Research Progress on Water Purification Efficiency of Multi-plant Combination in Constructed Wetland

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Abstract. The constructed wetland has the powerful purification sewage function, the plant is the core of the constructed wetland, playing the vital role in the water body decontamination restoration process. The common plant species in constructed wetland were summarized and classified (floating plants, floating plants, emergent plants, submerged plants, ornamental plants and economical plants). The factors and basic principles that need to be considered when configuring a variety of plants in a constructed wetland combination for decontamination are described, including decontamination purification capacity, environmental adaptability, and the economic and ornamental value of multiple plants, etc. The current research contents and directions are emphatically reviewed, focusing on the functions and efficacy of nitrogen and phosphorus removal and purification of heavy metal wastewater by various plant combinations in constructed wetlands. It is pointed out that there are many shortcomings in the research of decontamination process of many plants, such as imperfect planting standards, lacking of research on the mechanism of decontamination among various plants, between various plants and substrates, and root microorganisms. Many kinds of plants have not been dealt with properly after harvesting, resulting in waste of resources and secondary pollution and other problems. Therefore, in the future research on the purification and restoration of various plant waters in constructed wetlands, a universally applicable planting specification for various plants in constructed wetlands should be formulated; exploring and analyzing how various plants and various plants interact with substrates and root microorganisms function to achieve water purification and repair effects; In addition, fuel ethanol technology, Biogas fermentation and biomass solid fuel technology should be developed to realize the resource reuse of wetland plants and improve the purification efficiency of wetland plants.

1. Introduction

In recent years, the problem of water pollution has become more and more serious, and water purification has become a research focus in the field of water treatment [1, 2]. Constructed wetland as a kind of water treatment technology with simple process structure, low construction cost, high decontamination efficiency, stable operation and easy maintenance, has been widely used in the field of sewage purification treatment [3–5]. The water purification of constructed wetland is mainly achieved
through the adsorption, absorption and decomposition of the substrate, plants and microorganisms [6]. Research has shown that the constructed wetland system can remove 59.8% of NH4+-N, 44.3% of TN, 62.1% of TP, 73.4% of COD and 81.8% of BOD on average [7]. Wetland plants are the core of constructed wetlands and play an important role in the purification of sewage: on the one hand, they absorb, transform, and fix pollutants in the sewage through their own tissues, thereby reducing the concentration of pollutants and purifying the sewage; on the other hand, plant roots provide oxygen and secrete oxygen to form aerobic, facultative and anaerobic micro-environments around the rhizosphere, which provide habitats for microbial nitrification and denitrification, thereby promoting the degradation of pollutants in sewage [8, 9].

At present, many studies are limited to the research on the effect of single wetland plants on water purification, and single wetland plants are affected by various stress factors such as water pollution, seasonal changes, soil, etc., and their stability is poor, which is not conducive to the formation of long-term stable plant communities. It is difficult to achieve the ideal denitrification and dephosphorization effect. Compared with a single wetland plant, the construction of a variety of wetland plant ecological combinations encourages them to learn from each other's strengths, reduce the impact of stress factors, and form a more stable plant community, which not only achieves a more ideal purification effect, but also plays a role in beautifying the water landscape [10, 11]. At the same time, it plays an important role in promoting ecological restoration, managing agricultural non-point source pollution and improving the water environment [12]. Therefore, the deployment of multiple wetland plant combinations is very important in the field of sewage treatment and has become a research hotspot.

This study divides the types of plants commonly used in constructed wetlands, summarizes the factors and basic principles that need to be considered when configuring a variety of plants in constructed wetlands to decontaminate, and focuses on the effectiveness and application of multiple plant combinations in constructed wetlands in China. At the same time, the prospects for the future research focus on the purification and restoration of water bodies by multiple plants in constructed wetlands are put forward, which provides a certain theoretical basis and reference for the selection of multiple plant combinations in constructed wetlands and future research directions.

