



Effects of Submerged Macrophyte Decomposition on Water Quality

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ABSTRACT

Submerged macrophytes play an important role in aquatic ecosystems and are widely used in aquatic ecological restoration. However, when submerged macrophytes fade, litter, or even decompose, they may cause adverse effects on water quality. In this article, indoor experiments were carried out to study the quantitative influence of submerged plant decomposition on water quality. Six submerged macrophytes commonly used in aquatic ecological restoration in Sichuan Province, including *Elodea canadensis* Michx., *Potamogeton wrightii* Morong, *Potamogeton crispus* L., *Vallisneria spirulosa*, *Ceratophyllum demersum* L., and *Potamogeton pectinatus* L., were selected to measure the change processes of nutrients during macrophyte decomposition at 10°C, 20°C and 30°C. The results showed that the decomposition of submerged plants released nutrients into the water body, causing water pollution. At 10°C, the total phosphorus (TP) concentration of water bodies containing submerged plant litter increased by 1.97 to 5.97 times on the 50th day compared to the 5th day, while the TP concentration of the blank control group without hydrophytes decreased from 0.39 mg.L⁻¹ to 0.22 mg.L⁻¹ due to self-purification. The ammonia nitrogen (NH₃-N) concentration increased by 3.82-9.58 times on the 50th day compared with the 5th day, while the value in the blank control group decreased from 1.42 mg.L⁻¹ to 0.78 mg.L⁻¹. This result indicated that the water body had a certain self-purification ability, but the decomposition of aquatic macrophytes had a negative impact on this progress. Increasing temperatures could accelerate plant decay processes. Initially, the concentrations of NH₃-N and TP were high with high temperatures. After 45 days of reaction, the NH₃-N and TP concentration in the water bodies appeared to be 30°C < 20°C < 10°C, indicating that decomposition was further advanced when the temperature was higher. This study provides a theoretical basis for water ecological management and water quality protection.

INTRODUCTION

Submerged macrophytes, which are important parts of shallow lake ecosystems, play a crucial role in material circulation and abiotic and biotic processes in shallow lakes and are effective measures used to repair water pollution (Gao et al. 2017, Wang et al. 2018). However, a large amount of organic matter and nutrients can be released into the water column when submerged plants decay, a process in which plant tissues are broken down and discharged, causing the dissolved oxygen in the water to decrease, even forming black and odorous water (Zhang et al. 2018, Chen & Wang 2019). Therefore, it is necessary to study the decomposition of aquatic plants to provide scientific guidance for the removal of withered plants in aquatic ecological restoration and the long-term maintenance of water quality.

The decomposition process of aquatic macrophytes is related not only to the nature of the plants but also to

changes in the external environment (Zhou et al. 2018). Factors affecting the decomposition of aquatic macrophytes include plant species, dissolved oxygen, pH, temperature, microorganism species, and nutrient conditions (Liu et al. 2017, Yang et al. 2020). Corstanje et al. (2006) studied the effect of nutrient availability on the decay of aquatic plants, and the results showed that nutrient enrichment increased the decay rate of *Typha latifolia*, while the decomposition of *Cladium jamaicense* was not significant, which indicated that different plant species have different sensitivities to nutrient conditions. Li et al. (2014) simulated the decay process of *Hydrilla verticillata* Royle in Lake Taihu in spring at four biomass levels and found that there was no significant correlation between the decay rate and the initial biomass; however, different carbon: nitrogen (C:N) ratios and carbon forms could affect the concentrations of total nitrogen (TN) and total phosphorus (TP) in the decay process. Passerini et al. (Passerini et al. 2016) studied the de-

composition process of *Eichhornia azurea*, *Eleocharis* sp., and *Salvinia auriculata* and found that oxygen and temperature had a significant effect on decomposition. Compared with anoxic conditions, decomposition was accelerated by 1.25 times under conditions of oxygen availability, while a temperature increase of 10°C accelerated decomposition by 1.35 times. Zhang et al. (2017) conducted experiments to examine the effects of nitrogen enrichment and temperature in the decomposition processes of *Deyeuxia angustifolia* and *Carex lasiocarpa* and found that nitrogen enrichment slowed decomposition at 5°C and 15°C but had neutral or positive effects at 25°C, which suggested that increased temperatures were conducive to the decay process. Grasset et al. (2017) carried out an in situ decomposition experiment and selected three aquatic plants that were decomposed with different nutrient contents in seven wetlands along a nutrient gradient. The results showed that the plant mass loss for competitive and ruderal species was higher, and a higher nutrient content accelerated the decay rate. Yu et al. (2019) studied the decay process of *Zizania latifolia* and found that a large amount of nutrients was released into the overlying water during the experiment, and the nutrient content increased with increasing plant biomass. Due to the limitation of in situ experimental controllability, which is vulnerable to water temperature, water quality, plant biomass, and other experimental conditions, the results are not consistent. Meanwhile, related studies did not use raw water in laboratory experiments, though there are differences between the test results and natural conditions. In addition,

the local dominant plants were selected in previous experiments, which limited the application of the test results in other regions. Furthermore, local dominant plants were used in most experiments, which limited the popularization and application of the achievements in other regions.

