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PERSPECTIVES FOR THE APPLICATION OF AQUATIC AND SEMI-AQUATIC PLANTS IN BIOMONITORING OF FRESHWATER, SALINE AND SODA AQUATIC ECOSYSTEMS

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Abstract

Aquatic plants are essential components of many freshwater and saltwater ecosystems. In this review, we provide information on aquatic and semi -aquatic vegetation, on ecology (habitat, ecological groups) and morphological features (heterophylly, root system and mechanical tissues are poorly developed etc.) of macrophytes, as well as on environmental factors (light, temperature, ph, etc.) affecting their development. This article also contains information on the role and importance of coastal aquatic vegetation. Aquatic and semi aquatic plants are used as raw materials such as the pulp for paper, medicines, perfume industry, building materials, and fertilizers. Since these plants have a selective ability to absorb various substances, aquatic plants can be used as the indicators of the presence of toxicants in water. That is why the importance and relevance of further study of aquatic and semi-aquatic plants is beyond doubt. Aquatic plants differ significantly from terrestrial plants in their anatomical and physiological characteristics, life forms, and the ability to tolerate inorganic and biological stressors. Key examples of inorganic stressors are extreme flow rates, illumination, salinity, ice cover, temperature, nutrients and pollutants. Some aquatic plants have a worldwide distribution and display high polymorphism and phenotypic plasticity in response to variations in environmental factors. These qualities allow them to manifest and survive in a wide range of environmental conditions. However, some other species have a narrower area of distribution. In this review, we examined the key environmental factors affecting aquatic plants and also discussed their potential use as indicators at local and regional levels and the importance of monitoring, rational use and conservation of aquatic and semi-aquatic plants.

Key words: Aquatic macrophytes, Lake, Pan, Aquatic vegetation, Biomonitoring, Indicators, Utilization of aquatic plants.

Introduction

Saline and soda lakes, or pans (playas), are widespread but less numerous than other types of lakes (Hammer, 1986). Most of them are shallow with extreme physical and chemical conditions, a special biogeochemical cycle, and unique biological communities (Schagerl & Burian, 2016; Boros *et al*., 2017).

Saline lakes are unique natural ecosystems with a significant amount of mineral salts. Soda lakes are also considered a special type of such inland waters. Moreover, these types of lakes serve as important natural resources of high aesthetic, cultural, economic, recreational, scientific, conservation, and environmental value (Wurtsbaugh *et al*., 2017).

In recent years, the study of such lakes has received more attention. Many studies addressed the chemical properties of salt and soda lakes, as well as their associated microbial, floral and faunal diversity (Madsen *et al*., 2006; Sorokin *et al*., 2014; Sorokin *et al*., 2015; Díte *et al*., 2017; Namsarev & Barhutov, 2018).

The composition and spatial structure of vegetation in aquatic ecosystems have been of interest to researchers (Likens, 2009). However, information about salt lake flora and the role of water mineralization as a limiting factor on the composition and structure of plant groups is limited.

A study of aquatic and semi-aquatic plants, macrophytes and other vegetation of ponds that fall under the definition given by the Convention on wetlands (the city of Ramsar, Iran, 1971) (The Convention, 1971) is of interest both from the point of view of identifying the level of phytodiversity of the region, and to identify the animal food base, because this type of vegetation is a source of food for most of the organisms living both at the bottom of the reservoir, on surface and in the surrounding area.

Aquatic plants include all plants living in the water column (*Potamogeton perfoliatus*, *Ceratophyllum demersum* etc.) and on its surface (*Nymphaea cultivar*, *Lemna minor* etc.), as well as coastal plants (mangroves (*Avecinia marina*, *Rhizophora*), *Phragmites australis*, *Typha latifolia*, *Cyperus papyrus* etc.).

On the basis of growing conditions, plant communities can be distinguished in to four groups (Sadchikova & Kudryashova, 2005):

- Semi-aquatic or wetland plants;
- Air-water or semi-submerged plants;
- Plants with leaves floating on the water surface;
- Submerged plants.

Study of aquatic and semi-aquatic vegetation: Aquatic and semi-aquatic plants are among the most important components of aquatic ecosystems and belong to the azonal type of vegetation, which is determined primarily by the connection of plants with the aquatic environment. However, climatic, soil and other zonal conditions can affect the aquatic flora and water overgrowth. The distribution and abundance of aquatic and semi-aquatic plants depend on abiotic factors, including water temperature, pH, dissolved oxygen, nutrients, turbidity, precipitation type, currents, depth, and changes in the water level (Squires *et al*., 2002).

The potential for the uses of aquatic and semi-aquatic plants are of substantial research interest. For instance, together with phytoplankton this group of plants participates in the trophic cycle of biocenoses, providing relevant products to different trophic levels of the food chain. Aquatic plants serve as food for animals including vertebrate (fish, birds, and mammals) and invertebrate (mollusks, crustaceans, insects). With moderate overgrowth of a water body, favorable conditions are formed for the development of the phytophilic invertebrate fauna (Hasan & Chakrabarti, 2009; Gidudu *et al*., 2011). In addition, aquatic and semi-aquatic plants are important for many bioecological processes in aquatic and coastal ecosystems. Most aquatic plants are biological indicators of eutrophication (O'Hare *et al*., 2018).

At the beginning of the twenty-first century, researchers acknowledged the fundamental importance of plants that grow around water bodies and interact with the aquatic environment (Wood *et al*., 2017).

Over the last century, the study of aquatic plants has expanded significantly due to an increased recognition of their importance to fundamental ecosystem processes. Specialized journals have been established, such as Aquatic Botany and The Journal of Aquatic Plant Management, and conferences dedicated to the study of aquatic plants have been organized. As a consequence of the growing interest about aquatic and semi-aquatic plants, views on many key points in aquatic botany are changed (Dudgeon *et al*., 2006; Vörösmarty *et al*., 2010; Vermaat & Gross, 2016; Phillips *et al*., 2016).