2. Classification of plants

Plants constitute the main body of constructed wetlands. Many scholars divide their types into floating plants, emergent plants, submerged plants, ornamental plants and economic plants according to their morphology, lifestyle and economical value. Common floating plants include *Eichhornia crassipes, Pistia stratiotes, Salvinia natans, Azolla imbricate* and *Nymphaea tetragona*, etc. Common emergent plants include *Canna indica, Acorus calamus, Iris pseudacorus, Typha orientalis, Thalia dealbata* and *Phragmites communis*, etc. Common submerged plants include *Hydrilla verticillata, Ceratophyllum demersum, Myriophyllum verticillatum* and *Ottelia acuminata*, etc. Common ornamental plants include *Monstera deliciosa, Pachira glabra, Gardenia jasminoides, Spathiphyllum kochii, Anthurium andraeanum* and *Chlorophytum comosum*, etc. Common economical plants include *Solanum lycopersicum, Oryza sativa, Brassica juncea var, Medicago hispida, Ipomoea aquatica* and *A. tuberosum*, etc.

3. Principles for the allocation of multiple plants in constructed wetlands

The selection and configuration of plants is very important for constructed wetlands. Differences in plant growth characteristics in constructed wetlands will significantly affect the purification effect of sewage. Blind application of plant configuration models in other regions may lead to low efficiency of sewage denitrification and phosphorus removal, and even bring foreign sources. The problem of plant invasion. Many scholars have focused on the following factors in the research on the decontamination process of the combined deployment of multiple plants in constructed wetlands:
3.1. Pollution tolerance of plants, the effect of nitrogen and phosphorus removal

Plants are an important part of constructed wetlands, and the selection of plants first considers their stain resistance and decontamination properties. Different types of plants have obvious differences in pollution tolerance and purification ability to pollutants. A comparative analysis of the nitrogen and phosphorus purification effects between *Oryza sativa* and *Ipomoea aquatica* economic plants showed that *Ipomoea aquatica* has better pollution resistance and purification ability than *Oryza sativa* [14]. Through the research on the sewage purification effect of emergent plants and submerged plants, the results show that the average removal rate of total nitrogen, total phosphorus, and permanganate index of *Eichhornia crassipes* reached 46.25%, 36.84%, and 42.27% respectively. The effect of sewage treatment Obviously [15]. Research on the denitrification and dephosphorization effects of 29 different types of wetland plants found that *Phragmites communis*, *Canna indica*, *Typha orientalis* and *Arundo donax* have high sewage purification capacity; *Zantedeschia aethiopica*, *Cyperus alternifolius*, *Nymphaea tetragona* and *Pistia stratiotes* have medium purification capacity; and *Trapa bispinosa* wastewater purification ability is low [14].

In order to enhance the efficiency of nitrogen and phosphorus removal in constructed wetlands, when selecting plants, the ability of different plants to purify sewage should be considered. Studies have shown that *Eichhornia crassipes* has a better denitrification effect [17]; *Bambusa multiplex* can widely reduce the nitrogen concentration, and the *Epipterygium aureum* can treat water with higher concentration of nitrogen [18]; *Eichhornia crassipes*, *Imperata cylindrica* and *Ipomoea aquatica* have better dephosphorization effects [19]; *Morus alba* is suitable for a wide range of phosphorus water bodies, *Juncus effusus* are suitable for high-concentration phosphorus water bodies, and *Sesbania cannabina* is suitable for low-concentration phosphorus water bodies [20]; *A. tuberosum* can absorb As, Cr and Hg heavy metals to the greatest extent [21].

3.2. Environmental adaptability of plants

Since different regions have different environmental backgrounds, the growth of wetland plants is closely related to the local climate, soil and other regional environments. Therefore, the selection of various plants in constructed wetlands should be adapted to local conditions to achieve a more ideal sewage purification effect.