Therefore, this paper selected submerged macrophytes commonly used in aquatic ecological restoration in Sichuan Province and conducted experiments with natural raw water to study the impact of aquatic plant decomposition on the C, N, and P of the overlying water under controlled temperature conditions to guide the design, management, and maintenance of submerged macrophytes in local aquatic ecological restoration.

MATERIALS AND METHODS

Experiments were conducted at the State Key Laboratory of Hydraulics and Mountain River Engineering (SKLH) at the Sichuan University of China. Submerged plants were placed in water columns at specific temperatures for the decomposition experiments. Meanwhile, an experiment was carried out in a water column without submerged macrophytes and used as a blank control group to determine the changes in various water quality indicators in the overlying water.

Experimental Materials

Macrophytes: Six submerged macrophytes, including *Elodea canadensis* Michx., *Potamogeton wrightii* Morong, *Potamogeton crispus* L., *Vallisneria spirulosa*, *Ceratophyllum*



Fig. 1: Submerged macrophytes selected for experiments.

demersum L., and *Potamogeton pectinatus* L. were selected as research objects (Fig. 1).

The initial fresh weight was 25 g, and the distribution density of submerged macrophytes in the water column was $6.25 \text{ g}\cdot\text{L}^{-1}$. Using nylon bags to conduct decomposition experiments of the submerged macrophytes, large mesh litter bags were considered likely to cause plant decomposition, and litter bags that were 200 mesh in size were selected; the weighed plants into them and immersed in the water column.

Sampled water: To ensure the consistency of pollutant characteristics between the experimental water and the natural river water, the Jinjiang River in Chengdu was sampled as the reaction water. The location of the sampling site is shown in Fig. 2.

Sediment: In the experiments, the surface sediment of the same reach of the Jinjiang River was collected synchronously with sampled water, and the freshly collected sediment was treated with an 18-mesh screen to remove plant residues and debris. A 10-cm-thick layer of treated sediment was placed at the bottom of the water column as the reaction basis.

Experimental Device

A plexiglass cylinder with a height of 50 cm and a diameter of 11 cm was selected as the experimental container, where the water column was 4 L, and the thickness of the bottom sediment was 10 cm. Submerged macrophytes were placed in the cylinder to monitor the changes in water quality indicators during the decay process. The experimental device is shown in Fig. 3. To control the experimental temperature conditions, experiments were conducted under conditions of constant temperature and humidity at the laboratory of Sewth-Z-285.

Setup of Scenarios

Water temperature conditions of 10°C , 20°C , and 30°C were set. The experimental scenarios are shown in Table 1.

Methods for Monitoring and Measurement

To comprehensively reflect the changes in water quality during the submerged plant decay process, the water quality detection indexes during the experiments were selected as follows: pH, DO (dissolved oxygen), water temperature,

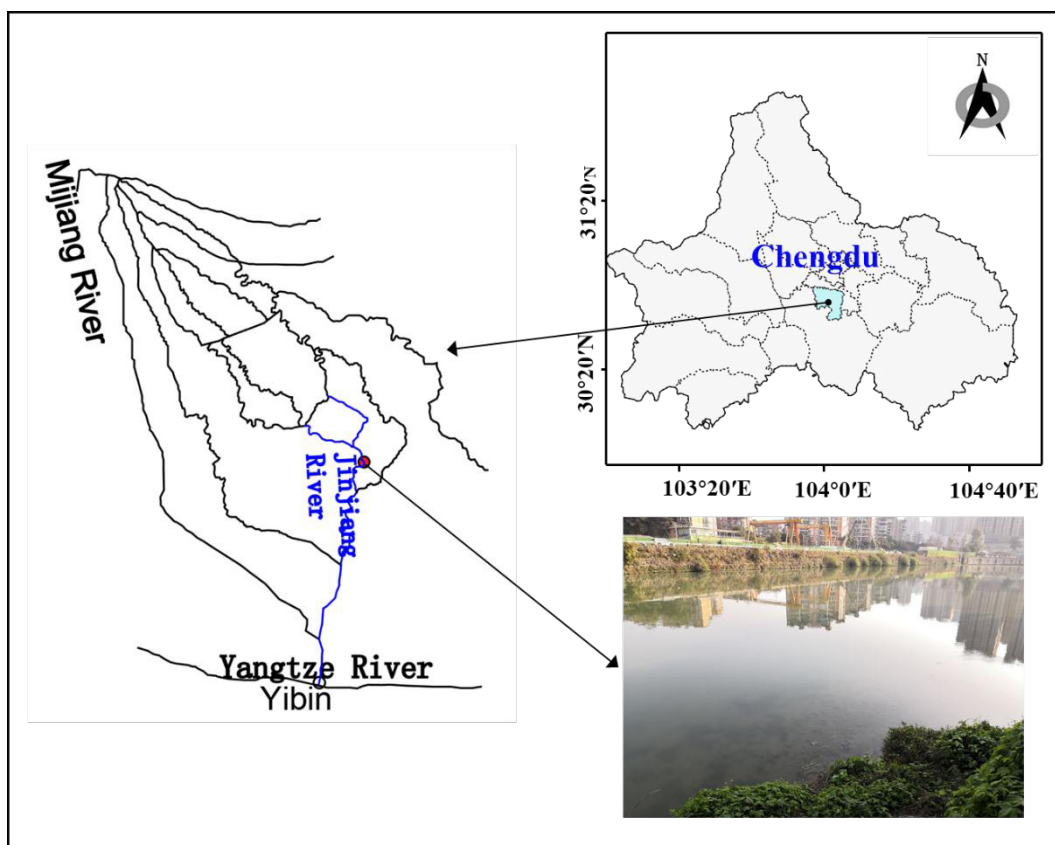


Fig. 2: Location of the sampling site.

