



# Measuring the Effectiveness of an Ecosystem Service to Regulate Air Quality in Wetland, South Korea

Jung In Kim<sup>1</sup>, Kyungeun Lee<sup>1</sup>, Inae Yeo<sup>1</sup>, Tae-Young Choi<sup>1</sup>, Beom Hee Lee<sup>1</sup>, Pil Mo Jung<sup>1</sup>,  
Wooyeong Joo\*<sup>1</sup>

National Institute of Ecology, Seocheon, Korea

## ABSTRACT

This study aimed to verify the suitability of an air quality regulating service for wetland ecosystem service evaluation by investigating the effect of reducing particulate matter (PM) on vegetation in wetlands. We installed tunnel-type experimental plots at Yonghwasil Pond in the National Institute of Ecology and set up the input and output of PM by applying the natural vegetation of the relevant wetlands. We took measurements by replicating four different conditions four times each. The air quality regulating service in each experimental plot was measured based on PM<sub>10</sub> concentration; further, the difference between the input and the output concentration of PM passing through the *Phragmites australis* community tunnel was measured using a light scattering method. For the *Phragmites australis* community in the outdoor conditions and bare land, the PM concentration was measured with the same specifications as tunnel-type experimental plots without setting up the input and output. For the tunnel-type experimental plots, PM<sub>10</sub> concentration was significantly lower in the output than in the input. Furthermore, in the outdoor conditions, a comparison between the *Phragmites australis* community and bare land showed that the concentration was relatively low in the former than in the latter. This confirmed the PM reducing effect due to the blockage and absorption of PM depending on the growth of *Phragmites australis*. Based on the results of this study, we assessed the air quality regulating service in wetlands as an evaluation indicator.

**Keywords:** Air Pollution, Particulate matter, Wetlands

## Introduction

Wetlands refer to the transition zone between terrestrial and water environments, particularly the land that covers the earth surface either for a year or for a considerable amount of time, including the growth period of living things. The land in which underground water is distrib-

uted near the ground surface can also be referred to as a wetland (Koo *et al.*, 2013). Wetlands have an abundant biodiversity and provide ecosystem services to humans through various functions (de Groot *et al.*, 2006; Gu *et al.*, 2013; Halls 1997; Millennium Ecosystem Assessment, 2005; Ministry of Environment, 2018; Joo *et al.*, 2019). Existing policies on designation, conservation, and management of wetland protection areas were implemented with a focus on species/habitats. However, it is also necessary to perform ecosystem service evaluation to actually assess the functions of wetlands as well as ecosystem service (Joo *et al.*, 2018; 2019).

Ecosystem service evaluation refers to quantitative as-

**Received** September 11, 2020; **Revised** December 17, 2020;  
**Accepted** December 17, 2020

\***Corresponding author:** Wooyeong Joo  
**e-mail** [wjoo@nie.re.kr](mailto:wjoo@nie.re.kr)  
 <https://orcid.org/0000-0003-1755-6868>



This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

assessment of the provisioning, regulation, and cultural services provided by wetlands as well as the functions of wetlands (Joo *et al.*, 2018; 2019). The qualitative assessment of wetland ecosystem service is focused on provisioning service such as water, fishery, and agriculture; regulating service such as flood protection and water purification; and cultural service such as ecotourism, leisure, and landscape value. However, there is a significant inadequacy in the assessment of an air quality regulating service (Table 1) (Janse *et al.*, 2019; MA, 2005; Mcinnes, 2013; Ramsar Convention on Wetlands, 2011; 2018; Russi *et al.*, 2013).

The air quality regulating service refers to absorbing, adsorbing, and eliminating contaminants from the air during the process of plant respiration based on the material cycling function of the ecosystem (de Groot *et al.*, 2006; Joo *et al.*, 2017). The indicators to assess the air quality regulating service include gaseous and particulate contaminants such as NO<sub>2</sub> and SO<sub>2</sub> (Joo *et al.*, 2018; 2019).

