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# AQUATIC MACROPHYTES: ECOLOGICAL FEATURES AND FUNCTIONS

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The article is devoted to the analysis of current data on the ecological features and functions of the aquatic macrophytes which are important components of aquatic and wetland ecosystems across the globe. Macrophytes comprise a taxonomically diverse group of macroscopic plants including representatives of vascular aquatic plants, bryophytes, as well as green macroalgae and charophytes. An assemblage of macrophytic vegetation consists of emergent species whose vegetative parts emerge above the water surface, submerged and floating species, with each ecological group having specific features in morphology and physiological processes. A wide range of the adaptive mechanisms developed by aquatic macrophytes at the morphological, physiological, and biochemical levels enables them to inhabit various types of freshwater, brackish-water, and marine habitats. Macrophytes are an important component of aquatic food webs and perform a host of ecological functions in water ecosystems. The main ones are synthesis and storage of organic compounds and oxygen release, absorption and accumulation of chemical elements, water filtration and detoxification of pollutants, release of biologically active compounds involved in interspecies communications, provision of food, shelter and feeding places for aquatic animals, impact on the hydrological regime of water bodies, etc. A wide array of macrophyte species arесed in various human activities, including bioindication of water quality, phytoremediation of contaminated water bodies and wastewater treatment. However, human activities leading to surface water pollution, eutrophication and global warming have led to a concomitant decrease in macrophyte diversity in many freshwater ecosystems and in marine environment. Therefore, proper management of aquatic and wetland ecosystems, including their monitoring and control, is a prerequisite for a successful conservation of habitats and species richness of the aquatic macrophytes.

***Keywords:*** aquatic macrophytes, bryophytes, hydrophytes, aquatic ecosystems, wetlands

## INTRODUCTION

Aquatic macrophytes (often referred to as hydrophytes) constitute an assemblage of taxonomically diverse macroscopic plants whose life cycle takes place completely or periodically in the aquatic environment. Adaptive mechanisms evolved by macrophytes allow them to optimally respond to environmental heterogeneity and inhabit various types of aquatic habitats, including freshwater bodies, watercourses, wetlands, swamps, seasonally flooded areas, as well as brackish and marine environments [48, 56, 78]. From a systematic point of view, aquatic macrophytic vegetation encompasses members of different groups, including green macroalgae (Chlorophyta, e.g. *Cladophora* spp.), charophytes (Charophyceae, e.g. *Chara* and *Nitella* spp.) and higher aquatic plants, the latter being represented by both vascular plants (Tracheophyta) and bryophytes [22, 66]. According to some studies, macroalgae of the groups Rhodophyta and Xanthophyta can also be categorized as aquatic macrophytes [17].

Vascular plants of aquatic ecosystems are significantly inferior to terrestrial tracheophytes in their diversity and abundance, accounting for only about 1 % of the total number of vascular flora. It is estimated that aquatic tracheophytes are represented by 33 orders and 88 families, numbering about 2614 species in 412 plant genera [17]. Most of aquatic vascular plants are represented by angiosperms (Magnoliopsida), but aquatic vegetation also includes representatives of the classes Polypodiopsida and Lycopodiopsida [17, 78]. A small percentage of gymnosperms have been recorded to date as those capable of growing in an aquatic environment, among which *Retrophyllum minus* (Pinopsida) was identified as the only obligatory inhabitant of aquatic habitats [37]. Among bryophytes, aquatic species make up about 0.5 % of all species, being found in all three divisions: Bryophyta, Marchantiophyta and Anthocerotophyta (mosses, liverworts and hornworts, respectively) [63].

According to the traditional point of view, representatives of aquatic vascular vegetation evolved from terrestrial plants that subsequently made a transition back to aquatic environments [19]. However, some studies have provided evidence of the aquatic origin of several groups of aquatic angiosperms [24].