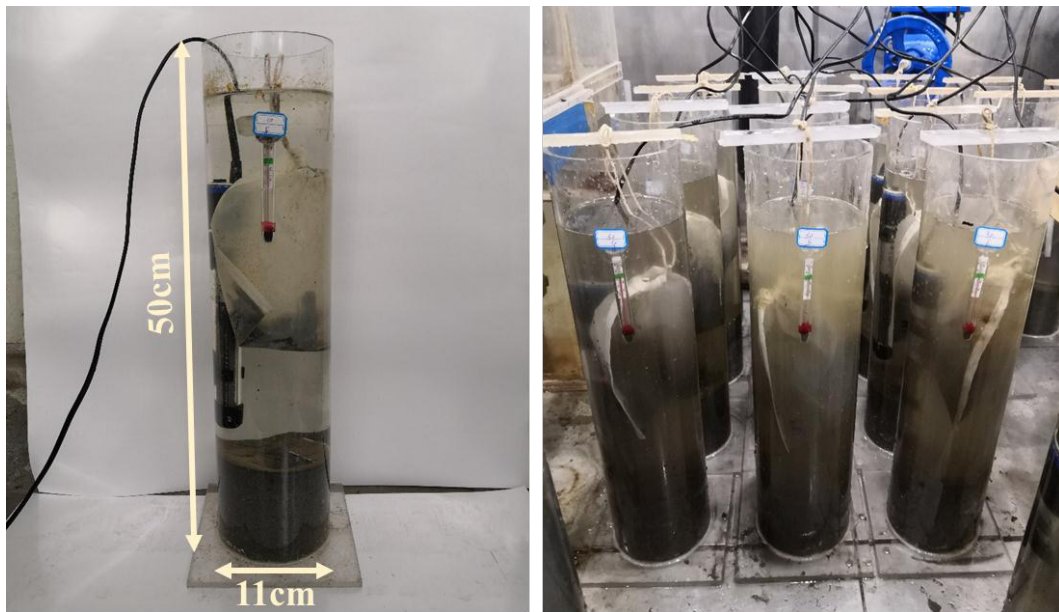


Fig. 3: Experimental device used to study the decomposition of submerged macrophytes.

Table 1: Scenarios of decomposition experiments.

Selected submerged macrophyte	Water temperature [°C]	Name of scenario
<i>Elodea canadensis</i> Michx.	10	10-1
	20	20-1
	30	30-1
<i>Potamogeton wrightii</i> Morong	10	10-2
	20	20-2
	30	30-2
<i>Potamogeton crispus</i> L.	10	10-3
	20	20-3
	30	30-3
<i>Vallisneria spirulosa</i>	10	10-4
	20	20-4
	30	30-4
<i>Ceratophyllum demersum</i> L.	10	10-5
	20	20-5
	30	30-5
<i>Potamogeton pectinatus</i> L.	10	10-6
	20	20-6
	30	30-6
Blank	10	10-0
	30	30-0

Cond (conductivity), SD (Secchi depth; transparency), TOC (total organic carbon), COD (chemical oxygen demand), TP (total phosphorus), $\text{NH}_3\text{-N}$ (ammonia nitrogen), $\text{NO}_2\text{-N}$ (nitrite nitrogen), and $\text{NO}_3\text{-N}$ (nitrate-nitrogen). During the decay process, the wet-weight biomass of submerged plants was measured simultaneously. The measurement methods of each index are shown in Table 2.

RESULTS AND DISCUSSION

Biomass of Submerged Macrophytes and Apparent Properties of Water Bodies

As shown in Fig. 4, the biomasses of six submerged plants during the decay process were compared. Different plants had different changes under the same temperature conditions, and the biomass changes of the same plant were also different under different temperatures. At 10°C, the wet-weight biomass of most submerged macrophytes increased after the decay process, which may have been due to the transportation and shelving of experimental plants, in which a great amount of the initial moisture content of plants was lost. After the aquatic plants were placed in the litter bags and decomposed in the water column, the water absorption of the plant residue increased, which led to an increase in the moisture content of the residue in the litter bag. Among all submerged plants, the wet-weight biomass of *Potamogeton pectinatus* L. increased the most, which might have been

Table 2: Determination methods of the decay experiment index.