Based on the particle size, particulate contaminants are classified into total suspended particles (TSP) for particles below 50 µm, particulate matter (PM) for extremely small particles, and dust particles for those smaller than 10 µm,

which are classified as PM<sub>10</sub>, and dust particles for those smaller than 2.5 µm, which are classified as PM<sub>2.5</sub> (Ministry of Environment, 2016; National Institute of Forest Science, 2019). PM has harmful effects on the respiratory and cardiovascular systems such as lungs and blood vessels (Bae *et al.*, 2011; Bae & Hong, 2018; Jang, 2014; Myong, 2016). The International Agency for Research on Cancer (IARC) operating under World Health Organization (WHO) concluded that PM is highly carcinogenic to the human body, and thus, designated it as a Group 1 carcinogen (IARC, 2016). The PM concentration in Korea has decreased since 1995 when observations were first made, but there is not significant change after 2010. Korea has approximately 1.4–2.8 times higher PM concentration compared to Los Angeles (United States), London (England), Paris (France), and Tokyo (Japan) (Cha *et al.*, 2018; Lee, 2018). To address this issue, the government is defining air pollutants, climate/ecosystem-changing substances, and specified hazardous air pollutants in Articles 2-4 of the Enforcement Decree of the Clean Air Conservation Act to reduce and manage the level PM. Moreover, the government selected “creating a pleasant air environment without concerns of particulate matter” as a major government project and is making policy efforts such as

**Table 1.** Evaluation indicators for wetland ecosystem regulating service

MA (2005)	de Groot <i>et al.</i> (2006)	Ramsar Convention on Wetlands (2011)	Ramsar Convention on Wetlands (2018)	Russi <i>et al.</i> (2013)	McInnes (2013)	Janse <i>et al.</i> (2019)
	Air quality regulation		Air quality regulation			
Climate regulation	Climate regulation	Climate change mitigation and adaptation	Climate regulation	Carbon sequestration Maintenance of temperature, precipitation	Climate regulation	Carbon Local Climate
Hydrological regimes	Hydrological regimes	Groundwater replenishment	Water Regulation		Maintenance of hydrological regimes	
Pollution control and detoxification	Pollution control and detoxification	Water purification	Water purification and waste treatment	Water purification	Pollution control and detoxification	Water quality
Erosion protection	Erosion protection	Flood control	Erosion regulation	Erosion control	Erosion protection	Extreme events mitigation
Natural hazard	Natural hazard mitigation Biological regulation		Natural hazard mitigation Pest regulation Disease regulation Pollination	Flood protection	Hazard reduction Biological control of pests and disease Pollination	

establishing the Comprehensive Plan on Particulate Matter (2020-2024) (Government Performance Evaluation Committee, 2020; Interagency, 2019). However, studies on PM reduction are still limited to research on absorption and adsorption of trees in forests or plants of interior landscaping (Jo *et al.*, 2002; Kwon & Park, 2018; Manes *et al.*, 2016; Nowak & Heiser, 2010), whereas it is still necessary to establish reduction plans that can be applied extensively to various ecosystems.

Studies on the air quality regulating service that reduces gaseous substances in the wetland ecosystem have been verified to a certain extent (Novitzki *et al.*, 2001; Roucoux *et al.*, 2017). However, studies on the air quality regulating service that reduces particulates or PM are nonexistent, except for research that compared the changes in concentration and plant dry weight after creating artificial wetlands and infusing PM<sub>2.5</sub> and PM<sub>10</sub> into the air (Son & Kim, 2020).

This study aims at assessing the reduction levels of PM in the natural vegetation of wetlands that lacks sufficient research in relation to the air quality regulating service in wetlands. We intend to quantitatively measure the level of PM reduction while maintaining the natural attributes as they are without damaging the wetland ecosystem as

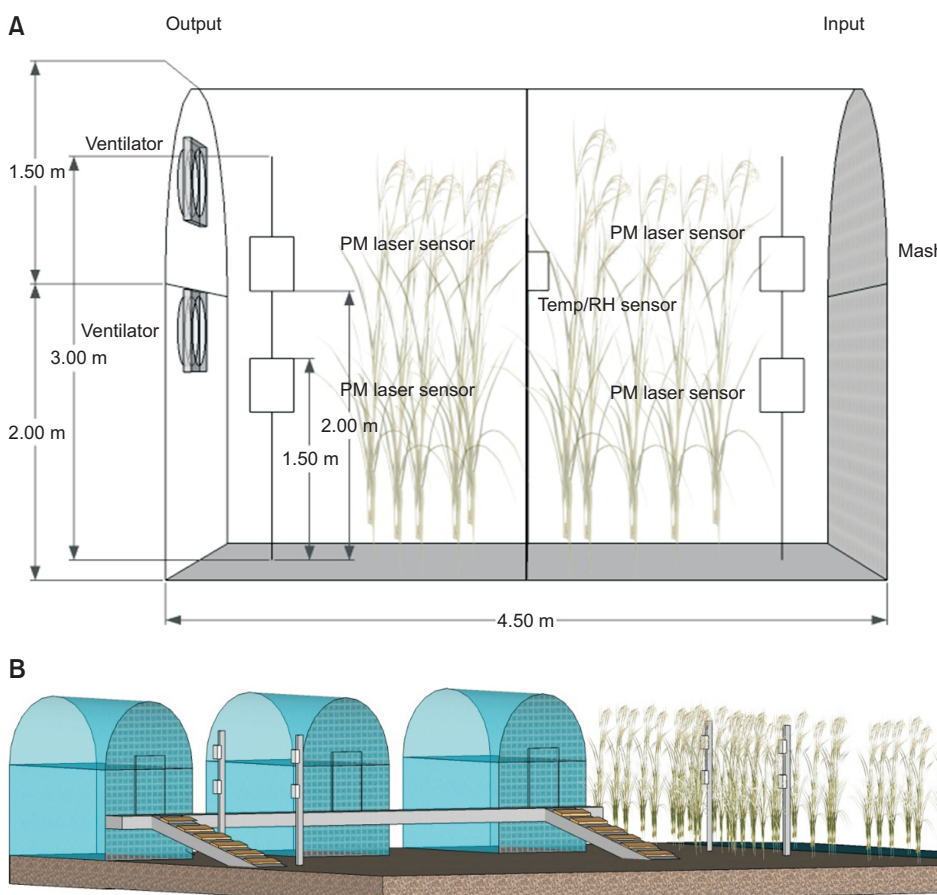
much as possible. Finally, we will establish the grounds for objective evaluation indicators for the air quality regulating service in the wetland ecosystem.

