demand, total nitrogen, and total phosphorus. It has good social benefits, environmental benefits, and broad application prospects. Against the backdrop of domestic wastewater treatment, the mixed plant-type artificial floating island, which include pickerel weed, *Scirpus tabernaemontani*, and bog rushes, was put into a test environment. Through the analysis of the adsorption and the absorption effect of various plants, the purifying effect of the mixed type of plant artificial floating island was thus determined and summarized based on the known total nitrogen, total phosphorus, and chemical oxygen demand values. According to the test results, it can be concluded that the effect of the mixed type of plant artificial floating island system in treating domestic wastewater is significant. The removal rate of total nitrogen and total phosphorus reached 55.12 % and 37.59 %, respectively, and the removal rate of chemical oxygen demand reached 47.85 %. The mixed type of plant artificial floating island can effectively dispose the nitrogen and phosphorus in the water.

Palabras clave: plantas mixtas, purificación del agua, tratamiento de aguas residuales, tasa de remoción

RESUMEN

La isla flotante artificial es una tecnología de restauración ecológica del medio acuático basada en el principio de la hidráulica ecológica destinada a resolver el problema del agua eutrófica mediante la degradación de la demanda química de oxígeno, nitrógeno total y fósforo total. Tiene buenos beneficios sociales, beneficios ambientales y amplias perspectivas de aplicación. Contra el telón de fondo del tratamiento de aguas residuales domésticas, una isla flotante artificial de tipo mixto, que incluye la hierba pontederia, *Scirpus tabernaemontani* y juncos de pantano, se puso a prueba. Mediante el análisis de la adsorción y el efecto de absorción de varias plantas, el efecto purificador de la isla flotante artificial de tipo mixto se determinó y resumió con base en los valores conocidos de nitrógeno total, fósforo total y demanda química de oxígeno. De acuerdo con

los resultados de la prueba, se puede concluir que el efecto de la isla flotante artificial vegetal de tipo mixto en el tratamiento de aguas residuales domésticas es significativo. La tasa de eliminación de nitrógeno total y fósforo total alcanzó el 55.12 % y 37.59 %, respectivamente, y la tasa de eliminación de la demanda química de oxígeno alcanzó el 47.85 %. La isla flotante artificial vegetal de tipo mixto puede disponer con eficacia del nitrógeno y el fósforo en el agua.

INTRODUCTION

With the continuous improvement of the living standards, people pay more and more attention to the ecological environment, especially the domestic sewage treatment, which is related to the development of sustainable development strategy, so it has become a hot topic in the current scientific field. Since 1980s, to improve the water quality of reservoirs, lakes and drinking water, Japan, United States, and other developed countries have adopted the plant ecological floating bed technology to treat water areas and achieved the goal of purifying water (Zhang et al. 2016). At present, artificial floating island technology has obtained a lot of applications in closed waters and has achieved a certain effect, but only restricted to multiple types of single plants as artificial floating island culture plants. While there are few studies on the effects of mixed cultivation of different types of plants and the treatment effect of domestic sewage (Yan et al. 2018).

The mixed type-plant artificial floating island refers to the integration of a variety of terrestrial plants and placing them in a carrier that can withstand plant growth in the water, to absorb nitrogen and phosphorus in the water with the help of plant growth, to purify water. Yang el al. (2019) chose *Cyperus alternifolius*, *Scirpus tabernaemontani* and loose strife to conduct their experiment, to solve the problem of eutrophication in the wetland of South China Sea. The results show that the hybrid plant artificial floating island is better than the single artificial floating island in removing the nitrogen and phosphorus and other organic matter, among which the artificial floating island mixing these plants is the best in treating nitrogen and phosphorus and other organic matter (Kong et al. 2019).

