Taiwania 70(3): 481–486, **2025**
DOI: 10.6165/tai.2025.70.481

Special Issue

Water and nutrient budget models suggest strategy for improving water quality of the Fushan Ecological Pond

Ting-Fen Tu[1,†], Wei-Jen Lin[2,†], Chiao-Wen Lin[3,4], Chuan-Wen Ho[1], Sheng-Shan Lu[5], Hsing-Juh Lin[1,*]

*1. Department of Life Sciences and Innovation and Development Center of Sustainable Agriculture, National Chung Hsing University, Taichung 402202, Taiwan. 2. Department of Biological Resources, National Chiayi University, Chiayi 600355, Taiwan. 3. Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung 804201, Taiwan. 4. The Center for Water Resources Studies, National Sun Yat-sen University, Kaohsiung 804201, Taiwan. 5. Taiwan Forestry Research Institute, Ministry of Agriculture, Taipei 100051, Taiwan. †Contributed equally to the work, *Corresponding author's email: hjlin@dragon.nchu.edu.tw*

(Manuscript received 10 October 2024; Accepted 24 December 2024; Online published 18 March 2025)

ABSTRACT: Eutrophication, driven by nutrient accumulation, alters species composition, food chains, and nutrient cycling in aquatic ecosystems. In the Fushan Ecological Pond, nutrient inputs have led to flourishing aquatic plants, indicating a shift towards eutrophic conditions. This study conducted in October 2020 analyzed water flow, quality, and nutrient concentrations to construct water and nutrient budgets for exploring nutrient stocks and flows in the pond. The results show that the Fushan Ecological Pond was approaching eutrophic condition. The water budget shows that the change of water capacity was 2.95 $m^3\ h^{-1}$, and the residence time was as long as 45.7 days, indicating that the water body was poorly flushed. In the nutrient budget, 61% of nitrogen came from the surface runoff, and 92% of the phosphorus input was contributed by the release from sediment. The submerged plant *Hydrilla verticillate* absorbed most of the nitrogen, and *Spirogyra* sp. absorbed most of the phosphorus. The nitrogen and phosphorus budgets show that 0.100 g N h^{-1} and 0.437 g P h^{-1} were accumulating in the pond. Collectively, this study suggests that future management efforts should focus on reducing N input from the inlets by installing simple constructed wetlands at the inlets to purify the water entering the pond. To mitigate nutrient accumulation, management should reduce nitrogen input via constructed wetlands and prevent sediment disturbance to limit phosphorus release. These actions would help mitigate the ongoing accumulation of nutrients in the pond and improve its ecological condition and function.

KEY WORDS: Eutrophication, nitrogen budget, phosphorous budget, residence time, water budget.

INTRODUCTION

Eutrophication is a slow natural process of aquatic succession, but human activities have accelerated this process. Excessive use of high-nutrient agricultural fertilizers, industrial wastewater discharge, and synthetic cleaning agents have led to the rapid accumulation of nutrients in aquatic systems (Ansari and Khan, 2014; Huang *et al.*, 2017). Wang *et al.* (2023) compiled physiochemical measurements of 217 lakes in China and demonstrated that the trophic status of freshwater lakes is positively correlated with the degree of anthropogenic impact. In addition, natural conditions (e.g., heavy rain) may accelerate phytoplankton or cyanobacterial blooms due to high nutrient inputs (Li *et al.*, 2015). The nitrogen (N) and phosphorus (P) in the water are key nutrient elements that accelerate the eutrophication of aquatic systems. The two elements will cause a significant algal increase, leading to the "algal bloom" phenomenon. When algae die and decompose, a large amount of oxygen in the water is consumed, leading to low dissolved oxygen levels and anaerobic conditions in the water. This results in the death of aquatic organisms, the production of toxins, and impacts on the system (Oberholster *et al.*, 2009).

The United Nations Environment Programme (UNEP) states that approximately 30 to 40% of the world's lakes and reservoirs are experiencing eutrophication. According to the International Lake Environment Committee (ILEC) statistics, 54% of lakes and reservoirs in Asia are already eutrophic. Lake Taihu in China has been facing eutrophication issues, leading to a lack of adequate water for domestic and drinking purposes (Qin *et al.*, 2010). Lake Erhai in China was investigated and found to be in a eutrophic to hypertrophic state, which caused an algal bloom and led to a deterioration in water quality (Chen *et al.*, 2022). Lake Sabalan in Iran is highly eutrophic due to intense agricultural activities in the surrounding area (Noori *et al.*, 2021). In Taiwan, apart from Lake Yuan-Yang in Hsinchu which is in an oligotrophic state (Tsai *et al.*, 2016), Lake Tsuei-Feng in Yilan, Lake Tai in Kinmen, and Lake Bi in Taipei have all shown eutrophication, ranging from mesotrophic to eutrophic conditions (Li, 1996; Chiu *et al.*, 2020; Chen and Chen, 2022). Chang and Chuang (2001) investigated twenty reservoirs in Taiwan from 1994 to 1998 and found that 37.5% of the reservoirs were eutrophic in 1994, which increased to 77.8% by 1998.