Due to the relative stability of the aquatic environment, most aquatic and semi-aquatic plants have a wide distribution area, and some of them are cosmopolitan (*Bolboshoenus maritimus*, *Eleocharis palustris*, *Scirpus lacustris*, *Agrostis stolonifera* and *Phragmites australis*) (Table 1). Cosmopolitan plants usually have high adaptability and ecological valence. Aquatic plants make up the majority of cosmopolitans. This is explained by the high homogeneity of the aquatic environment and how easily the plants reproduce (Chen *et al*., 2012). Due to wide ecological adaptation, this group also includes weeds and ruderal plants: *Taraxacum*, *Atriplex*, *Plantago*, etc. This type of vegetation can grow in a wide variety of conditions. Weeds can live in both fresh and mineralized water. Terrestrial forms can exist for a relatively long time on land, in damp places or in costal environments. One of the main features of aquatic and semi-aquatic plants of soda and saline lakes is their adaptation to extreme environmental conditions. However, the floristic diversity of such lakes is relatively low. In a biological sense, resistance is the ability of plants to tolerate unfavorable (extreme) conditions while maintaining growth and the ability to reproduce. Among the aquatic and semi-aquatic plants listed in Table 1, no endemic species have been identified. Endemic species are indicators of the specificity of a particular flora (Tashpulatov *et al*., 2019).

Many aquatic and semi-aquatic plants are used in agriculture, forestry, fish farming, pharmacology, and medicine. Among them there are many industrial plants (*Phragmites*, *Typha*, *Scirpus*) used as fuel and chemical raw materials, as well as in paper production and construction. Medicinal plants such as *Acorus*, *Bidens*, *Mentha*, and *Lythrum* are used in medicine, pharmacology, homeopathy and perfumery. Some plants are good honey plants (*Polygonum*, *Butomus*, *Iris*). Plants such as *Phragmites*, *Typha*, *Scirpus*, and *Potamogeton* are used to protect shores from erosion. Decorative aquatic plants (*Nymphaea*, *Caltha*, *Acorus*, *Iris*, *Calla*, etc.) are used for ornamental purposes. The use of aquatic and semi-aquatic plants opens up wide opportunities for breeding and seed production. This vegetation type produces a large amount of biomass, which can be consumed by mammals and birds. It is a reliable source of nutrition and cheap fodder. *Phragmites*, *Typha*, *Scirpus*, *Potamogeton*, *Cyperus*, *Ceratophyllum*, *Lemna*, etc. can be fed to animals as fresh food. The other part of plants can be used as feed additives and roughage (hay, chaff, silage). These plants are economically important, because they can be helpful in alleviating feed shortages, especially in areas with arid climates (Rockwell, 2003; Knight *et al*., 2014; Wersal & Madsen, 2012).

Phragmites is an example of wide range of applications. This species can be found all over the world, except for Antarctica. *Phragmites* can be used as a raw material, energy source for the production of pellets and biofuels, as lignocellulosic biomass for the production of high-strength fibers for new construction and packaging materials, and as innovative polymers for lightweight engineering plastics and adhesive coatings (Köbbing *et al.*, 2013; Köbbing *et al*., 2016; Baibagyssov *et al*., 2020).

Ecology of aquatic and semi-aquatic plants: Aquatic and semi-aquatic plants are partially or completely submerged in water. Ecological groups of aquatic plants are distinguished by the degree of their dependence on the aquatic environments, which varies greatly with the habitat moisture availability.

In evolutionary terms, all aquatic and semi-aquatic plants are secondary aquatic, i.e., they have adapted to life in water (Sadchikova & Kudryashova, 2005). Due to the relative stability of the aquatic environment, most aquatic plants are widespread, and some are even cosmopolitan. Aquatic and semi-aquatic plants are mainly rhizomatous perennials, characterized by a wide ecological amplitude; they can grow in a wide variety of conditions, can live in both fresh and mineralized water, in the aquatic environment and in terrestrial forms, can exist on land for a relatively long period in wet places or near shore areas of the seas. Among aquatic and semi-aquatic plants there are significantly fewer annual species than perennial ones.

Semi-aquatic plants occupy a special place in the plant world due to their morphological, biological and ecological features. Plants of the aquatic habitats and coastal areas have developed special features. Among aquatic plants, there are relatively few endemics, which are explained by the physical and chemical conditions of the aquatic environment (Knight *et al*., 2014).

Like other plants, aquatic and semi-aquatic plants require light and carbon dioxide (or another source of inorganic carbon) for photosynthesis, oxygen for respiration, and water and nutrients such as nitrogen, phosphorus, etc. for growth and development. Plants with incipient or floating leaves form some of the most productive communities in the world, because they are rarely limited by the water availability. When leaves are exposed to air, they have a ready source of light, carbon dioxide, and oxygen (Freedman & Lacoul, 2006).

Table 1. List of aquatic and semi-aquatic plants (Zarybina & Durnikn, 2005, Boros *et al*., 2013, Elias *et al*., 2013, Li, 2019).

		Carpathian Basin (Boros *et al*., 2013) Ph ≈ 7,5-9,5 the salinity range ≈ (3 – 20 g/l)	Lakes of the Kulunda plain, Western Siberia (Zarybina *et al*., 2005) Ph ≈7-8,5 the salinity range ≈ (2,5 – 40 g/l)	East China, Bohai Gulf (Li, 2019) Ph ≈ 7 – 8 the salinity range ≈ (2,5 – 40 g/l)	Pannonia-Balkan region (Elias *et al*., 2013) Ph ≈ 8 - 9,5 the salinity range ≈ (3 – 25 g/l)
1.	*Equisetum fluvlatile*		+		
2.	*Nymphaea candida*		+		
3.	*Nymphaea tetragona*		+		
4.	*Ceratophyllum demersum*	+	+		
5.	*Ceratophyllum submersum*	+			
6.	*Batrachium circinatum*		+		
7.	*Batrachium divaricatum*		+		
8.	*Caltha palustris*		+		
9.	*Ranunculus aquatilis*	+			
10.	*Ranunculus baudotii*	+			
11.	*Ranunculus petiveri*	+			
12.	*Ranunculus polyphyllus*	+	+		
13.	*Ranunculus repens*		+		
14.	*Ranunculus trichophyllus*	+			
15.	*Myosurus minimus*	+			
16.	*Arenaria leptoclados*				+
17.	*Arenaria serpyllifolia*				+
18.	*Cerastium dubium*	+			+
19.	*Dianthus chinensis*			+	
20.	*Gypsophila muralis*				+
21.	*Spergularia media*	+			
22.	*Spergularia salina*	+			
23.	*Atriplex littoralis*	+			
24.	*Atriplex patula*	+			
25.	*Atriplex prostrata*	+			
26.	*Bassia sedoides*	+			
27.	*Camphorosma annua*	+			+
28.	*Camphorosma monspeliaca*				+
29.	*Chenopodium album*				+
30.	*Chenopodium chenopodioides*	+			
31.	*Chenopodium glaucum*	+			
32.	*Chenopodium strictum*				+
33.	*Chenopodium suecicum*				+
34.	*Petrosimonia triandra*				+
35.	*Salicornia europaea*				+
36.	*Salicornia herbacea*				+
37.	*Salicornia prostrata*	+			
38.	*Salsola soda*	+			
39.	*Suaeda glauca*			+	

Table 1. (Cont'd.).