Monitoring index	Determination method	National standard
pH	Glass electrode method	GB 6920-86
DO	Electrochemical probe method	HJ 506-2009
Water temperature	Thermometer or reversing thermometer method	GB 13195-91
Conductivity	Conductivity metre method	GB/T 6908-2008
SD	Diaphanometer and disc method	SL 87-1994
TOC	Combustion oxidation nondispersive infrared absorption method	HJ 501-2009
COD	Dichromate method	HJ 828-2017
TP	Ammonium molybdate spectrophotometric method	GB 11893-89
NH ₃ -N	Nessler's reagent spectrophotometry	HJ 535-2009
NO ₂ ⁻ -N	Diazo-couple spectrophotometry	GB/T 5750.5-2006
NO ₃ ⁻ -N	Thymol spectrophotometry	GB/T 5750.5-2006

due to the strong water absorption and relatively difficult decomposition process. At 20°C and 30°C, after a period of decomposition, the biomass of *Elodea canadensis* Michx. and *Potamogeton crispus* L. both decreased, which may have been related to the temperature difference. Under aerobic conditions, decomposition was independent of temperature variation, and the effect was always antagonistic; however, in anaerobic decomposition, the increase in temperature advanced decomposition (Paccagnella et al. 2020).

As shown in Fig. 5, at the initial state of the experiments, the transparency of most water bodies was poor. In the control

group without submerged plants, the transparency of the water column was greatly improved. Compared with the transparency of water columns under different temperatures, the transparency of water bodies containing submerged plants was already very low at the initial state, which may have been due to the transparency being measured after the experimental water body was stable, in which the soluble organic compounds leached faster, causing the water transparency to decrease (Tamire et al. 2017). The transparency changed slightly except for the groups containing *Potamogeton pectinatus* L., which might have been because *Elodea canadensis*

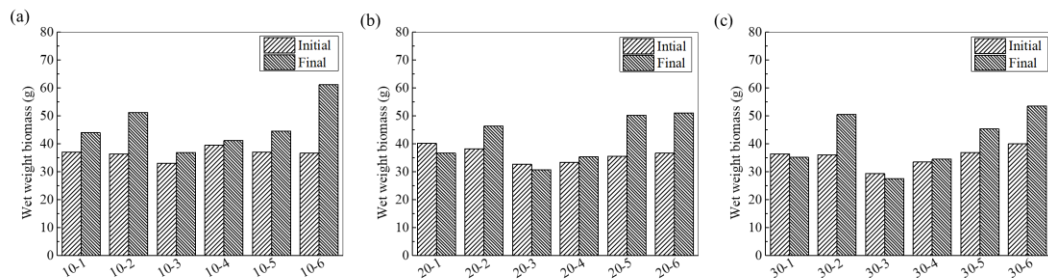


Fig. 4: Comparison of the initial and final states of wet-weight biomass of submerged macrophytes.

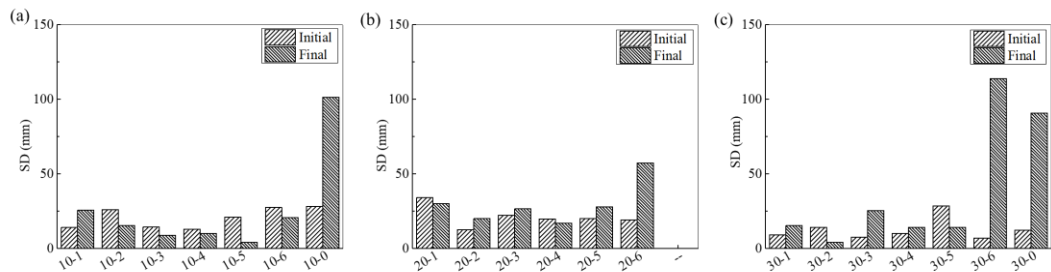


Fig. 5: Comparison of the initial and final states of transparency of the water column.

Michx., *Potamogeton wrightii* Morong, *Potamogeton crispus* L., *Vallisneria spinulosa* and *Ceratophyllum demersum* L. experienced a rapid leaching stage, in which the organic matter was broken and released into the water body; in contrast, *Potamogeton pectinatus* L. was hard to decompose, and its shape was well preserved, so the transparency of the water body was less affected.

Basic Physicochemical Properties of Water Bodies

As shown in Fig. 6, all of the water bodies were weakly alkaline. At different temperatures, the pH of the water bodies containing submerged plants was 7.2-7.9 in the initial state. After the reaction period, it increased slightly to 7.8-8.5. In general, the pH in all water bodies increased slightly after the reaction, which might have been due to hydrogen ions produced by nitrification reacting with carbonic acid, which caused the pH value to rise, leading to the pH of the final state being slightly higher than that the initial state. Because nitrifying bacteria can remain active in a pH range of 6.5-8.5 (Tyson et al. 2004), the pH of all water bodies was conducive to the progress of nitrification.

