

Article

Effects of Aquatic Vegetation Decomposition River Nutrient Conditions: A Case Study on the Jeonjucheon River, South Korea

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Abstract: Aquatic vegetation plays an important role in maintaining the health of river ecosystems. However, few studies have evaluated the impact of vegetation decomposition on water quality in rivers. Therefore, we aimed to analyze the effect of aquatic vegetation decomposition on nutrient conditions in the Jeonjucheon River in South Korea. To this end, we determined the distribution and biomass of four dominant species: *Phragmites japonica* Steud., *Phragmites australis* (Cav.) Trin. ex Steud., *Miscanthus sinensis* Andersson, and *Rumex crispus* L. Additionally, we conducted a nutrient leaching experiment to determine the contributions of different species to the nutrient status of the river. We found that the decomposition concentrations of total nitrogen (TN) and total phosphorus (TP) were the highest for *P. japonica* (7.74 mg/L) and *R. crispus* (1.59 mg/L). The annual load of TN from decomposition was 536,171.6 kg/yr and that of TP was 57,547.1 kg/yr. The total pollution load for the Jeonjucheon River was 2,903,885.3 kg/yr for TN and 17,602.1 kg/yr for TP. However, the TN and TP contribution from vegetation decomposition was negligible compared to that from other sources. This study serves as a valuable reference for sustainable management of river vegetation and water pollution.

Keywords: sustainable rivers; river vegetation management; aquatic vegetation; river nutrients; water quality; nitrogen; phosphorus



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1. Introduction

Climate change caused by global warming has led to rapid changes in natural ecosystems. The influx of non-point source pollutants from floods has contributed to increased levels of nutrients in water bodies such as rivers [1]. High nutrient levels and rising water temperatures support the mass production of algae, leading to eutrophication, which disrupts the balance of aquatic ecosystems and worsens water quality [2]. Aquatic vegetation can effectively control eutrophication in rivers by removing water pollutants. Plants perform many important ecosystem services including purifying water and providing feeding and spawning habitats for aquatic organisms [3].

Aquatic vegetation plays an important role in maintaining the ecological environment of water bodies owing to their ability to absorb nitrogen and phosphorus from rivers through physicochemical and biological interactions between the plant tissues, soil, microorganisms, and water-soluble nutrients [4]. Additionally, vegetation reduces erosion on the waterfront of rivers and prevents soil abrasion. Plant leaves generate oxygen in the water and their roots absorb carbon dioxide and nutrients. In the water, the amount of dissolved oxygen is increased through photosynthesis, which promotes the decomposition of organic phosphorus by aerobic microorganisms. In addition to absorbing nutrients from the water to support its growth, aquatic vegetation releases nutrients back into the water when it decays, particularly during the dormant period in winter. To minimize the impact of this seasonal influx of nutrients on river water quality, aquatic vegetation can be removed

or managed [5]. Thus, aquatic plants maintain the biodiversity of the aquatic ecosystem by regulating nutrient levels.

Numerous studies were conducted on aquatic vegetation in the 1970s [6–8]. Related research is still ongoing, including Xiang et al. [9], Zhang et al. [10], and Nengwang et al. [11]. Many studies have been conducted on aquatic vegetation in South Korean rivers and lakes [12], and potential uses for vegetation removed from water bodies have been investigated. Han et al. [3] evaluated the fertilizer value of biochar produced from decomposed aquatic vegetation. Choi et al. [5] analyzed the suitability of composting decomposed aquatic vegetation for agricultural use. However, Son et al. [13] proposed retaining and utilizing decaying aquatic vegetation in pond-type wetlands in rural and urban areas to improve vegetation diversity, increase the organic matter content, and improve the soil environment. Previous studies on aquatic vegetation have mainly focused on its water purification effect through evaluations of total phosphorus (TP) and total nitrogen (TN) content. However, few studies have investigated the impact of aquatic vegetation decomposition on river water quality.

According to the Korea Institute of Construction Technology (KICT) [14], approximately 33.8% of the national rivers in South Korea are encroached by vegetation, and the rate of vegetation recruitment is predicted to increase with increasing temperatures under climate change. Therefore, sustainable river management is crucial for maintaining the health of aquatic ecosystems. In this study, we aimed to quantitatively analyze the effects of aquatic vegetation decomposition on the nutrient conditions in the Jeonjucheon River in South Korea. We determined that decomposition of the main vegetative species added to the TN and TP nutrient load of the river, but the impact on water quality was negligible.

2. Materials and Methods

2.1. Study Area

The Jeonjucheon River (Figure 1) is the first tributary of the Mangyeong River, with a basin area of 272.6 km², a river length of 32 km, and a national river section of 7.00 km managed by the government. The Jeonjucheon River is part of the Geum River region, which has a vegetation recruitment rate of 38.6% according to the KICT [14]. However, Jeonjucheon has a wider vegetation area than other rivers in this region. In particular, the national river section of Jeonjucheon is located in the downstream part of the first tributary that borders the Mangyeong River and is expected to have high nutrient concentrations due to the inflow of various tributary streams such as Geumhakcheon, Samcheon, and Wondangcheon. Therefore, the national river section of Jeonjucheon was selected as the study area [15].