## Materials and Methods

### Experimental design

The study site was Yonghwasil Pond (68,199 m<sup>2</sup>) in the National Institute of Ecology located in Maseo-myeon, Seocheon-gun, Chungcheongnam-do. The experimental plots were installed in the most dominant *Phragmites australis* community in Yonghwasil Pond considering the ease of installation and accessibility (36°02'34.19"N, 126°43'04.71"E).

To measure the PM reduction effect of wetlands, we installed three tunnel-type experimental plots using a greenhouse (Fig. 1). Their size was 10.8 m<sup>2</sup> (W 2,400 mm×L 4,500 mm×H 3,500 mm), and 2 out of 3 experimental plots maintained the *Phragmites australis* community in natural state, whereas the remaining one had all plants removed. The input, through which PM in the air flows in, was made with a mesh (air gap 1.2 mm), and the output was set up to induce PM to pass through *Phragmites australis*. The PM was discharged via a shutter-type



**Fig. 1.** Design of particulate matter reduction measuring device for *Phragmites australis*. (A) Tunnel-type, (B) outside condition. PM, particulate matter.

electric ventilator (600×600×490×750 W-1hp, Daeheung Industry, Korea) installed 2 m and 2.5 m above ground. To measure the level of PM reduction by analyzing the difference in PM concentration at the input and output of the experimental plots, we installed the PM measuring sensor at 1.5 m and 2.0 m above ground, separated at a 50-cm distance each from the input and output.

There are various methods of measuring the PM such as the gravimetric method,  $\beta$ -ray absorption method, and light scattering method. This study applied the light scattering method that can take real-time measurements under natural conditions, which are easy to set up, and is relatively inexpensive (Cha *et al.*, 2018). Laser Sensor (SDS011 v1.3; Nova Fitness Co. Ltd., Jinan, Shandong Province, China) was used as the PM measuring sensor and PM<sub>10</sub> was measured every minute.

We also installed the ATMOS 14 sensor (METER group, Inc., Pullman, WA, USA) to measure the temperature and humidity inside the tunnel-type experimental plots.

To compare the PM reducing effect in outdoor conditions, we installed only the PM measuring sensor in the *Phragmites australis* community and bare land (plants artificially removed) at the same height and with the same gap as that of the tunnel-type experimental plots (Fig. 1).

We measured the PM a total 4 times from April to June

2020 (9 a.m.-6 p.m.) and surveyed the plants that appeared inside and outside the experimental plots as well as the height and cover of *Phragmites australis* on the days of sensor data collection and the findings are shown in Table 2. The findings indicate that *Phragmites australis* cover is highest in both inside and outside the experimental plots, and *Beckmannia syzigachne*, *Alopecurus aequalis*, *Ranunculus sceleratus*, and *Cardamine flexuosa* also appear (Table 3). From May (Date 2-Date 4), *Phragmites australis* cover was maintained at 100%, and the height increased up to 3.5 m (Experimental Plot 3) and the findings are summarized in Table 2.

The morphological characteristics of *Phragmites australis* were analyzed using ultra-high-resolution field-emission scanning electron microscopy (FE-SEM, SU8220; Hitachi, Tokyo, Japan).