Conductivity is a measure of the ability of a substance or solution to conduct electrical current through water, and this value can reflect the concentration of dissolved inorganic salts and be used as a basis for the determination of water quality (Gupta et al. 2013). As shown in Fig. 7, the conductivity of the water bodies containing submerged plants was between 456-584 μS in the initial state and increased to 615-

953 μS in the final state. Under the same water temperature conditions, there was no significant difference in the conductivity of each group of water bodies containing submerged plants, but there was an obvious difference under different water temperature conditions, indicating that the conductivity may be more susceptible to the influence of temperature than to the difference in plant species. The higher the temperature was, the faster the conductivity increased, and the maximum increase in conductivity was observed at 30°C.

DO is an important indicator in water bodies and can directly reflect their state. As shown in Fig. 8, at 10°C, the DO value of the water bodies containing submerged plants was severely anoxic, with a DO value of 0.40-4.21 mg/L, and the DO value of all water bodies was very low in the final state. At 30°C, the DO concentration of the water bodies containing *Elodea canadensis* Michx., *Potamogeton crispus* L., *Vallisneria spinulosa*, and *Potamogeton pectinatus* L. was lower, which indicated that the increase in temperature promoted decomposition. In the final state, the DO concentration of water bodies was lowest at 10°C. The DO concentration of water bodies at 20°C and 30°C was slightly higher than that at 10°C, which might have been due to the slower decay of submerged plants at 10°C, causing the decay process at 10°C to lag behind that at 20°C and 30°C. It can be seen from the DO concentration of various water bodies under different temperatures that water bodies containing submerged plants had already experienced serious oxygen consumption in the initial state, and the low dissolved oxygen concentration of

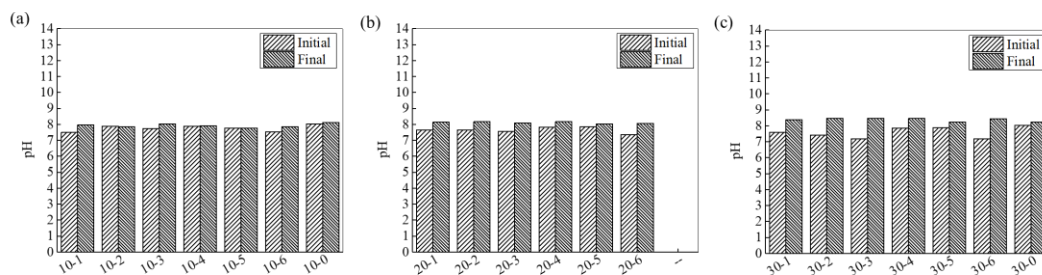


Fig. 6: Comparison of the initial and final states of the pH values of the water bodies.

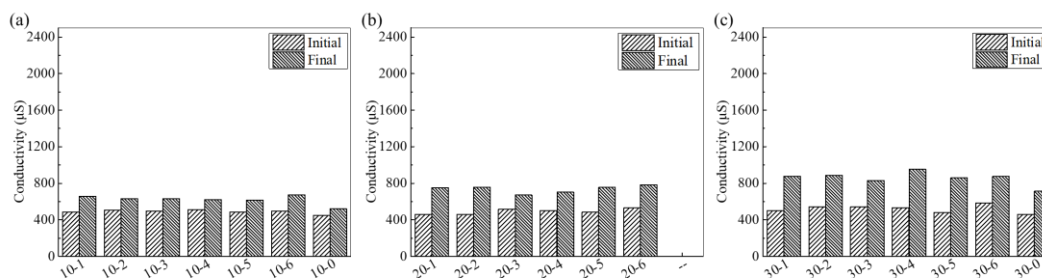


Fig. 7: Comparison of the initial and final states of conductivity of water bodies.

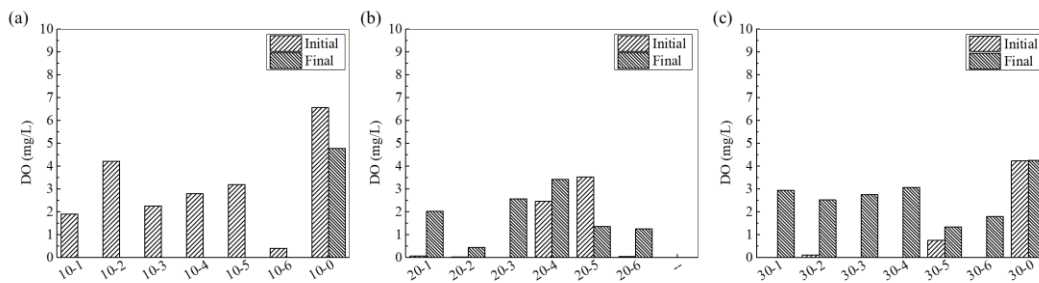


Fig. 8: Comparison of the initial and final states of the DO concentration of water bodies.

the water body caused by oxygen consumption might have induced the black and odorous water.

Contents of C, N and P in Water Bodies

As shown in Fig. 9, compared with the control group, the COD concentration of water bodies containing submerged plants did not increase significantly at 10°C, which might have been due to the slow decay process and the mild release of organic matter under this water temperature. At 20°C and 30°C, the COD concentration of the water bodies containing submerged plants increased after decomposition. In the initial stage, a large amount of soluble substances in the plant residues dissolved quickly, which led to an increase in organic matter and other reducing substances in the water body. As the decay process continued, the dissolved oxygen in the water body was consumed and decreased to a low degree,

which might have inhibited the decomposition of organic matter; additionally, the increase in the DO concentration in the later period would increase the degradation of organic matter (Wu et al. 2017). Thus, the overall COD concentration showed a trend of first increasing and then slowly decreasing.