Macrophytes, being an important part of various types of aquatic ecosystems, have a wide array of environmental functions and practical applications. The aim of this article was to analyze ecological groups and adaptation features of aquatic macrophytes, as well as their functional role in aquatic ecosystems.

## 1. ECOLOGICAL GROUPS AND ADAPTATION FEATURES OF AQUATIC MACROPHYTES

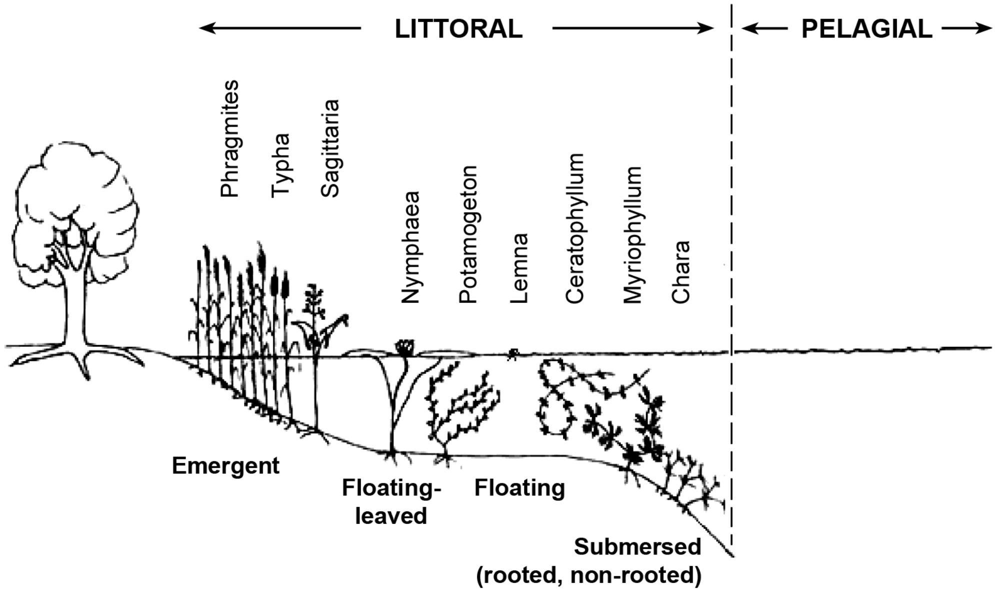
Aquatic macrophyte plants are widespread throughout the globe. Most macrophyte species are cosmopolitan, while groups of closely related species are known to replace each other in aquatic ecosystems of different parts of the world [60, 80]. Aquatic macrophytes are characterized by diverse growth forms and plasticity of physiological and metabolic processes, depending on changes in environmental conditions. Macrophytic vegetation includes deep-water and shallow-water species and species that actively grow in water in an emergent, submerged or floating state. Some species are strictly aquatic, because they need to be submerged in water to complete their life cycle, while other species possess the ability to grow and reproduce in periodically inundated environments, can adapt to changes in water level or inhabit the so-called ephemeral water bodies (e.g. floodplains, temporary springs, ponds, etc.) [19, 35].

Vegetative and clonal propagation is considered the main mechanism of macrophyte reproduction and population growth, while sexual reproduction and genetic recombination are often subordinate strategies [78]. In aquatic angiosperms, pollination and dispersal of fruits and seeds are mainly mediated by water (hydrochory). Besides, propagation of vascular aquatic plants in running waters strongly depends on the hydrochorous distribution of vegetative fragments [12]. Furthermore, zoochory (dispersal with the participation of animals) and anemochory (dispersal via wind) have been widely described as vectors for the distribution of aquatic angiosperms [17, 73]. In aquatic bryophytes, hydrochorous dispersal of spores is rare, and vegetative propagation is prevalent in watercourses and connected lake systems [12]. In this context, the dispersal of unspecialized vegetative fragments by flowing water is of great importance. Zoochorous and anemochorous distribution of propagules of aquatic bryophytes has also been shown to occur in aquatic ecosystems [10, 11].