### Statistical analysis

The light scattering method used in this study to measure PM has the disadvantage of being vulnerable to humidity (Cha *et al.*, 2018). Actual measurement results showed that PM concentration was highly correlated with relative humidity. To make up for this, we excluded PM concentration during precipitation days and when the relative humidity levels were over 55%.

**Table 2.** Schedule and experimental conditions for measurement of particulate matter reduction

Sampling	Day	Temperature (°C)		Reed height (m)			Reed cover (%)		
		Tunnel	Outside	Tunnel 1	Tunnel 3	Outside	Tunnel 1	Tunnel 3	Outside
DATE 1	4.21-4.24	0.9-23.3	5.2-21.3	0.40	0.50	0.01	67	33	0.01
DATE 2	5.21-5.25	8.2-31.1	10.3-26.4	2.30	2.50	1.70	100	100	100
DATE 3	5.28-5.30	10.8-34.1	12.4-27.3	2.80	3.00	2.00	100	100	100
DATE 4	6.80-6.90	17.2-38.0	16.4-33.9	3.25	3.49	2.40	100	100	100

**Table 3.** Specifications of tunnel-type experimental plots

Equipment	Species*	Sensor (ea)	Humid sensor (ea)
Tunnel 1	<i>Phragmites australis</i> <i>Beckmannia syzigachne</i> <i>Ranunculus sceleratus</i> <i>Alopecurus aequalis</i> <i>Cardamine flexuosa</i>	Input 2 Output 2	○
Tunnel 2	-	Input 2 Output 2	○
Tunnel 3	<i>Phragmites australis</i> <i>Ranunculus sceleratus</i> <i>Alopecurus aequalis</i> <i>Cardamine flexuosa</i>	Input 2 Output 2	○
Reed	<i>Phragmites australis</i>	4	×
Bare land	-	4	×

\*Only species with at least 30% cover.

To test the statistical significance of the differences in the concentration of PM concentration between input and output of each experimental plot as well as PM concentration between *Phragmites australis* community and bare land, we transformed the variables to log and conducted a paired sample t-test (using IBM SPSS Statistics for Windows, Version 25.0; IBM Co., Armonk, NY, USA).

### Results and Discussion

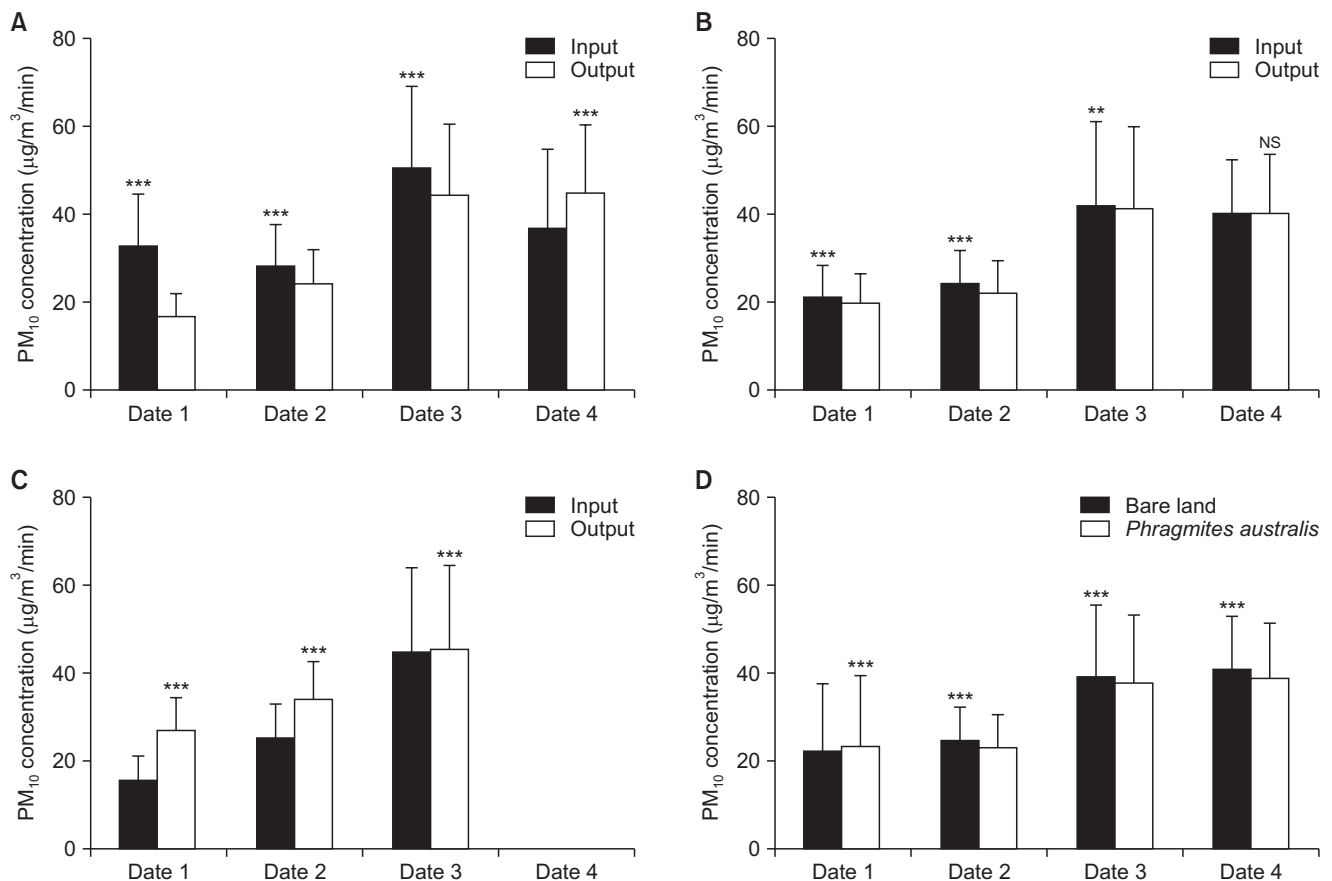
#### PM<sub>10</sub> purification effect of wetlands