Fig. 10 shows the total organic carbon (TOC) concentrations of all groups in the initial and final states. In the initial state, the TOC concentration of water bodies under different temperatures was as follows: 10°C > 20°C > 30°C. In the final state, the TOC concentrations of water bodies under different temperatures had only small differences. In the early period of decomposition, the dissolution of soluble organic carbon in the plant residues led to a rapid increase in the TOC concentration, and then, due to the degradation of microorganisms, it gradually decreased. After some time, sparingly soluble substances appeared in the decomposition process,

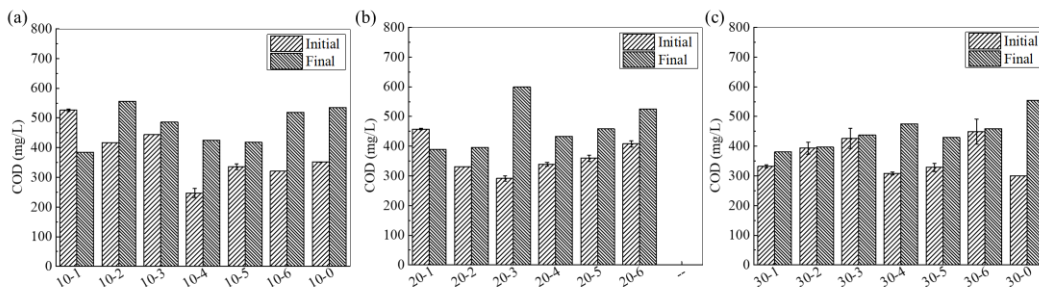


Fig. 9: Comparison of the initial and final states of the COD concentration of water bodies.

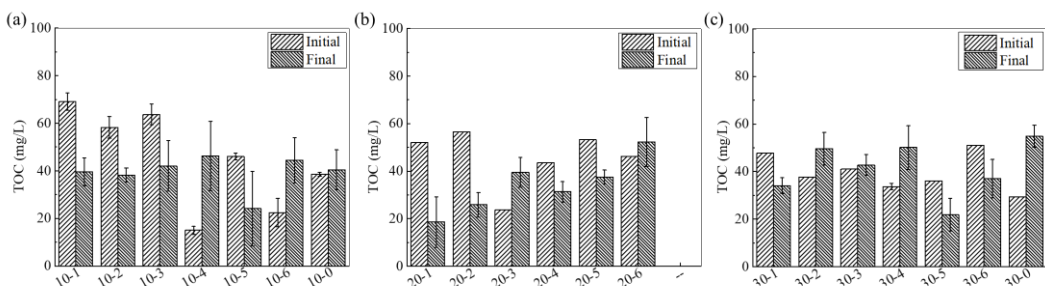


Fig. 10: Comparison of the initial and final states of the TOC concentration of water bodies.

and the TOC concentration in the water bodies tended to be stable. Since the initial state of the experiments measured in this article had already experienced the reaction for 5 days, the TOC concentration in water bodies had reached a high concentration, and the increased temperature accelerated the degradation of organic matter. Thus, the experiments had already reached the next stage in the 20°C and 30°C conditions, so the TOC concentrations of all water bodies appeared higher in the initial state at 10°C. Because the decay process had progressed to a stable stage in the final state, there was no significant difference in the TOC concentration of all groups at different temperatures.

Fig. 11 shows that the $\text{NH}_3\text{-N}$ concentration in water bodies in the final state was significantly higher than that in the initial state, and the $\text{NH}_3\text{-N}$ concentration in water bodies under different temperatures showed different changes. In the initial state of decomposition, the concentration of all groups

showed a trend of having a higher temperature and a higher initial concentration, that is, $30^\circ\text{C} > 20^\circ\text{C} > 10^\circ\text{C}$. However, after 45 days of reaction, the $\text{NH}_3\text{-N}$ concentration in all water bodies was as follows: $30^\circ\text{C} < 20^\circ\text{C} < 10^\circ\text{C}$. In the initial stage of the decay process, the leaching and mineralization of organic nitrogen led to a rapid increase in the $\text{NH}_3\text{-N}$ concentration in the water bodies, which was subsequently affected by nitrification and gradually decreased (Huang et al. 2017). In the initial state, the $\text{NH}_3\text{-N}$ concentration in the water bodies was higher when the temperature was higher, which was caused by the increased water temperature promoting nutrient release. After the reaction proceeded for some time, the $\text{NH}_3\text{-N}$ concentration of the water bodies under low temperature was greater than that under higher temperature, which might have been because the low temperature caused a slower decay rate, delaying the release of $\text{NH}_3\text{-N}$ caused by aquatic plant decomposition.