Regarding the eutrophication problem in lakes, there are many successful cases worldwide where the issue has been effectively addressed or alleviated. For instance, Lake Caron in the United States showed significant improvement in water quality through the implementation

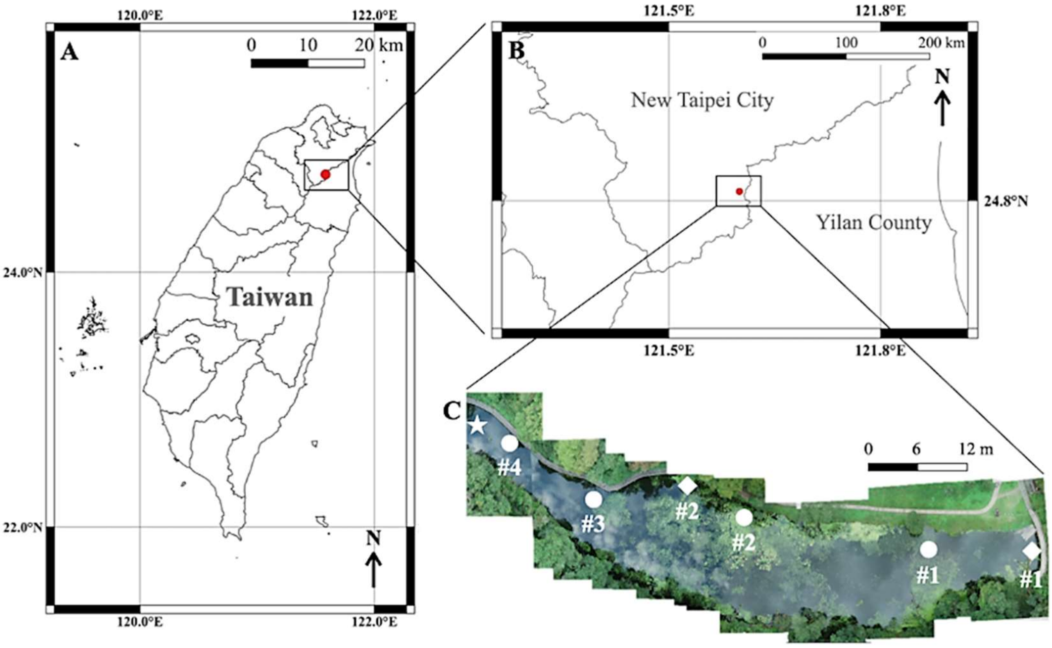

Fig. 1. Four sampling sites (circle), two inflow sites (diamond), and one outflow site (star) at the Fushan Ecological Pond of Taiwan Forestry Research Institute, Ministry of Agriculture of Taiwan in northern Taiwan.

of sediment and algae filtration treatments (Veetil *et al.*, 2021). From 2005 to 2016, the water quality and ecological stability of Lake Pickerel in the United States was successfully improved by removing the carp from the lake. This case also proposed that controlling nutrient inputs alone may not be sufficient to alleviate eutrophication in the water (Huser *et al.*, 2021).

Previous studies typically used Carlson's Trophic State Index (TSI) to assess the eutrophic condition of water. However, this index only provides a eutrophication indicator and cannot identify the underlying mechanism or solutions. As a result, some studies have proposed the use of static and dynamic models to predict nutrient fluxes in lakes, providing more accurate results and explanations (Bryhn and Håkanson, 2007). In Lake Peipus in Russia, Fink *et al.* (2018) successfully gained insights into nutrient retention within the lake by developing a large-scale hydrological model. This model enabled a thorough understanding of the hydrodynamic processes and nutrient cycling in the lake, allowing for predictions of future conditions and proposing potential solutions to address the challenges.

The Fushan Ecological Pond serves multiple functions, such as conservation, education, and recreation. It is not merely a pond but also a habitat with aquatic plants seving multiple functions. Over the past few years, the Fushan Ecological Pond has experienced excessive growth of aquatic plants, leading to poor water flow and accelerated sedimentation. This issue has been tried to solve by intervention. Initially, the introduction of herbivorous fish was considered for the removal of overgrown aquatic plants; however, their feeding activities resulted in the disturbance of the sediment and nutrient accumulation, causing more abundant floating aquatic plants and algae. This, in turn, triggered eutrophication and landscape deterioration. Consequently, the use of fish for intervention was terminated. Nevertheless, the overgrowth of aquatic plants has continued to be a persistent problem for the management of the pond. Therefore, finding appropriate management strategies for the ecological pond is an urgent task. To facilitate proper management, this study aims to establish the water and nutrient budgets to understand the dynamic conditions of the water and nutrient content of the Fushan Ecological Pond. Based on the model results, appropriate management suggestions are proposed.

MATERIALS AND METHODS

Study site

The Fushan Ecological Pond is located in the Fushan Botanical Garden of Taiwan Forestry Research Institute, Ministry of Agriculture of Taiwan in northern Taiwan, at the border between New Taipei City and Yilan County (Fig 1). It is situated at an elevation of approximately 650 m, with an average water depth of 0.99 m, and a water surface area of 2913.68 m^2. The pond has a wider front and a narrower back. In this study, four sampling sites, two inflow sites, and one outflow site were set up in the Fushan Ecological Pond. Hydrological and water quality measurements were conducted on October 9, 2020, from 10:00 AM to 12:00 PM, to establish the water and nutrient budget models of the Fushan Ecological Pond.