In the northeast Harbin area, *Typha orientalis* and *Sagittaria trifolia* have been proved to have strong environmental adaptation and sewage purification capabilities [22]; In the Guanting Reservoir area of North China, *Pistia stratiotes* has better denitrification and phosphorus removal effects[23]; In eastern China, *Vetiveria zizanioides* and *Canna indica* are suitable for sewage remediation and purification plants[24]; In the Hubei reservoir area of Danjiangkou in central China, *Oenanthe javanica*, *Ramunculus sceleratus* and *Miscanthus floridulus* are more suitable for sewage treatment[25]; In the coastal areas of South China, *Kandelia candel* and *Laguncularia racemosa* have the strongest tolerance to water pollutants[26]; In the southwestern region of China, the decontamination ability of *Cyperus alternifolius* is better and is less affected by the local climate [27]; In the northwestern region of China, *Phragmites communis* have strong decontamination and drought tolerance[28]; In the islands and coastal areas of China, the salt tolerance, wetland tolerance and sewage purification effect of the *Bolboschoenus planiculmis*, *Rupiaceae*, *Suaeda salsa* and *Sesuvium* are better [29]. In addition, in different seasons in the same area, the effects of nitrogen and phosphorus removal by wetland plants are also different. On the whole, the decontamination and purification effect of wetland plants on sewage shows that summer > spring > autumn > winter [30, 31].

The growth and reproduction of wetland plants are closely related to the local climate, soil and geographical conditions, and are also restricted by the degree of pollution of the water body, which affects the effect of wetland plants on sewage treatment. When the sewage concentration is too high, it may cause wetland plants to wither and die; when the sewage concentration is too low, it is not conducive to the absorption of N, P, K and other nutrients by the plants and affect their growth and reproduction. Studies have found that under the condition of 200 mg L⁻¹ of TAN in sewage, *Canna indica* and *Iris tectorum* grow well and have good decontamination effects [32]; When the concentration of Kjeldahl
nitrogen in the sewage is 54.5 mg/L, the Typha orientalis in the constructed wetland will turn yellow and even die [33]. Therefore, different types of wetland plants should be allocated scientifically and rationally according to the degree of pollution of the water body in order to maximize the decontamination ability. Research on the effects of different submerged plants on the denitrification and phosphorus removal of low, medium and high concentrations of domestic sewage, it is found that Hydrilla verticillata has good decontamination effects in high-concentration sewage, while Ceratophyllum demersum and Ottelia acuminata var. are in medium and low-concentration sewage. The effect of denitrification and phosphorus removal is good [34]; Through the analysis of the decontamination and purification effects of different economic plants on different pollution levels of water bodies, the results show that A. tuberosum and Medicago hispida are more suitable for higher polluted water bodies, Phyllostachys heteroclada is more suitable for lower polluted water bodies, and Colocasia esculenta is not suitable for artificial use [35]; By comparing the advanced treatment of water with different pollution levels by different ornamental plants, it is found that in the sewage area with a higher degree of pollution at the front end of the constructed wetland, water purification such as Bambusa multiplex, Pachira glabra, Spathiphyllum kochii and Epipremnum aureum can be planted. In the sewage area with low pollution at the end of the constructed wetland, Monstera deliciosa and Gardenia jasminoides can be planted for restoration Water quality [17].

3.3. Ornamental value of plants
Ornamental value is one of the important factors in the selection of artificial wetland plants. The ecological aesthetic value of wetland plants plays a vital role in optimizing the artificial wetland environment, regulating and enriching people's spiritual world [36]. Therefore, the relationship between plant species collocation, reasonable layout and landscape aesthetics should be fully considered, and scientific configuration should be carried out to maximize the ornamental value of plants [37]. In the horizontal layout, the collocation of ornamental plants and foliage plants should be followed. In the spatial configuration, the collocation of deep-rooted plants and shallow-rooted plants should be considered, and in the time configuration, the collocation of evergreen plants and seasonal plants should be taken into consideration. There are flowers in the four seasons and the unique artificial wetland landscape in each season [38]. In the Ams Lake Plan of St. Paul City, the United States, a variety of native emergent, floating, submerged and xerophyte plants were used in a reasonable configuration [39]. In the artificial wetland system of the Olympic Forest Park, a variety of native foliage plants, flower plants, aquatic ornamental plants, habitat plants, etc. are reasonably selected to match each other [40], which visually constructs an artificial integration of nature and humanity. The wetland landscape not only enhances the capacity of the constructed wetland to purify sewage to a certain extent, but also shows the aesthetic value of the ecosystem to the greatest extent.