	Carpathian Basin (Boros *et al.*, 2013) Ph ≈ 7,5-9,5 the salinity range ≈ (3 – 20 g/l)	**Lakes of the Kulunda plain, Western Siberia (Zarybina *et al.*, 2005) Ph ≈7-8,5 the salinity range ≈ (2,5 – 40 g/l)**	**East China, Bohai Gulf (Li, 2019) Ph ≈ 7 – 8 the salinity range ≈ (2,5 – 40 g/l)**	**Pannonia-Balkan region (Elias *et al.*, 2013) Ph ≈ 8 - 9,5 the salinity range ≈ (3 – 25 g/l)**
40. *Suaeda pannonica*	+			
41. *Suaeda prostrata*	+			
42. *Polygonum amphibium*	+			
43. *Limonium gmelinii*	+			
44. *Elatine alsinastrum*	+			
45. *Diospyros kaki*				
46. *Glaux maritima*	+			
47. *Salix discolor*			+	
48. *Lepidium cartilagineum*	+			
49. *Lepidium crassifolium*	+			
50. *Rorippa amphibia*	+	+		
51. *Hibiscus syriacus*				
52. *Euphorbia cyparissias*				+
53. *Sedum spectabila*			+	
54. *Crataegus cuneata*			+	
55. *Potentilla anserina*				+
56. *Potentilla reptans*				+
57. *Potentilla supina*	+			
58. *Rosa chinensis*			+	
59. *Lythrum salicaria*	+	+		
60. *Myriophyllum sibiricum*		+		
61. *Myriophyllum verticillatum*		+		
62. *Trifolium balansae*				+
63. *Trifolium fragiferum*				+
64. *Trifolium micranthum*				+
65. *Trifolium nigrescens*				+
66. *Trifolium repens*				+
67. *Trifolium resupinatum*				+
68. *Trifolium striatum*				+
69. *Trifolium subterraneum*				+
70. *Trigonella monspeliaca*				+
71. *Linum maritimum*	+			
72. *Cornus alba*	+			
73. *Daucus carota*				+
74. *Oenanthe aquatica*	+			
75. *Pimpinella saxifraga*				+
76. *Sium latifolium*		+		
77. *Dipsacus fullonum*				+
78. *Asperula cynanchica*				+

Table 1. (Cont'd.).

		Carpathian Basin (Boros *et al.*, 2013) Ph ≈ 7,5-9,5 the salinity range ≈ (3 – 20 g/l)	**Lakes of the Kulunda plain, Western Siberia (Zarybina *et al.*, 2005) Ph ≈7-8,5 the salinity range ≈ (2,5 – 40 g/l)**	**East China, Bohai Gulf (Li, 2019) Ph ≈ 7 – 8 the salinity range ≈ (2,5 – 40 g/l)**	**Pannonia-Balkan region (Elias *et al.*, 2013) Ph ≈ 8 - 9,5 the salinity range ≈ (3 – 25 g/l)**
79.	*Galium palustre*				+
80.	*Galium uliginosum*				+
81.	*Galium verum*				+
82.	*Galium wirtgenii*				+
83.	*Centaurea littorale*	+			
84.	*Fraxinus Americana*			+	
85.	*Myosotis laxiflora*				+
86.	*Myosotis nemorosa*				+
87.	*Myosotis palustris*				+
88.	*Myosotis scorpioides*				+
89.	*Myosotis sicula*				+
90.	*Buddleja alternifolia*			+	
91.	*Limosella aquatica*		+		
92.	*Veronica anagallis-aquatica*		+		
93.	*Veronica anagalloides*	+			
94.	*Veronica beccabunga*		+		
95.	*Callitriche hermaphroditica*		+		
96.	*Callitriche palustris*	+			
97.	*Plantago coronopus*				+
98.	*Plantago maritima*	+			+
99.	*Plantago tenuiflora*	+			+
100.	*Utricularia australis*	+			
101.	*Utricularia intermedia*		+		
102.	*Utricularia minor*		+		
103.	*Utricularia vulgaris*	+	+		
104.	*Caryopteris clandonensis*			+	
105.	*Lycopus europaeus*	+			
106.	*Mentha aquatica*	+			
107.	*Stachys palustris*	+			
108.	*Thymus glabrescens*				+
109.	*Thymus pannonicus*				+
110.	*Achillea millefolium*				+
111.	*Artemisia santonica*	+			+
112.	*Aster laevis*				+
113.	*Aster lanceolatus*				+
114.	*Aster novi - belgii*				+
115.	*Aster tripolium*	+			+
116.	*Bidens tripartita*	+			
117.	*Centaurea calcitrapa*				+

Table 1. (Cont'd.).

	Carpathian Basin (Boros *et al*., 2013) Ph ≈ 7,5-9,5 the salinity range ≈ (3 – 20 g/l)	**Lakes of the Kulunda plain, Western Siberia (Zarybina *et al*., 2005) Ph ≈7-8,5 the salinity range ≈ (2,5 – 40 g/l)**	**East China, Bohai Gulf (Li, 2019) Ph ≈ 7 – 8 the salinity range ≈ (2,5 – 40 g/l)**	**Pannonia-Balkan region (Elias *et al*., 2013) Ph ≈ 8 - 9,5 the salinity range ≈ (3 – 25 g/l)**
118. *Cichorium intybus*				+
119. *Crepis setosa*				+
120. *Inula britannica*				+
121. *Leucanthemum vulgare*				+
122. *Matricaria recutita*	+			
123. *Scorzonera parviflora*				+
124. *Taraxacum bessarabicum*	+			
125. *Butomus junceus*		+		
126. *Butomus umbellatus*		+		
127. *Hydrocharis morsus-ranae*		+		
128. *Alisma bjoerkqvistii*		+		
129. *Alisma gramineum*	+	+		
130. *Alisma lanceolatum*	+			
131. *Alisma plantago-aquatica*		+		
132. *Sagittaria natans*		+		
133. *Sagittaria sagittifolia*		+		
134. *Triglochin maritimum*	+			
135. *Potamogeton alpinus*		+		
136. *Potamogeton berchtoldii*		+		
137. *Potamogeton compressus*		+		
138. *Potamogeton filiformis*	+			
139. *Potamogeton gramineus*	+			
140. *Potamogeton lucens*	+			
141. *Potamogeton macrocarpus*		+		
142. *Potamogeton marinus*		+		
143. *Potamogeton natans*	+	+		
144. *Potamogeton pectinatus*	+	+		
145. *Potamogeton perfoliatus*		+		
146. *Potamogeton pusillus*	+	+		
147. *Potamogeton praelongus*		+		
148. *Potamogeton vaginatus*		+		
149. *Zannichellia palustris*	+	+		
150. *Zannichellia pedunculata*		+		
151. *Caulinia flexilis*		+		
152. *Najas marina*	+	+		
153. *Iris germanica*			+	
154. *Hemerocallis hybridus*			+	
155. *Orchis elegans*				+
156. *Orchis laxiflora*				+