**Growth forms of aquatic macrophytes**. Since aquatic macrophytes are very diverse in their systematic affiliation, these plants are traditionally divided into several groups on the basis of their growth forms and ecological traits (emergence or submergence; floating or attachment in sediments by roots or root analogues). Based on the classic work of A. Arber (1920) and later studies, two principal groups of aquatic macrophytes are usually distinguished, namely macrophytes, which are rooted (or attached) in bottom sediments, and free-floating plants [5, 56, 78]. Macrophytes of the first group are further subdivided into the following subgroups (see Figure): 1) emergent macrophytes, including both erect emergents (representatives of the genera *Phragmites*, *Typha*, *Sagittaria*, *Butomus*, etc.) and creeping emergents (e.g. *Myriophyllum aquaticum*, *Nasturtium aquaticum*, *Hydrocotyle* spp., etc.), which grow in shallow littoral waters and form aerial leaves and flowers; these plants are suited for life in environments where the soil is saturated with water (wetlands, marshes, swamps, flooded areas), and their root and rhizome systems are often adapted to constantly anaerobic sediments [56]; 2) floating-leaved macrophytes, such as *Nymphaea* spp., *Nuphar lutea*, *Potamogeton natans*, which may root or attach in sediments by creeping rhizome and possess floating or aerial reproductive organs; 3) submerged macrophytes, which complete their life cycle under the water surface; this group includes many angiosperms (*Elodea* spp., *Myriophyllum* spp., *Potamogeton perfoliatus*, etc.), numerous bryophytes that grow attached to a stony bottom, rocks, wood or other underwater substrates, some lycopods (*Isoetes* spp.) and charophytes (*Chara* spp., *Nitella* spp.) [56, 78].

In contrast to rooted macrophytes, free-floating aquatic plants are not attached to bottom sediments and float on the surface of water or in the water column. The group of macrophytes floating on the water surface includes species such as *Eichhornia crassipes*, representatives of Lemnoideae (e.g. *Spirodella polyrhysa*; *Lemna* spp., except *L. trisulca*; *Wolffia* spp. and *Wolffiella* spp.), water ferns *Azolla* spp. and *Salvinia* spp., and others. Some of the angiosperms that grow beneath the surface of the water are *L. trisulca* and *Ceratophyllum demersum*. Free-floating macrophytes can possess well-developed submerged roots without attachment to bottom soil, such as *Eichhornia crassipes* and *S. polyrhysa*, while others have very short roots (*L. minor*) or have no roots (*L. trisulca*). The reproductive organs of these plants are floating and aerial, but rarely submerged (e.g. in *Ceratophyllum* spp.) [78]. Along with floating vascular plants, there are several species of floating bryophytes, such as the liverworts *Ricciocarpos natans* and *Riccia fluitans*. The former grows on the water surface, frequently found in association with Lemnoideae species or *Azolla* fern, while *R. fluitans* can form thick rugs both on the surface and under the surface of water [3, 28].

Additionally, aquatic macrophytes are divided into several ecological groups according to their relation to environmental factors: hydatophytes (submerged species), pleistophytes (species with floating leaves) and helophytes (emergent aerial-water species) [58].




Growth forms of aquatic macrophytes in the littoral zone of a freshwater body (modified from [22])

Форми росту водяних макрофітів у прибережній зоні прісноводних водойм (модифіковано [22])

Macrophytes growing at the margins of lakes or rivers and often facing challenges associated with fluctuations in water level are usually classified as a separate ecological group. These plants, commonly referred to as amphibious species, are capable of growth and reproduction in both aquatic and terrestrial environments. Amphibious plants have developed adaptations that allow them to withstand rapid emersion and submersion, including the plasticity of the leaf shape and photosynthesis process [40, 42, 74].

