

Article

Lake Water Quality Under Biomass Removal Scenarios: Integrating Observations and Modeling Approaches

Judita Koreivienė ^{1,*} , Ali Erturk ^{2,3} , Jūratė Kasperovičienė ¹ , Ričardas Paškauskas ¹ , Vaidotas Valskys ⁴  and Jūratė Karosienė ¹ 

- ¹ Laboratory of Algology and Microbial Ecology, State Scientific Research Institute Nature Research Centre, Akademijos Str. 2, 08412 Vilnius, Lithuania; ricardas.paskauskas@gamtc.lt (R.P.); jurate.karosiene@gamtc.lt (J.K.)
- ² Department of Freshwater Resources and Management, Faculty of Aquatic Sciences, Istanbul University, Istanbul 34134, Türkiye
- ³ Laboratory of Nuclear Geophysics and Radioecology, State Scientific Research Institute Nature Research Centre, Akademijos Str. 2, 08412 Vilnius, Lithuania
- ⁴ Laboratory of Climate and Water Research, State Scientific Research Institute Nature Research Centre, Akademijos Str. 2, 08412 Vilnius, Lithuania
- * Correspondence: judita.koreiviene@gamtc.lt

Abstract

Eutrophication, driven by excessive nutrient inputs from agriculture, wastewater, and aquaculture, remains a pressing challenge for freshwater ecosystems. In response, the EU Nature Restoration Law (2024) sets ambitious targets for restoring degraded ecosystems, emphasizing the need for effective and scalable lake management strategies. In this study, we assessed current water quality in Lake Simnas (Lithuania) and applied dynamic modeling to evaluate two in-lake restoration scenarios: removing scum-forming cyanobacteria and harvesting emerged macrophytes. While both interventions reduced local biomass, neither led to substantial improvements in chlorophyll-a concentrations or total phosphorus levels. Macrophyte harvesting was particularly ineffective because of the low phosphorus content, limited spatial coverage, and slow growth. In contrast, simulations showed that a 50% reduction in external phosphorus inputs led to a significant improvement in water quality, including a 58% drop in mean TP and a 47% decrease in peak chlorophyll-a. These findings support prioritizing catchment-scale nutrient reduction over isolated biomass removal and highlight the importance of sustained monitoring and integrated management for restoring shallow eutrophic lakes.

Keywords: biomass removal; cyanobacteria; eutrophication; freshwater lakes; macrophytes; nutrient reduction; lake restoration; water quality modeling



Academic Editors: Daniela R. De Figueiredo and Patrícia S. M. Santos

Received: 30 September 2025

Revised: 31 October 2025

Accepted: 4 November 2025

Published: 10 November 2025

Citation: Koreivienė, J.; Erturk, A.; Kasperovičienė, J.; Paškauskas, R.; Valskys, V.; Karosienė, J. Lake Water Quality Under Biomass Removal Scenarios: Integrating Observations and Modeling Approaches. *Water* **2025**, *17*, 3211. <https://doi.org/10.3390/w17223211>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Freshwater ecosystems, though covering only about 4% of the world's non-glaciated land area [1], are ecologically sensitive and highly significant. They accumulate nutrients and pollutants from surrounding landscapes, often leading to eutrophication. Excessive nitrogen and phosphorus inputs—originating from agriculture, wastewater discharge, and aquaculture—can significantly degrade water quality and lead to harmful algal blooms (HABs), oxygen depletion, disruption of food webs, and biodiversity loss [2–4]. HABs pose ecological and societal challenges worldwide. Annual economic losses are estimated to exceed USD 1 billion for European coastal waters and USD 2.4 billion for inland waters in

the United States [5]. While tourism and recreation are typically the most impacted sectors, aquaculture is particularly vulnerable in low-income countries [6]. Population growth, urbanization, the increasing demand for limited freshwater resources, and climate change all contribute to these growing anthropogenic pressures [7].

The European Union's *Nature Restoration Law*, which came into force in August 2024, sets ambitious goals: restoring at least 20% of degraded EU habitats by 2030 and all such ecosystems by 2050. Globally, lake restoration initiatives typically focus on reducing nutrient inputs and mitigating eutrophication [6]. The most effective measures combine catchment-scale nutrient reduction with in-lake interventions [6]. However, restoration techniques vary greatly in terms of cost, efficiency, application frequency, and scale [4,8]. Restoration costs also depend on lake size, the degree of eutrophication, nutrient sources, and the methods applied. Therefore, lake managers should begin with a robust assessment before choosing from the broad set of available interventions [4].

The susceptibility of lakes to eutrophication depends on their morphology, catchment area, and landscape position. The integration of long-term hydrochemical monitoring with catchment-scale models is vital for assessing ecosystem responses to anthropogenic and climatic pressures. Such modeling approaches support informed water management and restoration strategies. In their analysis, Withers et al. [7] stressed that climate change mitigation efforts should be more accurately apportioned in relation to multiple nutrient sources and therefore require more sophisticated catchment-based allocation tools and indicators to identify which sources need to be tackled first. They also mentioned that an assessment of time lags in waterbody responses was required. As ecosystem models have improved, authorities can now better plan restoration measures with predictive insights [9].

In Lithuania, Povilaitis and Querner [10] applied the SIMGRO model to assess combined surface and subsurface water flow scenarios in the Dovinė River Basin. Lake Simnas, a part of this catchment, is a highly valued site for recreation and fishing. However, the lake suffers from eutrophication due to decades of nutrient loading, primarily from agricultural sources covering over 80% of the catchment. Its shallow littoral zones are densely overgrown with aquatic vegetation [11], and cyanobacterial blooms occur regularly. Water quality in Lake Simnas has been classified as critical [11,12], necessitating urgent intervention. Measures such as aquatic vegetation removal have been implemented. During a five-year EU investment program [13], 41 and 123 ha of macrophytes were removed from the Dovinė River and Lake Simnas, respectively. Additionally, the EU LIFE project “AlgaeService for LIFE” proposed cyanobacterial scum removal (<https://algaeservice.gamtostyrimai.lt/background-information/> accessed on 10 July 2025).

Targeted nutrient reduction in both the catchment and the lake remains the most effective approach to remediation [6]. In-lake measures—such as biomass removal, chemical treatment, artificial mixing, aeration, dredging, flushing, and biomanipulation—can be particularly useful when external loading is persistent or when internal nutrient cycling is high [3,4,8,14,15]. These interventions are often part of broader efforts to accelerate recovery, especially when sediment nutrient release continues even after external load reductions [4,16]. Additionally, removing biomass from primary producers can support circular economy goals by converting aquatic waste into usable products [16].

Restoration must be lake-specific, as aquatic systems vary widely. Therefore, effective restoration begins with sound, location-specific diagnostics and modeling. Models can simulate management scenarios to estimate the effect of vegetation or cyanobacterial removal on water quality. In this study, we aimed to assess water quality in Lake Simnas and use ecosystem modeling to evaluate whether the removal of cyanobacterial and/or macrophyte biomasses can reduce blooms and enhance lake water quality.

2. Materials and Methods

2.1. Physico-Geographical Characteristics of Lake Simnas and Its Catchment

Lake Simnas is located in the southern part of Lithuania ($54^{\circ}24'10.79''$ N, $23^{\circ}38'22.89''$ E). The town of Simnas, with a population of approximately 1800 inhabitants, is situated on the southeastern shore of the lake [11]. Lake Simnas belongs to the heavily modified catchment area of the Dovinė River, which covers approximately 588.7 km². More than 80% of the Dovinė River catchment is used for agriculture, while forested areas are sparse, covering only 16% [10]. The catchment area of Lake Simnas (178.6 km²) is more than seventy times larger than the lake's surface area (2.44 km²), and the average annual water exchange rate is 171%.

Lake Simnas is a shallow, polymictic water body with an average depth of 2.3 m and a maximum depth of 4.6 m. Its shores are flat and overgrown with a narrow strip of shrubs, bordered by pastures and cultivated fields. The lake is surrounded to the south, west, and north by the ~110 ha Balos swamp. Along the shoreline, there are wide (10–45 m) and dense belts of macrophytes. The shallow zones of the lake are mostly overgrown with reeds, lakeshore bulrush, and yellow water lilies [12]. Sand and mud are the predominant bottom sediments. Black mineral silt accounts for a total area of 5 million m³, with an average layer thickness of 4.54 m, with the thickest deposits being located in the western part of the lake [12]. The sludge contains 20% organic matter, 8.9 g/kg of nitrogen, and 0.74 g/kg of phosphorus; therefore, dredging the sediments is not recommended as a measure for improving water quality.

There are two tributaries and one outflow connected to Lake Simnas. The Simnyčia River carries water from the nearby Lake Giluitis. The Spernia River, another tributary, flows from Lake Dusia through the Simnas experimental fish farm and the town of Simnas before reaching Lake Simnas. The lake's water level is artificially raised by a dam, which has made the entire western shoreline waterlogged and swampy. A sluice was constructed in 1972 on the Bambena River, the lake's outflow channel leading to Lake Žuvintas. After the dam's construction, the average water level of Lake Simnas rose by 0.83 m, increasing the lake's surface area by 6.8 ha. Spernia and Bambena are often considered different sections of the Dovinė River, whose hydrological regime and catchment structure were substantially altered in the second half of the 20th century [17].