There are dry plant floating islands and wet plant floating islands, which are two common types at present. The former needs a bearing vessel, which is also the culture substrate of plants, while the latter uses a variety of materials to keep plants floating on the water surface and uses plant roots to form a floating bed. The selection of plants is the key to ensuring the efficient operation of artificial floating island (Yang et al. 2021). For this reason, according to the five principles of selecting floating island plants that is, strong pollution resistibility and purification capacity, developed root system, dense stems and leaves, adaptation to local conditions with native plants as focus, as well as high economic and ornamental value, this paper choose three plants to build a mixed artificial floating island, and tests the floating island in the experimental water (Jiang et al. 2018). On the one hand, it is necessary to verify the treatment effect of the mixed artificial floating island of domestic sewage. On the other hand, it is also necessary to compare and analyze the application effect of a single plant-type floating island and a mixed plant floating island, to clarify the application value of the mixed plant floating island, which is of great significance for water purification and environmental pollution resistance.

TEST MATERIALS AND METHODS

Test materials

In this experiment, pickerel weed, *Scirpus tabernaemontani*, and rush were selected as the raw materials to constitute the mixed artificial floating island, for the above three plants have high economic benefits and ornamental value, and they are easy to obtain in the local market. The height, fresh weight, and growth of the plants of same species are basically the same. The experimental material for simulating the artificial floating island is polystyrene foam board: 30 cm in length, 30 cm in width and 3 cm in thickness. The foam board is perforated, and the intervals are adjusted according to characteristics of the different plants to ensure that the foam board always floats on the water surface. At the same time, a bucket is chosen as the water carrying vessel. The inner diameter of the bucket is 30 cm, the height is 35 cm, and the total effective volume is 25 L (Wu et al. 2019, Zhao et al. 2019). The diameter and the height of the inner diameter of the pail should meet the placement requirements of the foam board. The

TABLE I. CONDITIONS OF TEST WATER.

Indicators for analyzed water	TN (mg/L)	TP (mg/L)	COD (mg/L)	pH
Average value of concentration	6.10	2.41	84.6	7.9-8.9
Range of concentration value	5.68-7.18	2.23-2.62	82.3-86.5	7.9-8.9

TN: total nitrogen, TP: total phosphorus, COD: chemical oxygen demand.

domestic sewage of a residential area is selected as the test water, and the relevant information of water is shown in **table I**.

Test method

The purpose of this experiment is to test the purification effect of a mixed plant floating island. The individual single-plant floating islands were separately put into the test water to monitor the changes in total nitrogen (TN), total phosphorous (TP), and chemical oxygen demand (COD) conditions. At the same time, the plants were mixed to test the purification effect of mixed type-plant floating island. By comparing the treated water with the conventional water with the quality index, the concrete effect of combinations of different types of plants can be clarified (Liao et al. 2019). By measuring and comparing the traditional water quality indexes of pond effluent treated by artificial floating islands, we can figure out which of the artificial floating islands are best capable of dealing with sewage water. At the same time, the plants on various floating islands are selected. The specific procedures are shown in **figure 1**.

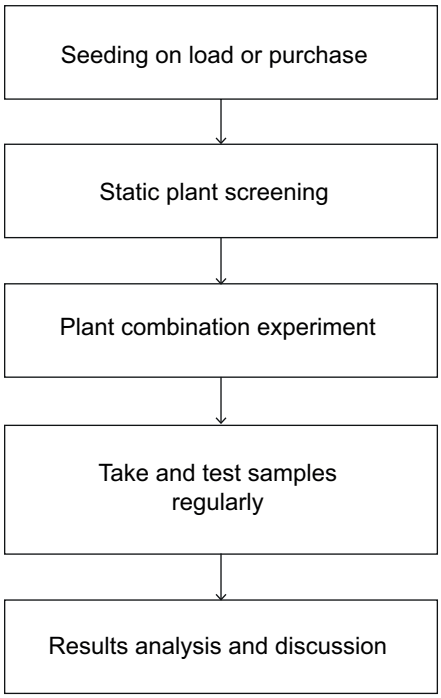

Fig. 1. Experimental procedure chart.