**Plant growth conditions in the aquatic environment**. Aquatic environment is characterized by a number of factors that limit the growth of land plants, but aquatic macrophytes are endowed with special adaptations to life in the submerged conditions or on the water surface. In addition to the climatic factors, such as light regime and temperature, inorganic carbon availability and specific factors related to aquatic environment determine the assemblage and distribution of aquatic macrophytes [7]. The main ones are the water level and flow velocity, the structure and density of bottom sediments, the chemical composition of water, including salinity and nutrient concentrations, as well as pH, transparency, gas saturation, conductivity and other physicochemical parameters of water [8, 32]. The importance of individual abiotic environmental factors to aquatic macrophytes may vary in different ecological groups. While limitations on the amount of $CO_2$ and sunlight for photosynthesis rarely occur in emergent macrophytes and those floating on the water surface, the growth of submerged macrophytes is strongly affected by the amount of penetrated light and the level of gas saturation [31]. Biological factors, such as competition for light, nutrients and space, grazing by herbivores, as well as anthropogenic activities also affect macrophyte distribution.

Sufficient light is required for the normal development of aquatic plants, since it ensures the functions of a photosynthetic system. Aquatic macrophytes are found mainly at depths of 0 to 4 m; however, their occurrence at depths exceeding 6 m has been reported, with vascular plants being found at maximum depths of about 12 m [13, 29]. Bryophytes and charophytes are generally found in deeper waters than angiosperms [13]. In deep-water habitats, mosses frequently constitute the dominant vegetation owing to their better adaptability to lower light intensities and lower temperatures compared with vascular plants [15]. In temperate regions, submerged mosses have been recorded in lakes of over 120 m depths [79]. Being common in oligotrophic waters, bryophytes are often the only submerged plants in subpolar and polar lakes. In Antarctic lakes, the greatest depth of moss distribution was recorded at 81 m in Radok Lake (East Antarctica) characterized by oligotrophic to ultra-oligotrophic conditions [77]. In tropical regions, permanently submerged bryophytes are found mainly in high mountain lakes [29]. Unlike bryophytes, aquatic vascular plants are rare or absent in arctic and high-alpine lakes [15, 29].

An important restrictive factor for the growth of submerged macrophytes is the depth of light penetration. It is considered that the depth limit for their distribution occurs when water transparency allows <1–4 % of light to reach plants [61]. In turn, light penetration through the water column is largely dependent on the abundance of phytoplankton, the concentration of suspended solids and dissolved material, which affect water transparency [60].

Temperature is an equally important factor determining the distribution of aquatic macrophytes [7, 13, 60]. Some species of macrophytes grow exclusively in tropical areas, while others are distributed only in the waters of the temperate climate zone [17]. Within the thermal tolerance limits, an increase in water temperature promotes macrophyte reproduction and growth; however, a decrease in water temperature may cause a reduced seasonal growth of macrophytes [7]. Temperature can alter plant phenology, such as bud-burst, flowering period, nutrient absorption, photosynthesis, respiration, and metabolic processes [31]. On the other hand, aquatic macrophytes are exposed to less extremes of temperature in comparison with terrestrial plants. Aquatic and wetland plants exhibit a very weak response to drought, because the need for water during the drought period is compensated by submerged leaves, which act as water absorbing organs.

Water movement in the form of waves and currents plays an important role in aquatic ecosystems and influences all aquatic organisms, including various groups of macrophytes. Water flow can be stressful and directly affect macrophytes, especially submerged plants, causing stretching and mechanical damage, as well as indirectly, due to changes in gas exchange and sediment characteristics [78]. At high velocities, water flow usually reduces macrophyte growth and considerably decreases photosynthesis rate; however, it stimulates plant diversity at low to moderate velocities, in particular by increasing the supply of $CO_2$ and nutrients [43, 78].