2.2. Collection and Processing of Environmental Samples and Water Quality Evaluation

Sampling was conducted in Lake Simnas between April and September from 2018 to 2023, and in the Spernia, Simnyčia, and Dovinė rivers from March to August of 2021–2023 (Table 1). Water samples were collected from the surface layer of the lake using a Ruttner sampler (KC, Silkeborg, Denmark) and as integrated samples from the euphotic zone at four pelagic stations. An additional surface sediment sample was collected from the central part of the lake at a depth of 3.5 m using a Stratometer Kajak Corer (KC, Silkeborg, Denmark) in order to analyze inorganic nutrients.

Water temperature, pH, conductivity, and dissolved oxygen were measured *in situ* using a portable WTW F/Set-3 multimeter (Xylem, Nottingham, UK) with selective electrodes. Secchi depth was measured with a standard Secchi disk. Chlorophyll-a (Chl-a) concentrations were determined using an AlgaeLabAnalyser fluorometer (bbe Moldaenke GmbH, Schwentinental, Germany). Total nitrogen, inorganic nitrogen species, and total phosphorus were determined according to standard analytical methods (LST EN ISO 10304 [18], LST EN ISO 14911 [19]).

Water samples (1 L) for phytoplankton analysis were preserved with 4% (*v/v*) formaldehyde solution. The modified Utermöhl method was used to evaluate phytoplankton, and this method has previously been validated using samples from other Lithuanian

lakes. Species identification and cell counting were conducted in a Nageotte chamber (Carl Roth GmbH, Karlsruhe, Germany) under a light microscope. A minimum of 600 counting units per sample were evaluated [20]. Biomass was calculated using geometric-shape-based volume formulas, as described by Olrik et al. [20] and Olenina et al. [21]. Species identification was conducted based on morphological features, using taxonomic keys and descriptors.

Table 1. Sampling dates for Lake Simnas and its tributary rivers.

Sampling Point	Sampling Dates
Lake Simnas	2018-08-08; 2019-06-04; 2019-07-19; 2019-08-09; 2019-08-27; 2020-08-10; 2021-05-14; 2021-06-04; 2021-06-21; 2021-07-07; 2021-07-22; 2021-08-12; 2021-08-24; 2021-09-14; 2022-04-20; 2022-07-20; 2023-08-04
Rivers Spernia, Simnyčia and Dovinė	2021-03-20; 2021-05-14; 2021-06-04; 2021-06-21; 2021-07-07; 2021-09-14; 2021-07-22; 2021-08-12; 2022-04-21
Sediments	2022-04-20

The ecological status of the water was assessed in accordance with the Regulation of the Minister of Environment of the Republic of Lithuania (No. DI-905, 2018-10-23). According to the national typology, Lake Simnas is classified as a Type I lake: shallow, with a mean depth of less than 3 m. The threshold values for physical, chemical, and biological quality parameters for Type I lakes are provided in Table 2.

Table 2. Ecological status classes of Lithuanian lakes based on physicochemical parameters and the chlorophyll-a index, Phytoplankton index (EQR), and Macrophyte ecological index (MEI) (Regulation of the Minister of Environment of the Republic of Lithuania, No. DI-905, 2018-10-23).

Quality Element	Parameter	Lake Type	Ecological Status Classes				
			Very Good	Good	Moderate	Bad	Very Bad
Nutrients	TN (mg/L)	1–3	<1.00	1.00–2.00	2.01–3.00	3.00–6.00	>6.00
	TP (mg/L)	1	<0.040	0.040–0.060	0.061–0.090	0.091–0.140	>0.140
Organic matter	BDS ₇ (mg O ₂ /L)	1	<2.30	2.30–4.2	4.3–6.0	6.1–8.0	>8.00
Transparency	S (m)	1	>2.00	2.00–1.3	1.2–0.8	0.7–0.5	<0.5
Chl-a index value		1	0.5–1.5	1.51–2.5	2.51–3.5	3.51–4.5	4.51–5.5
EQR		1	0.81–1.0	0.61–0.8	0.41–0.6	0.21–0.4	0.0–0.2
MEI		1–3	1.00–0.75	0.74–0.50	0.49–0.25	0.24–0.01	0.00

2.3. Evaluation of the Area Covered with Aquatic Vegetation

A fixed-wing UAV was used to capture aerial images for the analysis of aquatic macrophytes in Lake Simnas. The UAV acquired images from an altitude of 100–200 m using a visual-spectrum camera. Image processing was conducted using Agisoft Metashape Professional, Trimble eCognition Developer, and ArcGIS Pro 2.5–2.6 software, following a workflow that included image segmentation, classification of vegetation zones, and estimation of macrophyte biomass. This analysis was supported by biomass coefficients derived from the literature. This methodology enabled the differentiation of aquatic plant types and the quantification of their spatial coverage.

2.4. Evaluation of Cyanobacterial Biomass Collection Efficiency

As part of the EU LIFE project AlgaeService for LIFE (No. LIFE17 ENV/LT/000407; 2018–2023), a prototype device named AS-LAND (patent No. 7081, registered at the State Patent Bureau of the Republic of Lithuania, Baltic UAV Services, Jovariškės, Lithuania) was developed for the collection of scum-forming cyanobacteria. The active collection area of the prototype is 4 m². Although the prototype was not tested in Lake Simnas, data from ten efficiency trials conducted in 2023 in the Kaunas Reservoir and the Simnas fishponds were used for modeling purposes.

The collection rate varied significantly depending on the dominant cyanobacterial species and their concentrations in the water (Figure 1). The average cyanobacterial biomass concentration during the tests was 11.3 ± 8.3 g/L, while the mean collection rate reached 13.9 ± 10.9 L of wet biomass per hour per square meter.

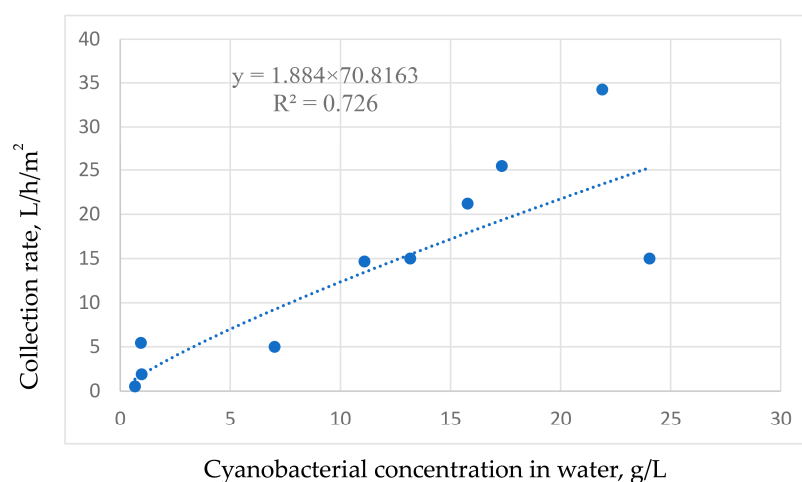


Figure 1. The relationship between the cyanobacterial concentration in water (g/L) and the collection rate (L/h/m²) of the AS-LAND prototype, based on experimental data from the Kaunas Reservoir and Simnas fishponds.

2.5. Modeling of Biomass Elimination

The Lake Simnas model is a mass balance model that represents a simplified version of the real Lake Simnas ecosystem. The model's state variables—those for which mass balances are calculated—were selected based on the objectives of this study and the anticipated scenarios related to eutrophication and water quality management. The model's overall structure is summarized in Figure 2.

The model focuses on the primary production of both phytoplankton and rooted aquatic macrophytes. It includes built-in functions to simulate the harvesting of phytoplankton (specifically cyanobacteria) and macrophytes (specifically *Phragmites australis*). The state variables comprise the following:

- Dissolved inorganic nutrients (ammonium nitrogen, nitrate nitrogen, and phosphate phosphorus) in both the water column and sediments;
- Dissolved organic matter and associated nutrients (dissolved organic carbon, nitrogen, and phosphorus) in the water column and sediments;
- Particulate detrital organic matter and associated nutrients (particulate detrital carbon, nitrogen, and phosphorus) in the water column and sediments;
- Several functional groups of phytoplankton biomass;
- Macrophyte biomass, divided into shoot biomass in the water column and root biomass in the sediment.