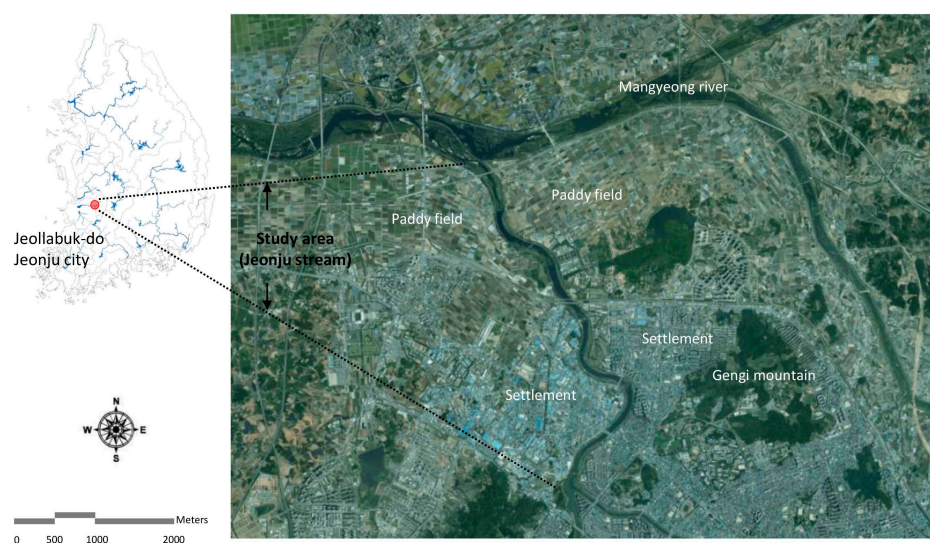


Figure 1. Study area.

2.2. Site Investigation

A field survey was conducted to determine the current status of aquatic vegetation growing naturally in the Jeonjucheon River. Dominant species were identified through the survey results, and the biomass weight and dry weight of the dominant species were determined.

The vegetation area for the dominant species was determined using image analysis through aerial photography and unmanned (drone) aerial photography. Based on the field survey results, the area was calculated by preparing a rough vegetation distribution map and computer-aided design. The distribution area of the dominant species was set to 100 m in the upstream, midstream, and downstream regions of the Jeonjucheon River, and it was subsequently applied to 7 km.

The samples used to analyze the contribution of aquatic vegetation to river water pollution were divided into the upstream, midstream, and downstream vegetation groups, and two square holes of 1 × 1 m were installed to collect the ground vegetation. *Miscanthus sinensis* Andersson (MISSI) in the upstream and midstream sections, and *Phragmites japonica* Steud. (PHRJA) in the midstream and downstream sections were collected twice owing to overlapping vegetation distribution areas, and *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU) was sporadically distributed across the midstream and downstream sections and was found once in the downstream section. As *Rumex crispus* L. (RUMCR) was distributed only in the upstream region, it was collected only once. The sample collection points were selected based on growth conditions and plant density, and vegetation was collected on 9–10 November 2020.

The weight of the collected samples before and after drying was designated as the biomass weight and dry weight, respectively (Table 1). The bio weight was the highest for PHRJA (2.83 kg/m²) at the downstream site and the lowest for RUMCR (0.54 kg/m²) at the upstream site. The dry weight followed a similar trend as that of the bio weight, and the water content was the highest for RUMCR (77.78%) in the upstream area and the lowest for MISSI (62.90%) in the upstream area.

Table 1. Bio and dry weights of dominant vegetation.

Classification		Vegetation	Biomass Weight (kg/m ²)	Dry Weight (kg/m ²)	Moisture Content (%)
Upstream	0.25 km section	MISSI	0.62	0.23	62.90
	0.25 km section	RUMCR	0.54	0.12	77.78
Midstream	0.31 km section	PHRJA	1.25	0.35	72.00
	4.50 km section	MISSI	1.02	0.32	68.63
Downstream	5.60 km section	PHRJA	2.83	0.76	73.14
	6.62 km section	PHRAU	1.52	—	76.32

Note: *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU), *Miscanthus sinensis* Andersson (MISSI), *Phragmites japonica* Steud. (PHRJA), and *Rumex crispus* L. (RUMCR).

2.3. Sample Analysis

To analyze the nutrient status of the Jeonjucheon River according to the decomposition of aquatic vegetation, a nutrient leaching experiment was conducted as shown in Figure 2.

Nutrients refer to salts that affect phytoplankton reproduction, such as phosphates, nitrates, and silicates. In this study, we analyzed the concentrations of TN and TP, which are representative nutrients [16–18].

The conditions for the dissolution experiment were set to induce the decomposition of aquatic vegetation in a manner as similar to natural conditions as possible. The samples of the dominant species of aquatic vegetation collected through field surveys in natural conditions were dried before use, and the water used in the experiment was collected from the same spot where the dominant species were collected. An aerator (BT-A65; PhilGreen, Seoul, Republic of Korea) was installed in the experimental vessel to maintain aerobic

conditions. In addition, to continuously maintain the appropriate temperature and prevent disturbance of the experimental results due to photosynthesis, two incubators were used, and the detailed dissolution test conditions were set as shown in Table 2.