To verify whether the *Phragmites australis* community had PM purification effect, we compared the differences between the PM concentration of the input and that of the output for the experimental plots (Fig. 2). In Experimental Plot 1 with *Phragmites australis*, the concentration of input at the beginning of the experiment (Date 1) was 32.7 μg/m<sup>3</sup> on average, but the output decreased to 16.8 μg/m<sup>3</sup>. Furthermore, on Date 2, the input was 28.4 μg/m<sup>3</sup> and the output was 24.3 μg/m<sup>3</sup>, but on Date 4, the output was 44.9 μg/m<sup>3</sup> and the input was 36.9 μg/m<sup>3</sup>,

showing that the concentration in the input was higher. Experimental plot 3 also showed lower PM<sub>10</sub> concentration in the output than compared to that in the input on Date 1 and Date 2. On Date 3, concentration in the output was lower, but there was no statistical significance. On Date 4, the concentration in the output (40.3 μg/m<sup>3</sup>) was higher than that of in input (40.2 μg/m<sup>3</sup>), which is the same as Experimental Plot 1.

On the other hand, Experimental Plot 2 without plants showed a higher concentration in the output. The difference in the concentration of the input and output varied depending on the point of measurement, but the difference was maintained at a significant level.

April (Date 1) is the time when *Phragmites australis* was germinated, which is why the new *Phragmites australis* was in form of sprouts, while maintaining the plant wastes from the previous year in standing position. Therefore, the wastes may have filtered and reduced the PM<sub>10</sub> entering from the outside. In other words, even though *Phragmites australis* had withered, there was a PM reducing effect if the plant wastes had not fallen, thereby



**Fig. 2.** Input and output concentration of PM<sub>10</sub> of tunnel 1 (A), tunnel 3 (B), tunnel 2 (C) and outside condition (D). Vertical bars indicate average±standard deviation. Paired-Samples t-test was performed that variance between input and output concentration within a date. PM, particulate matter; NS, not significant at  $P<0.05$ . \* $P<0.05$ , \*\* $P<0.01$ , \*\*\* $P<0.001$ .

blocking the movement of PM like plants (Fuchs, 1964).

Moreover, the inside of the experimental plots had a higher temperature than that of the outside, which accelerated the growth rate of *Phragmites australis*. It had grown to a high-density cover, filling up the inside of the experimental plots by May (Date 2-3). Thus, the PM<sub>10</sub> purification effect was expected to increase as time passed, but there was no significant difference in June (Date 4). This may be due to the aphid infestation that occurred inside the experimental plots (Fig. 3). As the weather got warmer, the temperature and humidity increased inside the experimental plots that also significantly increased the density of *Phragmites australis* causing aphid infestation to expand explosively almost to the point of covering all leaves. There was aphid outside as well, but the frequency was not high. Aphid infestation caused the adsorptive function of leaves to decline, which is likely to have decreased the effect of reducing the PM, but this could have been verified by a close, detailed analysis of leaves.