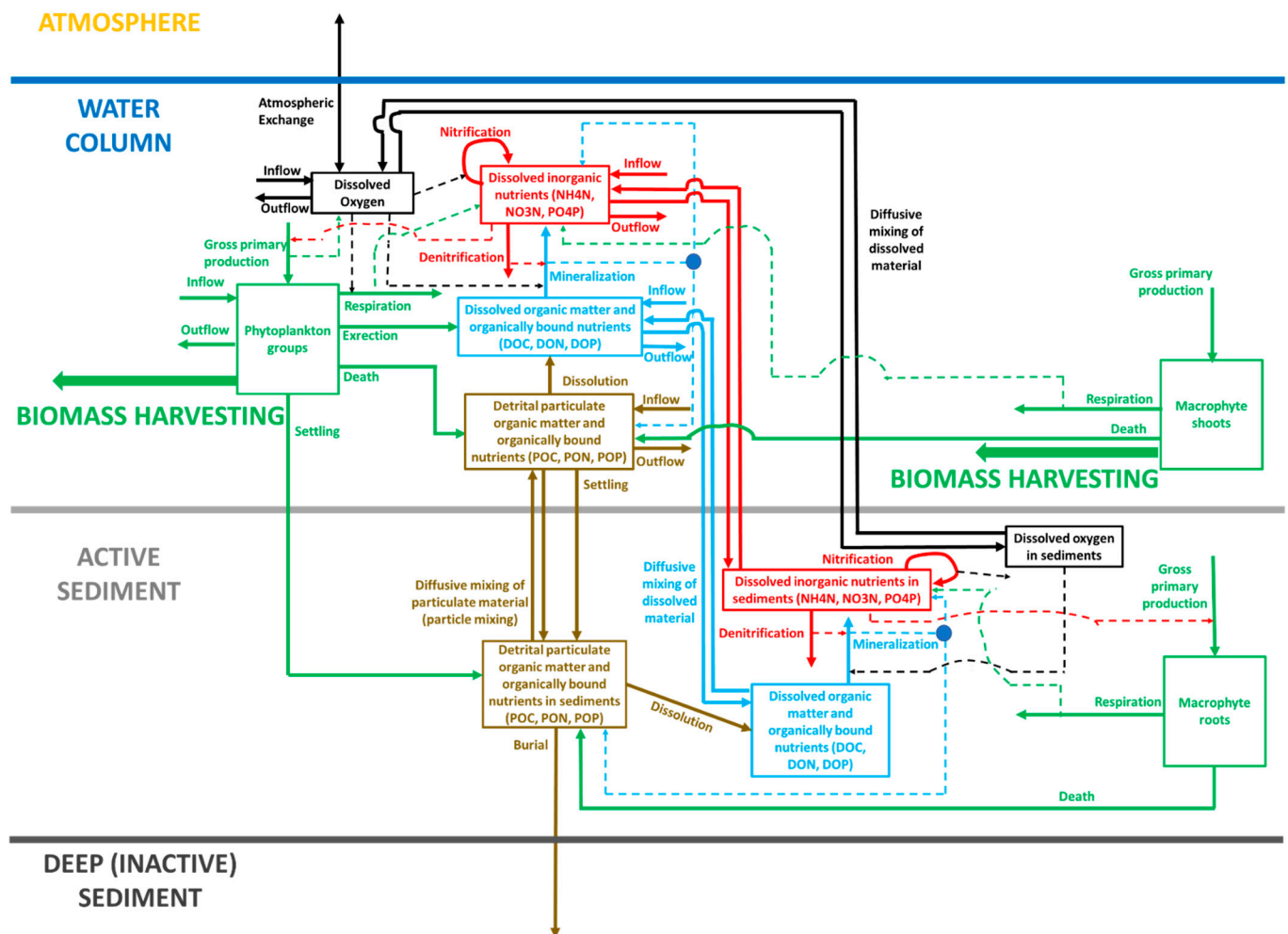


Figure 2. Schematic representation of the Lake Simnas mass-balance model used for biomass elimination assessment.

The model has a self-sustained structure with four main components, which are listed below:

- Hydrology and hydrography:** This component manages lake water volume, inflows and outflows, and nutrient loading from the watershed. As only annual water balance data were available, weekly inflows were estimated according to the methods reported by Håkanson and Boulion [22]. Weekly nutrient loads were calculated using weekly flows and annual nitrogen input estimates for the Dovinė River basin [23], considering nutrient retention in upstream lakes. Nitrogen retention was estimated using the equations developed by Bachman [24], with lake-specific parameters from Kasperovičienė [25]. Phosphorus loads were derived from weekly flows and annual total phosphorus data provided by Taminskas et al. [26]. For both nitrogen and phosphorus, constant concentrations as assumed by Håkanson and Boulion [22] and fixed proportions of nutrient species (organic nitrogen, ammonia nitrogen, nitrate nitrogen, and phosphate phosphorus) were assumed to be in the inflow. While this approach may seem to be an oversimplification because, basically, a constant concentration is assumed for river inflows, it is important to note that the mean residence time of the lake was calculated to be approximately two months, which is considerably longer than a week that corresponds to flows indicating a considerable smoothing effect of inflow nutrient concentrations. Furthermore, most of the nutrient loads from the larger part of the Dovinė Basin enter Lake Dusia, which has a relatively high

residence time (on the order of decades). This additional retention further dampens potential short-term fluctuations in nutrient flows that ultimately reach Lake Simnas as inflow concentrations.

- **Water column sub-model:** Given that Lake Simnas is a shallow, polymictic water body, the water column was modeled as a fully mixed system. While this approach justified for a shallow lake, it might not account for potential short-term stratifications or spatial heterogeneity. However, considering that, in this study, we performed an investigation of the possibilities related to the improvement of the lakes' eutrophic state in general, such possible but relatively local and short-term heterogeneities are not a real concern at this stage. Phytoplankton were treated as primary producers. Although cyanobacteria were the main focus, additional phytoplankton groups were included to account for potential species shifts following cyanobacterial biomass harvesting. The modeled groups were Bacillariophyta, Cyanophyta, Cryptophyta, Chrysophyta, Chlorophyta, and other planktonic algae not classified under these divisions. Phytoplankton biomass was expressed in terms of carbon, with fixed stoichiometric ratios for C:N and C:P based on the work of Chapra [27]. Standard conversion factors were used for wet-to-dry biomass.
- **Sediment sub-model:** The sediment model was developed based on DiToro [28]. Active sediments are represented as two layers: the first layer is approximately 1 cm thick, and the second is around 10 cm thick. The deeper sediment layer is considered inactive and does not interact with the active sediment layers. In other words, the model assumes that once material is buried in the deep sediments, and it does not return to the system. The upper (active) layer is assumed to exchange with the overlying water column. Only diffusive transport processes are considered molecular diffusion for dissolved substances and particle mixing for particulate substances, both driven by concentration gradients.
- **Rooted aquatic macrophytes sub-model:** Two functional groups of macrophytes were modeled based on Lake Simnas data: helophytes (represented by *Phragmites australis* and *Schoenoplectus lacustris*) and nymphaeids (represented by *Nuphar lutea*). Model parameters were derived from the literature, e.g., [29–35]. Model outputs were validated against biomass data from comparable shallow eutrophic lakes [36,37].

The model was run in the Goldsim system dynamics simulation environment (Version 14) in a hierarchical fashion. Goldsim was used because for the following reasons:

- **Clarity and ease of use:** Goldsim allows the development of models in a manner similar to how live documents behave, where all the model equations are simply entered in a relatively human-readable form, supported by hyperlinks to further documentation. All the numerical integration, as well as the management of time-dependent data, is handled by Goldsim itself, leaving numerical algorithms at a more hidden level, allowing the users to concentrate on ecological process rates for the mass balance model rather than its solution.
- **Applications to environmental problems:** Even though it is also a general system dynamics simulation software, Goldsim, version 14 is tailored and has a long history of use in environmental applications [38].
- **Distribution to others:** Goldsim has a player mode where the model, even though not further developed, can be viewed and even run by other users requiring verification of a Goldsim license.
- **Availability:** Both institutes involved in this study had already acquired legal licenses for this software.

Because of the comprehensive size of the model equations and supporting structures in the model, a full description of the mass balance model cannot be given here. The readers

are therefore referred to an electronic supplement, where a read-only version of the model is provided as a link (Supplementary Information Section).

3. Results

3.1. Water Quality of Lake Simnas Based on Physico-Chemical and Biological Data

Water quality monitoring in Lake Simnas was conducted between 2018 and 2023 (Table 3). The mean Secchi depth in the summer ranged from 0.37 to 0.70 m, while the mean total phosphorus (TP) concentrations differed by a factor of five, total nitrogen (TN) varied more than sixty-fold (mean TP 0.028–0.123 mg/L; mean TN 1.32–2.13 mg/L). The highest TP and TN values were recorded in August 2018 (0.149 mg/L and 2.29 mg/L, respectively), likely due to a short-term release of untreated wastewater from nearby fishponds. Collectively, these environmental parameters indicate persistent hypereutrophic conditions in Lake Simnas.

Among the biological parameters, the mean Chl-a concentrations ranged from 22.4 to 96.4 µg/L (Table 3), with the most intense bloom recorded in 2018, when the mean Chl-a concentration reached 377.7 µg/L and the maximum value was 1650 µg/L. The total phytoplankton biomass (mean 6.47–27.02 mg/L) was typical for highly eutrophic water bodies (Table 3). During the summer months, cyanobacteria accounted for more than 50% of the total phytoplankton biomass. The dominant taxa included *Aphanizomenon gracile* (0.08–2.90 mg/L; 7.0–36.9% of the plankton community), *Microcystis* spp. (1.15–2.55 mg/L; 10.4–36.2%), *Dolichospermum* spp. (0.77–11.08 mg/L; 0.6–39.4%), and *Planktolyngbya* sp. (0.29–2.93 mg/L; 11.8–31.6%). These species are known producers of various cyanotoxins.

During the 2018–2023 period, cyanotoxin concentrations in Lake Simnas ranged from 0.16 to 2.40 µg/L for microcystins (MCs), 0.0 to 4.57 µg/L for anatoxins (ATX), and 0.046 to 0.083 µg/L for saxitoxins (SXT). Overall, cyanotoxin concentrations (Table 4) remained below the World Health Organization [39] guideline values for recreational waters: 24 µg/L for MCs, 60 µg/L for ATX-a, and 30 µg/L for STX. However, in areas where cyanobacterial scum accumulates, the risk for bathers may increase significantly, as MCs concentrations can reach up to 566 µg/L more than 20 times the WHO threshold for safe recreational exposure. Therefore, the removal of cyanobacterial surface scum may substantially reduce health risks for bathers. An open question remains: could such harvesting also lead to broader improvements in water quality since nutrients are concurrently removed with the biomass?