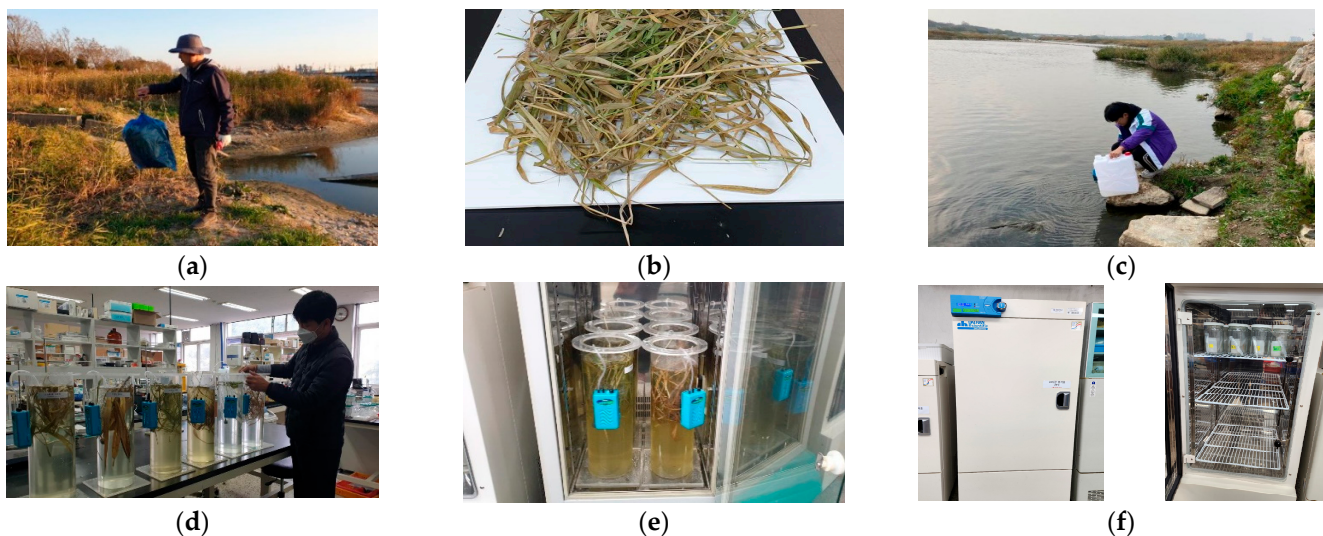


Figure 2. Dissolution test: (a) vegetation sampling, (b) dryness measurement (based on 1 m², (c) water sampling, (d) initiator operation (maintaining aerobic state), (e) incubator (maintained at 24–26 °C), (f) status inside (right) and outside (left) the incubator.

Table 2. Dissolution test conditions.

Classification	Temperature	Dissolved Oxygen	pH	Sample Amount	Volume
Conditions	24–26 °C	6.0 mg/L	6.0–7.0	10 g	7.0 L

For general river water quality testing, water collection is conducted by dividing the river based on water depth, depending on the size and characteristics of the river. However, in this study, water collection was conducted at the same point where the aquatic vegetation was collected to induce decomposition in a manner similar to that in a natural setting. We used a low-temperature incubator (BOD IR-250) for the dissolution experiment, and the temperature was set to maintain normal brightness at 24–26 °C.

As the decomposition process of aquatic vegetation growing naturally on the waterside of rivers mainly proceeds in an aerobic state, similar environmental and experimental conditions were established (Table 2). We analyzed the TN and TP six times over 42 days at intervals of 7 days using UV spectrophotometry for TN analysis and spectrophotometry for TP analysis, according to the Water Pollution Process Test Standards [19]. For pretreatment of the TN analysis sample, 50 mL of water was collected from an experimental container (7 L) and placed in a decomposition bottle, 10 mL of alkaline potassium persulfate solution was added, and the bottle was placed in an autoclave where it was heated and then cooled. For the TP analysis sample, pretreatment was performed using the same methods as those used for TN, except 10 mL of 4% potassium persulfate solution was used. Temperature and dissolved oxygen were measured using an HI 9146 (Hanna Instruments) and pH was measured using a CAS PM-1 Plus.

For comparison with our experimental results, we analyzed the pollution load in the Jeonjucheon River. The surveys were conducted in December 2020 and February, April, and June 2021, and the TN and TP loads were calculated based on the results of the four surveys. The detailed investigation points are shown in Figure 3. After pretreatment, the samples were transported to the laboratory refrigerated, and analyzed according to the Water Pollution Process Test Standards [19].

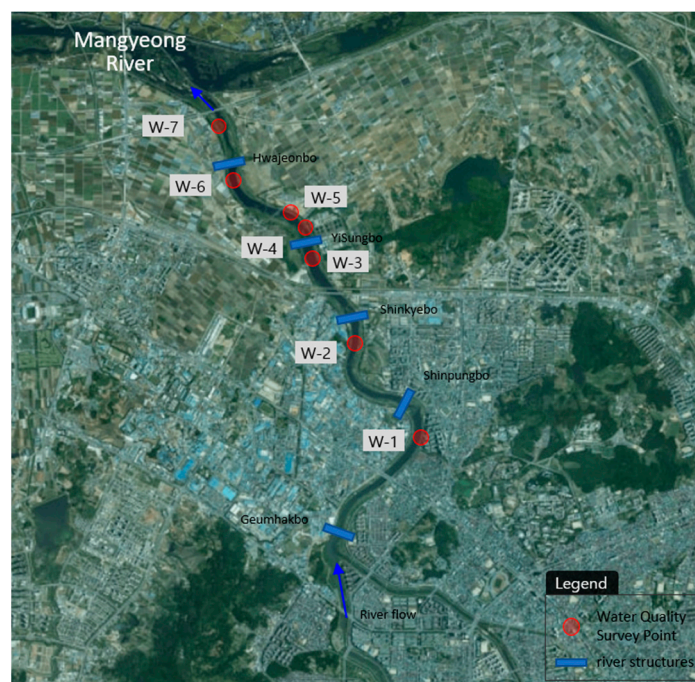


Figure 3. Jeonjucheon River water quality survey sites.