4. Research on the decontamination and purification effects of different plant configuration combinations

4.1. Research on nitrogen and phosphorus removal by different plant combinations
Nitrogen and phosphorus in domestic sewage are not only the nutrients needed for plant growth and reproduction, but also the main substances that cause eutrophication and pollution of water bodies. Therefore, the research on solving the problem of water pollution through the absorption and transformation of nitrogen and phosphorus by plants has become a focus of attention. The mechanism of plant denitrification is to convert ammonium nitrogen and nitrate nitrogen in sewage into nitrogenous compounds such as amino acids, and become a component of the plant body through assimilation and transformation to achieve the denitrification effect. The mechanism of plant dephosphorization is to absorb the phosphorus in the sewage in the form of orthophosphate by plants, and the ATP of synthetic plants is fixed by the plant to achieve the dephosphorization effect [41].

Different plants in constructed wetlands have different sewage denitrification and dephosphorization purification capabilities [42]. Many scholars used a variety of plant combinations to construct a
constructed wetland system for decontamination and purification studies. The results showed that the combined removal rate of TP, TN, and COD in the constructed wetland combination of Cyperus alternifolius + Myriophyllum verticillatum + Sparganium stoloniferum was 98.36%, 98.64% and 95.49% [43]; The removal rates of TP, TN, and COD by the combination of Lemna minor + Spirodela polyrrhiza + Pistia stratiotes were 80%, 90%, and 75%, respectively [44]; The average removal rates of TP, NH3-N, COCdr and SS by the combination of Cyperus alternifolius + Phragmites communis + Canna indica + Acorus calamus were 95%, 95%, 62.4% ± 11.2%, 86.5% ± 6.7% [45]; The maximum removal rate of TP, NH3-N and COD in livestock wastewater by the combination of Pontederia cordata + Canna indica + Trapa incisa + Ceratophyllum demersum were 94.66%, 92.77%, 92.88% [46]; The decontamination rate of Myriophyllum spicatum + Iris wilsonii + Scirpus validus on TP and TN in sewage reached 74.38% and 89.73%, respectively [47]; The removal rate of TP, TN, NO3- -N, NH3-N, and DIP by the combination of Hydrocotyle verticillata + Pistia stratiotes is 64. 5%, 68. 6%, 62. 6%, 78.2%, 80%, respectively [48]. Numerous studies have found that compared with a single plant control group, the decontamination and purification effect of a constructed wetland system constructed by a combination of multiple wetland plants is more obvious [49–51]. Comparing the decontamination effects of various plant combinations, it was found that the combination of Cyperus alternifolius + Myriophyllum verticillatum + Sparganium stoloniferum became the most significant plant configuration for denitrification and phosphorus removal. The research on the decontamination and purification of various plant configurations in constructed wetlands mainly focuses on the simple description of their decontamination efficiency, and does not specifically analyze how a variety of plants work together to achieve water purification and restoration effects. Therefore, in the future research directions, it should be more in-depth Research on the mechanism of cooperative decontamination mechanism of various plants provides a strong reference for water purification and restoration.