Table 1. (Cont'd.).

	Carpathian Basin (Boros *et al*., 2013) Ph ≈ 7,5-9,5 the salinity range ≈ (3 – 20 g/l)	**Lakes of the Kulunda plain, Western Siberia (Zarybina *et al*., 2005) Ph ≈7-8,5 the salinity range ≈ (2,5 – 40 g/l)**	**East China, Bohai Gulf (Li, 2019) Ph ≈ 7 – 8 the salinity range ≈ (2,5 – 40 g/l)**	**Pannonia-Balkan region (Elias *et al*., 2013) Ph ≈ 8 - 9,5 the salinity range ≈ (3 – 25 g/l)**
157. *Orchis palustris*				+
158. *Juncus bufonius*	+			+
159. *Juncus compressus*		+		
160. *Juncus gerardii*		+		+
161. *Juncus maritimus*	+			
162. *Juncus ranarius*				+
163. *Juncus salsuginosus*		+		
164. *Bolboschoenus glaucus*	+			
165. *Bolboschoenus laticarpus*	+			
166. *Bolboschoenus maritimus*	+	+	+	
167. *Bolboschoenus planiculmis*	+	+		
168. *Carex acuta*		+		
169. *Carex distans*				+
170. *Carex nigra*		+		
171. *Carex otrubae*				+
172. *Carex pseudocyperus*		+		
173. *Carex riparia*		+		
174. *Carex rostrata*		+		
175. *Carex stenophylla*				+
176. *Carex vesicaria*		+		
177. *Carex vulpina*				+
178. *Cyperus fuscus*				
179. *Cyperus longus*	+			+
180. *Cyperus pannonicus*	+			
181. *Eleocharis palustris*	+	+		+
182. *Eleocharis sareptana*		+		
183. *Eleocharis uniglumis*	+			+
184. *Scirpus hippolyti*		+		
185. *Scirpus lacustris*	+	+		+
186. *Scirpus litoralis*	+			
187. *Scirpus tabernaemontani*		+		
188. *Spergularia maritima*	+			
189. *Agrostis canina*				+
190. *Agrostis stolonifera*	+	+		+
191. *Alopecurus aequalis*		+		
192. *Alopecurus creticus*				+
193. *Alopecurus pratensis*	+			+
194. *Alopecurus utriculatus*				+
195. *Beckmannia eruciformis*	+			+

Table 1. (Cont'd.).

	Carpathian Basin (Boros *et al*., 2013) Ph ≈ 7,5-9,5 the salinity range ≈ (3 – 20 g/l)	Lakes of the Kulunda plain, Western Siberia (Zarybina *et al*., 2005) Ph ≈7-8,5 the salinity range ≈ (2,5 – 40 g/l)	East China, Bohai Gulf (Li, 2019) Ph ≈ 7 – 8 the salinity range ≈ (2,5 – 40 g/l)	Pannonia-Balkan region (Elias *et al*., 2013) Ph ≈ 8 - 9,5 the salinity range ≈ (3 – 25 g/l)
196. *Bolboschoenus koshewnikowii*				+
197. *Bolboschoenus maritimus*				+
198. *Bolboschoenus yagara*				+
199. *Bromus hordeaceus*				+
200. *Cynodon dactylon*				+
201. *Crypsis aculeata*	+			
202. *Crypsis alopecuroides*	+			
203. *Crypsis schoenoides*	+			
204. *Dactylis glomerata*				+
205. *Echinochloa crusgalli*	+			
206. *Elymus repens*				+
207. *Festuca pseudovina*	+			+
208. *Glyceria fluitans*				+
209. *Glyceria maxima*		+		
210. *Glyceria nodosa*				+
211. *Hordeum geniculatum*				+
212. *Phalaroides arundinacea*		+		
213. *Pholiurus pannonicus*	+			+
214. *Phragmites australis*	+	+	+	
215. *Poa angustifolia*				+
216. *Poa bulbosa.*	+			+
217. *Poa humilis*				+
218. *Poa pratensis*				+
219. *Poa sylvicola*				+
220. *Puccinellia distans*				+
221. *Puccinellia festuciformis*				+
222. *Puccinellia limosa*	+			+
223. *Schoenus nigricans*	+			
224. *Scolochloa festucacea*		+		
225. *Acorus calamus*		+		
226. *Calla palustris*		+		
227. *Lemna minor*		+		
228. *Lemna trisulca*		+		
229. *Lemna turionifera*		+		
230. *Sparganium emersum*		+		
231. *Sparganium erectum*		+		
232. *Typha angustifolia*	+	+		
233. *Typha latifolia*	+	+		
234. *Typha laxmannii*	+	+		

However, submerged plants are usually less productive. Light energy is rapidly attenuated as it enters the water, and so it becomes a limiting resource for the growth of submerged plants. They need to get carbon dioxide and oxygen from the water. The stem function of such plants is more restricted than that of the above-water species. Propagation through water is slow, which further reduces plant growth. Plants are rooted in the lake bottom, where there is usually a ready source of nutrients such as nitrogen and phosphorus. Algae, as well as free-floating plants obtain nutrients from the water column; this can restrict their growth.

The depth of the aquatic plant distribution is controlled by the amount of light penetrating through the water column. A strong gradient of light energy also results in the natural zoning of aquatic plants in lakes, with plant communities being stratified by depth. This natural "depth zoning" is a common feature of aquatic plant communities around the world.