2.4. Statistical Analysis

To verify the significance of differences in decomposition concentration about TP and TN among aquatic vegetation species, one-way analysis of variance (ANOVA), which allows comparison of averages between three or more groups, was performed using IBM SPSS statistics v. 26. The Scheffe and Bonferroni methods were used in the post hoc analysis—multiple comparisons; the significance level was set at 0.05, and Microsoft Office EXCEL 2019 was used for statistical analysis of the data.

3. Results

3.1. Status of Vegetation and Dominant Species

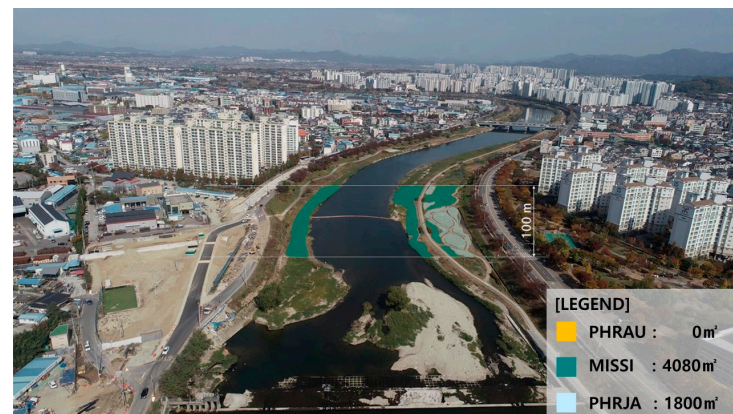
The vegetation area of the Jeonjucheon River was divided into the upstream, mid-stream, and downstream sections and subdivided based on the installation of weirs, which are barriers that alter the water flow, into six zones, as presented in Table 3. The area of each zone was then calculated. District 3 of the midstream section had the largest area at 175,158 m², District 2 of the upstream section had an area of 168,677 m², and District 6 of the downstream section had an area of 146,157 m². Upstream District 1 had an area of 48,468 m² and showed the smallest scale of vegetation distribution.

Table 3. Current status of the vegetation area in the Jeonjucheon River.

Classification		Upstream		Midstream		Downstream	
		District 1	District 2	District 3	District 4	District 5	District 6
Section	Sum	Confluence–Geumhakbo	Geumhakbo–Shinpungbo	Shinpungbo–Shinkyabo	Shinkyabo–Yisungbo	Yisungbo–Hwajeonbo	Hwajeonbo–Mangyeong River
Extension (m)	7000	400	1800	1500	1150	1250	900
Area (m ²)	757,409	48,468	168,677	175,158	82,937	136,013	146,157

Through field investigation, the dominant species were determined to be PHRAU, MISSI, PHRJA, and RUMCR (Figure 4). The distribution area for each dominant species

was calculated by comparing that of the dominant species to the length (m) of the standard area. This value was then applied to the total river extension of 7 km of the Jeonjucheon River, as presented in Table 4. The area covered by MISSI was 241,500 m², which accounted for approximately 57% of the total area of the dominant species, whereas PHRJA, PHRAU, and RUMCR covered areas of 151,200, 28,233, and 1517 m², respectively.



(a)



(b)



(c)

Figure 4. Current status of dominant species in Jeonjucheon River: (a) area of the dominant species in the upstream region (100 m section), (b) area of the dominant species in the midstream region (100 m section), and (c) area of the dominant species in the downstream region (100 m section). Dominant species include *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU), *Miscanthus sinensis* Andersson (MISSI), and *Phragmites japonica* Steud. (PHRJA). Note: *Rumex crispus* L. (RUMCR) was excluded owing to its small distribution size.

Table 4. Area covered by the dominant species in the Jeonjucheon River.

Classification	Total Area (a)	Interval Mean (b)	Upstream 100 m Section (c)	Midstream 100 m Section (d)	Downstream 100 m Section (e)
PHRAU	28,233	403	—	260	950
MISSI	241,500	3450	4080	1870	4400
PHRJA	151,200	2160	1800	840	3840
RUMCR	1517	26	30	35	—
Sum	422,450	6039	6010	3105	9290

Note: *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU), *Miscanthus sinensis* Andersson (MISSI), *Phragmites japonica* Steud. (PHRJA), and *Rumex crispus* L. (RUMCR), $a = b \times 70.0$, $b = (c + d + e)/3$.

