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Editorial

Diversity of Inland Wetlands: Important Roles in Mitigation of Human Impacts

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1. Introduction

Inland wetlands are one of the most vulnerable ecosystems on Earth and have one of the highest rates of decline in surface and biodiversity. They were often considered as wasted land for agriculture, infrastructure, and a source of disease for people. Several local and national governments have launched huge projects for their extermination, and permanent endeavors have been focused on their conversion to something more neat and obviously useful for humans. There has been a fast rate of wetland loss in the last 120 years, with a loss of 64–71% of wetlands since 1900 AD [1]. Losses have been larger and faster for inland than coastal natural wetlands. Moreover, between 1970 and 2015, inland wetlands declined by approximately 35%, three times the rate of forest loss [2].

However, wetlands are vital for human survival and include some of the world's most productive ecosystems, providing ecosystem services leading to countless benefits [3]. They provide ecosystem services like water purification, runoff and river discharge mitigation, and the production of food and fiber. It was not a coincidence that thousands of years ago, wetlands along large rivers, with their fertile land and high productivity, helped ancient cultures like China along the Yellow river, Egypt along the Nile, or Mesopotamia along the Euphrates and Tigris emerge. These civilizations were constantly supplied with water, food, and building materials. Wetlands served as shelter from enemies as well as transport routes.

Over the centuries, these roles have been forgotten, and wetlands have been often treated as wastelands. It has become apparent that climate changes and their consequences will continue to take their toll, and adaptation to these changes is urgent. Loss of biodiversity, eutrophication of aquatic ecosystems, extinction of rare species, increasing flood risk, and adverse climatic conditions are issues which can be mitigated with proper management and maintenance of various wetlands, from marshes, swamps, bogs, fens, shallow lakes, and ponds to anthropogenic wetlands which need human interventions like wet-meadows, storm-ponds and constructed wetlands.

We use the definition and classification of wetlands of Davidson and Finlayson [4], who defined two classes of inland wetlands according to their origin, which are further divided to types according to the environmental conditions: (a) Inland natural wetlands: rivers and streams, natural lakes and pools, peatlands (bogs, mires, fens), marshes and swamps, and groundwater-dependent wetlands (karst and cave systems, springs); (b) Human-made wetlands: reservoirs, ponds, wet grasslands, and constructed wetlands for wastewater treatment. This classification is very broad, inclusive, and similar to the definition used by the Ramsar Convention.

The Ramsar Convention is the only international legal treaty with a primary focus on wetlands, signed in 1971 in Ramsar and which came into force in 1975 [2]. Over the years, 170 countries have joined as Contracting Parties. According to Davidson et al. [5], the network of 2301 Ramsar sites covers 18.6% of the global wetland area, which represents one of the major successes of the convention.

This Special Issue aims to emphasize the importance of different types of wetlands in our environment to maintain ecological balance and reduce the vulnerability of aquatic systems to various environmental and meteorological conditions. We received many contributions from experts studying a plethora of wetland types and the communities thriving in them. Three review articles were gathered in the first part of the Special Issue, presenting an introduction to the topic with a review of wetlands' most typical species; a review of one of the adaptations to these specific abiotic conditions; and another review showing proof that wetlands host a great number of threatened species, making another argument for preserving these ecosystems. The Special Issue continues with 14 original articles coming from four continents and documenting research in study areas in 12 countries, namely Italy, Slovenia, Croatia, Serbia, Bosnia and Herzegovina, Poland, Lithuania, Kazakhstan, Morocco, China, Thailand, and the United States of America. The list of countries where contributing authors live and work is even longer, as it also includes France, Germany, Sweden, Czechia, Slovakia, Ukraine, Greece, and Israel. This embeds the Special Issue in an international context, and we expect it will reach an audience around the globe.