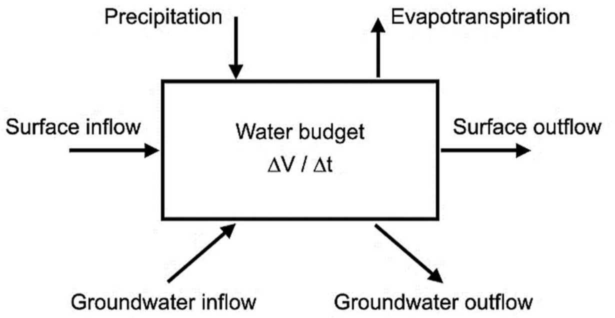

Fig. 2. The water budget model of the Fushan Ecological Pond.

Table 2. Coverage and biomass of three major aquatic plants in the Fushan Ecological Pond.

Site	*Hydrilla verticillate* Coverage (%)	*Hydrilla verticillate* Bioamss (g m^{-2})	*Spirogyra* sp. Coverage (%)	*Spirogyra* sp. Bioamss (g m^{-2})	*Lemna minor* Coverage (%)	*Lemna minor* Bioamss (g m^{-2})
1	30	5239.33	-	-	8	2.76
2	30	4016.33	7	189.6	10	4.26
3	30	1568.67	33	2.93	2	0.003
4	30	2191.33	24	2.93	-	-

Note: We assumed the coverage of *Hydrilla verticillate* to be 30% (Zeng *et al.*, 2022).

Aquatic plant biomass

In the Fushan Ecological Pond, *Hydrilla verticillata* is dominant as a submerged aquatic plant, while *Lemna minor* is dominant as a floating aquatic plant. Plant coverage and density were assessed by capturing images using a digital camera within randomly selected four quadrats (50 cm × 50 cm). Plant specimens within the central area of the quadrats (10 cm × 10 cm each) were collected and weighed in the laboratory, and the plant biomass per unit area (g m^{-2}) was determined. Finally, the plant biomass within the ecological pond was estimated by extrapolating these measurements to the entire pond.

Water budget model

The water budget model (Fig. 2) provides a method to assess the turnover of water within a closed aquatic system. In this study, we assumed that the input of groundwater was equal to the output of groundwater. The formula for the water budget is listed below:

$$\Delta V/\Delta t = P_n + S_i - (ET + S_o) \quad \text{Equation 1}$$

where ΔV/Δt is the change of water volume over time (m^3 h^{-1}), P_n is net precipitation, S_i is surface inflow, ET is evapotranspiration, and S_o is surface outflow.

Surface inflow and outflow (S_i and S_o) were measured using a flow meter (Sontek FlowTrack Handheld ADV, SonTek, San Diego, CA, USA) at Inflow 1 and Outflow site. Due to the difficulty in accessing Inflow 2, the flow rate at Inflow 2 was assumed to be equal to the flow rate at Inflow 1. Hourly precipitation (mm hr^{-1}) and monthly evapotranspiration (mm month^{-1}) were derived from the Meteorological Data Annual Report in 2020 and multiplied by the total surface area of the pond to assess the input of precipitation (m^3 h^{-1}) and output of evapotranspiration (m^3 h^{-1}).

To understand the residence time of water within the Fushan Ecological Pond, the following formula was used to calculate the duration of water retention.

$$t^{-1} = \frac{Q_t}{V} \quad \text{Equation 2}$$

where t represents the residence time (day^{-1}), Qt is the total inflow rate (m^3 day^{-1}), and V is the total volume of the pond (m^3)

Analysis of water nutrient concentration

Water samples were collected from two inflow and outflow inlets, as well as four sampling sites in Fushan Ecological Pond, using opaque plastic bottles with a volume of 100 ml. After filtration through 0.45 μm filter paper, the water samples were refrigerated and transported to the laboratory for nutrient concentration analysis. Water samples that were not analyzed immediately were stored in a freezer at -20°C for preservation.

The analysis of nutrient concentrations in the water included dissolved inorganic phosphate (DIP) and dissolved inorganic nitrogen (DIN). The concentration of DIP was measured as orthophosphate (PO_4^{3-}), following the molybdenum blue method (Murphy and Riley, 1962). The DIN concentration was determined by measuring nitrite (NO_2^-), nitrate (NO_3^-), and ammonium (NH_4^+). Nitrite concentration was measured using a colorimetric method (Bendschneider and Robinson, 1952), nitrate concentration was determined by the brucine colorimetric method (Jenkins and Medsker, 1964), and ammonium concentration was measured using the indophenol blue method (Pai *et al.*, 2001). All four nutrient concentrations were analyzed using a spectrophotometer (U-5001, HITACHI, Tokyo, Japan).

Nutrient budget models

Nutrient budget model (Fig. 3) provides a scientific basis for understanding the flux of nutrients to assess the nutrient behavior within a closed aquatic system. In this study, we constructed the nitrogen and phosphorus budgets based on the difference between nutrient flow into and out of the pond. The formula of the nutrient budget is listed below:

$$\Delta N, P/\Delta t = N, P_{inflow} + N, P_{sediment} - N, P_{outflow} - N, P_{uptake} \quad \text{Equation 3}$$

where ΔN, P/Δt is the change in nitrogen and phosphorus over time, respectively (g N, P h^{-1}), N, P_{inflow} is the N and P input via surface inflow, N, $P_{sediment}$ is the N and P released from the sediment, N, $P_{outflow}$ is the N and P output via surface outflow and N, P_{uptake} is the N and P absorbed by aquatic plants in the pond.