Morphological features of aquatic and semi-aquatic plants: Aquatic and semi-aquatic plants occupy a special place among plants due to their morphological, biological and ecological features. Aquatic and coastal environments have contributed to the development of special morphological traits, among which there is a significant increase in the specific leaf area. This makes it easier to absorb oxygen and other gases, the concentration of which is higher in the air than in the water. The increase in the surface area is achieved by the development of large thin leaves, deeply divided lamina into thin filiform segments, perforation of leaves or the development of air-bearing cavities and large intercellular spaces. Many aquatic plants are heterophyllous; their underwater, floating, and aerial leaves differ significantly in both internal and external structure. Thus, whereas underwater leaves do not have stomata, floating leaves do have stomata only on the upper side, and aerial leaves have stomata on both sides (Scheffer, 2004). The number of stomata is higher in aquatic plants than in terrestrial plants. The surface of the floating leaves is sometimes covered with a waxy coating, which prevents the leaves from getting wet; in some species the edges of the leaf blade bend up (Kokin, 1982).

Due to high water density, the mechanical tissues of aquatic and semi-aquatic plants are poorly developed. However, they have a greater flexibility as a result of the few mechanical elements located closer to the center. As a result of the low light intensity in aquatic environments, many plants have developed chlorophyll grains in the epidermis cells. In the conductive bundles of macrophytes, vessels are poorly developed or even absent. The root system is also poorly developed, and there are no root fibrillas (Scheffer, 2004).

Most of the higher aquatic plants are perennial. In winter, they descend to the lake bottom wholly or overwinter in the form of rhizomes, tubers or turions i.e. morphologically modified shoots that store nutrients in the form of starch. Some aquatic plants (*Najas marina*, *Ceratophyllum demersum* and etc.) are pollinated under water, and others have flowers that rise above the water, where pollination occurs. At low temperatures, the reproductive process is suppressed and replaced by vegetative reproduction. Aquatic plants grow faster than terrestrial plants, which is due to a shorter growing season (Kokin, 1982). The above traits of aquatic plants indicate the ability to tolerate the existing adverse environmental conditions and adapt to new ones.

They grow mainly in the littoral and sublittoral zone, forming a continuous or intermittent strip of varying width along costal lines, around islands and shoals, but rarely covering the entire lake. The depth of aquatic plant distribution depends on the amount of water transparency and varies from two to four meters, and in rare cases reaches eight meters (Sadchikova & Kudryashova, 2005).

The processes of absorption, assimilation and detoxification of heavy metals, phenols, petroleum products, and synthetic surfactants by aquatic plants have been studied in detail (Wani *et al*., 2017; Selvaraj &Velvizhi, 2021). However, only a few studies have addressed the salt resistance and demineralization ability of hydrophytes (Casabianca & Laugier, 1995).

Lakes can be polluted by anthropogenic sources for a long time without any obvious signs of damage (Oyewale & Musa, 2006), that is why it has long attracted scientific and environmental interest. Among pollutants, heavy metals are the most toxic, persistent and abundant. Plants can accumulate in aquatic environments, and their concentration increases through biomagnification (Sin *et al*, 2001; Kishe & Machwa, 2003; Ahmed *et al*., 2005). The most toxic heavy metals are Cr, Ni, Pb, Cd and As. Cr (VI): Ni and Cd are carcinogens; As and Cd have teratogenic properties; and the health effects of Pb include neurological impairment and central nervous system disorders (Prasad *et al*., 2001; Nadal *et al*., 2004). Although some heavy metals such as Fe, Mn, Co, Cu, and Zn are important trace elements required for fauna and flora, they become dangerous at high concentrations (An, 2006). Increased concentrations of basic and heavy metals can have a significant impact on the health, reproduction and survival of aquatic organisms. Through the food chain, pollutants are eventually passed on to humans and can produce a wide range of adverse effects on human organisms (Singht *et al*., 2011).

There are two aspects of the interaction between plants and heavy metals. Firstly, heavy metals have a negative effect on plants. Secondly, plants have their own mechanisms for the resistance to toxic effects and detoxification of heavy metal pollution (Cheng, 2003; Nayeka *et al*., 2010). However, over the past few decades, the rapid expansion of human activity has increased the risk of heavy metal pollution (Moore *et al*., 2009).

Determining the upper thresholds and studying the adaptive mechanisms of salt resistance of hydrophytes is an important task in the process of optimizing the selection of species and the formation of bioplato for the phytoremediation of natural and wastewater in arid zones and in the case of combined pollution (Selvaraj &Velvizhi, 2021).

Environmental factors affecting the development of aquatic and semi-aquatic plants: The intensity of development of aquatic and semi-aquatic plants is influenced by many factors, among them the water transparency and temperature, biogenic macro- and micronutrients, dissolved gases, pH, etc.

Climatic factors: The key climatic factors influencing aquatic plants are ambient temperature, ice cover, and hydrology.

Temperature: The thermal regime of water bodies is determined by their geographical location, depth, water circulation, and many other factors. The water temperature depends on the amount of solar radiation, and therefore has a zonal character. With increasing latitude, reservoirs become cooler and less thermally stable, especially the surface layers. The water temperature has a strong influence on photosynthesis and the distribution of plants in the water column. Warm and temperate waters are optimal for the development of aquatic and semi-aquatic vegetation. In warm waters (tropics, subtropics), aquatic plants continue to grow almost all year round. In temperate latitudes with sharp annual fluctuations of the water temperature, the vegetation of plants begins immediately after the melting of spring ice. However, at low water temperatures the growth of plants is quite slow. The phenological season of plant development largely depends on the water temperature (Barko & Smart, 1985; IPCC, 2001).

Wind: Wind and wind-generated hydrodynamics affect aquatic plants through pollination, nutrient cycling, uprooting, and leaching. The intensity, strength, and frequency of wind and waves can have positive or negative effects on aquatic plants (Madsen, 2001).

Geomorphology: Major geomorphological settings include marshes, streams, rivers, lakes and ponds. Geomorphology influences key habitat factors for aquatic plants, including hydrology, habitat area, shoreline development, depth gradients, and water chemistry (Freedman & Lacoul, 2006).

The water movement: This property has a variable ecological value. Water has a high density, and therefore waves, rotational motion, and currents are very important and often limit plant life, especially in flowing water reservoirs and in open sea areas. On the other hand, the mixing of water has a positive effect, as it contributes to the balanced distribution of oxygen and mineral salts dissolved in water. Water movement can cause plants to develop special adaptations to the strong currents and waves. Rapid currents have a formative effect on *Potamogeton* sp, *Nymphoides sp* and other plants. In such conditions, the stem of *Potamogeton* becomes elongated and the internodes reach lengths of 20–30 cm; the leaf petioles of *Nymphoides sp* increase by up to 1.5–2 cm (Madsen, 2001).