4.2. Study on the absorption of heavy metals in sewage by different plant combinations

In constructed wetlands, plants mainly remove heavy metal elements in sewage through the following two ways: First, the roots of wetland plants change the rhizosphere by secreting oxygen, sugar, enzymes, organic acids, amino acids, endogenous hormones and some secondary metabolites. The environment can inactivate, activate or change the valence of heavy metal ions and reduce toxicity; the second is that wetland plants directly absorb and transport the ionic state of heavy metals, so that heavy metals can be adsorbed and accumulated in the above-ground parts of plants, thus achieving Degradation and removal of heavy metals [36].

Many studies have found that different wetland plants have different adsorption and degradation effects on different types of heavy metals in sewage. In order to improve the overall removal efficiency of different types of heavy metals in sewage, scholars have configured different plant combinations to remove and degrade heavy metals in sewage. The study found that the maximum removal rate of total Cr and Gr6+ of the combination of Iris pseudacorus + Pistia stratiotes + Hydrilla verticillata in the constructed wetland was 52.8% and 56.4%, respectively, and the adsorption effect of heavy metals was obvious [52]; The average cumulative removal rate of Cr, Pb, Cu, and Zn in the sewage by the combination of Cyperus sylvestris + Phragmites communis + Scirpus validus + Typha orientalis was 86.62%, 54.50%, 2.74% and 44.21%, respectively, removal and degradation efficiency is significant [53]; Compared with the control group, the combination of Iris tectorum + Lythrum salicaria + Phalaris arundinacea has the best absorption and absorption capacity for sewage Pb2+ [54]; Scirpus triqueter + Canna indica + Iris pseudacorus + Lythrum salicaria is the best plant combination configuration for removing Cr, Zn, Fe, Mn, Ni, Cu and other heavy metals in sewage [55]; The combination of Lemna minor + Ipomoea aquatica + Eichhornia crassipes significantly improved the decontamination effect of sewage Pb2+/Cd2+ [56]. At present, researches on the removal of heavy metals in sewage with multiple plant configurations are mostly focused on the absorption and degradation of heavy metals by plant selection and configuration, while ignoring the problems of waste of resources and secondary pollution that are not properly treated after harvesting a variety of plants. Therefore, in the future research direction, it is necessary to further study fuel ethanol technology, biogas fermentation, and biomass solid
briquette technology to realize the resource reuse of various wetland plants and improve the overall removal effect of heavy metals.

5. Conclusions and prospects
At present, the research on the purification of sewage with a variety of plant combinations in constructed wetlands mainly focuses on plant selection and configuration, plant combination denitrification, phosphorus removal efficiency, and analysis of heavy metal reduction functions in sewage, and significant results have been achieved. However, there are still many shortcomings, such as imperfect planting specifications, lack of research on the synergistic decontamination mechanism among various plants, various plants and substrates, and root microorganisms. Many plants have not been properly treated after being harvested. Problems such as waste of resources and secondary pollution. Therefore, the future research on the water purification and restoration of a variety of plant combinations in constructed wetlands will focus on the following:

More suitable specifications for planting intervals, suitable water levels, and suitable soils for various plants in constructed wetlands should be formulated. The adaptability and detergency of constructed wetland plants are promoted to a relatively ideal state through appropriate man-made adjustment of environmental factors.

It is necessary to carry out further research on the physiological and ecological mechanism of the plant combination of constructed wetland and the dynamic mechanism of decontamination and purification, Explore and analyze how various plants can synergistically achieve purification and restoration effects, and provide a more powerful theoretical basis for the construction, management, and operation of constructed wetlands.

Water purification and restoration are mainly accomplished through matrix adsorption, plant absorption and enrichment, and root microbial nitrification and denitrification. Strengthen the coupling between a variety of plants and different substrates and root microorganisms to achieve the purpose of synergistically removing water pollutants.

In-depth research must be conducted on fuel ethanol technology, biogas fermentation, and biomass solid briquette technology to realize the resource reuse of multiple plant combinations, improve the overall purification effect, and avoid a variety of plants that are not properly treated after being harvested, resulting in resource waste and secondary pollution and other issues.

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