The N and P input via surface inflow (N, P_{inflow}) was estimated by multiplying the N and P concentration with the surface inflow and outflow (S_i and S_o) derived from the water budget.

Table 1. Environmental factors of four sampling sites and inflow and outflow sites in the Fushan Ecological Pond.

	Inflow 1	Site 1	Site 2	Inflow 2	Site 3	Site 4	Outflow	Fushan Ecological Pond
Water depth (m)	-	1.10	1.10	-	0.85	0.94	-	0.99
Area (m^2)	-	800.55	1176.52	-	759.41	206.63	-	2943.11
Volume (m^3)	-	792.54	1164.76	-	751.81	204.56	-	2913.68
Water velocity ($m\ h^{-1}$)	0.030	-	-	0.030[A]	-	-	0.025	-
NO_3^- ($mg\ L^{-1}$)	1.22 ± 0.46	1.31 ± 0.16	0.14 ± 0.027	0.97 ± 0.34	1.45 ± 0.014	1.18 ± 0.076	1.32 ± 0.091	1.02 ± 0.07
NO_2^- ($\mu g\ L^{-1}$)	5.9 ± 4.2	9.0 ± 0.3	1.0 ± 1.4	4.0 ± 2.1	5.0 ± 0.0	7.0 ± 0.3	7.7 ± 1.0	5.6 ± 0.5
NH_4^+ ($mg\ L^{-1}$)	0.087 ± 0.061	0.075 ± 0.033	0.106 ± 0.028	0.049 ± 0.019	0.035 ± 0.012	0.022 ± 0.010	0.039 ± 0.002	0.060 ± 0.020
PO_4^{3-} ($mg\ L^{-1}$)	0.058 ± 0.017	0.060 ± 0.014	0.063 ± 0.006	0.022 ± 0.014	0.029 ± 0.002	0.022 ± 0.000	0.021 ± 0.002	0.044 ± 0.005
Dissolved Oxygen ($mg\ L^{-1}$)	8.92 ± 0.02	5.62 ± 0.21	4.90 ± 1.26	9.71 ± 0.38	9.49 ± 0.22	10.00 ± 0.23	8.68 ± 0.55	7.50 ± 2.61
Electrical conductivity ($\mu s\ cm^{-1}$)	64.87 ± 5.14	56.70 ± 2.86	58.40 ± 8.46	67.53 ± 5.78	60.33 ± 5.43	55.47 ± 0.46	55.53 ± 1.37	57.73 ± 2.11
pH	7.40 ± 0.08	7.05 ± 0.06	6.77 ± 0.04	7.69 ± 0.08	7.47 ± 0.08	8.09 ± 0.34	7.16 ± 0.12	7.35 ± 0.57
Turbidity (NTU)	2.5 ± 1.0	4.3 ± 0.9	2.3 ± 0.2	2.8 ± 0.6	3.3 ± 0.4	5.0 ± 0.2	5.3 ± 0.6	3.7 ± 1.2
Transparency (m)	-	1.36 ± 0.17	2.00 ± 0.10	-	1.59 ± 0.11	1.21 ± 0.02	-	1.53 ± 0.34
Chlorophyll *a* ($\mu g\ L^{-1}$)	-	7.54 ± 3.24	23.00 ± 10.00	-	2.86 ± 0.23	4.27 ± 0.96	-	9.42 ± 3.61
Suspended solids ($mg\ L^{-1}$)	-	3.17 ± 0.94	15.25 ± 10.49	-	2.08 ± 0.82	2.00 ± 0.24	-	5.63 ± 3.12

Note: Data are presented as mean ± SD (n=3). ND denotes the environmental factor was not assessed.
[A] Due to the lack of flow rate measurement at Inflow 2, we assumed that the flow rate was the same with that at Inflow 1.

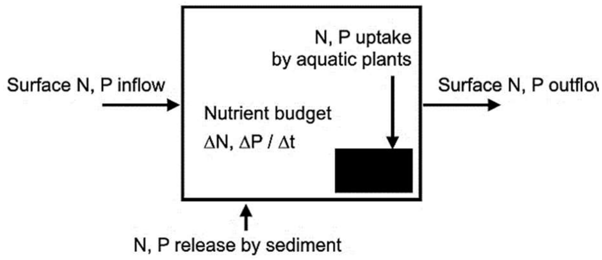

Fig. 3. Nutrient budget model of the Fushan Ecological Pond

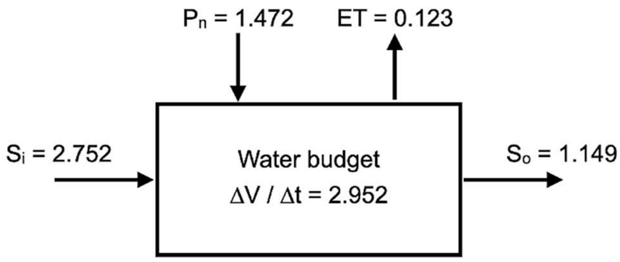

Fig. 4. The water budget model of the Fushan Ecological Pond on October 9, 2020. Units of each process are $m^3\ h^{-1}$.

Since N, $P_{sediment}$ was not measured in this study, we used the rates (0.68 mg NH_4^+ m^{-2} h^{-1} and 0.14 mg P m^{-2} h^{-1}) derived from Yang *et al*. (2020). These rates were multiplied with the surface area of the Fushan Ecological Pond (m^2).