Inorganic nutrients: Nitrogen is one of the most important elements of plant nutrition. Plant productivity, both on land and in water, depends on the nitrogen availability. In the process of the nitrogen cycle in nature, it is transformed from one form to another.

Higher aquatic plants mostly consume nitrogen in the form of nitrates, but they can also utilize other forms of nitrogen. The intensity of consumption of other forms depends largely on the concentration of nitrates. At the same time, some plant species (in particular, reeds) grow better on an ammonia nitrogen medium than on a nitrate medium. Some plants are also able to utilize amino acids. With a lack of nitrogen in the water column, many plants are able to extract it from the bottom sediments with their roots (White & Brown, 2010).

Phosphorus is one of the most limiting elements influencing plant development. In terms of importance, it ranks second after nitrogen. The main physiological significance of this element is the part of the macro-energy compounds involved in the storage and expenditure of energy in the process of cellular metabolism.

In natural aquatic systems, phosphorus is mostly found in three forms: dissolved ortho-phosphate; dissolved organic and undissolved organic (in suspended particles).

In addition, it forms primary minerals and calcium phosphates or iron oxyphosphates.

Nitrogen and phosphorus content do not usually limit the aquatic and semi-aquatic plant development, unlike that of phytoplankton living in the open water. Plants consume these elements from the aquatic environment and the bottom sediments. In addition, a significant amount of nitrogen and phosphorus enters water bodies with rainwater and floods (Rabalais, 2002).

Water transparency: Light is a necessary resource for the existence of all photosynthetic organisms, including aquatic and semi-aquatic vegetation. Sun rays are partially reflected by the water surface and partially transmitted into the water. The amount of reflected light depends on the angle at which sun rays hit the water surface.

Most of the sun energy entering the water is absorbed by water molecules, and by dissolved and suspended substances. Dissolved organic matter, primarily water humus, mineral particles, and planktonic organisms are major obstacles to the penetration of light into the water column (Vestergaard & Sand-Jensen, 2000).

Light: Light plays a crucial role in photosynthesis and limits the distribution of aquatic and semi-aquatic plants. Shade tolerance and related morphological adaptations acquired by some species can provide a competitive advantage in low-light conditions, thereby influencing the plant community structure. There is evidence that with the decreased water transparency or increased depth and the amount of light available for photosynthesis decreases accordingly.

The ability of aquatic plants to survive in various light conditions depends on their shape and growth rate. In general, low-light conditions in the shallow coastal zone contribute to the predominance of helophytes, while at greater depths, hydrophytes with free-floating leaves predominate (Riis *et al.*, 2000). Mature specimens of macrophytes with floating leaves, such as Nelumbo and Nymphaea, grow well in water with low transparency. As a rule, above-water or aquatic plants with floating leaves rarely grow in water deeper than three meters. Some species of submerged macrophytes are extremely intolerant of shading, for example, *Chara* spp. and *Potamogeton alpinus*, while others can grow in places under a well-rooted canopy, for example, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Myriophyllum spicatum*, *Potamogeton crispus*, *P. pectinatus*, *Urtricularia vulgaris* etc. (Freedman & Lacoul, 2006).

Turbidity: Water turbidity is a measurement of its murkiness. Turbidity is caused by particles suspended or dissolved in water that scatter light and make the water appear murky. Particles can be formed by sediments, especially clay and silt, fine organic and inorganic matter, soluble colored organic compounds, algae, and other microscopic organisms (Johnson *et al*., 2007).

Some surveys demonstrated that high water turbidity could limit the development of aquatic vegetation (Hilton & Phillips, 1982; Lou & Ridd, 1997; Olesen, 1996), while many small-scale experiments showed that vegetation could reduce turbidity by decreasing water flow, stabilizing sediments, and competing with phytoplankton for nutrients (Benoy & Kalff, 1999; Nepf & Koch, 1999).

Danish scientists confirmed the presence of a systematic correlation between transparency and macrophyte abundance in large lakes. For example, Jensen *et al*., (1991) and Jeppesen (1990) showed that a large number of shallow lakes with a well-developed vegetation cover have higher transparency than lakes without dense vegetation. However, this result is based on an assessment of the presence and absence of (dense) vegetation and can have several alternative explanations:

- Some lakes have more vegetation than others due to unknown causes and this vegetation reduces turbidity or turbidity has a negative effect on vegetation and is affected by other factors or there is an unknown factor that stimulates vegetation and reduces turbidity at the same time.

Beside this, the following facts should be taken into account:

- Turbidity increases with an increase in the nutrient amount;
- Vegetation reduces turbidity; and vegetation disappears entirely when a critical turbidity is exceeded (Dítě *et al*., 2017).

A study was conducted by a group of scientists (Austin, *et al*., 2017) to explore the relationships between aquatic vegetation and turbidity variation with season and spatial scale through causal modeling by using field survey data.

Based on the analysis of the field data collected along 360-kilometer long strip of the Baltic Sea coastline, the researchers concluded that in spring and summer, a dense aquatic vegetation cover plays an important role in reducing turbidity. Therefore, the mechanisms by which aquatic plants regulate turbidity in small-scale experimental studies (Nepf & Koch, 1999) can also be seen on a large spatial scale (van der Heide *et al*., 2011). From a coastal management perspective, this indicates that, in addition to reducing nutrient load in coastal areas, protecting and (where necessary) restoring submerged aquatic vegetation can be helpful in maintaining high water quality in shallow coastal areas.

In shallow soda and salt lakes, turbidity is one of the physical key factors, alongside other extreme factors such as salinity, pH, polyhumic organic carbon concentration, and high alkalinity (Boros *et al*., 2017).

Water pH: In natural reservoirs, the pH value depends on many physical, chemical, and biological factors. Among the physical and chemical factors, the presence of carbon dioxide and carbon dioxide salts – carbonates and bicarbonates – in the environment is of the greatest importance. These substances mainly regulate the pH of the environment, both in marine and freshwater reservoirs (Brouwer *et al*., 2002).