Test conditions

The three types of plants (pickerel weed, *Scirpus tabernaemontani*, and rush) were soaked in the plastic bucket for five days and then put into domestic sewage water. The test started on September 1, 2020, and ended on September 20, 2020, lasting for 20 days. At the same time, the water temperature in the test process is controlled between 25 ºC and 30 ºC to simulate the normal growth environment of plants. During the trial, the changes of domestic sewage were detected and analyzed and the growths of the three plants recorded at the same time. The data was collected at the fifth, tenth, fifteenth and twentieth day (Yang et al. 2016, Zhang et al. 2019). The actual application effect of artificial floating islands was determined by analyzing the changes of test water as well as the growing conditions of plant floating island .The floating island samples in this experiment were blank, pickerel weed floating island, *Scirpus tabernaemontani* floating island, rush floating island, mixed floating island of pickerel weed and *Scirpus tabernaemontani*, mixed floating island of pickerel weed and rush, and mixed floating island of *Scirpus tabernaemontani* and rush (Cui et al. 2016). The specific setting of artificial floating island is shown in **table II**.

Sampling

During sampling and analysis, 10 stere of domestic was injected into the test bucket for the first time, and then samples were taken from both the surface and bottom of the test water every five days during the soaking process. A total of 10 mL of samples was removed. After each sampling, the samples were evenly shaken to reduce the analysis error (Lu et al. 2019).

TABLE II. SETTINGS OF SIMULATED ARTIFICIAL FLOATING ISLANDS.

Category or floating island	Combinations
Blank water	Floating islands without any plants
Pickerel weed floating island	The six treated pickerel weeds were divided into three rows and fixed on the plastic foam board with two plants in each row
Scirpus tabernaemontani on floating island	The six treated green scirpus tabernaemontanionion were divided into three rows and fixed on the plastic foam board with two plants in each row
Rush floating island	The six treated rushes were divided into three rows and fixed on the plastic foam board with two plants in each row
Mixed floating island of pickerel weed and *Scirpus tabernaemontani*	The two types of plants were fixed on the plastic foam in two rows, with three pickerel weeds in one row and three *Scirpus tabernaemontani* in another row
Mixed floating island of pickerel weed and rush	The two types of plants were fixed on the plastic foam in two rows, with three pickerel weeds in one row and three rush weeds in another row
Mixed floating island of *Scirpus tabernaemontani* and rush	The two types of plants were fixed on the plastic foam in two rows, with three *Scirpus tabernaemontani* in one row and three rush weeds in another row

Test methods

Total nitrogen was determined by persulphuric acid clock oxidation ultraviolet spectrophotometry (UV-5200, Metash). Total phosphorus was determined by ammonium molybdate spectrophotometry (GL-660C, GLKRUI). COD was determined by heavy complex acid Bell method (COD-571, Leici). The fourth edition of Water and Waste water Monitoring and Analysis Methods (Wei 2002) are referred to decide the monitoring indexes and analysis methods. Water temperature, height of plant growing height, plant survival rate and so on were measured by the instrument on site.

RESULTS ANALYSIS AND DISCUSSION

When analyzing the purification effect of the floating island of plants, the growth of the three test plants should be clarified at first, that is, the survival rate and growth height of the plants should be counted. The specific situation is shown in **table III**.

Total nitrogen treatment of mixed plant floating island in test water

First, we analyzed the total nitrogen purification effect of various floating island samples in domestic sewage, that is, the TN removal effect of the test water; the results are shown in **table IV**.

Figure 2 shows the TN purification effect of various types of floating island samples in domestic sewage over time.

According to **table IV**, the TN value of domestic sewage remains the decline in the test cycle. Specifically speaking, the TN value of the original blank water is 6.10 mg/L, but when no artificial plant floating island is placed, the TN concentration value declines to 5.12 mg/L 20 days later. This decline in TN is due to volatilization in standing of the water (Zhang et al. 2018). Using different plants to make artificial floating islands, purification effect of TN in domestic sewage is roughly the same (Wang et al. 2018). Contrapose the analysis of the purification effect of mixed plant floating island, when using the mixed floating island of pickerel weed, *Scirpus*

TABLE III. SURVIVAL RATE AND GROWTH HEIGHT OF PLANTS.