The nutrient uptake rates of phytoplankton and aquatic plants (N, P_{uptake}) in the pond were estimated using the Michaelis-Menten model, as shown in Equation (4).

$$v_0 = \frac{V_{max}[S]}{K_m + [S]} \qquad \text{Equation 4}$$

This study utilized the maximum uptake parameters (V_{max}) and Michaelis constant (K_m) derived from previous studies on similar species (Priscu *et al.*, 1985; Borchardt *et al.*, 1994; Cedergreen and Madsen, 2002; Zhang *et al.*, 2014; Xiong, 2019). Using the concentrations of nitrogen (N) and phosphorus (P) in the water, the N and P uptake by phytoplankton and aquatic plants was calculated by the Michaelis-Menten model.

RESULTS

The low chlorophyll *a* concentration in the water suggests that phytoplankton or cyanobacteria did not bloom in Fushan Ecological Pond (Table 1). The flow rate at Inflow 1 of Fushan Ecological Pond (0.030 $m^3\ h^{-1}$) was slightly higher than the rate at Outflow (0.025 $m^3\ h^{-1}$). The inputs of N and P (2.326, 0.058 mg L^{-1}) were also higher than the outputs of N and P (1.359, 0.021 mg L^{-1}). Compared to other sampling sites, the N concentration at Site 2 is the lowest, but the chlorophyll *a* concentration and suspended solids are the highest. The Carlson Trophic State Index of the Fushan Ecological Pond is calculated to be 49.99 using total P concentration, chlorophyll-*a* concentration, and transparency, indicating that the water of the Fushan Ecological Pond is approaching eutrophic conditions.

The total water input from Inflow 1 and 2 was 2.752 $m^3\ h^{-1}$, while the water output via Outflow was 1.149 $m^3\ h^{-1}$. During the study period, the rainfall was 0.50 mm h^{-1}, and the evaporation rate was 0.04 mm h^{-1}. Based on the

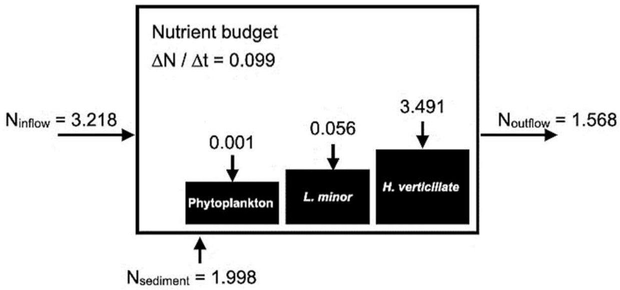

Fig. 5. The N budget model of the Fushan Ecological Pond on October 9, 2020. Units of each process are g N h^{-1}.

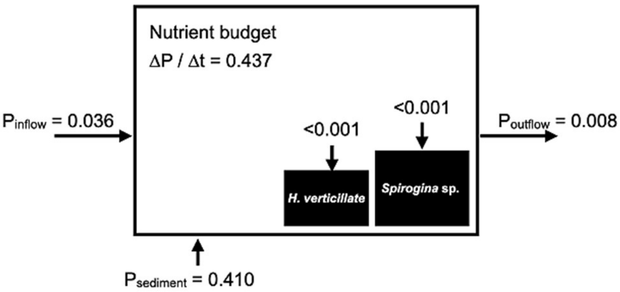

Fig. 6. The P budget model of the Fushan Ecological Pond on October 9, 2020. Units of each process are g P h^{-1}.

surface area of the Fushan Ecological Pond, the rainfall input was calculated to be 1.472 m^3 h^{-1}, and the evaporation output was 0.123 m^3 h^{-1}. Using the water budget model of the Fushan Ecological Pond (Fig. 4), the total water input was 4.224 m^3 h^{-1}, and the total water output was 1.272 m^3 h^{-1}, resulting in a net water increase of 2.952 m^3 h^{-1}. Furthermore, the water retention time of the pond was estimated to be 45.7 days.

The N inputs from Inflow 1 and 2 were 1.810 g N h^{-1} and 1.408 g N h^{-1}, respectively, while the N output via Outflow was 1.568 g N h^{-1}. The N released from the sediment to the water was estimated to be 1.998 g N h^{-1}. Among the aquatic plants in the pond, *Hydrilla verticillata* and *Lemna minor* absorbed 3.491 g N h^{-1} and 0.056 g N h^{-1}, respectively. Phytoplankton absorbed 0.001 g N h^{-1}. In the N budget model (Fig. 5), the total N input to the Fushan Ecological Pond was 5.216 g N h^{-1}, and the N removal was 5.116 g N h^{-1}, resulting in a net N accumulation of 0.10 g N h^{-1}.

The P inputs from Inflow 1 and 2 were 0.026 g P h^{-1} and 0.010 g P h^{-1}, respectively, while the P output via Outflow was 0.008 g P h^{-1}. The P released from the sediment to the water was estimated to be 0.410 g P h^{-1}. Among the aquatic plants in the pond, *Hydrilla verticillata* and *Spirogina* sp. absorbed less than 0.001 g P h^{-1}, respectively. In the P budget model (Fig. 6), the total P input to the Fushan Ecological Pond was 0.446 g P h^{-1}, and the P removal was 0.008 g P h^{-1}, resulting in a net P accumulation of 0.437 g P h^{-1}.