Chemical composition of water, including salinity, strongly influences the growth and spreading of aquatic macrophytes. The distribution of macrophytes in freshwater ecosystems also depends on the nature of geological formations, as well as on the degree of anthropogenic pressure exerted on the aquatic ecosystems. Numerous studies correlated the distribution of aquatic macrophytes with water chemical parameters. In accordance with the requirements for the chemical composition of water, various groups of macrophytes are distinguished, including: species that grow in soft, neutral or slightly acidic waters; species adapted to freshwater rich in calcium carbonate; species that are common in alkaline waters typical of arid and semi-arid regions; species that grow in marine and brackish waters [52, 60, 72].

Macrophyte species inhabiting saltwater environments exhibit wide tolerance to osmotic stress and can grow at different salinity. For example, seagrasses, a unique plant group of approximately 60 species, which encompasses members of the families Hydrocharitaceae, Cymodoceaceae complex, and Zosteraceae, are the only angiosperms living fully submersed in the sea [51]. Other plant species that have colonized saline waters (salt marsh plants, mangrove swamps, etc.) are members of several families, such as Potamogetonaceae and Ruppiaceae [60]. Aquatic bryophytes do not grow in marine ecosystems due to the fact that salt water has a negative effect on the development of these plants. However, some species of bryophytes are found in brackish-water habitats [59]. For instance, the species of the liverwort *Riella* grow in brackish water of temporary pools and streams in arid and semi-arid regions or in permanent water bodies [62].

Aquatic macrophytes, similarly to other plants, require a constant supply of nutrients and trace elements for growth and development [56]. Non-rooted macrophytes receive ions and chemical compounds necessary for nutrition directly from water, while most aquatic plants rooted or attached to the bottom absorb them both from water and from bottom sediments. In sandy and nutrient-poor sediments, the growth of aquatic vascular plants is suppressed [7].

**Adaptations of macrophytes to life in the aquatic environment**. Environmental restrictions for aquatic plants are often radically different from those that affect terrestrial plants, which is why aquatic macrophytes have developed a set of unique adaptations to life in the aquatic milieu. Gas diffusion in water occurs approximately 10,000 times slower, and the light intensity is much lower than in the terrestrial environment, which requires specialized mechanisms to ensure photosynthesis and respiration in aquatic plants [74]. One of the biochemical mechanisms ensuring the adaptation of aquatic plants to low oxygen supply is the capability of switching to anaerobic metabolism in order to generate ATP in the absence of $O_2$ [53]. To overcome the limitation of the supply of inorganic carbon for photosynthesis, specialized species of aquatic plants have developed $CO_2$ concentrating mechanisms, or can use either $HCO_3^-$ or sediment $CO_2$ as a carbon source [42, 47]. It should be noted that the use of $HCO_3^-$ is the most common carbon acquisition strategy in submerged angiosperms, especially in lakes with high alkalinity.

Well-known morphological and anatomical adaptations of aquatic plants to submergence include: elongation of shoot organs to restore contact with the atmosphere above the water surface; heterophylly (plasticity of leaf shape); formation of aerenchyma tissue; the presence of lacunae for transport of gases; reduction of cuticle in submerged parts of the plants; poor development of mechanical and conductive tissues in submerged plants, etc. [40, 47, 48, 69].

The development of aerenchyma tissue is an anatomical adaptation of particular importance for life in the aquatic environment. Aerenchyma consists of longitudinally interconnected gas spaces that provide fast transport of gases, including $O_2$ and $CO_2$, between and within shoots and roots [70]. Some aquatic plants form lacunae in the place of xylem, which resemble air chambers. The formation of lacunae provides transfer of $O_2$ to rhizomes and roots or transfer of $CO_2$ from roots to leaves [42].

Heterophylly is another one of widely known adaptations developed in many species of aquatic macrophytes (e.g. *Sagittaria sagittifolia*, *Ranunculus aquatilis*, *Azolla*, *Salvinia*, etc.). Heterophyllous plants are those having more than one type of leaves on the same plant, being capable of altering leaf morphology in response to environmental conditions [48]. In heterophyllous plants, submerged leaves often have a linear ribbon form or are dissected compared to floating leaves or those that are above the water surface. Thin and dissected leaves have less resistance to water flows, so plants are less affected by mechanical stress. Aquatic leaves are characterized by a high surface to volume ratio, which increases light interception and gas exchange; furthermore, these leaves possess thin cuticles and fewer stomata compared to aerial leaves [74].