The species of plant	Pickerel weed	*Scirpus tabernaemontani*	Rush
Rate of survival (%)	100%	100%	100%
The height of growth (cm)	4.2	3.8	3.6

TABLE IV. TN TREATMENT OF THE TEST WATER BY THE MIXED FLOATING ISLAND.

The species of floating island	Initial concentration (mg/L)	Concentration after the treatment (mg/L)	Purification efficiency (%)	Rate of relative purification (%)
Blank water	6.10	5.12	15.67	0.00
Barracuda floating island	6.10	3.06	48.84	33.06
Water onion floating island	6.10	3.68	38.86	23.08
Rush floating island	6.10	3.31	44.82	29.04
Mixed floating island of barracuda and water onion	6.10	2.81	52.87	37.09
Mixed floating island of barracuda and rush	6.10	2.67	55.12	39.34
Mixed floating island of water onion and rush	6.10	2.90	51.42	35.64

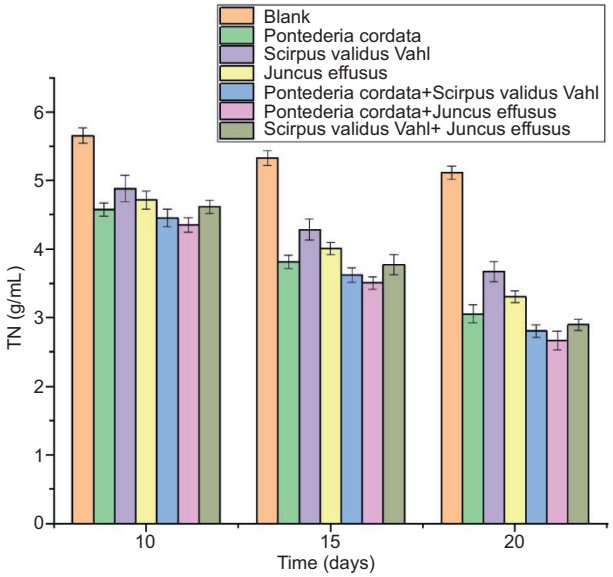

Fig. 2. TN of mixed floating islands to test water bodies over time.

tabernaemontani, the TN concentration was between 2.67 g/mL and 2.90 g/mL after 20 days. The application effect of the mixed plant floating island is more obvious than that of the single floating island, and the purification efficiency and relative purification rate can also be improved, indicating that the mixed plant floating island has a good treatment function for the total nitrogen in domestic sewage (Xinzhu et al. 2019). Therefore, it can be concluded that the TN removal effect of artificial floating island in blank water is relatively obvious, and mixed plant artificial floating islands perform better than single plant floating islands. During the first 10 days of the test period, the TN concentration in the water decreased slowly, and after 10 days, the rate of decrease increased. The reasons for this phenomenon may be when the experiment is carried out under static conditions, the early stage of the test mainly relies on the sedimentation of substances in the water. However, it takes time for the plant rhizosphere microbial community to form a biofilm with the plant root system on the artificial floating island, and the microbial identification and denitrification in the water are not obvious. This leads to the low utilization efficiency of the plant floating island, so the content removal effect is not obvious at the initial stage of treatment. After 10 days, the sedimentation is no longer a dominant factor, and plants in the artificial floating islands and microbes form a bio membrane system which strengthens the effect of treatment of plant artificial floating island. The efficiency of plants to adsorbing and absorbing soluble ammonia nitrogen and true nitrogen is increased. Due to mass propagation of plant secretions, the microbes in the water strengthen the nitrification and denitrification, leading to greater removal of ammoniacal nitrogen. That is why the removal rate is rapider late period of the experiment.

Total phosphorus treatment of mixed plant floating island in test water

Then, the purification effect of total phosphorus in domestic sewage of various floating island samples was analyzed, that is the removal effect of TP in the test water, which is shown in **table V**.

Figure 3 shows the TP purification effect of various types of floating island samples in domestic sewage over time.