DISCUSSION

The water budget model of the Fushan Ecological Pond shows an increase of 2.952 m^3 h^{-1}, which is higher than that of Menghuan Lake (1.068 m^3 h^{-1}, Shih and Hsu, 2021), a lake situated at an elevation of approximately 850 meters in northern Taiwan, with a water depth of less than 1 meter and a water surface area of approximately 3,000 m^2. In both water budget models, precipitation accounted for 29.1% to 34.9% of the total water input, indicating that precipitation is a major source of water input for mountain lakes. In terms of output, evaporation accounted for 9.7% of the total water output for the Fushan Ecological Pond and 23.9% for Menghuan Lake. In this study, groundwater input and output were assumed to be equivalent due to the difficulty in field measurement (Kansoh *et al.*, 2020). However, Hood *et al.* (2006) emphasized the critical role of groundwater in the water balance of lakes and wetlands. Therefore, it is needed to incorporate groundwater dynamics into the water budget model to achieve a more accurate understanding of the hydrological processes of mountain lakes.

Lake retention time is the average time that water remains in a lake before it is replaced by new water. The water retention time of the Fushan Ecological Pond was estimated to be 45.7 days, which is not only longer than the water exchange time of a coastal eutrophic lagoon in Taiwan (24 days, Su *et al.*, 2004), but also exceeds the water retention time of two high-altitude lakes in Taiwan: Lake Yuan-Yang (5.8 days, Lin *et al.* 2022), a lake situated at an elevation of approximately 1650 m in northern Taiwan, with a water depth of 4.3 m and a water surface area of approximately 350 m^2, and Lake Tsui-Fong (10 days, Lin *et al.* 2022), the other lake situated at an elevation of approximately 1850 m in northern Taiwan, with a water depth of 3 m and a water surface area of approximately 800 ~ 2500 m^2. The Fushan Ecological Pond has a relatively longer retention time, indicating a very lower water exchange rate. As a result, the accumulation of total N and P in the water increases over time. For future management of the Fushan Ecological Pond, it is suggested to increase the water outflow to enhance water exchange and reduce retention time. This can be achieved by either adding additional outlets or increasing the flow rate and volume of the existing outlet. Therefore, increasing the water outflow would facilitate the faster removal of nutrients from the pond, helping to prevent their accumulation.

Both N and P in the Fushan Ecological Pond exhibit an accumulative trend, with rates of 0.010 g N h^{-1} and 0.437 g P h^{-1}, respectively. The main source of N input was from the inflow (61%), while the main source of P was sediment release (92%). According to Vollenweider (1968), for lakes with a depth of less than 5 meters, the critical nutrient loading thresholds for N and P are 2.0 g N m^{-2} yr^{-1} and 0.13 g P m^{-2} yr^{-1}, respectively. When applied to the surface area of the Fushan Ecological Pond (2913.68 m²), these thresholds were converted to 1.663 g N h^{-1} and 0.043 g P h^{-1}. Although nitrogen inputs have not yet exceeded the critical loading threshold, they have increased by 3.3 times compared to the measurements in 2012–2014 (Wang *et al*., 2016), potentially due to wastewater from a public toilet near the pond. In contrast, total P inputs far exceed the critical threshold by approximately 10 times. The P budget model indicates that sediment is a significant source of P input (Wang *et al*., 2020; Xu *et al*., 2021).

According to the nutrient budget model constructed in this study, the Fushan Ecological Pond continues to accumulate N and P, leading to the excessive growth of aquatic plants such as *Hydrilla verticillata*, which negatively impacts local native aquatic species. In the past, to address this issue, management authorities (the Fushan Botanical Garden) introduced herbivorous fish (*Ctenopharyngodon idella*) to remove the overgrown aquatic plants. However, this led to the proliferation of periphyton. When manual removal was employed, the disturbance of the sediment during the process caused the release of nutrients accumulated in the sediment, further exacerbating nutrient accumulation in the water. This, in turn, promoted the growth of aquatic plants and periphyton, ultimately resulting in the deterioration of the aesthetic quality of the pond.

It is urgent to reduce the N and P accumulation in the Fushan Ecological Pond. Paerl (2009) emphasized the importance of the control of nutrients for long-term management of eutrophication along the freshwater-marine continuum. Zamparas and Zacharias (2014) proposed several remediation methods of internal nutrient release to control eutrophication by using the P inactivation agents. Collectively, this study suggests that future management efforts should focus on reducing N input from the inlets. This can be achieved by installing constructed wetlands at the inlets to purify the water before it enters the pond. Additionally, Hickey and Gibbs (2009) suggested enhancing water flushing and dredging to reduce P release from sediments. It is needed to avoid disturbing the sediment or remove the sediment to reduce P release. These actions would help mitigate the ongoing accumulation of nutrients in the pond and improve its ecological condition and function.

CONCLUSION

This study constructs water and nutrient budget models to understand the hydrological dynamics and N and P behaviors in the Fushan Ecological Pond. It was found that the pond accumulated water at a rate of 2.951 m^3 h^{-1}, with a retention time of 45.7 days. Due to the low water exchange rate, nutrients accumulated in the pond. The nutrient budget models reveal that N and P accumulated at rates of 0.010 g N h^{-1} and 0.437 g P h^{-1}, respectively, with the primary sources being the inlets for N and the sediment releasing for P.