Various studies addressed the chemical composition (pH concentration, ionic composition, etc.) of the water of salt and soda lakes in Europe and Central Asia. Saline waters are dominated by eight major solutes: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3, CO_3^{2-} , Cl^- and SO_4^{2-}, but some of them are incompatible between cations and anions (Sorokin *et al*., 2004; Namsaraev *et al*., 2010; Boros *et al*.,2014; Boros *et al*., 2017; Banda *et al*., 2019).

Brackish and alkaline lakes, or "soda lakes", have salty water with sodium (Na^+) and carbonates ($HCO_3^- + CO_3^{2-}$) as the dominant ions. In these lakes the water pH is above 9. Soda lakes typically have high concentrations of chlorides, varying concentrations of sulfates, and potassium, but they have very low concentrations of alkaline earth metals due to the equilibrium state with carbonate minerals (calcite, high-magnesium calcite, etc.). Since soda lakes are characterized by low levels of dissolved calcium and magnesium, as well as by the predominance of bicarbonate ($HCO_3^- >> Ca^{2+} + Mg^{2+}$) representing the most stable alkaline environment with one of the highest pH (pH> 9) on Earth, which clearly distinguishes them from other inland salt waters. The practical problem with the water pH is that it can significantly increase on a seasonal and daily basis if photosynthesic activity is high. The water pH is usually measured during the vegetative period and during the day, when photosynthesic activity is intensive. This can lead to an over estimation of the pH value in temporary alkaline saline lakes (Boros & Kolpakova, 2018).

For instance, Chinese researchers extensively studied the ecological state of the salt lakes of the Republic of China. They found out that fluctuations in the water salinity level were a key aspect of the ecological state of saline ecosystems. Salt lakes often change size depending on the salinity fluctuations. As a result, the biodiversity and structure of the food web in salt lakes is also variable and highly dependent on salinity and partly on the ionic composition of the water. The species richness of aquatic plants, phytoplankton and zooplankton decreases sharply with an increase in salinity from 0.8 to 6.4 g/L (Vignatti, *et al*., 2017; Xiaobin, 2019).

In hypersaline lakes, with salinity above 300 g/L, only a few halophilic species of algae or bacteria can be found. This is important because hypersaline lakes have a high and unique bacterial diversity, which is of scientific, ecological and biotechnological interest. Thus, with increased salinity, the structure of the food web in salt lakes becomes less diverse. However, the decline of biodiversity is not necessarily accompanied by a decrease in performance (Oren *et al*., 2018; Shadrin, 2018; Zheng *et al*., 2018).

The extreme environmental conditions are of great ecological importance. Variability in the pH of the medium affects the survival of organisms, the intensity of nutrition, growth, the level of gas exchange, and other life processes. The pH value affects all aquatic vegetation, but has the strongest effect on submerged vegetation. The most favorable conditions for the development of aquatic and semi-aquatic plants are slightly alkaline waters; in acidic reservoirs, the growth slows down. For instance, some submerged species able to use HCO3 (*Ceratophyllum demersum*, *Elodea canadensis* etc.), prefer to grow in alkaline water, while species (*Allium cepa*, *Rubus idaeus* etc.) grow best in slightly acidic water (Bornette & Puijalon, 2011).

Submerged aquatic vegetation is more dependent on the pH value, gas composition and concentration, and chemical composition of silt than plants with floating and above-water leaves. However, aquatic and semi-aquatic plants can adapt to the extreme conditions of soda and salt lakes (Brock & Lane, 1983).

Regulation of the aquatic and semi-aquatic vegetation growth: Moderate overgrowth of water reservoirs with macrophytes (up to 20% of the area) favorably affects the development of coastal fauna and flora. Run-off of biogenic substances from the land contributes to an excessive richness of nutrients in a water body. As a result, the primary production (of semi-aquatic plants and phytoplankton) sharply increases, and the natural course of transformation of organic matter in the reservoir changes.

An excessive amount of plant biomass leads to the accumulation of plant residues and increases the processes of their decomposition, which negatively affect the oxygen regime of the reservoir. Anaerobic processes further complicate the oxidation of organic matter, and contribute to the formation of toxic decomposition products (methane, hydrogen sulfide, etc.). All this negatively affects the organisms living in aquatic plant communities. In nature, accumulation of organic matter cannot be considered separately from the processes of its decomposition. Temporary removal of macrophyte biomass, regardless of the species, is the main method of eliminating secondary contamination of water reservoirs with their residues.

One of the defining conditions for avoiding macrophyte contamination of water reservoirs is harvesting and disposal of them for various human needs. Harvesting aquatic plants for feed production is one of the main approaches to reducing the secondary pollution of water reservoirs. The benefits of this approach are twofold: on one hand, there is an increase in feed production, and on the other, cleaning of water bodies from plant residues.

Methods of combating a dense growth of aquatic and semi-aquatic vegetation can be mechanical, chemical, and biological, often used simultaneously. Mechanical methods of control of aquatic and semi-aquatic vegetation are widespread. One example is grass mowing. Most often this method is used to combat reeds, cattails. Plants that have been mown below the water surface grow much more slowly than those that have been cut above the water surface. It is recommended to mow the grass 2 times in the spring, because the young stems of the plants can be used for animal feed or as green manure. In autumn, the mowing process becomes much more complicated and does not give such a positive effect (Sadchikova & Kudryashova, 2005).

Chemical methods of control of aquatic and semi-aquatic plants are widely used. A variety of herbicides in various concentrations and combinations are effective against most semi-aquatic plants However, herbicides that are toxic have a negative impact on the biocenosis of the reservoir either directly, or through food chains. The impact of herbicides on the decomposition of vegetation also has a negative effect and worsens the physicochemical water quality. This can lead to a reduction in the number of fish and invertebrates. (Sadchikova & Kudryashova, 2005).

In recent years, biological methods of suppressing undesirable species have become widespread. The goal of biological control is not to completely destroy the species, but only to contain its population at a level that does not cause damage to other, more useful species and to human economic activities.

To control aquatic and semi-aquatic vegetation, livestock grazing in shallow waters and waterfowl breeding are used. However, the most effective way to destroy aquatic and semi-aquatic vegetation is fish farming, and especially the herbivorous fish farming.

The choice of methods for limiting the growth of semi-aquatic plants depends on the specific conditions in the area. These methods allow scientists to sustainably manage aquatic plants and use reservoirs for various purposes. The best solution to this problem is to remove the excess of biomass from a reservoir and utilize it elsewhere. This makes it possible to use valuable products that are currently dying on the vine while polluting water reservoirs (Richardson, 2008).