3.2. Dissolution Test Results

The dissolution test was conducted six times using water collected from the upstream, midstream, and downstream sections of the Jeonjucheon River. The results are shown in Figure 5. The TN values of PHRJA were 3.76, 10.42, and 7.74 mg/L in the 1st, 4th, and 6th weeks, respectively. The TN values of MISSI were 3.11, 4.15, and 3.90 mg/L in the 1st, 4th, and 6th weeks, respectively. The TN values of PHRAU were 3.51, 5.42, and 4.20 mg/L in the 1st, 5th, and 6th weeks, respectively. The TN values of RUMCR were 1.59, 7.59, and 6.49 mg/L in the 1st, 4th, and 6th weeks, respectively.

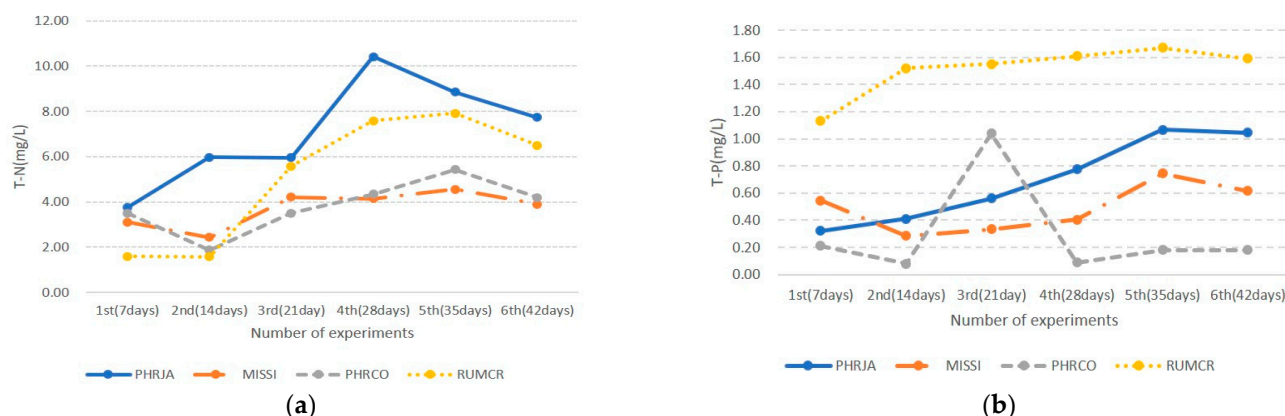


Figure 5. Changes in the (a) TN and (b) TP elution loads of the dominant vegetation in the Jeonjucheon River, including *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU), *Miscanthus sinensis* Andersson (MISSI), *Phragmites japonica* Steud. (PHRJA), and *Rumex crispus* L. (RUMCR). Note: For PHRJA and MISSI, the average values for the two sections were applied.

The TP values of PHRJA ranged from 0.26 to 0.38 mg/L, 1.05 to 1.08 mg/L, and 1.01 to 1.08 mg/L in the 1st, 5th, and 6th weeks, respectively. The TP values of MISSI ranged from 0.50 to 0.59 mg/L, 0.67 to 0.82 mg/L, and 0.41 to 0.82 mg/L in the 1st, 5th, and 6th weeks, respectively. The TP values of PHRAU were 0.21, 1.04, and 0.18 mg/L in the 1st, 3rd, and 6th weeks, respectively. The TP values of RUMCR were 1.13, 1.67, and 1.59 mg/L in the 1st, 5th, and 6th weeks, respectively.

Based on our experiments, we found that TN and TP showed the maximum values in the 4th and 5th weeks, and their concentrations tended to decrease in the 6th week. The TN of PHRJA and TP of RUMCR showed the highest loads, and a statistical analysis was conducted to test the difference in emissions by species. Table 5 presents the results of the descriptive statistical analysis. The average TN value of PHRJA was the highest at 7.12 mg/L, followed by those of RUMCR, PHRAU, and MISSI at 5.13, 3.81, and 3.73 mg/L, respectively. The average TP values of RUMCR, PHRJA, MISSI, and PHRAU were 1.51, 0.70, 0.49, and 0.30 mg/L, respectively, and are shown in Figure 6.

Table 5. Descriptive statistics by species.

Classification		Mean	S.D.	S.E.	95% Confidence Interval		Min.	Max.
					Lower Limit	Upper Limit		
TN	PHRJA	7.12	2.38	0.97	4.62	9.61	3.76	10.42
	MISSI	3.73	0.80	0.32	2.89	4.56	2.44	4.56
	PHRAU	3.81	1.18	0.48	2.57	5.05	1.87	5.42
	RUMCR	5.13	2.87	1.17	2.12	8.14	1.58	7.95
TP	PHRJA	0.70	0.33	0.13	0.35	1.04	0.30	1.07
	MISSI	0.49	0.18	0.07	0.31	0.68	0.29	0.75
	PHRAU	0.30	0.37	0.15	−0.09	0.68	0.08	1.04
	RUMCR	1.51	0.19	0.08	1.31	1.72	1.13	1.67