As can be seen from **table V**, the TP value of domestic sewage was also in a downward trend during the test period, but the overall change was not as obvious as the decrease of TN concentration. Specifically, the initial TP value in the blank water was 2.41 mg/L, and when the artificial plant floating island was not placed, the TP concentration value would drop to 2.26 mg/L after 20 days. In this case, the purification efficiency was 5.84 % and the relative purification rate was 0 %. At the same time, for the analysis of the floating island with single plants, the total phosphorus concentration was in the range

TABLE V. TP TREATMENT OF THE TEST WATER BY THE MIXED FLOATING ISLAND.

The species of floating island	Initial concentration (mg/L)	Concentration after the treatment (mg/L)	Purification efficiency (%)	Rate of relative purification (%)
Blank water	2.41	2.26	5.84	0.00
Pickerel weed floating island	2.41	1.71	27.67	21.72
Scirpus tabernaemontani floating island	2.41	1.87	21.32	15.37
Rush floating island	2.41	1.83	22.91	16.95
Mixed floating island of pickerel weed and *Scirpus tabernaemontani*	2.41	1.53	34.81	28.86
Mixed floating island of pickerel weed and rush	2.41	1.46	37.59	31.64
Mixed floating island of *Scirpus tabernaemontani* and rush	2.41	1.62	31.24	25.29

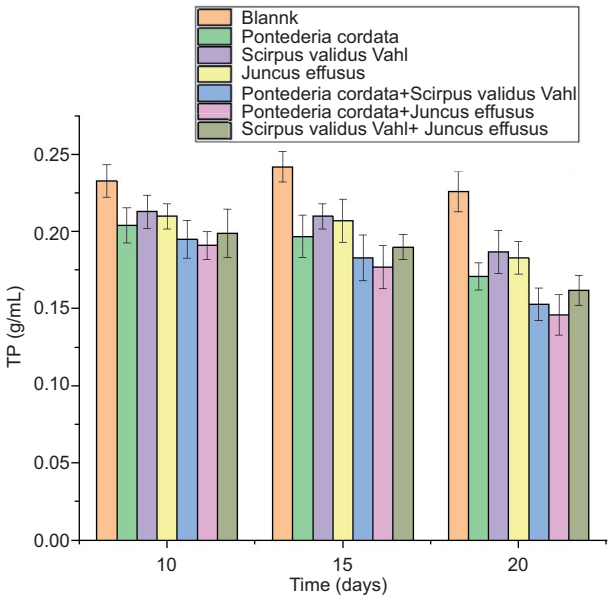

Fig. 3. TP of mixed floating islands to test water bodies over time.

of 1.46 ~ 1.87 g/ mL after 20 days, which had a very significant effect on removing total phosphorus compared with the blank water. For different kinds of plant floating island, the purification effect of pickerel weed floating island is slightly better than that of *Scirpus tabernaemontani* floating island and rush floating island (Schwantes et al. 2019. Then, according to the purification effect of the mixed plant floating island, it shows that the application effect of mixed plant floating island is more obvious than the one of single floating island, and both the purification efficiency and relative purification rate are improved. Among them, the mixed floating island of pickerel weed and rush can ensure the best total phosphorus removal effect (Ma et al. 2020). It can be concluded that the total phosphorus removal effect of artificial floating island in blank water is more obvious, and mixed plant artificial floating island is better than single plant floating island in removing the total phosphorus.