Among the dominant phytoplankton species in Lake Simnas, non-native cyanobacteria were prevalent, notably *Cuspidothrix issatschenkoi* (0.2–10.0 mg/L; 6.7–41.2%) and *Sphaerospermopsis aphanizomenoides* (0.10–5.87 mg/L; 2.4–39.1%). During certain periods, the green alga *Phacotus lenticularis* (0.14–16.55 mg/L; 0.5–49.2%) and the diatom *Aulacoseira italica* (0.89–1.40 mg/L; 9.82–10.31%) also contributed to the phytoplankton community structure, occasionally co-dominating with cyanobacteria.

The implementation of the Water Framework Directive requires EU Member States to define and harmonize ecological status class boundaries for physical, chemical, and biological quality elements. The water quality status of Lake Simnas is illustrated using color coding in Table 3. Of the assessed indicators, the Secchi depth and phytoplankton index (EQR) suggest a bad or very bad ecological status, while the phosphorus concentration indicates a moderate to bad status for the period up to 2017 (Table 3).

Table 3. Physico-chemical and biological parameters of the water in Lake Simnas during the period 2018–2023.

Year Parameter	2018	2019	2020	2021	2022	2023
Physico-chemical data						
Secchi depth, m	0.30-(0.38)-0.40	0.36-(0.58)-1.25	0.25-(0.40)-0.48	0.40-(0.58)-1.00	0.48-(0.54)-0.63	0.43-(0.52)-0.74
TP (mg/L)	0.107-(0.126)-0.149	0.034-(0.073)-0.110	0.053-(0.061)-0.065	0.017-(0.047)-0.094	0.012-(0.028)-0.041	0.013-(0.039)-0.057
PO ₄ ³⁻ -P (mg/L)	0.071-(0.089)-0.108	<0.010-(0.031)-0.070	<0.010-0.010	<0.010-(0.014)-0.020	<0.010-(0.017)-0.030	0.010-(0.020)-0.030
TN (mg/L)	1.85-(2.13)-2.29	0.87-(1.32)-1.96	1.19-(1.51)-1.88	0.52-(1.48)-2.28	1.16-(1.50)-1.73	1.60-(1.67)-1.70
NO ₃ ⁻ -N (mg/L)	<0.02	<0.02	<0.02	<0.02-0.53	<0.02-0.36	<0.02
NH ₄ ⁺ -N (mg/L)	0.49-(0.58)-0.69	<0.05-(0.18)-0.60	0.16-(0.21)-0.25	<0.05-(0.15)-0.27	<0.05-(0.40)-0.43	0.05-(0.35)-0.60
Water temp. (°C)	25.0-(25.5)-25.6	18.8-(21.3)-25.0	23.3-(25.1)-26.3	17.8-(21.4)-24.7	19.6-(19.8)-20.3	13.9-(19.3)-20.9
pH	8.82-(8.90)-8.97	8.32-(9.00)-9.80	9.35-(9.36)-9.48	7.51-(8.58)-9.29	10.35-(10.37)-10.40	8.27-(8.54)-8.74
Oxygen, (mg O ₂ /L)	12.00-(12.51)-14.45	8.12-(12.34)-20.00	11.20-(12.87)-14.7	4.22-(10.82)-13.26	9.89-(11.09)-12.74	6.85-(10.01)-14.65
EC (µS/cm)	306-(307)-308	313-(406)-491	322-(325)-327	365-(419)-490	413-(417)-419	371-(413)-473
Biological data						
Chl-a (µg/L)	102.6-(311.7)-1650.0	22.0-(88.6)-120.4	63.3-(96.4)-116.5	10.7-(35.7)-62.6	55.5-(54.8)-61.4	20.9-(22.4)-23.8
Phytoplankton biomass (mg/L)	5.22-(6.47)-9.03	7.91-(16.92)-24.87	22.61-(27.02)-33.66	nd	nd	nd
Cyanobacteria biomass (mg/L)	3.13-(4.17)-5.27	6.27-(13.39)-19.24	11.21-(15.49)-21.29	0.71-2.26-4.18	nd	nd

Notes: The variables in the blue areas are mandatory parameters for water quality evaluation, colors indicate Ecological status classes (see Table 2). Data represent: Min-(Mean)-Max.

Table 4. Concentrations of cyanotoxins (µg/L) in the water in Lake Simnas, phytoplankton biomass, and surface scum.

Year	Water	Biomass	Scum
2018	MCs 1.91; ATX 0.25; STX 0.0083	MCs 1.87; ATX 0.2; STX 0.002;	MCs 19.22
2019	MCs 0.67–2.40; ATX 0.25–4.57; STX 0.0–0.0096	MCs 0.67–2.31; ATX 0.17–4.29	MCs 566.88
2020	MCs 1.00–1.03; ATX 0.01–0.05; STX 0.0046–0.0084	MCs 0.96–1.00; ATX 0.02; STX 0.002–0.003	
2021	MCs 0.16–2.15; ATX 0.00–0.02; STX <0.020–0.083		
2022	MCs 0.11–0.63; ATX 0.06; STX 0.05		MCs 0.20–402.4; ATX 0.35; STX—0.24
2023	MCs 0.45–0.69; ATX 0; STX 0		

Note: Cyanotoxins: MCs—microcystins, ATX—anatoxins, STX—saxitoxin.

Nutrients enter Lake Simnas from surrounding agricultural fields and homesteads, via tributaries, and through resuspension from sediments. The lake has two inlets and one outlet. Physico-chemical data collected from the inlets and outlet during the 2021–2023 period is presented in Table 5. The mean concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP, expressed as PO₄-P), and total nitrogen (TN) were 4.0, 5.8, and 2.8 times higher, respectively, in the Spernia inlet relative to the Simnyčia inlet. In contrast, dissolved inorganic nitrogen (DIN, including NO₃-N and NH₄-N) and conductivity were higher in the River Simnyčia (Table 5). Nutrient concentrations in the outlet were comparable to those measured in Lake Simnas during the same period (Table 3). In pore water from surface sediments sampled in April 2022 at a depth of 3.5 m, the concentrations of dissolved inorganic nutrients were as follows: PO₄-P—0.666 mg/L, NO₂-N—0.019 mg/L, NO₃-N—0.176 mg/L, and NH₄-N—4.848 mg/L.

3.2. Area of Lake Simnas Covered with Macrophytes

Eliminating aquatic vegetation may offer an additional approach to reducing nutrient levels in the lake. This method could be particularly effective, as Lake Simnas contains extensive shallow zones densely colonized by macrophytes (Figure 3), offering data that

can be integrated into the mass balance model. Remote sensing analysis revealed that approximately 13% of the lake's surface is covered by helophytes and floating-leaved macrophytes (Table 6). Three macrophyte species dominate, with *Phragmites australis* being the most widespread, occupying an area of 13.85 hectares.

Table 5. Physico-chemical parameters in the inlets and the outlet of Lake Simnas (2021–2023).

Variables	Inlets		Outlet
	Spernia	Simnyčia	Dovinė
TP (mg/L)	<0.01-(0.044)-0.086	<0.01-(0.011)-0.013	0.010-(0.026)-0.037
PO ₄ ³⁻ -P (mg/L)	<0.010-(0.035)-0.080	<0.010-(0.006)-0.010	<0.01-(0.013)-0.020
TN (mg/L)	<0.1-(2.29)-5.96	0.80-(0.82)-2.67	<0.05-(1.50)-2.50
NO ₃ ⁻ -N (mg/L)	0.08-(2.63)-10.90	0.35-(3.00)-4.91	<0.10-(1.66)-1.73
NH ₄ ⁺ -N (mg/L)	<0.05-(0.12)-0.14	<0.05-(0.14)-0.23	<0.05-(0.18)-0.21
Water temp. (°C)	4.6-(18.0)-24.4	15.7-(20.6)-26.3	5.0-(18.9)-26.3
pH	7.30-(7.69)-8.80	7.68-(7.91)-8.16	7.30-(7.69)-8.80
Oxygen (mg O ₂ /L)	3.65-(7.04)-14.81	4.36-(6.50)-9.71	1.68-(7.00)-16.96
EC (μS/cm)	377-(426)-726	479-(505)-559	394-(460)-516

Note: Data represent: Min-(**Mean**)-Max.