This study suggests that future management efforts should focus on reducing N input from the inlets. This can be achieved by installing constructed wetlands at the inlets to purify the water before it enters the pond. Additionally, it is needed to avoid disturbing or totally remove the sediment, in order to reduce P release from the sediment. These actions would help mitigate the ongoing accumulation of nutrients in the pond and improve its ecological condition and function.

ACKNOWLEDGMENTS

This study was financially supported in part by the “Innovation and Development Center of Sustainable Agriculture” from The Featured Areas Research Center Program within the Higher Education Sprout Project by the Ministry of Education (MOE) of Taiwan. We extend our sincere gratitude for the invaluable assistance provided by Dr. Ming-Tang Shiao and Dr. Li-Ping Ju in the Fushan Botanical Garden, Forest Research Institute, Ministry of Agriculture, Taiwan. The data for this study were collected collaboratively during the Wetland Ecology course in 2020, with active participation from all the students in the Department of Life Sciences, National Chung Hsing University. Additionally, we would like to express our appreciation to the teaching assistants, En-Tse Chang, Meng-Chun Chou, and Wang-Lin Tsai, for their expert guidance and unwavering support throughout the data collection process. We sincerely appreciate the two anonymous reviewers for their valuable comments and feedback, which significantly improved the manuscript.

LITERATURE CITED

Ansari, A., Khan, F. 2014 Household detergents causing eutrophication in freshwater ecosystems. In: Ansari, A., Gill, S. (eds) Eutrophication: Causes, consequences and control. 139–163pp. Springer, Dordrecht.

Bendschneider, K., Robinson, R.J. 1952 A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. **11:** 87–96.

Borchardt, M.A., Hoffmann, J.P., Cook, P.W. 1994 Phosphorus uptake kinetics of *Spirogyra fluviatis* (Charophyceae) in flowing water. J. Phycol. **30(3):** 403–417.

Bryhn, A.C., and Håkanson, L. 2007 A comparison of predictive phosphorus load-concentration models for lakes. Ecosystem **10(7):** 1084–1099.

Cedergreen, N., Madsen, T.V. 2002 Nitrogen uptake by the floating macrophyte *Lemna minor*. New Phytol. **155(2):** 285–292.

Chen, C.-K., Chen, Y.-C. 2022 Detection of chlorophyll fluorescence as a rapid alert of eutrophic water. Water Supply **22(3):** 3508–3518.

Chen, K., Duan, L., Liu, Q., Zhang, Y., Zhang, X., Liu, F., Zhang, H. 2022 Spatiotemporal changes in water quality parameters and the eutrophication in Lake Erhai of Southwest China. Water **14(21):** 3398.

Chiu, C.-Y., Jones, J.R., Rusak, J.A., Lin, H.-C., Nakayama, K., Kratz, T. K., Liu, W.-C., Tang, S.-L., Tsai, J. W. 2020 Terrestrial loads of dissolved organic matter drive interannual carbon flux in subtropical lakes during times of drought. Sci. Total Environ. **717:** 137052.

Chang, S.-P., Chuang, S.-M. 2001 Eutrophication study of twenty reservoirs in Taiwan. Water Sci. Technol. **44(6):** 19–26.

Fink, G., Burke, S., Simis, S.G.H., Kangur, K., Kutser, T., and Mulligan, M. 2018 Management options to improve water quality in Lake Peipsi: Insights from large scale models and remote sensing. Water Resour. Manag. **34(7):** 2241–2254.

Hickey, C.W., Gibbs, M.M. 2009 Lake sediment phosphorus release management-Decision support and risk management framework. N. Z. J. Mar. Freshw. Res. **43(3):** 819–856.

Hood, J.L., Roy, J.W., Hayashi, M. 2006 Importance of groundwater in the water balance of an alpine headwater lake. Geophys. Res. Lett. **33(13):** L13405.

Huang, J., Xu, C.-C., Ridoutt, B.G., Wang, X.C., Ren, P.A. 2017 Nitrogen and phosphorus losses and eutrophication potential associated with fertilizer application to cropland in China. J. Clean. Prod. **159:** 171–179.

Huser, B.J., Bajer, P.G., Kittelson, S., Christenson, S., Menken, K. 2021. Changes to water quality and sediment phosphorus forms in a shallow, eutrophic lake after removal of common carp (*Cyprinus carpio*). Inland Waters **12(1):** 33–46.

Jenkins, D., Medsker, L.L. 1964 Brucine method for determination of nitrate in ocean, estuarine, and fresh waters. Anal. Chem. **36(3):** 610–612.

Kansoh, R., Abd-El-Mooty, M., Abd-El-Baky, R. 2020 Computing the water budget components for lakes by using meteorological data. Civ. Eng. J. **6(7):** 1255–1265.

Li, C.C. 1996 Eutrophication of two lakes in Kinmen Island (Taiwan). Chem. Ecol. **12(1-2):** 57–66.

Li, X., Huang, T., Ma, W., Sun, X., Zhang, H. 2015 Effects of rainfall patterns on water quality in a stratified reservoir subject to eutrophication: Implications for management. Sci. Total Environ. **521–522:** 27–36.