During the test period, the TP concentration in the water showed a dynamic change law: the early decline was faster, the mid-term decline rate slowed down, and then the later decline was faster. The reasons for this phenomenon may be as follows: under the condition of static test, the substances in the water are removed mainly due to sedimentation in the early period of test. A part of insoluble phosphorus and organic phosphorus subsides, and the rhizosphere microbial community of the floating island need time to take shape to form biofilm with the root system of the plant, which altogether made the utilization efficiency of the floating island low and the content removal effect not obvious at the early stage of treatment. The sedimentation test of insoluble phosphorus and organic phosphorus in water showed that the microbial community in the hovering rhizosphere takes time to generate, so the utilization efficiency of plant floating islands is low. For 10-15 days, the sedimentation effect was significantly weaker than that in the early stage of the experiment. The biofilm system formed by plants and microorganisms on floating

islands significantly enhanced the treatment effect of floating islands. Some soluble parts were adsorbed by plant roots and then absorbed by plant metabolism, which accelerated the decrease of TP content in the middle and late stage of the experiment. On the late period of experiment, rhizosphere aerobic microorganisms need a large amount of dissolved oxygen for mass reproduction, which leads to the content of dissolved oxygen failing to meet the biological needs of species in water ecological environment. Therefore, the aerobic microorganisms gradually perish, and the rhizosphere bio membrane fall off. When these microorganisms die, the insoluble phosphorus in the body will return to the water, so content will decrease slower and slower. The sedimentation of some substances in the water reduces the phosphorus content in the water, which is the reason for the decrease of phosphorus content in the blank sample.

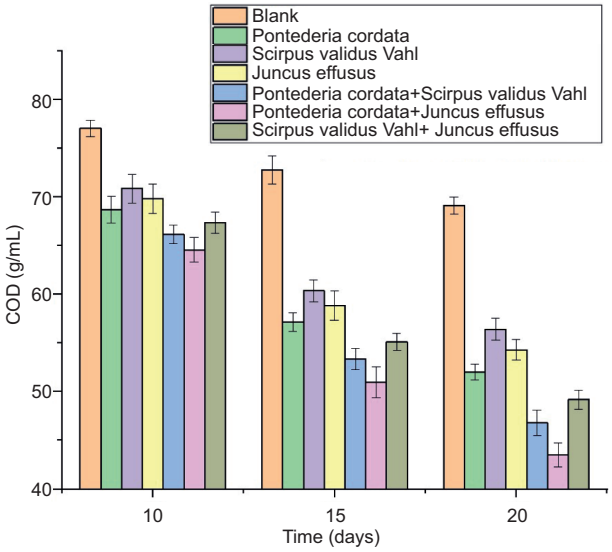

Fig. 4. COD of mixed floating islands to test water bodies over time.

The chemical oxygen demand treatment of mixed plant floating island in the test water

Finally, the COD purification effect of various floating island samples in domestic sewage is analyzed, as shown in **table VI**.

Figure 4 shows the COD purification effect of various types of floating island samples in domestic sewage over time.

It can be seen from **table VI** that the COD value of domestic sewage is in a downward trend during the test cycle. Specifically, the initial COD value of blank water is 84.6 mg/L, and when artificial plant floating island is not placed, the COD concentration will drop to 69.1 mg/L after 20 days. In this case, the purification efficiency is 17.98% and the relative purification rate is 0%. At the same time, according to the analysis results of floating islands with a single plant, the COD content in the water decreased significantly, and the purification effect of the floating island of pickerel weed was also better than that of the floating island of *Scirpus tabernaemontani* and rush, which was like the rule of the total ni-

TABLE VI. COD TREATMENT OF TEST WATER BY MIXED FLOATING ISLANDS.

The species of floating island	Initial concentration (mg/L)	Concentration after the treatment (mg/L)	Purification efficiency (%)	Rate of relative purification (%)
Blank water	84.6	69.1	17.98	0.00
Pickerel weed floating island	84.6	52.0	37.95	19.84
Scirpus tabernaemontani floating island	84.6	56.4	32.80	14.71
Rush floating island	84.6	54.3	35.25	17.16
Mixed floating island of pickerel weed and *Scirpus tabernaemontani*	84.6	46.8	44.00	25.91
Mixed floating island of pickerel weed and rush	84.6	43.5	47.85	29.76
Mixed floating island of *Scirpus tabernaemontani* and rush	84.6	49.2	41.20	23.11

trogen removal effect (Liu et al. 2019, Dong et al. 2020). In terms of the purification effect of mixed plant floating island, the mixed floating island of pickerel weed, and rush can ensure the best COD removal effect among all the different combinations of plants. Therefore, it can be concluded that the total phosphorus removal effect of artificial floating island for blank water is relatively obvious, and the COD removal effect of mixed plant artificial floating island is better than that of single plant floating islands (Xiao et al. 2018).