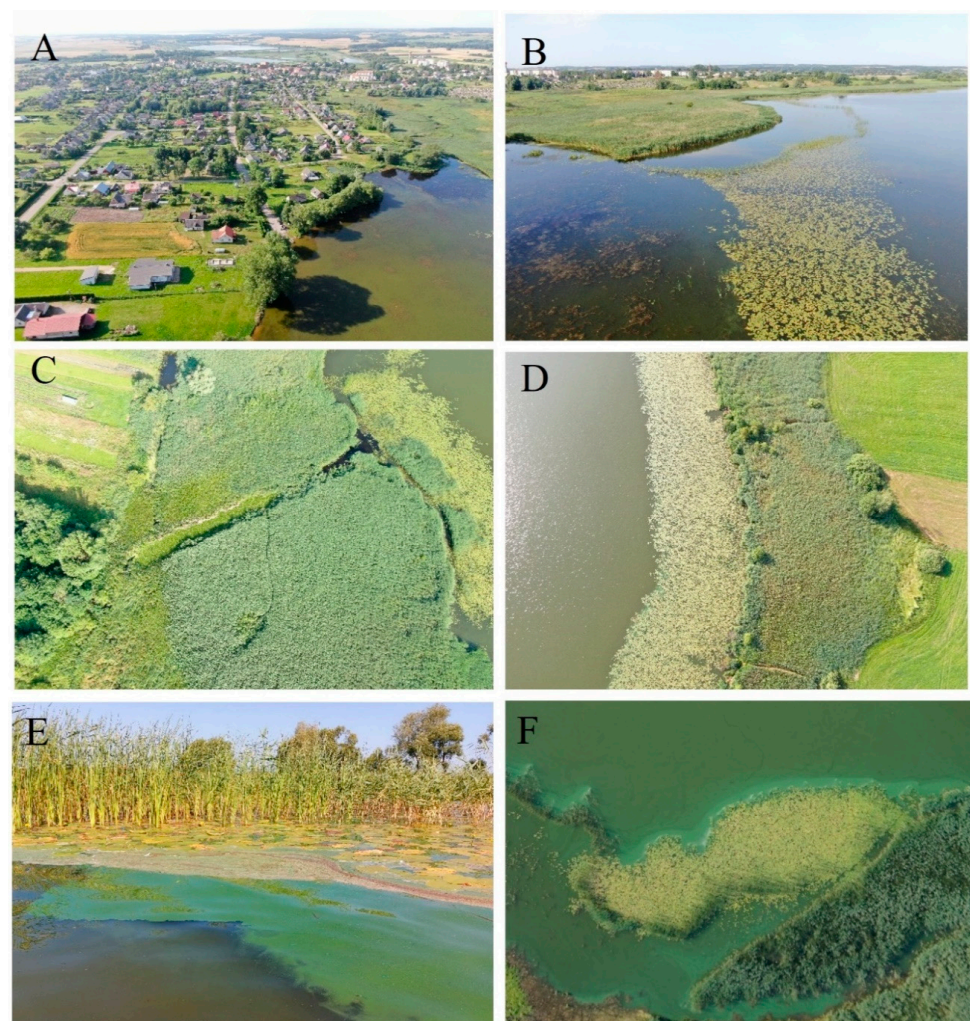


Figure 3. Belts of macrophytes and cyanobacterial blooms in Lake Simnas. (A) Simnas village; (B–D) belts of aquatic vegetations; (E,F) cyanobacterial scum near macrophytes. © UAV images were captured by A. Gedvilas.

Table 6. Areas covered by individual macrophyte species in Lake Simnas.

	Area, ha	Area, %
Open water	213.44	87.39
<i>Phragmites australis</i>	13.85	5.67
<i>Nuphar lutea</i>	8.62	4.04
<i>Shoenoplectus lacustris</i> & <i>Typha angustifolia</i>	8.27	3.39
Other species	0.05	0.02
Total area	244.24	100

3.3. Modeling Biomass Removal of Cyanobacteria and Aquatic Macrophytes

The model was calibrated with field data, where the coefficients of determination (R^2) were 0.84, 0.54, 0.92, and 0.79 for total phytoplankton, Cyanophyta, Chlorophyta, and Bacillariophyta biomasses, respectively, all expressed as Chl-a. The relative errors for phytoplankton were in the range of 8–21%. Considering the relative errors and the coefficients of determination which were reported by Arhonditsis and Brett [40] to be around 0.5 and 40%, respectively, serving as mean values for more than 140 published models our model's performance can be considered acceptable.

Based on the monitoring data, phosphorous in Lake Simnas can be considered a limiting nutrient since the TN/TP ratio is close to 30 (1256 $\mu\text{g N/L}$: 44.05 $\mu\text{g P/L}$). The model results comply with the field data about phosphorus being the limiting nutrient. The mean yearly average total phosphorus concentration was reproduced successfully with a relative error around of 17% (measured 44.05 $\mu\text{g/L}$, calculated 37.64 $\mu\text{g/L}$).

Representative values were determined for the rooted aquatic macrophytes since almost no macrophyte monitoring data was available for Lake Simnas. Therefore, as previously stated in the Section 2.5, the relevant model parameters were initially taken from the literature, and the model results were fitted to the literature based macrophyte biomass data from similar shallow and eutrophic environments. The simulations were conducted over a long time period of over 40 years to ensure stability, especially for helophytes and nymphaeid communities that react slower than phytoplankton (Figure 4).

The first set of simulations was conducted to investigate the effect of removing cyanobacteria biomass from Lake Simnas (Figure 5a,b). As wet biomass, biomass with intracellular water was included, and water surrounding the cyanobacterial cells, as well as any water in the harvested biomass, was excluded. The base case is considered “business as usual”, i.e., no removal of any biomass. Total phosphorus, which is considered the limiting nutrient, is provided as an output as well. Considering the results presented in Figure 5a,b, it is clear that relatively little can be achieved by removing the cyanobacterial biomass, and, in this case, Lake Simnas would remain in its eutrophic state. According to the simulation results, excess removal of cyanobacteria biomass would be compensated by other phytoplankton, especially Chlorophyta.

However, there is a theoretical optimum of around 1000 kg of wet biomass per day (removal in July, August, and September), where the “most” of the “little achievement” could be reached. These are, of course, theoretical results since cyanobacteria in Lake Simnas do not form scum where cyanobacteria harvesters could work efficiently. A second set of simulations was conducted on the impact of removing *Phragmites australis*, as shown in Figure 5c,d. In these scenarios, removal was simulated in autumn, when helophyte biomass peaks.

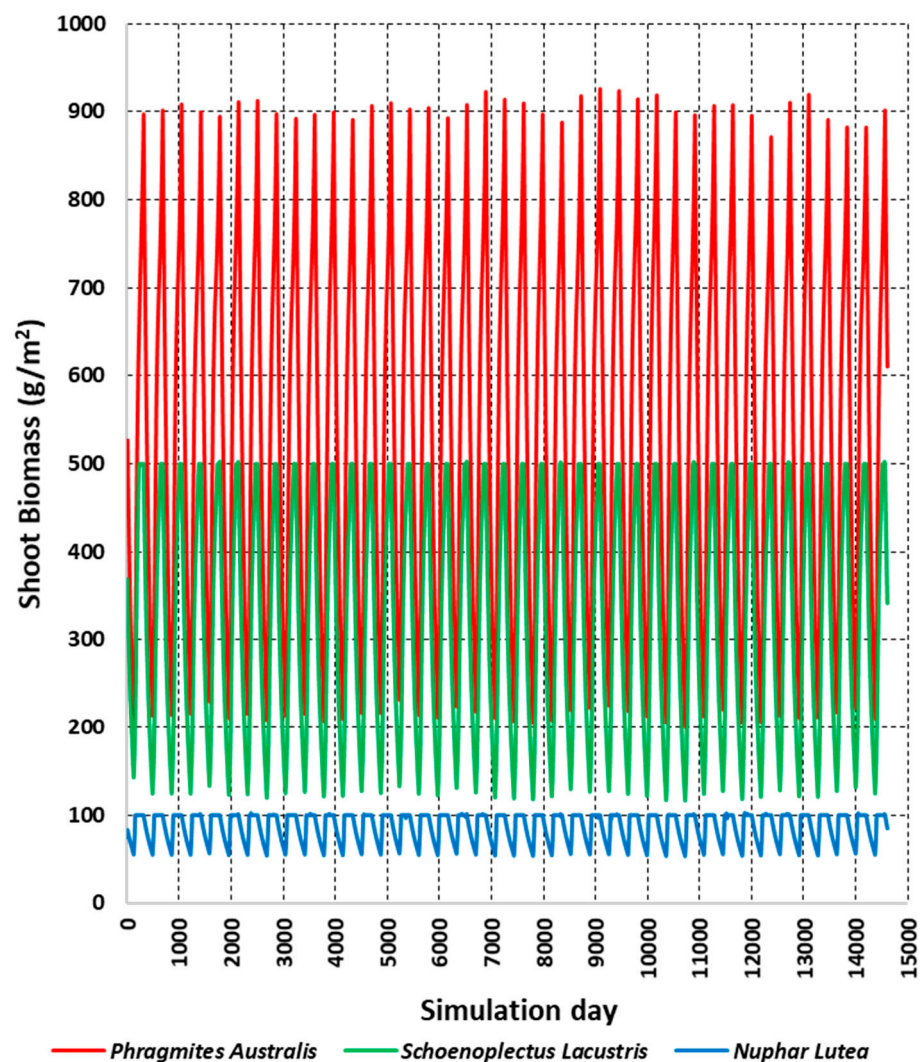


Figure 4. Time series results for rooted aquatic macrophytes.

As shown in Figure 5, the effects of macrophyte harvesting on eutrophication-related variables are even less pronounced than those of cyanobacterial biomass removal. This limited effect can be attributed to several factors:

- **Low phosphorus content in the helophyte biomass.** The phosphorus concentration in helophytes is relatively low ($C:P \approx 175:1$ by mass) compared to that in phytoplankton ($C:P \approx 40:1$), making them less effective for nutrient removal, particularly for phosphorus, the limiting nutrient in Lake Simnas.
- **Limited spatial coverage.** Although *Phragmites australis* forms dense stands, it occupies only a small portion of the lake surface (approximately 6%).
- **Slow growth dynamics.** Model calibration revealed that helophytes exhibit growth rates roughly two orders of magnitude lower than those of phytoplankton. Consequently, harvesting part of the helophyte biomass reduces their already limited nutrient uptake capacity, shifting the competitive balance in favor of phytoplankton.
- **Minimal nutrient recycling.** While the harvested helophyte biomass does not reintroduce nutrients into the water column (due to very low death and respiration rate constants), the overall contribution of this pathway is negligible.