We compared the differences in PM concentration between the input and output in each experimental plot and found that it was higher in Experimental Plot 1 than that in Experimental Plot 3. *Phragmites australis* was dominant in both plots, but unlike Experimental Plot 3, Experimental Plot 1 showed an extremely high-density cover of *Beckmannia syzigachne* (cover 50% or higher, height 1.6 m). Even though it was the *Phragmites australis* community, *Beckmannia syzigachne* in the lower layer may have affected the PM reducing effect. A separate research is needed on the PM reducing effect of *Beckmannia syzigachne*. However, the height of *Phragmites australis* in Experimental Plot 3 was about 20 cm greater



**Fig. 3.** Aphid bloom on *Phragmites australis* leaves.

than that in Experimental Plot 1, and the density was also higher. Nonetheless, the concentration gap in Experimental Plot 1 is greater due to the effect of another subdominant species *Beckmannia syzigachne*, which implies that *Beckmannia syzigachne* also show a PM reducing effect. Son and Kim (2020) claimed that if plant bodies contributing to PM reduction are single species, the reduction effect is greater when the plants that have little effect are combined.

To check the PM<sub>10</sub> purification effect in the natural conditions as well, we compared the *Phragmites australis* community distributed outside the experimental plots and the bare land without plants (Fig. 2). We found that the PM<sub>10</sub> concentration inside the *Phragmites australis* community was lower compared to that in the bare land without plants. As time passed, PM<sub>10</sub> concentration inside the *Phragmites australis* community was 23.4  $\mu\text{g}/\text{m}^3$ , 23.3  $\mu\text{g}/\text{m}^3$ , 37.9  $\mu\text{g}/\text{m}^3$ , and 38.8  $\mu\text{g}/\text{m}^3$  on average, whereas in the bare land it was 22.5  $\mu\text{g}/\text{m}^3$ , 25.0  $\mu\text{g}/\text{m}^3$ , 39.3  $\mu\text{g}/\text{m}^3$ , and 40.9  $\mu\text{g}/\text{m}^3$ , proving that PM<sub>10</sub> concentration inside the *Phragmites australis* community was lower than that in the bare land. The observation that concentration is lower where there is *Phragmites australis* compared to that in bare land without plants even in natural conditions with many variables indicates that it has a great reduction effect.

However, considering that the bare land in this study is a place where plants were artificially removed from the wetlands, the PM reduction level may vary depending on the points of measurement such as species composition of plants, cover area, density, etc., even in the same wetlands.

Qiu *et al.* (2015) also reported that the wetland ecosystem reduces PM, and PM that met the vapors in the wetlands are piled up in bubbles and settle in the water layer.

Son and Kim (2020), who designed an artificial wetland ecosystem environment with a small, simple greenhouse and compared the PM reducing ability in a terrestrial ecosystem, also reported that the wetland ecosystem has a greater PM reducing ability because the PM in the air is piled up in water that forms the wetlands and has sedimented, and is also adsorbed on the above-ground parts of wetland plants.

In general, the PM reducing ability is greater in the wetland ecosystem with high humidity, and the ability may be enhanced depending on the function of plant species that form the ecosystem.

#### PM purification effect of *Phragmites australis*

The fact that plants reduce PM has been proved by several studies (Jo *et al.*, 2002; Kwon & Park, 2018; Manes *et al.*, 2016; Nowak & Heiser, 2010). PM is absorbed by plant bodies or adsorbed on leaves, and this may vary depending on the plant structure and form (He *et al.*, 2020).



**Fig. 4.** Analysis of *Phragmites australis* leaf structure (FE-SEM). (A) Leaf surface, (B) stoma, (C) stoma from the side.

This study also proved, through the experimental plots, that *Phragmites australis* is effective in reducing PM. To morphologically verify the PM reducing ability of *Phragmites australis*, we observed the leaves using ultra-high-resolution field-emission scanning electron microscope (Fig. 4). As a result, the stoma of *Phragmites australis* has a major axis of 10–15  $\mu\text{m}$  and a minor axis of 4–7  $\mu\text{m}$ , with approximately 1,500 stomas distributed per 1  $\text{mm}^2$ . Moreover, the surface was uneven, and the stomas were sunken. In addition, 4–7  $\mu\text{m}$  long papillae shaped like eyelashes were surrounding the stomas in high density. This characteristic was equally observed in the study by Guan *et al.* (2019).  $\text{PM}_{10}$ , which is PM in the size of 10  $\mu\text{m}$ , is not sufficiently small to enter the stomas of *Phragmites australis*, and fine papillae are blocking the stomas as well, making it more difficult for  $\text{PM}_{10}$  to actually enter the stomas.