During the static test, the decrease rate of the COD concentration in the water was slow at first and then fast. The reasons for this phenomenon may be: when the experiment is carried out under static conditions, the early stage of the test mainly relies on the sedimentation of substances in the water. A part of the test water body subsides, and the rhizosphere microbial community of the floating island need time to take shape to form biofilm with the root system of the plant, which altogether made the utilization efficiency of the floating island low and the content removal effect not obvious at the early stage of treatment. After 10 days, the sedimentation was no longer dominant, but the comprehensive removal effect of microorganisms and plants was significantly enhanced, and the efficiency of plant adsorption and absorption in the test water was increased, so that the content was removed faster in the later stage of treatment.

DISCUSSION OF RESULTS

According to the test results, the artificial floating islands made up of pickerel weed, *Scirpus tabernaemontani* and rush plants can effectively remove nitrogen and phosphorus elements in domestic sewage, and the combination of different types of plants as a mixed floating island has a better application effect. Through the test of mixed floating island samples with different plants, the best removal rates of TN, TP and COD were 55.12%, 37.59% and 47.85% (ASS et al. 2018). In terms of the overall treatment of TN, TP, COD and so on in domestic sewage, we can see that hybrid floating island of pickerel weed and rushes can achieve the best effect of purification. Moreover, the relative purification rate is more obvious. Therefore, it is necessary to carry out in-depth analysis of the combined effect of the two in future research. At the same time, mixed plant floating island can improve the transparency of domestic sewage samples to a certain extent. Plants can also grow better by fully absorbing nitrogen and phosphorus elements in the water. Hybrid plant artificial floating island is more suitable for treating eutrophication in the water (Giang et al. 2017, Deng et al. 2018, Manikanda et al. 2018).

CONCLUSION

To sum up, in the improvement and construction of the national economic system, the natural environment has been damaged to a certain extent. At the same time, a large amount of sewage caused by people's work and life has also caused a great operating load on the ecological cycle. Therefore, it is necessary to apply modern science and technology reasonably, integrate the concept of sustainable development, and focus on people's livelihood projects, to provide a good living environment for people. Rational combination of mixed artificial floating island, on the one hand, can meet the needs of ecological and environmental protection, to achieve the role of purifying domestic sewage. On the other hand, the superfluous nutrient components in water can be used to promote plant growth, so as to achieve the complementary effect.

The research used a hybrid plant artificial floating island as a starting point. It took using pickerel weed, *Scirpus tabernaemontani* and rush as experimental materials, put different floating island mode into sewage sample in both separate and combined way. After test, this research analyzed the overall conditions according to total phosphorus and total nitrogen in water, and the COD removals so as to determine purification value of the mixed floating island. Combined with the test results, we can see that the floating island made up of pickerel weed, *Scirpus tabernaemontani* and rush can effectively remove nitrogen and phosphorus elements in domestic sewage, meanwhile, combining different types of plants into mixed floating island can achieve better effects. Through the test of mixed floating island samples with different combinations of plants, the best removal rate can be obtained as follows: the values of TN, TP and COD are 55.12%, 37.59% and 47.85% respectively. Compared with the best removal rate of single plant floating island, the values of TN, TP and COD respectively are 48.84%, 27.67% and 37.95%. The removal rate of TN, TP and COD of mixed floating island has obvious improvement with different plant collocation. In addition, the mixed plant floating island can effectively improve the transparency of sewage, and the nitrogen and phosphorus elements

in the water can provide sufficient nutrient support for the plant floating island. The mixed plant artificial floating island can be widely used in the future work of ecological protection and sewage treatment, to improve the economic applicability of related work and provide a stable impetus for the strategic goal of sustainable development in China.

AUTHOR DISCLOSURE STATEMENT

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