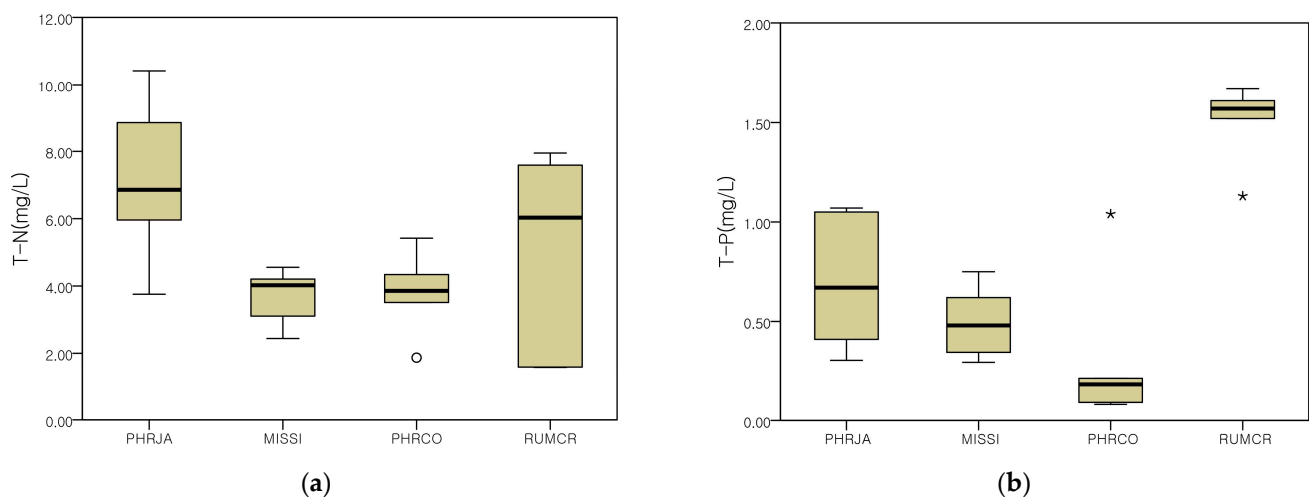


Figure 6. Box plot of the descriptive statistics of (a) TN and (b) TP values of the dominant vegetation in the Jeonjucheon River, including *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU), *Miscanthus sinensis* Andersson (MISSI), *Phragmites japonica* Steud. (PHRJA), and *Rumex crispus* L. (RUMCR). * means extremes (3 times the box length from 25% percentile).

In the one-way ANOVA, the dependent variables were TN and TP, and factors were set to vegetation type and analyzed, as presented in Table 6. We determined that TN and TP were statistically significant at the $\alpha = 5\%$ and $\alpha = 1\%$ levels, respectively. The effect of TN on the river was in the order of PHRJA > RUMCR > PHRAU > MISSI, while that of TP was in the order of RUMCR > PHRJA > MISSI > PHRAU.

Table 6. Results of ANOVA of TN and TP levels.

Classification	Value	df	M ²	F	p-Value
TN	45.181	3	15.060	3.787	0.027 *
TP	5.127	3	1.709	22.034	0.000 **

* Indicates significance at an alpha value of 5%, ** Indicates significance at an alpha value of 1%.

3.3. Load Calculation

The pollution loads generated by the decomposition of dominant aquatic vegetation in the Jeonjucheon River (Table 7) were calculated using the area (AREA) of dominant species derived from the field survey and the volume (VOLUME) per unit area for each dominant species, as shown in the equation below. The unit of pollution was set to kg/yr, as aquatic vegetation dies and decomposes in rivers every year.

$$\text{Pollution Loads (kg/yr)} = \text{AREA}_{\text{PHRJA} \sim \text{RUMCR}} (\text{m}^2) \times \text{VOLUME}_{\text{PHRJA} \sim \text{RUMCR}} (\text{m}^3/\text{m}^2)$$

The volume per unit area for each dominant species was derived using the dry weight per unit area for each dominant species based on the PHRAU's $0.57 \text{ m}^3/\text{m}^2$ [20]. In the case of MISSI, the volume per unit area was derived as $0.21 \text{ m}^3/\text{m}^2$ using the ratio of 1.00:0.36 based on PHRAU's dry weight per unit area of $0.76 \text{ kg}/\text{m}^2$ and MISSI's dry weight per unit area of $0.28 \text{ kg}/\text{m}^2$. As the ratio of RUMCR to PHRAU was 1.00:0.16, the volume per unit area was $0.09 \text{ m}^3/\text{m}^2$. The average value of the dissolution test for each species was applied to the concentration, and the pollution load was calculated by multiplying the concentration by the volume of each species.

As a result, the TN of PHRJA was 287,649.0 kg, that of MISSI was 186,286.8 kg, that of PHRAU was 61,533.5 kg, and that of RUMCR was 702.3 kg, resulting in a total annual nitrogen pollution load of 536,171.6 kg. In the case of TP, that of PHRJA was 28,124.9 kg, that of MISSI was 24,421.5 kg, that of PHRAU was 4793.4 kg, and that of RUMCR was 207.2 kg, resulting in a total annual phosphorus pollution load of 57,547.1 kg. Additionally, PHRJA had the highest load ratio of TN (53.6%) and TP (48.9%), which was calculated based on the ratio of TN and TP released from each dominant species to the total load, while RUMCR had the lowest at 0.1% and 0.4%, respectively.

Table 7. Calculation of pollution load according to the decomposition of aquatic vegetation.