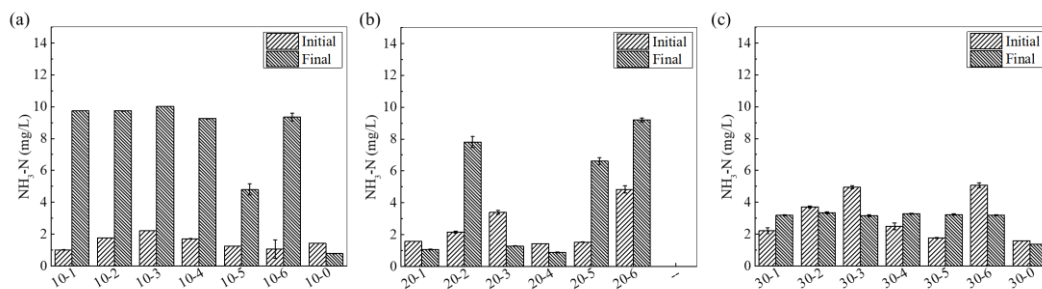


Fig. 11: Comparison of the initial and final states of the $\text{NH}_3\text{-N}$ concentration of water bodies.

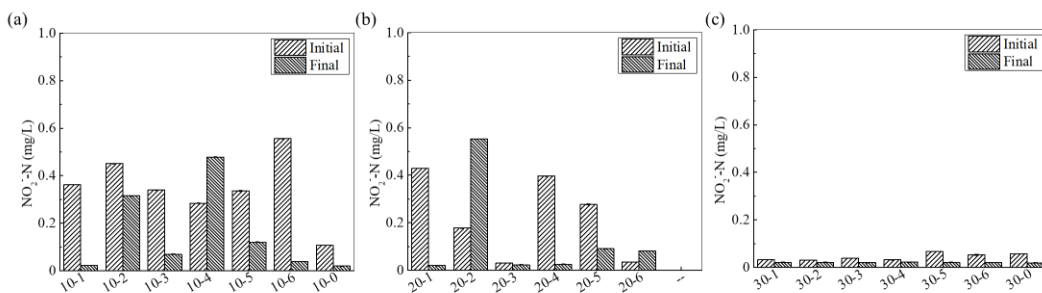


Fig. 12: Comparison of the initial and final states of the $\text{NO}_2\text{-N}$ concentration of water bodies.

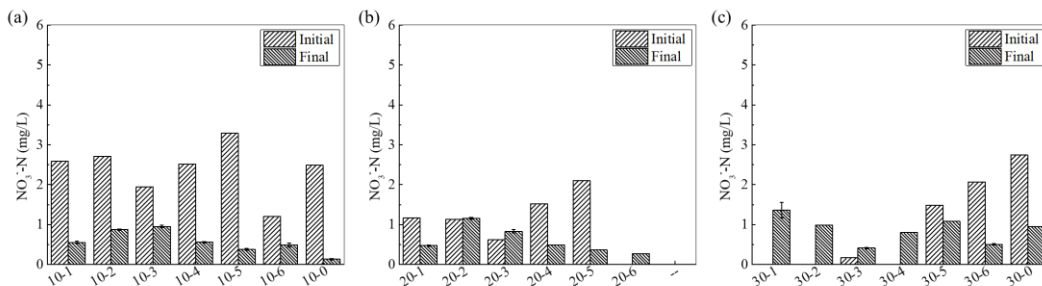


Fig. 13: Comparison of the initial and final states of the $\text{NO}_3\text{-N}$ concentration of water bodies.

The NO_2^- -N concentration of water bodies under different temperatures showed a trend in which the final state had a lower concentration than the initial state (Fig. 12). At 10°C , the NO_2^- -N concentration in water bodies was 0.11-0.56 mg/L in the initial state, except when it increased in the water bodies containing *Vallisneria spinulosa*; however, in the other groups, the value decreased to 0.02-0.32 mg/L after 45 days of reaction. At 20°C , the NO_2^- -N concentration in the water bodies was 0.03-0.43 mg/L in the initial state, except when it increased in the water bodies containing *Potamogeton wrightii* Morong; however, in the other groups, the value decreased to 0.02-0.09 mg/L in the final state. At 30°C , the NO_2^- -N concentration of water bodies was 0.03-0.07 mg/L in the initial state and decreased to approximately 0.02 mg/L in the final state.

The variation in the NO_3^- -N concentration in water bodies under different temperatures was different (Fig. 13). At 10°C , the NO_3^- -N concentration of the water bodies was 1.20-3.29 $\text{mg}\cdot\text{L}^{-1}$, and it significantly decreased to 0.13-0.95 $\text{mg}\cdot\text{L}^{-1}$ in the final state. At 20°C , the NO_3^- -N concentration of the water bodies containing submerged plants was lower than that at 10°C in the initial state. Except for the increase in NO_3^- -N concentration in the water bodies with *Ceratophyllum demersum* L. and *Potamogeton pectinatus* L., the values in the water bodies with the other species all decreased. At 30°C , the NO_3^- -N concentrations of the water bodies containing *Elodea canadensis* Michx., *Potamogeton wrightii* Morong, and *Vallisneria spinulosa* were all low, and the NO_3^- -N concentrations of the water bodies containing these three types of submerged plants and *Potamogeton crispus* L. increased in the final state.