2. Main Messages of the Special Issue and the Book

The common reed is probably the most characteristic plant species for wetlands. It can be found all around the globe in inland as well as coastal wetlands. Its successful strategy and high productivity also make this species invasive in some vulnerable wetland types. On the other hand, the common reed is also the most common species planted in constructed wetlands in Europe and elsewhere [6]. The review article by Čížková et al. [7] thoroughly presents the important role of the common reed in wetlands throughout Europe. One of the most important adaptations in the common reed and other wetland species to aquatic environments are their ventilation systems, enabling them to thrive in permanently or temporarily flooded soils. Ventilation systems, which offer a solution to hypoxic or even anoxic conditions in the substrata where they are rooted, are thoroughly discussed in Bjorn et al.'s paper [8].

The review by Čížková et al. [7] presents *Phragmites australis* as the most common and dominant species in European wetlands. Reed stands provide habitats for vulnerable bird species to nest, feed, or roost. On the other hand, it is the most frequently used plant species in constructed wetlands. However, its performance may vary in response to different combinations of environmental factors. Conservation measures aim to prevent or halt the decline of *P. australis* populations, known as "reed decline", and increase their microhabitat heterogeneity. Service-oriented actions aiming to create suitable conditions for the use of *Phragmites australis* include its use as roofing, as a renewable energy crop, or the use of reed-dominated habitats for waterfowl hunting and livestock grazing. In situations involving multiple uses, a modelling approach that considers the participation of all affected stakeholders can be a useful tool for resolving conflicts and developing a shared vision of the socioeconomic ecosystem in question.

Permanently or temporarily flooded areas require specific adaptations in plants to survive these special conditions. Even waterlogged soils and the absence of air in soil pores makes the thriving of plant root systems an issue that most plants cannot cope with. Molecular oxygen and carbon dioxide may be limited for wetland plants, but they have several mechanisms to obtain these gases from the atmosphere, soil, or through metabolic processes. Among the most common adaptations of partially or entirely submerged plants are various structures that allow the flow of gasses, which are thoroughly discussed by Björn et al. [8]. In emergent plants, gases can be transferred via molecular diffusion, pressurized gas flow, and Venturi-induced convection. In submerged species, direct exchange of gases occurs between submerged tissues and water, as well as the transfer of gases via aerenchyma. Photosynthetic O_2 flows into the rhizosphere, while CO_2 flows from the soil to the leaves, where it can be used for photosynthesis. Two strategies have emerged for plants with floating leaves anchored in anoxic sediment. In water lilies, for instance, air enters through the stomata of young leaves and flows through channels to the rhizomes and roots and back through the older leaves.

Wetlands are important habitats for hundreds of endangered species. The survival of numerous orchids in Europe largely depends on wetlands and their suitable management. The study by Djordjević et al. [9] provides an overview of the current knowledge on orchids of wetland vegetation in the Central Balkans. The orchids were analyzed from taxonomic, phytogeographical, ecological, and conservation perspectives. The most important taxa include the two Balkan endemics (*Dactylorhiza cordigera* subsp. *bosniaca* and *D. kalopissi* subsp. *macedonica*) and the three subendemics of the Balkans and the Carpathians (*Dactylorhiza cordigera* subsp. *cordigera*, *D. maculata* subsp. *transsilvanica*, and *Gymnadenia frivaldii*), as well as a number of Central European, Eurasian, and boreal species. Several orchid taxa found in the wet meadows and fens of the Central Balkans have a southern limit of their distribution in this part of Europe, suggesting that wetlands are important refuges for them. A total of 33 orchid taxa were recorded in different wetland plant communities. Most orchid taxa grow in the following wetland vegetation types: wet meadows (especially in order Molinietalia caeruleae); fens (in order Caricetalia fuscae); tall-herb vegetation along mountain streams and springs; and marshes and herbaceous vegetation of freshwater or brackish water bodies. In addition, detailed taxonomic, ecological, and chorological studies of wetland orchids need to be conducted in order to develop a successful plan for their conservation.