Classification	Area (m ²)	Unit Volume (m ³ /m ^{2.5}) *	Volume (m ³)	Ratio (%)	Concentration (mg/L)		Load (kg/yr)		Load Ratio (%)	
					TN	TP	TN	TP	TN	TP
PHRJA	151,200	0.27	40,419.1	37.9	7.12	0.70	287,649.0	28,124.9	53.6	48.9
MISSI	241,500	0.21	50,009.9	46.9	3.73	0.49	186,286.8	24,421.5	34.8	42.4
PHRAU	28,233	0.57	16,157.6	15.1	3.81	0.30	61,533.5	4793.4	11.5	8.3
RUMCR	1517	0.09	137.1	0.1	5.12	1.51	702.3	207.2	0.1	0.4
Sum	422,450	-	106,723.7	100.0	—	—	536,171.6	57,547.1	100.0	100.0

* *Phragmites australis* (Cav.) Trin. ex Steud. (PHRAU), *Miscanthus sinensis* Andersson (MISSI), *Phragmites japonica* Steud. (PHRJA), and *Rumex crispus* L. (RUMCR), volume per unit area was calculated using $0.57 \text{ m}^3/\text{m}^2$ as suggested by Lopatin and Lopatina (2017) [21], and the dry weight of each aquatic vegetation species (PHRJA $0.36 \text{ kg}/\text{m}^2$, MISSI $0.28 \text{ kg}/\text{m}^2$, PHRAU $0.76 \text{ kg}/\text{m}^2$, RUMCR $0.12 \text{ kg}/\text{m}^2$).

3.4. Pollution Load of Jeonjucheon River

The results of calculating the pollution load of the Jeonjucheon River to compare the results of nutrient conditions in the river according to the decomposition of aquatic vegetation (Table 8) showed deviations depending on the survey period. In the case of the upstream point W-1, the load was the highest in the 4th survey period under the influence of rainfall, followed by that in the 3rd, 1st, and 2nd survey periods. The midstream point W-4, with effluent discharge from the 1st and 2nd stages of the sewage treatment plant, showed a higher load than W-5, with effluent discharge from the 3rd stage of the sewage treatment plant. The effluents of the 1st and 2nd stages had a greater impact on the pollutant load of the Jeonjucheon River than those of the 3rd stage. In the downstream region, TN increased in the order of the 3rd, 2nd, 4th, and 1st survey periods, and TP increased in the order of the 4th, 3rd, 1st, and 2nd survey periods. In this study, the TN load was 7995.9 kg/day and the TP load was 48.2 kg/day, which are the average values of the downstream portion (W-7) where the highest load was measured; these values were used as the pollution load of the Jeonjucheon River. We converted this to annual pollution loads for TN and TP, which were 2,903,885.3 and 17,602.1 kg/yr, respectively.

Table 8. Load calculation results for each survey point of the Jeonjucheon River.

Classification			Load Average (kg/Day)	
			TN	TP
1st (December 20)	Upstream	W-1	10.5	0.3
		W-4	4496.3	73.6
	Midstream	W-5	1151.2	10.9
		W-6	5457.8	36.4
	Downstream	W-7	5372.4	32.2
2nd (February 21)	Upstream	W-1	1.5	0.0
		W-4	4795.1	14.0
	Midstream	W-5	1272.4	3.5
		W-6	9710.4	34.0
	Downstream	W-7	9312.5	31.7
3rd (April 21)	Upstream	W-1	66.8	2.5
		W-4	6023.8	25.9
	Midstream	W-5	1042.2	5.1
		W-6	9868.6	53.3
	Downstream	W-7	9917.6	52.6
4th (June 21)	Upstream	W-1	670.1	23.9
		W-4	3531.4	22.8
	Midstream	W-5	963.3	5.6
		W-6	7010.4	70.6
	Downstream	W-7	7220.9	76.4

Note: The average values of the TN and TP loads at the downstream point of the Jeonjucheon River (W-7) were 7955.9 and 48.2 kg/day, respectively.

4. Discussion

Hill [20] reported that large amounts of nutritional salts are absorbed underwater to support the growth of aquatic vegetation; however, the absorbed nutrients are released back into the water when the vegetation dies. Moreover, Park et al. [22] suggested that removing aquatic vegetation from the water system before and after death can prevent the release of nutritional salts from decaying vegetation into the water. Ro et al. [23] investigated the absorption of nitrogen and phosphorus by *Phragmites australis* in an aquatic ecosystem environment and suggested that nutrient salts can be released back into the water during the decomposition of solid parts of the vegetation during the non-growth period. However, Hwang et al. [24] estimated that removing dead vegetation would have little effect on the purification efficiency of wetlands, and the results of TP in this study correspond to the empirical results of previous studies. In particular, although the nutrients in dead vegetation are released back into the water, the amount is negligible; therefore, the amount of TN generated by decomposing dead vegetation is likely to have a small impact on the nutrient status of the river.

However, as indicated by Kim and Kim [25], the low contribution of solids cannot be excluded, because an increase in the vegetation area of a river can cause changes in the ecosystem as well as the physical structure. Additionally, Son et al. [13] demonstrated that some solids from autumn vegetation must naturally decompose in rivers to ensure that the water environment is not contaminated and improve the natural function of wetlands in urban areas.