The NO_2^- -N and NO_3^- -N concentrations in water bodies both declined, which might have been due to the nitrogen element in the water body and the sediment transformation from nitrogen to N_2O , N_2 , and other gases that escaped under the combination of ammonification, nitrification, and denitrification, resulting in the contents of NO_2^- -N and NO_3^- -N being lower in the final state than in the initial state.

The variation in the nitrate concentration was significantly related to temperature, and denitrification was inhibited under low temperatures; additionally, an increase in temperature was conducive to the progress of denitrification (Song et al. 2013). Thus, the nitrate concentration of water bodies was lower when the temperature was higher in the final state.

Fig. 14: Comparison of the initial and final states of the TP concentration of water bodies shows the comparison of the TP concentration in the initial and final states. At 10°C , the TP concentration in water bodies in the initial state was 0.34-0.53 $\text{mg}\cdot\text{L}^{-1}$, except when the value decreased in the control group; in the remaining groups, the TP concentration increased to 0.90-3.14 $\text{mg}\cdot\text{L}^{-1}$ in the final state. At 20°C , the TP concentration in the water bodies containing submerged plants was 0.38-1.23 $\text{mg}\cdot\text{L}^{-1}$ in the initial state and increased to 0.77-2.14 $\text{mg}\cdot\text{L}^{-1}$ in the final state. At 30°C , the TP concentration of the control group and that in the water bodies containing *Potamogeton crispus* and *Potamogeton wrightii* Morong decreased in the final state. In the early period of decomposition, the amount of P released from the plant residues to the water bodies increased rapidly, reaching a maximum after approximately 15 days, and then sedimentation occurred with an increase in time, resulting in a gradual decrease in the P concentration (Wang et al. 2018). The TP concentration of the control group in the final state was lower than that in the initial state, which might have been due to the sedimentation and transformation of TP in the absence of nutrient inputs, resulting in a decrease in the TP concentration. The TP concentration in the water bodies containing submerged plants increased in the final state, which might have been caused by the decomposition of submerged plants releasing P nutrients into the water bodies, increasing the TP concentration.

Uncertainty of Results

During the experiment, high-frequency continuous monitoring of the water quality change process was not conducted, and precise quantitative monitoring and descriptions of the

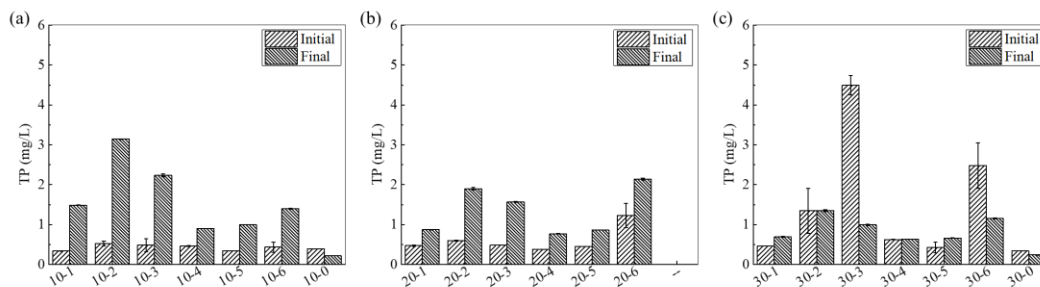


Fig. 14: Comparison of the initial and final states of the TP concentration of water bodies.

variations in some black and odorous indexes in the reaction process were not yet available.

This article measured the changes in water quality indicators during decomposition but did not consider the changes in various indicators in plant tissues and sediments. In the future, we will systematically study the cyclic transformation of substances in complex water-plant-sediment systems and add special monitoring and research on odor-causing factors to further analyze the impact of the plant decay process on the environment.

CONCLUSION

In this article, six submerged plants commonly used in aquatic ecological restoration in Sichuan Province, including *Elodea canadensis* Michx., *Potamogeton wrightii* Morong, *Potamogeton crispus* L., *Vallisneria spirulosa*, *Ceratophyllum demersum* L., and *Potamogeton pectinatus* L., were selected to conduct decomposition experiments under different temperature conditions.

The results showed that (1) the decomposition of submerged plants could release nutrients into water bodies. The TP concentration of the water bodies containing submerged plants at 10°C increased by 1.97-5.97 times on the 50th day compared with the 5th day, while the control group decreased from 0.39 mg.L⁻¹ to 0.22 mg.L⁻¹. The NH₃-N concentration of the water bodies containing submerged plants increased by 3.82-9.58 times on the 50th day compared with the 5th day, while the control group decreased from 1.42 mg.L⁻¹ to 0.78 mg.L⁻¹, which showed that the water body had a self-purification ability, but the decomposition of aquatic plants changed the self-purification ability of the water body, causing pollution. (2) The increase in temperature accelerated the decay processes of aquatic plants. In the final stage, the decay process was promoted by increasing the temperature. When the temperature was higher, the decomposition of aquatic plants progressed to a later stage, and the water quality was worse under lower temperatures.

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