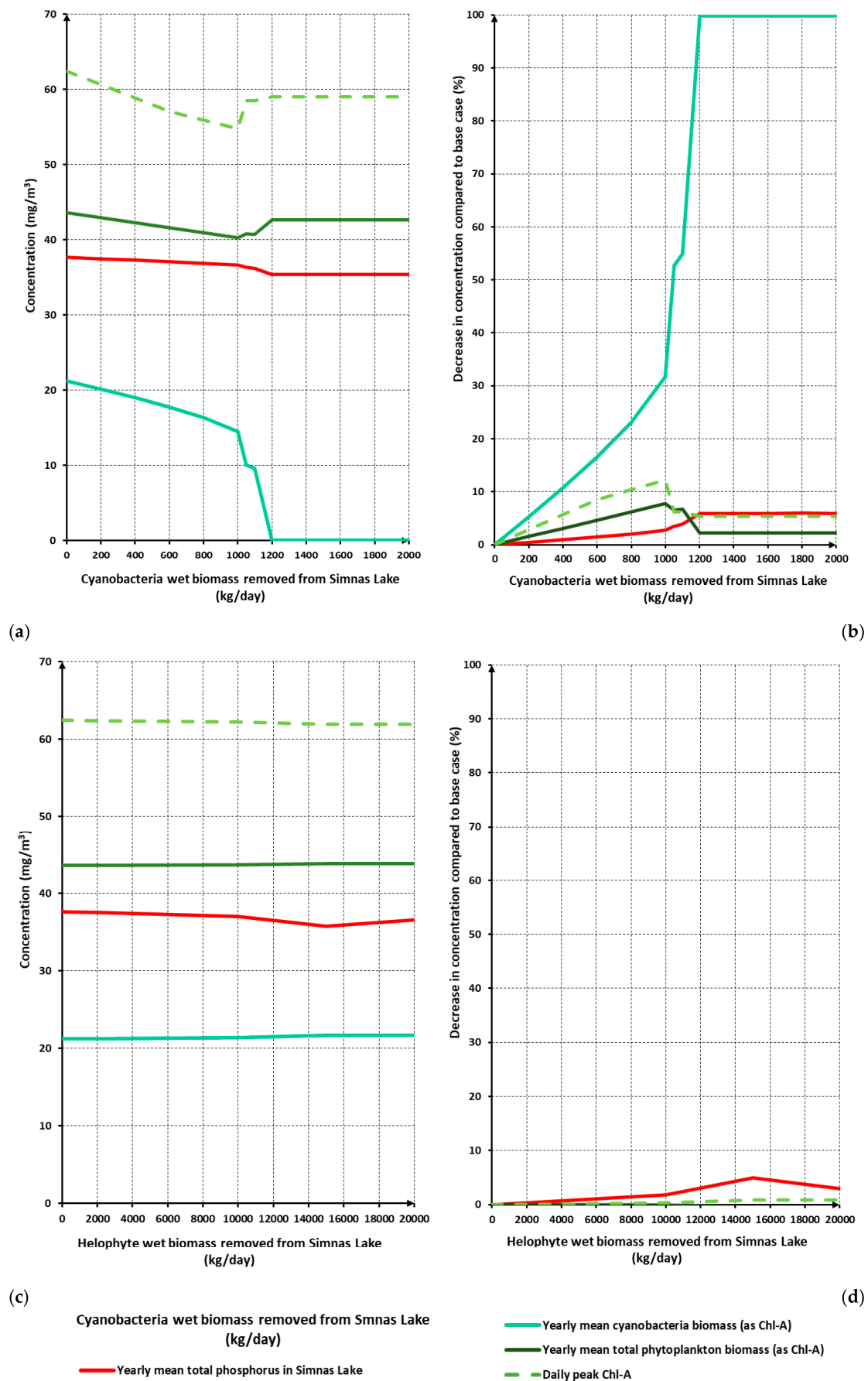


Figure 5. Simulations of cyanobacteria (a,b) and macrophyte (c,d) biomass harvesting.

4. Discussion

The Water Framework Directive requires all surface water bodies to achieve good ecological status [41]. However, meeting this target remains a significant challenge. Removing phytoplankton and macrophytes has been proposed as a potential strategy for restoring eutrophic lakes, since these primary producers assimilate nutrients and thus help close the loop of nutrient transfer from land to water [42,43]. Nonetheless, the effectiveness of biomass removal depends strongly on the specific characteristics of a water body, the dominant species present, and the surrounding environmental conditions.

Modeling approaches are powerful tools for supporting informed water management and restoration strategies. In Sweden, Sellergren et al. [14] applied a multi-criteria model using a Bayesian decision-analytical framework to identify cost-effective restoration strategies for eutrophic lakes. They concluded that aluminum treatment was the most efficient approach for reducing internal phosphorus loads, despite its high initial cost (~EUR 2 million for a 500 ha area). Similarly, Hilt et al. [44] applied the PCLake ecosystem model to investigate macrophyte dynamics under varying nutrient loads. Their findings revealed that external and internal restoration measures led to the development of different macrophyte communities and that stable, clear-water conditions with diverse vegetation only emerged decades after external nutrient loads were reduced or when multiple measures were combined.

These findings underscore the value of modeling as a decision-support tool in lake restoration. Following this rationale, a modeling approach, which integrates *in situ* data and enables scenario-based analyses, was applied to the case of Lake Simnas to explore effective management options. Lake Simnas has been significantly altered by damming, which raised the water level by an average of 0.83 m and increased the lake's area by 6.8 ha, leading to the formation of swampy zones along the western shoreline [11,17]. Povilaitis and Querner [10] employed the SIMGRO model to explore water management options for the Dovinè River basin, demonstrating how hydrological changes affect lakes and surrounding wetlands. We assessed the water quality of Lake Simnas, introduced a modeling approach for simulating management scenarios, and evaluated the potential benefits of removing phytoplankton biomass and aquatic vegetation.

Four decades ago (in 1986), total phosphorus concentrations in Lake Simnas (0.018–0.396 mg/L) indicated moderate water quality, while total nitrogen (0.48–2.42 mg/L) and Secchi depth (1.1–2.0 m) reflected good conditions. At that time, diatoms and cryptophytes prevailed in the phytoplankton community, with *Stephanodiscus hantzschii*, *S. minutulus*, *Synedra acus*, *Cryptomonas rostrata*, and *Rhodomonas pusilla* among the dominant species [45]. Annual average data provided by the EPA [46] for the years 2010, 2014, 2017, 2020, and 2023 show that total phosphorus and total nitrogen concentrations correspond to a very good or good ecological status for Lake Simnas (the averages for the period were 0.019 ± 0.005 mg/L and 1.02 ± 0.59 mg/L, respectively). In contrast, BDS_7 values indicate a moderate status (average 4.51 ± 0.70 mg O₂/L), while the EQR index decreased from bad (0.35) to very bad status (up to 0.10). During this period, the average chlorophyll-a concentration nearly doubled, increasing from 29.03 to 58.78 µg/L. As a result, Secchi depth decreased from 1.3 m to 0.8 m, indicating a shift from a good to moderate water transparency status.

Our data collected during the summer periods of 2018–2023 are consistent with EPO findings for several parameters, confirming that the water quality of Lake Simnas remains far from good status. The average summer chlorophyll-a concentrations range from 22.4 to 311.7 µg/L, while the average Secchi depth ranges from 0.38 m to 0.58 m. Since 1986, a clear shift has been observed from diatom- and cryptophyte-dominated phytoplankton communities to a current dominance by cyanobacteria, including species from *Aphanizomenon*, *Microcystis*, and *Dolichospermum* genera. These cyanobacteria have the potential to produce various cyanotoxins, with measured concentrations reaching up to 566 µg/L

during extensive blooms nearly 20 times higher than the WHO [39] guideline value for safe recreational use highlighting a serious risk for the local community. The establishment of alien species such as *Cuspidothrix issatschenkoi* and *Sphaerospermopsis aphanizomenoides* further reflects the ecosystem's vulnerability to biological invasions, posing an additional threat to lake stability [47,48].

Based on both historical and recent data, Lake Simnas can be classified as a eutrophic to hypertrophic water body, with water quality strongly influenced by catchment-derived nutrient inputs. Balevičius [11] likewise described the lake's ecological condition as critical and advocated for restoration, highlighting priority actions such as eliminating nutrient inflows from the local fish farm and the former municipal wastewater treatment plant. He also recommended the annual harvesting of macrophytes over an area of at least 15 hectares, supplemented by additional measures including partial sediment removal, installation of sludge collectors at inlets, removal of shoreline shrubs, and stocking with predatory fish. The total cost of the proposed interventions was estimated to be approximately EUR 1.1 million.

Following these recommendations, macrophyte removal was carried out in the Dovinė River inlet (41.13 ha) and Lake Simnas (122.87 ha) as part of the project "Improvement of Water Quality in Lake Simnas and the Dovinė River", funded by the European Union Funds Investment Operational Programme (measure 05.3.1-APVA-V-012). With a budget of approximately EUR 0.56 million, aquatic vegetation was harvested in strips to minimize disturbance to shallow-water habitats. In 2023, the local newspaper Alytaus Gidas [13] reported some improvements in water quality conditions.

In this study, a different modeling approach was applied to assess the effectiveness of biomass removal as a restoration measure for Lake Simnas. The simulations showed that the tested in-lake interventions namely, the removal of scum-forming cyanobacteria in the summer and the elimination of macrophytes in the autumn would not lead to substantial improvements in water quality. Biomass removal yielded only modest benefits, primarily in cases where cyanobacteria were partially replaced by green algae as the dominant phytoplankton group.