In the case of TN, we determined that the load due to aquatic vegetation decomposition was 536,171.6 kg/yr, which is approximately 18% of the total TN pollution load of

2,903,885.3 kg/yr in the Jeonjucheon River. In the case of TP, the load due to vegetation decomposition exceeded the total TP pollution load of the Jeonjucheon River, necessitating additional review and investigation. The decomposition concentration of TP was found to range from 0.08 to 1.67 mg/L, which is within the river living environment water quality standards (TP < 0.02 mg/L, very good; TP < 0.2 mg/L, normal; TP > 0.5 mg/L, very poor) according to the Framework Act on Environmental Policy [26]. In addition, in the water quality measurement network data of the Water Environment Information System [27] provided by the Ministry of Environment, TP was found to range from 0.07 mg/L to 0.14 mg/L during the period when the river pollution load was investigated. Therefore, we determined that the concentration in the aquatic vegetation dissolution test partially corresponded to the water quality grade of ‘very poor’ according to the standards and that there are limitations involved in making simple comparisons of the effect on TN nutritional status due to aquatic vegetation decomposition. Moreover, considering that the concentration of TP may vary depending on factors such as the survey time, survey method, and survey point, further research is required to calculate the load using a control group with the same environmental conditions in both the natural setting and the lab experiment. In addition, in natural river conditions, phosphorus compounds are absorbed into the soil, roots, and stems, but this was not taken into consideration in the dissolution experiment in this study. This likely contributed to the relatively high concentration. Therefore, it is necessary to conduct related research that accounts for the TP emitted from the roots of aquatic vegetation and the soil for comparison.

Meanwhile, in the one-way ANOVA of TN and TP concentrations released by the dominant species of aquatic vegetation, the difference in mean values was found to be significant. We determined that PHRJA and RUMCR had the greatest influence on the TN and TP nutrient status of the river, respectively. However, as the nutrient status of rivers is complicated by the inflow of non-point source pollutants, flow reduction, and sediment leaching in addition to TN and TP, future research should consider these factors.

As the temperature of the elution experiments in this study ranged from 24 to 26 °C, the appropriateness of the incubator temperature must be considered. According to data from the Public Data Utilization Support Center [28] of the Jeonjucheon River water quality monitoring network, the average temperatures of the Jeonjucheon River in 2021 were approximately 24, 25, and 26 °C from June to October, July to October, and July to September, respectively. Thus, the experimental temperature used in our study was within the range of average temperatures in the Jeonjucheon River. The total annual elution load calculated using the elution loads of each species and the weight of each species can be interpreted as the maximum value that can occur in the Jeonjucheon River. Accordingly, the temperature set during the elution test in our study is appropriate, and the actual contribution of the dominant species native to the Jeonjucheon River to water pollution is expected to be lower than that estimated by our results.

5. Conclusions

In this study, we selected the Jeonjucheon River as the study site, determined the dominant species native to the river, and analyzed the effect of aquatic vegetation decomposition on the nutritional conditions of the river through a dissolution experiment.

Based on the on-site survey of aquatic vegetation native to the Jeonjucheon River, we found that the dominant species were PHRAU, MISSI, PHRJA, and RUMCR, and they covered areas of 28,233, 241,500, 151,200, and 1517 m², respectively. Notably, PHRAU showed the largest distribution area. The dry weights of PHRAU, MISSI, PHRJA, and RUMCR samples used for the elution experiment were 0.76, 0.28, 0.36, and 0.12 kg/m², respectively. We found that the TN value of PHRJA was the highest at 7.12 mg/L, followed by those of RUMCR, PHRAU, and MISSI at 5.13, 3.81, and 3.73 mg/L, respectively. The TP values of PHRAU, PHRJA, MISSI, and PHRAU were 1.51, 0.70, 0.49, and 0.30 mg/L, respectively. Based on one-way ANOVA, which was performed to verify the statistical significance of the difference in the average value of decomposition concentration for

each species, TN and TP were found to be significant at $\alpha = 5\%$ and $\alpha = 1\%$, respectively. Using the decomposition concentration of each species and volume per unit area, the annual pollution load was calculated as 536,171.6 kg for TN and 57,547.1 kg for TP. In the Jeonjucheon River water quality survey results, the pollution load was found to be 2,903,885.3 kg/yr for TN and 17,602.1 kg/yr for TP. In the case of TN, nutrients amounting to approximately 18% of the total pollution load of the Jeonjucheon River can be considered to be released when aquatic vegetation decomposes, but variation from the inflow of non-point source pollutants and sediment leaching were not taken into consideration.

The quantitative analysis of the impact of aquatic vegetation decomposition on the nutritional status of the river that was performed in this empirical study provides foundational data for establishing and implementing sustainable river management measures in response to the increase in vegetation in rivers under climate change. In addition, the leaching concentration of each species evaluated in this study can be used as a reference when determining priorities for the management of aquatic vegetation growing in rivers.

Meanwhile, in the case of the volume per unit area used when calculating the pollution load due to the decomposition of aquatic vegetation, an additional investigation of the actual measurements of native vegetation is recommended. This will improve the accuracy of the load calculated from each decomposing species. In addition to the four dominant species analyzed in this study, the applicability of our results can be further expanded if future studies also consider aquatic vegetation that is generally native to rivers, such as *Typha orientalis* and *Zizania latifolia*.

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