Diatoms are among the most important primary producers on Earth. It is estimated that they contribute up to a quarter of organic matter production on a global level. However, their role as primary producers in wetlands is rarely of great importance, and they have often been neglected. Cantonati et al. [10] found three new diatom species in two contrasting spring types in the northern Apennines (Italy). They describe three species new to science, belonging to the genera *Eunotia* Ehrenb., *Planothidium* Round and L. Bukht. and *Delicatophycus* M.J. Wynne. These species differ morphologically from the most similar species, but the authors were also able to refine the knowledge of the ecological profiles of these species. *Eunotia crassiminor* sp. nov. appears to live in colder inland waters with a circumneutral pH and a strict oligotrophy, even with respect to nitrogen, compared to *Eunotia minor*. The typical habitat of *Planothidium angustilanceolatum* sp. nov. appears to be oligotrophic flowing springs with low conductivity. *Delicatophycus crassiminutus* sp. nov. is probably restricted to hard water springs and similar habitats where CO_2 degassing results in carbonate precipitation. Springs are a unique but highly threatened wetland type. Thus, in-depth knowledge of the taxonomy and ecology of the characteristic diatom species is important because diatoms are excellent indicators of the quality and integrity of these particular ecosystems in the face of direct and indirect human impacts.

Novak and Zelnik [11] investigated the relations between benthic diatom communities and characteristics of karst ponds in the alpine region of Slovenia. Their objective was to examine the structure of the benthic diatom community and its relationships with selected environmental parameters. Since the predominant substrate in these ponds was clay, the epipelic community was analyzed. Hydromorphological characteristics and physical and chemical conditions were also measured at each site. They found 105 diatom species belonging to 32 genera. The most common taxa were *Gomphonema parvulum* Kützing, *Navicula cryptocephala* Kützing, *Sellaphora pupula* Mereschkowsky, and *Achnanthidium pyrenaicum* Kobayasi. The pond with the lowest diversity was located at the highest elevation, while the pond with the highest species richness was located at the lowest elevation. As for ecological types, the most common were motile diatom species. They calculated a positive correlation between the species number and oxygen saturation of water, while the correlation between species richness and NH4-N was negative. The concentrations of NO3-N and NH4-N explained around 20% of the variability in the epipelic diatom community. Contrary to our expectations, we calculated a negative correlation between macroinvertebrate diversity and diatom diversity, which is probably a result of different responses to environmental conditions.

In wetlands where open water habitats are found, as well as sufficient water retention time and low content of inorganic suspended solids, phytoplanktonic communities can also develop. The study by Barinova et al. [12] presents the spatial distribution of the taxonomic diversity of phytoplankton of the shallow Lake Borovoe in the Burabay National Natural Park (Kazakhstan), which is found in the middle of the steppe and is frequently visited by tourists. The phytoplankton of the protected lake was studied in summer of 2019. They found 72 algal and cyanobacterial species in the phytoplankton. The most species rich group were diatoms, followed by green algae and cyanobacteria. They also assessed the ecological status of the lake using species richness, abundance, biomass, and organic pollution and toxic impact indices. Statistical mapping, community similarity, and correlation analyses identified zones impacted by human activities. These were located in the lake shores and in low-alkaline water with a saprobic index of 1.63–2.00, which indicates the oligotrophic-to-mesotrophic status of the lake. Multivariate analysis enabled the assessment of the ecological status of the lake, which may be the result of the interaction of many external environmental factors, such as climatic conditions, the accumulation of organic matter, anthropogenic pressure, and internal processes in the lake. Their results indicate that the eutrophication of Lake Borovoe tends to increase due to pollution from the human-impacted zones on the shores of the lake.

The plant community structure in wetland ecosystems is often influenced by several environmental factors. In wetlands with temporary aquatic periods, most studies focus on the variation resulting from inundation and desiccation patterns. The responses of plant functional groups can provide insights into patterns of cover and richness. Rios et al. [13] studied these relationships in vernal pools of California, which have an intermittent character. The objective of their study was to evaluate how algae and plant functional groups respond to variations in hydro-regime (stable and unstable), nutrient addition (none and added), and straw addition (none, native plants, alien plants). They measured algal cover, total species richness, and functional group cover over two years. Algal cover increased with unstable hydroperiods and nutrient addition. Algae were also negatively related to aquatic plant cover. Aquatic plant cover increased with a stable hydro-regime and decreased with increased thatch. Terrestrial plant cover increased with an unstable hydro-regime and decreased with the addition of straw. Thatch accumulation and excess nutrients may be associated with human activities that directly and indirectly alter plant community composition. The interactions of these factors with the hydro-regime should be considered when evaluating the response of a plant community to changing environmental conditions. Overall, these results are necessary for the conservation and management of essential wetland functions and services.