Plasticity of the leaf shape is especially characteristic of amphibious plants whose resilience to fluctuations in water level is partly due to the ability to form specialized leaves when submerged or emerged. Production of an appropriate leaf form, depending on the environment (light intensity, ambient temperature, water availability) and mediated by an endogenous growth regulator network, improves the gas exchange of plants under the water surface or prevents desiccation in aerial conditions [40, 75]. Amphibious plants also possess the plasticity of photosynthesis and metabolism of carbon and nitrogen, due to which they are capable of photosynthesis both in air and in water [42].

## 2. ECOLOGICAL FUNCTIONS OF AQUATIC MACROPHYTES

Macrophyte vegetation is an important component of various types of aquatic ecosystems. Together with phytoplankton species, these autotrophic organisms are the primary producers that provide the conversion of light energy into organic carbon compounds, thereby contributing to the formation of the trophic structure of aquatic ecosystems. During photosynthesis, macrophytes not only synthesize organic substances, but also release oxygen, which is necessary for the respiration of aquatic organisms and decomposition of organic matter. Aquatic macrophytic vegetation is a food resource for a wide range of herbivores, both invertebrates (snails, crayfish, insect larvae) and vertebrates; in addition, many species of aquatic and wetland macrophyte plants is consumed by humans and used for medical purposes [6, 41, 54]. Macrophytes, especially submerged species, are important for aquatic food webs and affect the interaction between predatory, planktivorous and benthivorous fish, as well as between fish and invertebrates [32]. According to available data, 37 freshwater herbivorous fish species belonging to 24 families feed on macrophytes [50]. Some other aquatic or semi-aquatic vertebrates, such as waterfowl, turtle, nutria, muskrat, manatee, and others, use aquatic macrophytes as food [51, 54]. Freshwater and marine macrophytes also affect communities of animals and other aquatic organisms through a chain of habitat-related mechanisms, including by providing nursery, living and feeding places [34, 51, 71].

Macrophytes, similarly to other aquatic organisms (e.g. phytoplankton, cyanobacteria), are producers and emitters of biologically active substances (allelochemicals), including low molecular weight volatile organic compounds, which play an important role in interspecies communication and competition. Allelochemicals released by aquatic plants perform a variety of functions, thereby affecting the composition and development of aquatic communities [27, 39, 82]. These substances mediate allelopathic activity against competitors, perform a protective role or can act as attractants, exhibit antimicrobial activity and inhibit the growth of pathogenic microorganisms and harmful algal blooms [27, 44]. It is assumed that inhibition of phytoplankton and bacterioplankton, including cyanobacteria species, by allelochemical compounds secreted by macrophytes contributes to the stabilization of clear water states in shallow lakes [18, 44]. Additionally, macrophytes affect aquatic ecosystems through their influence on hydrological regime of water bodies (e.g. flow velocity, formation of surface waves, etc.), bottom sediment formation and water quality [23, 45]. Noticeable changes in pH values, dissolved gas concentrations and ionic composition of water may result from their metabolism. Macrophytes that grow in near-shore areas can promote the stabilization of shores and contribute to reduction in erosion rates [71].