Therefore, PM is not reduced by the adsorption on the stoma but the blocking effect of similar to trees. Moreover, the surface of *Phragmites australis* leaves was burr with small papillae distributed on them. Some research findings suggest that the plants with wrinkles on the back of their leaves are more effective in adsorbing PM than those with many leaf hairs. With too many leaf hairs, it is difficult to adsorb PM due to electrical phenomenon (Rural Development Administration Press Release, 2019). Furthermore, since there are wax layers on the surface of *Phragmites australis* leaves, they are likely to adsorb PM (Guan *et al.*, 2019). It is necessary to verify more closely the adsorption effect through further research including the component analysis of the surface of *Phragmites australis* leaves. However, morphologically, the leaves have a structure effective in adsorption and thus contribute to PM reducing effect.

To determine more closely the PM reducing ability in the wetland ecosystem, it is necessary to examine the PM reducing ability of the major plant species that form the wetlands, reduction effects depending on the size of plant bodies, patterns of PM, and tracer studies.

This study is of great significance in that it verified the

PM reducing ability of the wetland ecosystem in natural conditions while eliminating artificial manipulation as much as possible. Moreover, we also discovered that wetlands contribute to the purification of not only the water quality but also air quality. The PM reducing ability of the wetland ecosystem is one of the ecosystem services that must be considered as a suitable indicator for value assessment of wetlands.

### Conflict of Interest

The authors declare that they have no competing interests.

### Acknowledgments

This study was funded by National Institute of Ecology’s “Assessment of key ecosystem assets and their services and development of conservation strategies.”

### References

- Bae, H.J., Youn, D.O., Ha, J.S., Shin, Y.S., Gong, S.Y., Moon, N.K., *et al.* (2011). *Evaluation of Impacts of Climate Change on Air Pollution and Health*, Incheon: National Institute of Environmental.
- Bae, S.H., and Hong, Y.C. (2018). Health effects of particulate matter. *Journal of the Korean Medical Association*, 61, 749–755.
- Cha, J.G., Choi, T.Y., Moon, H.G., Kang, D.I., and Park, E.J. (2018). *Study on the Regulating Function of Particulate Matter in Urban Green Space*, Seochon: National Institute of Ecology.
- de Groot, R., Stuij, M., Finlayson, M., and Davidson, N. (2006). *Valuing Wetlands: Guidance for Valuing the Benefits Derived from Wetland Ecosystem Services*, Gland: Ramsar Convention Secretariat.
- Fuchs, N.A. (1964). *The Mechanics of Aerosols*, Oxford: Pergamon.
- Government Performance Evaluation Committee. (2020). *2019 Job/major government project assessment: Report on each major government project*. Office for Government Policy Coordination.
- Gu, B.H., You, Y.H., Kim, H.D., Kim, J.G., Yang, H.S., Rho, P.H.,