Thermally abnormal waters are safe sites for alien invasive plants that require warmer conditions than ambient temperatures in the temperate zone. The mentioned sites are often colonized by tropical and subtropical plants. Šajna et al. [14] studied a case of *Pistia stratiotes*, which occurs in southeastern Slovenia. Based on a literature review, they found that at least 55 alien aquatic plant taxa from 21 families have been found in thermally abnormal waters in Europe. Most of these taxa are submerged or rooted macrophytes. Among them is *Pistia stratiotes*, which occurs in seven European countries, with most evidence of its occurrence being recent. Authors studied the growth of *P. stratiotes* in a thermally abnormal stream, where a persistent population could survive harsh winters. Models showed that the optimal temperature for this species biomass was 28.8 ± 3.5 °C. Here, they show that air temperatures had a greater influence on the photosynthetic efficiency of *P. stratiotes*, estimated using chlorophyll fluorescence measurements, than water temperatures. In general, the growth and, consequently, surface cover of free-floating plants cannot be explained by thermally abnormal water temperatures alone. The authors conclude that although the majority of thermophilic alien plants have occurred through intentional introductions, thermally abnormal waters pose an invasion risk for further deliberate, accidental, or spontaneous dispersal, which is more likely for free-floating macrophytes.

Wetland forests and scrub (WFS) are conditioned by the strong influence of water. They consist of different types of vegetation depending on many factors, such as the type and duration of flooding, the height of the water table and its fluctuations, the velocity of the river current, and the capacity of the substrate to retain water. Koljanin et al. [15] used numerical classification and classified the WFS of the Western Balkans at the level of alliances. Their aim was also the identification of the most important ecological gradients influencing the variation in floristic composition. A large set of all published and available unpublished relevés from Slovenia, Croatia, and Bosnia and Herzegovina was classified using the EuroVegChecklist Expert System. In the second step, each of the four classes (Alno glutinosae-Populetea albae, Salicetea purpureae, Alnetea glutinosae, and Franguletea) were analyzed separately, which revealed eight alliances, namely Salicion albae, Salicion triandrae, Salicion eleagno-daphnoidis, Alno-Quercion, Alnion incanae, Alnion glutinosae, Betulion pubescentis, and Salicion cinereae. Edaphic factors were the most important in determining the species composition and differentiation of the studied WFS.

Vukov et al. [16] studied the influence of environmental factors on the functional diversity of aquatic macrophyte communities. They focused on altered waterbodies and included data from 46 sites, which hosted 59 macrophyte species. They calculated seven functional diversity indices and used a set of multivariate analyses to examine the relations between environmental factors, functional diversity indices, and plant traits. The redundancy analysis showed that the environmental factors explained 47.4% of the variability in the functional diversity. The elevation, hemeroby (a measure of the human intervention influence) of riparian land, and water conductivity were the most important factors. Their research also revealed that floating and emergent plant characteristics are a strategy to increase light absorption efficiency at high nutrient concentrations in lowland waters, while submerged plants dominate in more nutrient-poor waters at higher elevations.