Macrophytes possess a great potential to concentrate mineral elements from the aquatic environment and bottom sediments, and some species are known as metal hyperaccumulators, which is based on their metabolic features and high metal tolerance [4, 14, 38, 64]. By absorbing mineral ions, these plants participate in the processes of biogeochemical cycling of elements, nutrient turnover and water self-purification; by removing excess nutrients such as phosphates and nitrogen compounds, macrophytes are capable of counteracting the eutrophication processes in water systems. On the other hand, aquatic and wetland macrophytes are capable of accumulating non-metallic inorganic and organic pollutants; moreover, macrophyte species can detoxify some organic xenobiotics by absorbing them from the aquatic environment and transforming these compounds after absorption [57, 64]. Therefore, macrophytes are increasingly used in phytoremediation processes of contaminated water bodies, as well as in engineered systems known as constructed wetlands, for the treatment and purification of domestic, agricultural, mining and industrial wastewaters [76].

An artificially constructed wetland is an environmentally friendly technology in which aquatic plants or a combination of plants and sediments are applied to remove nutrients (nitrogen and phosphorus), oil hydrocarbons, heavy metals, pharmaceuticals and other contaminants from water [1, 36]. The most frequently used macrophyte species for this purpose are emergent species, namely representatives of *Typha*, *Phragmites*, *Scirpus*, *Iris* and other genera [1, 70, 76]. While emergent vegetation absorb nutrients and polluting substances mainly from sediments, submerged and floating macrophytes, such as *Myriophyllum* spp., *Elodea* spp., *Potamogeton* spp., *Azolla* spp., duckweeds (*Lemna* spp., *Spirodela* spp.), *Eichhornia crassipes*, *Pistia stratiotes* can effectively absorb contaminants from water [9, 16, 38, 64, 70]. Aquatic macrophytes are considered more suitable for wastewater treatment than land plants because of their faster growth, greater biomass production, higher ability to absorb pollutants and better cleaning efficiency due to direct contact with contaminated water [64].

Aquatic macrophytes are widely used as biological indicators for assessing water quality [46, 65, 75]. Macrophytes can be used in three ways to assess environmental factors and environmental impact, namely, as indicators, monitors and test-systems. In accordance with the European Water Framework Directive (WFD) 2000/60/EC, macrophytes are an obligatory element in monitoring the ecological quality of rivers [26]. It has been shown that macrophytes can be distinguished in terms of their requirements for nutrient concentration in water, and this can be used in the assessment of freshwater quality [68]. Macrophytes are sensitive indicators of eutrophication of calm and running waters; in addition, these plants are also recognized as indicators of acidification, water flow and morphological degradation [67].

Along with the important role of aquatic macrophytes in maintaining the biodiversity, structure and function of aquatic ecosystems, many of these species can be harmful if present in excess in an aquatic ecosystem. This applies in particular to aquatic weeds, that is, species that have spread outside their original geographical area [15]. For some of them, the new natural environment turns out to be very favorable, which allows them to spread and propagate excessively, competing with local species for habitat and resources. Some environmental factors causing stress in freshwater ecosystems (such as eutrophication) can lead to reduced growth of inidgenous macrophyte species and contribute to the spread of invasive alien macrophytes [17]. Owing to their excessive growth and rapid colonization rates, invasive macrophytes can establish abundant populations that adversely affect the dynamics of aquatic communities and threaten native biodiversity through various physical, chemical and biological impacts [20]. In many European countries, including Ukraine, the distribution of species such as *Eichhornia crassipes*, *Elodea nuttallii*, *Myriophyllum aquaticum*, *Myriophyllum heterophyllum* and *Pistia stratiotes*, which possess a high invasive potential, is of particular concern [25, 30, 55].