- et al. (2013). *Understanding of Wetland*, Changnyeong: Ministry of Environment.
- Guan, H., Feng, X., Zhang, J., Niu, S., and Han, Z. (2019). Phragmites communis leaves with anisotropy, superhydrophobicity and self-cleaning effect and biomimetic polydimethylsiloxane (PDMS) replicas. *Coatings*, 9, 541.
- Hails, A.J. (1997). *Wetlands, Biodiversity and the Ramsar Convention: the Role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity*, Gland: Ramsar Convention Bureau.
- He, C., Qiu, K., and Pott, R. (2020). Reduction of urban traffic-related particulate matter-leaf trait matters. *Environmental Science and Pollution Research International*, 27, 5825-5844.
- Interagency. (2019). *Master Plan on Management of Particulate Matter (2020~2024)*, Sejong: Ministry of Trade Industry and Energy.
- International Agency for Research on Cancer (IARC). (2016). *Outdoor Air Pollution IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 109*, Lyon: IARC.
- Jang, A.S. (2014). Impact of particulate matter on health. *Journal of the Korean Medical Association*, 57, 763-768.
- Janse, J.H., van Dam, A.A., Hes, E.M.A., de Klein, J.J.M., Finlayson, C.M., Janssen, A.B.G., et al. (2019). Towards a global model for wetlands ecosystem services. *Current Opinion in Environmental Sustainability*, 36, 11-19.
- Jo, H.K., Cho, Y.H., and Ahn, T.W. (2002). Capacity and value of atmospheric purification for Namsan Nature Park in Seoul. *Korean Journal of Environment and Ecology*, 16, 172-178.
- Joo, W.Y., Kwon, H.S., Jang, I.Y., Jung, P.M., Kim, M.H., Park, H.J., et al. (2017). *Establishment of Ecosystem Services Assessment Framework at National Level*, Seocheon: National Institute of Ecology.
- Joo, W.Y., Kwon, H.S., Jang, I.Y., Jung, P.M., Park, H.J., Kim, J.I., et al. (2018). *Assessment of Key Ecosystem Assets and their Services and Development of Conservation Strategies*, Seocheon: National Institute of Ecology.
- Joo, W.Y., Yeo, I.A., Jang, I.Y., Jung, P.M., Park, H.J., Kim, J.I., et al. (2019). *A Guideline for Ecosystem Services Assessment of Wetland Protected Areas*, Seocheon: National Institute of Ecology.
- Koo, B.H., Yoo, Y.H., Kim, H.D., Kim, J.K., Yang, H.S., Rho, P.H., et al. (2013). *Understanding of Wetland*, Changnyeong: Ministry of Environment.
- Kwon, K.J., and Park, B.J. (2018). Particulate matter removal of indoor plants, *Dieffenbachia amoena* 'Marianne' and *Spathiphyllum* spp. according to light intensity. *Journal of the Korean Institute of Landscape Architecture*, 46, 62-68.
- Lee, S.H. (2018). Direction for research and adaptive measures in healthcare after the announcement of the 9.26 comprehensive plan on management of particulate matter. *Health and Welfare Issue and Focus*, 346, 1-8.
- Manes, F., Marando, F., Capotorti, G., Blasi, C., Salvatori, E., Fusaro, L., et al. (2016). Regulating ecosystem services of forests in ten Italian metropolitan cities: air quality improvement by PM<sub>10</sub> and O<sub>3</sub> removal. *Ecological Indicators*, 67, 425-440.
- McInnes, R.J. (2013). Recognizing ecosystem services from wetlands of international importance: an example from Sussex, UK. *Wetlands*, 33, 1001-1017.
- Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being: Wetlands and Water: Synthesis*, Washington: World Resources Institute.
- Ministry of Environment. (2016). *You See What You Know: What is Particulate Matter?* Sejong: Ministry of Environment.
- Ministry of Environment. (2018). *Wetland Conservation Plan (2018-2022)*, Sejong: Ministry of Environment.
- Myong, J.P. (2016). Health effects of particulate matter. *Korea Journal of Medicine*, 91, 106-113.
- National Institute of Forest Science (2019). *New Project Guidelines for (Particulate Matter Reduction) Urban Forest Formation and Management*, Daejeon: Korea Forest Service.
- Novitzki, R.P., Smith, R.D., and Fretwell, J.D. (2001). *Restoration, creation, and recovery of wetlands wetland functions, values, and assessment*. Retrieved Sep 1, 2020 from <http://water.usgs.gov/nwsum/WSP2425/functions.html>.
- Nowak, D., and Heisler, G. (2010). *Air Quality Effects of Urban Trees and Parks*, Ashburn: National Recreation and Parks Association Research Series.
- Qiu, D., Liu, J., Zhu, L., Mo, L., and Zhang, Z. (2015). Particulate matter assessment of a wetland in Beijing. *Journal of Environmental Sciences (China)*, 36, 93-101.
- Ramsar Convention on Wetlands. (2011). *Wetland Ecosystem Services- an Introduction*, Gland: Ramsar Convention Secretariat.
- Ramsar Convention on Wetlands. (2018). *Global Wetland Outlook: State of the World's Wetlands and their Services to People*, Gland: Ramsar Convention Secretariat.
- Roucoux, K.H., Lawson, I.T., Baker, T.R., Del Castillo Torres, D., Draper, F.C., Lähenteenoja, O., et al. (2017). Threats to intact tropical peatlands and opportunities for their conservation. *Conservation Biology*, 31, 1283-1292.
- Rural Development Administration. (2019). *Plants are effective in reducing indoor particulate matter: 3-5 pots of plants with 1 m<sup>2</sup> leaf area in the living room (20 m<sup>2</sup>) reduce ultrafine particles by 20%*. Retrieved Sep 1, 2020 from [http://www.rda.go.kr/board/board.do?mode=view&trgId=day\\_farmprmninfoEntry&dataNo=100000753646](http://www.rda.go.kr/board/board.do?mode=view&trgId=day_farmprmninfoEntry&dataNo=100000753646).
- Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., et al. (2013). *The Economics of Ecosystems and Biodiversity for Water and Wetlands*, Gland: Ramsar Secretariat.
- Son, G.Y., and Kim, J.G. (2020). Assessing removal effects on particulate matters using artificial wetland modules. *Journal of Wetlands Research*, 22, 24-30.