The European Habitats Directive has become an important measure for biodiversity protection in the European Union. Three aquatic macrophyte species protected by the mentioned Directive have been found in Lithuania, such as *Aldrovanda vesiculosa*, *Caldesia parnassifolia*, and *Najas flexilis*. Sinkevičienė et al. [17] studied the past and present distributions of these target species, as well as their conservation status. Surveys were conducted from 2015 to 2021 in 73 natural lakes in Lithuania. They confirmed extant populations of *Aldrovanda vesiculosa* in four lakes, *Caldesia parnassifolia* in two, and *Najas flexilis* in four lakes in the northeastern part of Lithuania. The populations of *A. vesiculosa* were surveyed three times. Population densities of *Aldrovanda vesiculosa* ranged from 193.4 ± 159.7 to 224.0 ± 211.0 individuals/m^2. The number of generative individuals of *Caldesia parnassifolia* varied greatly between years. All populations of *Najas flexilis* were small, although the potential habitats in the studied lakes cover relatively large areas. The authors proposed that all lakes with populations of *Aldrovanda vesiculosa*, *Caldesia parnassifolia*, and *Najas flexilis* should be designated as special protection areas and that action plans for the conservation of these species and their habitats be developed and implemented.

Zelnik et al. [18] surveyed macrophyte communities in natural and human-made waterbodies in the active floodplain of the Drava River in northeastern Slovenia. At the same locations, they also measured selected environmental parameters. The main question of their study was whether the presence of alien invasive species *Elodea canadensis* and *E. nuttallii* affected the diversity of macrophyte communities, which were considered as harbors for a great number of native aquatic species. The number of macrophytes in the surveyed water bodies varied from 1 to 23. In addition, *Elodea nuttallii* and *E. canadensis* were present in 19 out of 32 sample sites, with *E. nuttallii* predominating. The less invasive *E. canadensis* was abundant in side-channels but absent from ponds and oxbows, while *E. nuttallii* was dominant in ponds and present in all types. Correlation analyses showed no negative effect of the invasive alien species *Elodea nuttallii* or *E. canadensis* on the species richness and diversity of native aquatic vegetation. A positive correlation was found between the abundance of *E. nuttallii* and water temperature, which could facilitate its spread in the future.

Li et al. [19] analyzed the effects of different types of sediments on the distribution and diversity of plant communities in the Poyang Lake wetlands. Lake Poyang was designated as a Ramsar Wetland more than 30 years ago. It is the largest freshwater lake in China, but the extent of its water surface varies dramatically due to the changeable hydrological regime of its tributaries. At small scales, sediment types mediate hydrologic changes that influence the wetland vegetation's distribution patterns and species diversity. They divided the soil into three types, namely lacustrine, fluvio-lacustrine, and fluvial sediments, and analyzed the distribution and diversity of plants. They discovered that plant communities with *Carex cinerascens*, *Carex cinerascens*–*Polygonum criopolitanum*, *Polygonum criopolitanum*, and *Phalaris arundinacea* exist within the elevation range. The multivariate analyses performed showed that soil texture and flood duration in 2017 resulted in a different distribution of wetland plant communities under the conditions of the three sediment types along the littoral zones. They also revealed that plant communities on lacustrine sediments had the highest species diversity among the studied vegetation types.

The Yellow River is the sixth longest river on Earth and is considered the mother river of China. Fertile wetlands along the Yellow River supported the rise of Chinese civilization and culture thousands of years ago. Nowadays, the conservation of biodiversity in the middle and lower reaches of the Yellow River is an urgent concern due to the effects of sediment deposition and, above all, human activities. Yuan et al. [20] analyzed over 800 plots that were established in seven nature reserves. The aim of their study was to survey the diversity of plant communities in wetlands along the mentioned reaches from the perspective of the natural environment and human disturbance. A total of 184 plant species belonging to 135 genera and 52 families were recorded. Variation partitioning analysis showed that the effects of environmental factors, such as elevation, precipitation, evaporation, and temperature on wetland plants' beta diversity were the strongest (15.5% and 17.1%, respectively), followed by the effects of human disturbance factors, expressed as population density, industrial output value, and agricultural output value (15.13% and 16.71%, respectively). The wetland species showed strong associations with the nature reserves protecting the Yellow River wetlands in Henan Province. The results shed light on the conservation of plant diversity in wetlands along the river.