Lin, H.-C., Tsai, J.-W., Tada, K., Matsumoto, H., Chiu, C.-Y., Nakayaman, K. 2022 The impacts of the hydraulic retention effect and typhoon disturbance on the carbon flux in shallow subtropical mountain lakes. Sci. Total Environ. **803:** 150044.

Murphy, J., Riley, J.P. 1962 A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta **27:** 31–36.

Noori, R., Ansari, E., Jeong, Y.-W., Aradpour, S., Maghrebi, M., Hosseinzadeh, M., Bateni, S.M. 2021 Hyper-nutrient enrichment status in the Sabalan Lake, Iran. Water **13(20):** 2874.

Oberholster, P.J., Botha, A.M. Ashton, P.J. 2009 The influence of a toxic cyanobacterial bloom and water hydrology on algal populations and macroinvertebrate abundance in the upper littoral zone of Lake Krugersdrift, South Africa. Ecotoxicology **18(1):** 34–46.

Pai, S.-C., Tsau, Y.-J., Yang, T.-I. 2001 pH and buffering capacity problems involved in the determination of ammonia in saline water using the indophenol blue spectrophotometric method. Anal. Chim. Acta **434(2):** 209–216.

Paerl, H.W. 2009 Controlling eutrophication along the freshwater-marine continuum: Dual nutrient (N and P) reduction are essential. Estuaries and Coasts **32(4):** 593–601

Priscu, J.C., Axler, R.P., Goldman, C.R. 1985 Nitrogen metabolism of the shallow and deep-water phytoplankton in a subalpine lake. Oikos **45(1):** 137–147.

Qin, B., Zhu, G., Gao, G., Zhang, Y., Li, W., Paerl, H.W., Carmichael W.W. 2010 A drinking water crisis in Lake Taihu, China: Linkage to climatic variability and lake management. Environ. Manag. **45:** 105–112.

Shih, S.-S., Hsu, Y.-W. 2021 Unit hydrographs for estimating surface runoff and refining the water budget model of a mountain wetland. Ecol. Eng. **173:** 106435.

Su, H.-M., Lin, H.-J., Hung, J.-J. 2004 Effects of tidal flushing on phytoplankton in a eutrophic tropical lagoon in Taiwan. Estuar. Coast. Shelf Sci. **61(4):** 739–750

Tsai, J.-W., Kratz, T.K., Rusak, J.A., Shih, W.-Y., Liu, W.-C., Tang, S.-L., Chiu, C.-Y. 2016 Absence of winter and spring monsoon changes water level and rapidly shifts metabolism in a subtropical lake. Inland Waters **6(3):** 436–448.

Veetil, D.P., Arriagada, E.C., Mulligan, C.N., Bhat, S. 2021 Filtration for improving surface water quality of a eutrophic lake. Journal of Environmental Management **279:** 111766.

Vollenweider, R.A. 1968 S Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication**.** OECD Tech. Rep. DAS/CS/ 68.27, Paris, France.

Wang, Y., Kong, X., Peng, Z., Zhang, H., Liu, G., Hu, W., Zhou, X. 2020 Retention of nitrogen and phosphorus in Lake Chaohu, China: implications for eutrophication management. Environ. Sci. Pollut. Res. **27(33):** 41488–41502.

Wang, C.H., Yu, H.M., Liu, C.B. 2016 Water quality dynamics in Fushan Ecological Pond. Forestry Research Newsletter **23(5):** 57–61. [in Chinese]

Wang, Q., Li, Y., Liu, L., Cui, S., Liu, X., Chen, F., Jeppesen, E. 2023 Human impact on current environmental stae in Chinese lakes. J. Environ. Sci. **126:** 297–307.

Xiong, H.F. 2019 Uptake kinetics of NH_4^+, NO_3^- and $H_2PO_4^-$ by submerged macrophytes *Elodea nuttallii* (St. John, 1920) and *Vallisneria natans* (Jussieu, 1826). Appl. ecol. environ. res. **17(1):** 1027–1037.

Xu, H., McCarthy, M.J., Paerl, H.W., Brookes, J.D., Zhu, G., Hall, N. S., Qin, B., Zhang, Y., Zhu, M., Hampel, J.J., Newell, S.E., Gardner, W.S. 2021 Contributions of external nutrient loading and internal cycling to cyanobacterial bloom dynamics in Lake Taihu, China: Implications for nutrient management. Limnol. Oceanogr. **66(4):** 1492–1509.

Yang, C., Yang, P., Geng, J., Yin, H., Chen, K. 2020 Sediment internal nutrient loading in the most polluted area of a shallow eutrophic lake (Lake Chaohu, China) and its contribution to lake eutrophication. Environ. Pollut. **262:** 114292.

Zamparas, M., Zacharias, I. 2014 Restoration of eutrophic freshwater by managing internal nutrient loads. A review. Sci. Total Environ. **496:** 551–562.

Zeng, Q., Wei, Z., Yi, C., He, Y., and Luo, M. 2022 The effect of different coverage of aquatic plants on the phytoplankton and zooplankton community structures: a study based on a shallow macrophytic lake. Aquat. Ecol. **56(4):** 1347–1358.

Zhang, K., Chen, Y.-P., Zhang, T.-T., Zhao, Y., Shen, Y., Huang, L., Guo, J.-S., Guo, J.-S. 2014 The logistic growth of duckweed (*Lemna minor*) and kinetics of ammonium uptake. Environ. Technol. **35(5):** 562–567.