The effects of macrophyte harvesting were even more limited, reflecting their relatively small contribution to phosphorus uptake and the slower dynamics of aquatic plants relative to phytoplankton. Moreover, the spatial extent of helophyte coverage in Lake Simnas is restricted, and their removal was found to decrease overall nutrient uptake capacity, indirectly favoring phytoplankton growth. These findings are consistent with the broader scientific consensus that sustainable recovery of eutrophic lakes typically requires long-term reductions in nutrient loading, often in combination with multiple management measures [44]. Additional insights from AQUATOX modeling [49] similarly suggest that cyanobacterial responses to interventions are influenced by system productivity and nutrient availability, with outcomes varying according to the dominant taxa and ecological context.

Overall, the model results indicate that active biomass removal in Lake Simnas is unlikely to facilitate substantial improvements in ecological status. In contrast, phosphorus load reduction at the watershed level appears to be a far more effective strategy. The relationship between external phosphorus input and in-lake concentrations tends to be approximately linear; for instance, a 50% decrease in total phosphorus loads would result in a comparable reduction in in-lake phosphorus concentrations and levels of associated eutrophication indicators (Table 7).

Table 7. Simulation results on the effect of a 50% reduction in total phosphorus load in Lake Simnas.

Scenario	Yearly Average TP	Yearly Average Cyanobacteria-Based Chl-a	Yearly Average Chl-a	Daily Peak Chl-a
Business as usual	37.64 µg/L	21.26 µg/L	43.63 µg/L	62.41 µg/L
50% TP reduction	15.81 µg/L	11.66 µg/L	27.85 µg/L	32.83 µg/L
Decrease	57.99%	45.12%	36.18%	47.40%

These findings underscore the importance of evidence-based management in eutrophic lake restoration. Although biomass removal provides a direct means of reducing nutrient levels and cyanotoxins, its ecological outcomes are complex and highly context-dependent. Such interventions are most effective when integrated with broader measures aimed at reducing external nutrient inputs. Additionally, the harvested biomass may offer secondary benefits such as potential for use in animal feed or as fertilizer, thus contributing to sustainability goals and advancing the circular economy [42,43].

In conclusion, Lake Simnas has experienced persistent eutrophication caused by agricultural runoff, municipal wastewater discharge, and fishpond effluents, with internal phosphorus loading from sediments further exacerbating the issue. The lake remains a eutrophic-to-hypertrophic system, with water quality strongly influenced by nutrient inputs from its catchment. Previous macrophyte removal efforts led to only marginal improvements in water quality. Our modeling results suggest that large-scale biomass harvesting of macrophytes (specifically helophytes) and/or cyanobacteria alone is insufficient to achieve lasting ecological improvements. Moreover, macrophyte removal may even aggravate eutrophication by releasing stored phosphorus, potentially enhancing cyanobacterial growth. While removing cyanobacterial biomass could reduce toxin concentrations and health risks locally, the measure's overall impact on trophic status indicators, such as chlorophyll-a and phosphorus, remains limited. Instead, restoration efforts should prioritize reducing external phosphorus inputs, including by upgrading the Simnas wastewater treatment plant and constructing wetlands to intercept nutrient runoff from aquaculture facilities. A 50% reduction in phosphorus input is expected to yield comparable improvements in in-lake concentrations and eutrophication indicators. Biomass removal may serve as a supporting measure within an integrated management framework, offering additional benefits such as nutrient recycling and contributions to the circular economy. However, the long-term recovery of the lake's ecological status ultimately depends on consistent nutrient load reduction and coordinated catchment-wide restoration efforts.

Supplementary Materials: A read-only version of the Simnas Lake mass balance model can be accessed as supplementary material at <https://doi.org/10.5281/zenodo.17234402>.

Author Contributions: Conceptualization, J.K. (Judita Koreivienė); investigation, A.E., J.K. (Jūratė Kasperovičienė), J.K. (Jūratė Karosienė), R.P. and V.V.; writing—original draft preparation, J.K. (Judita Koreivienė), A.E.; writing—review and editing, all; visualization, J.K. (Judita Koreivienė) and A.E.; supervision, J.K. (Judita Koreivienė); project administration, J.K. (Judita Koreivienė) and J.K. (Jūratė Karosienė); funding acquisition, J.K. (Judita Koreivienė). All authors have read and agreed to the published version of the manuscript.

Funding: This research was partly funded by EU LIFE project “AlgaeService for LIFE” No. LIFE17 ENV/LT/000407.

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Materials. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors are grateful to Ričardas Skorupskas and Antanas Gedvilas for capturing UAV images of Lake Simnas and conducting the macrophyte coverage assessment. We

would like to sincerely thank the reviewers for their valuable and constructive comments, which have helped us to improve the quality and clarity of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Verpoorter, C.; Kutser, T.; Seekell, D.A.; Tranvik, L.J. A global inventory of lakes based on high-resolution satellite imagery. *Geophys. Res. Lett.* **2014**, *41*, 6396–6402. [CrossRef]
2. Anderson, D.M.; Glibert, P.M.; Burkholder, J.M. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. *Estuaries* **2002**, *25*, 704–726. [CrossRef]
3. Wagner, T.; Erickson, L. Sustainable management of eutrophic lakes and reservoirs. *J. Environ. Prot.* **2017**, *8*, 436–463. [CrossRef]
4. Lürling, M.; Mucci, M. Mitigating eutrophication nuisance: In-lake measures are becoming inevitable in eutrophic waters in the Netherlands. *Hydrobiologia* **2020**, *847*, 4447–4467. [CrossRef]
5. Wurtsbaugh, W.A.; Paerl, H.W.; Dodds, W.K. Nutrients, eutrophication and harmful algal blooms along the freshwater to marine continuum. *WIREs Water* **2019**, *6*, e1373. [CrossRef]
6. Poikane, S.; Kelly, M.G.; Free, G.; Carvalho, L.; Hamilton, D.P.; Katsanou, K.; Lürling, M.; Warner, S.; Spears, B.M.; Irvine, K. A global assessment of lake restoration in practice: New insights and future perspectives. *Ecol. Indic.* **2024**, *158*, 111330. [CrossRef]
7. Withers, P.J.A.; Neal, C.; Jarvie, H.P.; Doody, D.G. Agriculture and eutrophication: Where do We go from here? *Sustainability* **2014**, *6*, 5853–5875. [CrossRef]
8. Mendiondo, E.M. *Global Review of Lake and Reservoir Eutrophication and Associated Management Challenges*; The International Lake Environment Committee Foundation ILEC: Shiga, Japan, 2014.
9. Bhagowati, B.; Ahamad, K.U. A review on lake eutrophication dynamics and recent developments in lake. *Ecohydrol. Hydrobiol.* **2019**, *19*, 155–166. [CrossRef]
10. Povilaitis, A.; Querner, E.P. *Analysis of Water Management Measures in the Dovine River Basin, Lithuania*; Alterra: Wageningen, The Netherlands, 2006; p. 67.
11. Balevičienė, J.; Balevičius, A.; Bukelskis, E.; Ciūnys, A.; Stanevičius, V.; Vaitkus, G.; Valiuškevičius, G.; Stankevičienė, D.K.; Uselyte, R.; Šalčiūnienė, K.; et al. Galutinė ataskaita I dalis. In *Restauruotinių Lietuvos Ežerų Nustatymas ir Preliminarus Restauravimo Priemonių Parinkimas Šiems Ežerams, Siekiant Pagerinti Jų Būklę*; Probleminių Ežerų Restauravimo Planai; UAB „Senasis ežerėlis”: Vilnius, Lithuania, 2009; p. 142.
12. Balevičienė, J.; Balevičius, A.; Bukelskis, E.; Ciūnys, A.; Stanevičius, V.; Vaitkus, G.; Valiuškevičius, G.; Stankevičienė, D.K.; Uselyte, R.; Šalčiūnienė, K.; et al. Galutinė ataskaita II dalis. In *Restauruotinių Lietuvos Ežerų Nustatymas ir Preliminarus Restauravimo Priemonių Parinkimas Šiems Ežerams, Siekiant Pagerinti Jų Būklę*; Probleminių Ežerų Restauravimo Planai; UAB „Senasis ežerėlis”: Vilnius, Lithuania, 2009; p. 239.
13. Alytaus gidas. Simno Ežero ir Dovinės Upės Vandens Būklė Pagerėjo. Available online: <https://alytausgidas.lt/alytaus-rajonas/simno-ezero-ir-dovines-upes-vandens-bukle-pagerejo> (accessed on 20 October 2023).
14. Sellergren, M.; Li, J.; Drakare, S.; Thöns, S. Decision support for lake restoration: A case study in Swedish freshwater bodies. *Water* **2023**, *15*, 668. [CrossRef]
15. Pereira, A.C.; Mulligan, C.N. Practices for eutrophic shallow lake water remediation and restoration: A critical literature review. *Water* **2023**, *15*, 2270. [CrossRef]
16. Tammeorg, O.; Chorus, I.; Spears, B.; Nöges, P.; Nürnberg, G.K.; Tammeorg, P.; Søndergaard, M.; Jeppesen, E.; Paerl, H.; Huser, B.; et al. Sustainable lake restoration: From challenges to solutions. *WIREs Water* **2024**, *11*, e1689. [CrossRef]
17. Taminskas, J.; Institute of Geology and Geography, University of Vilnius, Vilnius, Lithuania. Dovinės Baseino Hidrogeologinės-Hidrocheminės Situacijos Studija ir Žuvinto Ežero Vandens Kokybės Modeliavimas // Natura 2000 Teritorijų Tvarkymas ir Atstatymas Parengiant Integruotą Dovinės Baseino Valdymo Planą; PINMatra projektas Nr. 2003/Tarpinė ataskaita. 2004; Unpublished project report.
18. *LST EN ISO 10304*; Water Quality—Determination of Dissolved Anions by Liquid Chromatography of Ions—Part 1: Determination of Bromide, Chloride, Fluoride, Nitrate, Nitrite, Phosphate and Sulfate. Lietuvos Standartizacijos Departamentas: Vilnius, Lithuania, 2009.
19. *LST EN ISO 14911*; Water quality—Determination of dissolved Li⁺, Na⁺, NH₄⁺, K⁺, Mn²⁺, Ca²⁺, Mg²⁺, Sr²⁺ and Ba²⁺ Using ion Chromatography—Method for Water and Waste Water. Lietuvos Standartizacijos Departamentas: Vilnius, Lithuania, 2000.
20. Olrik, K.; Blomquist, P.; Brettum, P.; Cronberg, G.; Eloranta, P. *Methods for Quantitative Assessment of Phytoplankton in Freshwaters, Part I*; Naturvårdsverket förlag: Stockholm, Sweden, 1998; p. 86.
21. Olenina, I.; Hajdu, S.; Edler, L.; Andersson, A.; Wasmund, N.; Busch, S.; Gobel, J.; Gromisz, S.; Huseby, S.; Huttunen, M.; et al. *Biovolumes and Size-Classes of Phytoplankton in the Baltic Sea*; HELCOM Baltic Sea Environment Proceedings No. 106; Helsinki Commission (HELCOM): Helsinki, Finland, 2006; p. 144.