## 3. CURRENT STATE OF AQUATIC MACROPHYTE VEGETATION

Anthropogenic activities affect biological diversity, including a wealth of macrophytes, by changing their habitat and the structure of the surrounding landscape. This refers especially to freshwater bodies and wetlands, which are recognized as some of the most human-influenced ecosystems in the world [21, 59]. Aquatic macrophyte plants in freshwater ecosystems are currently threatened due to the anthropogenic and climatic factors, including physical destruction and transformation of physicochemical features of water in small rivers, shallow lakes and ponds and also because of eutrophication, chemical pollution and invasion of alien species [2, 49]. Anthropogenic factors that negatively affect freshwater ecosystems and their biodiversity include: intensification of agriculture (plowing of coastal areas, unreasonable land reclamation, overgrazing), development of transport and engineering infrastructure, urbanization, human recreational activities and chemical pollution [58]. According to numerous studies, human activities leading to surface water pollution and eutrophication have led to a concomitant decrease in macrophyte diversity and changes of aquatic vegetation complexes in many freshwater ecosystems throughout Europe, including Ukraine [22, 58, 81]. Rapid environmental changes and global warming as a result of human activities have also led to changes in the structure of marine vegetation and a decrease in seagrass populations [50]. Therefore, the proper management of aquatic and wetland ecosystems, including their monitoring and control, is an important measure to protect and restore natural habitats and macrophyte vegetation.

## CONCLUSIONS

Aquatic macrophytes comprise a systematically heterogeneous group of macroscopic plants including representatives of both vascular and non-vascular higher plants, as well as green macroalgae and charophytes. Macrophytes inhabit various types of freshwater, brackish-water, and marine ecosystems and are characterized by various growth forms and plasticity of metabolism depending on environmental conditions. Macrophytic vegetation plays an important role in the trophic, structural and functional aspects of aquatic ecosystems, contributing to the formation of organic carbon compounds and oxygen release, influencing the hydrological regime of water bodies, providing food and shelter for ichthyofauna and aquatic invertebrates, as well as by influencing water quality. Macrophyte species are widely used by humans for bioindication and phytoremediation of polluted water bodies, treatment of various types of wastewater, for medical purposes, etc. However, the diversity of aquatic macrophytes in freshwater and marine ecosystems is currently threatened due to anthropogenic and climatic factors such as destruction of natural habitats, water pollution, eutrophication and global warming.

## COMPLIANCE WITH ETHICAL STANDARDS

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Animal Rights:** This article does not contain any studies with animal subjects performed by the any of the authors.

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## ВОДЯНІ МАКРОФІТИ: ЕКОЛОГІЧНІ ОСОБЛИВОСТІ Й ФУНКЦІЇ

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Стаття присвячена аналізу сучасних даних щодо екологічних особливостей і функцій водяних макрофітів, які є важливими компонентами водних та водно-болотних екосистем. Макрофіти являють собою таксономічно різноманітну групу макроскопічних водяних рослин, яка охоплює представників судинних рослин, мохоподібних, зелених водоростей і харофітів. Макрофіти представлені видами, які ростуть, виринаючи з води, занурені або плавають на поверхні чи у товщі води, причому кожна екологічна група має специфічні особливості в морфології та фізіологічних процесах. Широкий спектр адаптаційних механізмів, розроблених макрофітами на морфологічному, фізіологічному та біохімічному рівнях, дає їм змогу заселяти прісноводне й морське середовища. Водяні макрофіти є важливим компонентом трофічних ланцюгів і виконують різноманітні екологічні функції у водних екосистемах. До основних з них належать: синтез і накопичення органічних речовин, виділення кисню, поглинання й акумуляція хімічних елементів, фільтрація води та детоксикація забруднювальних речовин, вивільнення біологічно активних сполук, що беруть участь у міжвидових взаємовідносинах, надання сховку та забезпечення живленням водяних тварин, вплив на гідрологічний режим водних об'єктів тощо. Багато видів водяних макрофітів мають застосування в різних видах людської діяльності, зокрема, під час біоіндикації якості води, фіторемедіації забруднених водних об'єктів і очищення стічних вод. Однак антропогенна діяльність і кліматичні зміни призвели до суттєвого зменшення видового різноманіття макрофітів у прісноводних та морських екосистемах. Тому належне управління екологічним станом водних екосистем є необхідною умовою для успішного збереження оселищ і видового багатства водяних макрофітів.

***Ключові слова*:** водяні макрофіти, мохоподібні, гідрофіти, водні екосистеми, водно-болотні угіддя

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