Malinowska and Novak [21] present the results of a study of barium, lithium, and titanium content in six plant species and from the soils sampled in wet mid-field depressions. These occasionally flooded depressions were in fact temporary wetlands surrounded by cropland, permanent grassland, and shrubland. The study area was located in east-central Poland. The following plant species were used in the experiment: *Mentha arvensis* L., *Comarum palustre* L., *Potentilla anserina* L., *Achillea millefolium* L., *Lysimachia vulgaris* L., and *Lycopus europaeus* L. The content of Li, Ba, and Ti in plants, bottom sediment, and soil was determined using the ICP-AES method after dry mineralization. *Mentha arvensis* has the greatest accumulation potential for these chemical elements among the studied species. However, no excessive Ba, Li, or Ti content was found in plants growing at different distances from cropland, permanent grassland, and shrub vegetation. The highest Ba content was found in periodically flooded soil, while the highest contents of Li and Ti were measured in non-flooded soils.

Ruengsawang et al. [22] analyzed sponge-dwelling aquatic insects in the Lower Mekong Basin in eastern Thailand. For the purpose of this study, they established a group of shallow-water sponges attached to a raft in the Pong River, which is a tributary of the Mekong River. They investigated the aquatic insect metacommunity in habitat-forming sponges *Corvospongilla siamensis* (Demospongiae: Spongillidae), which is endemic to Southeast Asia. The model sponges harbored four orders of insects belonging to 10 families and 19 genera/species, capable of living in water-bearing channels, at the body surface, or in the extracellular matrix. Trichoptera and Diptera were the predominant orders. In the studied river, dominated by soft bottoms, sponges play a functional role, since the insects use them as a substrate, nursery, food source, and as shelter from predators and harsh environmental conditions. The feeding behavior of these insects indicates the adaptive trait of recycling sponge siliceous spicules as a source of exogenous material to strengthen larval and pupal cases and the digestive system. These results, together with the global inventory, focus on sponges as key habitat-forming species and ecosystem engineers for river/lake/wetland insect communities and as promising candidates for tropical freshwater ecosystem restoration projects through bioremediation.

Taybi et al. [23] aimed to provide an updated list of alien species, their main pathways of introduction, and their possible threats to native species. Their dataset was based on an extensive literature review, amended by their research work. The main areas where alien animal species occur in Moroccan freshwaters correspond to protected areas (e.g., Ramsar Site). These areas currently host 41 confirmed ASs, belonging to different taxonomic groups. Fishes are the most abundant taxonomic group, with 21 species, followed by 7 species of mollusks, as well as 7 species of arthropods. Almost half of the ASs were intentionally introduced. They correspond to restocking programs and are probably the greatest threat to native species diversity through predation, competition, and hybridization. Commercial activities around aquariums and ornamental fish species appear as the second source encouraging colonization by AS. The introduction and implementation of protective regulations for the import of exotic species in Morocco seems urgently needed to protect native diversity. In addition, detecting and monitoring the expansion of ASs in colonized areas and studies to improve biological and ecological knowledge seem crucial to mitigate their potential impact on native communities.

3. Conclusions

Wetlands, in all of their forms and sizes, could offer a solution to mitigating the consequences of climate change, which seems to be a major threat to our welfare and an issue hard to address. One of the most crucial mitigation measures is to increase the retention time of water in landscapes. Wetlands retain water and prevent excessive runoff, which affects microclimatic conditions and reduces the probability and magnitude of floods. The water which is stored in wetlands can have beneficial effects on various aspects, such as the local climate and water discharge management. In this respect, wetlands help us adapting to climate changes. The evapotranspiration from wetlands could mitigate the increasing temperatures, especially in urban landscapes/areas, where it could have a cooling effect. The water entering the landscape in the form of watercourses or precipitation could be stored in wetlands and provide the water supplies during dry periods and prevent extreme drops in the groundwater table. But what is even more important is that wetlands could serve as buffers to compensate for flood waves threatening populated areas and infrastructure.

Another major role of wetlands in their broadest sense is biodiversity conservation. Different types of wetlands host numerous vulnerable or threatened species, which can survive only if their habitats—wetlands—remain healthy, or in other words, in good ecological status. Our Special Issue and the contributions within it discuss many problems connected to biodiversity conservation, but also give advice on how to manage specific types of wetlands to prevent further loss of biodiversity.

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