22. Håkanson, L.; Boulion, V.V. *The Lake Foodweb-Modelling Predation and Abiotic/Biotic Interactions*; Backhuys Publishers: Warmonderweg, The Netherlands, 2002; p. 344.
23. Gaigalis, K.; Kutra, G.; Šmitienė, A. Nitrogen load assessment and pollution mitigation measures in the Dovinė watershed. *Ekologija* **2007**, *53*, 37–43.
24. Bachmann, R.W. Prediction of total nitrogen in lakes and reservoirs. In *Restoration of Lakes and Inland Waters, Proceedings of the International Symposium on Inland Waters and Lake Restoration, Portland, ME, USA, 8–12 September 1980*; US EPA: Washington, DC, USA; EPA 440/81-010; 1981; pp. 320–324.
25. Kasperovičienė, J. Assessment of ecological status of the Dovinė river catchment area lakes according to phytoplankton data. *Ekologija* **2007**, *53*, 13–21.
26. Taminskas, J.; Linkevičienė, R.; Šimanauskienė, R. Loading and retention of phosphorus in riverine systems. *Ekologija* **2007**, *53*, 30–36.
27. Chapra, S.C. *Surface Water-Quality Modeling*; Waveland Press Inc.: Long Grove, IL, USA, 2008; p. 844.
28. DiToro, D.M. *Sediment Flux Modeling*; John Wiley & Sons: New York, NY, USA, 2001; p. 656.
29. Alaez, M.F.; Alaez, C.F.; Becares, E. Nutrient content in macrophytes in Spanish shallow lakes. *Hydrobiologia* **1999**, *408*, 317–326. [[CrossRef](#)]
30. Dykijova, D.; Ondok, P.J.; Hradecka, D. Growth rate and development of the root/shoot ratio in reedswamp macrophytes grown in hydroponic cultures. *Folia Geobot. Phytotaxon.* **1972**, *7*, 259–268. [[CrossRef](#)]
31. Gacia, E.; Bernal, S.; Nikolakopoulou, M.; Carreras, E.; Morgado, L.; Ribot, M.; Isnard, M.; Sorolla, A.; Sabater, F.; Marti, E. The role of helophyte species on nitrogen and phosphorus retention from wastewater treatment plant effluents. *J. Environ. Manag.* **2019**, *252*, 109585. [[CrossRef](#)]
32. Ho, Y.B. Chemical composition studies of some aquatic macrophytes in three Scottish lochs chlorophyll, ash, carbon, nitrogen and phosphorus. *Hydrobiologia* **1979**, *63*, 161–169. [[CrossRef](#)]
33. Lopez, D.; Sepulveda, M.; Vidal, G. *Phragmites australis* and *Schoenoplectus californicus* in constructed wetlands: Development and nutrient uptake. *J. Soil Sci. Plant Nutr.* **2016**, *16*, 763–777. [[CrossRef](#)]
34. Muvzarova, E.T.; Lorenzen, B.; Brix, H.; Votrubova, O. The effects of NH_4^+ and NO_3^- on growth, resource allocation and nitrogen uptake kinetics of *Phragmites australis* and *Glyceria maxima*. *Aquat. Bot.* **2005**, *81*, 326–342.
35. Schoelynck, J.; Bak, K.; Verschoren, V.; Penning, E.; Struyf, E.; Bouma, T.; Meire, D.; Meire, P.; Temmerman, S. Different morphology of *Nuphar lutea* in two contrasting aquatic environments and its effect on ecosystem engineering. *Earth Surf. Process. Landf.* **2014**, *39*, 2100–2108. [[CrossRef](#)]
36. Hu, W.; Wei, W.; Ye, C.; Li, C.; Zheng, Y.; Shi, X.; Chang, M.; Chen, H. Determining the optimal biomass of macrophytes during the ecological restoration process of eutrophic shallow lakes. *Water* **2021**, *13*, 3142. [[CrossRef](#)]
37. Kulikova, Y.; Gorbunova, J.; Aleksandrov, S.; Krasnovskih, M.; Gurchenko, V.; Babich, O. Analysis of resource potential of emergent aquatic vegetation in the Curonian Lagoon of the Baltic Sea. *Water* **2023**, *15*, 2136. [[CrossRef](#)]
38. Skuratovič, Ž.; Mažeika, J.; Petrošius, R.; Jefanova, O.; Romanenko, V.; Paškauskas, R.; Adamovich, B.; Erturk, A. Tritium transport in the transboundary Neris River during the routine operation of the Belarusian Nuclear Power Plant: A Monitoring and Modeling Approach. *Water* **2025**, *17*, 2580. [[CrossRef](#)]
39. World Health Organization. *World Health Organization Guidelines on Recreational Water Quality*; Volume 1: Coastal and Fresh Waters; WHO: Geneva, Switzerland, 2021; p. 139.
40. Arhonditsis, G.B.; Brett, M.T. Evaluation of the current state of mechanistic aquatic biogeochemical modeling. *Mar. Ecol. Prog. Ser.* **2004**, *271*, 13–26. [[CrossRef](#)]
41. European Parliament and the Council of Union European. Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for Community Action in the Field of Water Policy. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF (accessed on 22 June 2025).
42. Quilliam, R.S.; van Niekerk, M.A.; Chadwick, D.R.; Cross, P.; Hanley, N.; Jones, D.L.; Vinten, A.J.A.; Willby, N.; Oliver, D.M. Can macrophyte harvesting from eutrophic water close the loop on nutrient loss from agricultural land? *J. Environ. Manag.* **2015**, *152*, 210–217. [[CrossRef](#)]
43. Macário, I.P.E.; Ventura, S.P.M.; Gonçalves, F.J.M.; Torres-Acosta, M.A.; Pereira, J.L. The “bright side” of cyanobacteria: Revising the nuisance potential and prospecting innovative biotechnology-based solutions to integrate water management programs. *ACS Sustain. Chem. Eng.* **2021**, *9*, 7182–7197. [[CrossRef](#)]
44. Hilt, S.; Alirangues Nuñez, M.M.; Bakker, E.S.; Blindow, I.; Davidson, T.A.; Gillefalk, M.; Hansson, L.A.; Janse, J.H.; Janssen, A.B.G.; Jeppesen, E.; et al. Response of submerged macrophyte communities to external and internal restoration measures in north temperate shallow lakes. *Front. Plant Sci.* **2018**, *9*, 194. [[CrossRef](#)]
45. Kavaliauskienė, J. *Lietuvos Dumblių*; P. Kalibato II “Petro ofetas”: Vilnius, Lithuania, 1996; p. 173.

46. EPA: Environmental Protection Agency of Lithuania. Available online: <https://aaa.lrv.lt/lt/veiklos-sritys/vanduo/upes-ezerai-ir-tvenkiniai/valstybinis-upiu-ezeru-ir-tvenkiniu-monitoringas/ezeru-ir-tvenkiniu-monitoringo-rezultatai/> (accessed on 1 July 2025).
47. Wilk-Woźniak, E.; Solarz, W.; Najberek, K.; Pocięcha, A. Alien cyanobacteria: An unsolved part of the “expansion and evolution” jigsaw puzzle? *Hydrobiologia* **2016**, *764*, 65–79. [[CrossRef](#)]
48. Šuikaitė, I.; Karosienė, J.; Koreivienė, J. A snapshot of alien cyanobacteria found in northeastern European freshwaters–Lithuania case. *J. Limnol.* **2024**, *83*, 2183. [[CrossRef](#)]
49. Savadova-Ratkus, K.; Grendaitė, D.; Karosienė, J.; Stonevičius, E.; Kasperovičienė, J.; Koreivienė, J. Modelling harmful algal blooms in a mono- and a polydominant eutrophic lake under temperature and nutrient changes. *Water Res.* **2025**, *275*, 123138. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.