Ecological role and importance of aquatic and semi-aquatic plants: Macrophyte communities - higher aquatic and semi-aquatic plants - are an important component of aquatic ecosystems. They actively participate in self-purification of reservoirs from suspended solids, organic pollutants, nutrients, petroleum products, pesticides, and heavy metals. Coastal vegetation can serve as a biological filter for water polluting substances, while the vegetation abundance and projective cover can serve as a measure of the organic matter content in reservoirs (Madsen *et al.*, 2006).

Sadchikova & Kudryashova, (2005) showed that costal vegetation releasing oxygen during photosynthesis has a beneficial effect on the oxygen regime of the coastal zone. Bacteria and algae (periphyton) that live on plants play an active role in water purification. In the thickets of aquatic and semi-aquatic plants, phytofauna develops, which is also involved in the self-purification of water and bottom sediments. Benthic organisms utilize the organic matter of silt and the bacteria that live there. Under the influence of all these processes, the content of dissolved oxygen in water increases, the water transparency and nutrient content also increase, while the water mineralization and the amount of intermediate products of organic matter decomposition decreases.

Macrophytes are also successfully used in water purification from biogenic elements, phenols, aromatic hydrocarbons, trace elements, oil and petroleum products, heavy metals, various mineral salts from wastewater and natural waters, as well as in disinfection of livestock runoff from various forms of pathogenic microorganisms. The role of aquatic and coastal plants in the self-purification of reservoirs in general comprises:

- Mechanical cleaning function, when suspended and weakly soluble organic substances are retained in thickets of aquatic vegetation;
- Mineralization and oxidative function;
- Detoxification of organic pollutants.

In their work "Ecology of semi-aquatic plants" (Sadchikova & Kudryashova, 2005), it is pointed out that semi-aquatic plants are more conservative than phyto-, zooplankton, and benthic communities; therefore the species composition of macrophytes, their biomass, and their projective cover can indicate a change in the water quality.

Thus, species composition of semi-aquatic plant communities makes it possible to accurately characterize the ecological state of an ecosystem. Currently, the method of water quality assessment using biological indicators is widely used, also in hydrobiological research (Resende *et al*., 2010).

Higher aquatic plants, such as reeds, cattails, and pondweed, have a strong effect on water quality. They are used for wastewater treatment by metallurgical and coal industry enterprises, livestock complexes, as well as for the household wastewater treatment. By absorbing a substantial amount of nutrients, higher aquatic plants reduce the level of eutrophication of reservoirs. Higher aquatic and semi-aquatic plants absorb and process various substances (phenols, DCT) thus contributing to the deposition of suspended and organic matter, saturate the water with oxygen and create favorable conditions for fish spawning (Anufriieva *et al*., 2017).

A number of researchers studies report that the higher wetland plants are purifiers of the aquatic environment from various pollutants (Yan *et al*., 2018; Sandoval *et al*., 2019; Li *et al*., 2021). In different studies information was provided on the possibility of using macrophytes for water purification from biogenic elements, phenols, aromatic hydrocarbons, trace elements, oil and petroleum products, heavy metals, various mineral salts from wastewater and natural waters and in the disinfection of livestock runoff from various forms of pathogenic microorganisms (Bhupinder *et al*., 2009). For example, in Russia, a technology for wastewater treatment using water hyacinth (*Eichornia crassipus*) has been developed (Zimmels *et al*., 2004). In China, water hyacinth is used for wastewater treatment with the subsequent use of purified water by households (Adeniran, 2015). Reed vegetation has also been used for the treatment of domestic wastewater in China (Yanhua, 1992).

According to the definition given by Kipriyanova (2020), macrophyte communities - higher aquatic and semi-aquatic plants - are an important component of aquatic ecosystems that actively participate in the process of self-purification of reservoirs from suspended solids, biogenic substances, petroleum products, pesticides and heavy metals. Natural and artificially created thickets of higher aquatic and semi-aquatic plants are a cheap natural filter. They are effectively used in many countries to strengthen the banks, and to provide tertiary treatment of sewage and river water before it enters reservoirs, used as sources of industrial and municipal water supply (Kipriyanova, 2020).

According to Melikhova, (2007), coastal vegetation, especially tall vegetation, has a mechanical and physico-chemical effect on the aquatic environment in which it develops. That is why aquatic ecosystems with a well-developed vegetation belt are highly resistant to anthropogenic pollution. The state and diversity of coastal vegetation can be considered as an indicator of the dynamics of natural and anthropogenic processes.

Some macrophytes are a source of essential fatty acids for water animals. Therefore, higher aquatic plants, when in the form of extracts or dry powder, can be used as biologically active additives a feed used in agriculture and fish breeding (Neori *et al*., 2000). Aquatic vegetation is also used as raw materials in paper production, medicine production, the perfume industry, as well as building material and fertilizer.

By taking into account the selective ability of plants to absorb various substances, it is possible to use aquatic plants as indicators for the presence of toxicants in water and bottom sediments. However, plants show significant resistance to short-term pollution outbreaks and can accumulate toxicants in their tissues in large quantities without visible functional changes (Geng *et al*., 2019, Vonk *et al*., 2020).

Therefore, natural communities of freshwater and marine plants provide important ecosystem services such as nutrient cycling, flood control, protection of shellfish and aquatic birds, juvenile fish from predators, food provision for waterfowls, fish and mammals, wave energy absorption, oxygen production and water transparency improvement due to the stabilization of bottom sediments (Gidudu, 2011). Aquatic plants indirectly provide economic benefits, such as maintaining fish stocks, water supply, and recreation activities. The economic importance of sustainable natural populations alone guarantees their protection and improvement.

Monitoring, conservation and rational use of aquatic and semi-aquatic plants: Biodiversity decline is a major environmental problem. Biodiversity is considered at four levels of organization: genetic, population, species, and ecosystem. For the survival of species and natural communities, all levels of biodiversity are necessary, and they are equally important for humans. The concept of biodiversity commonly underlies the assessments of the state and ecological well-being of ecosystems.

The main method for assessing the state of biological systems is monitoring, which is a system of long-term observations, assessment, control, and prediction of the state and changes of objects (Ansari *et al*., 2017).

An equally important component of ecomontoring is environmental quality monitoring, which makes it possible to assess abiotic (chemical parameters of air, water, soil, etc.) and biotic changes (changes in the composition, abundance, distribution of species and communities) in the ecosystem. Aquatic ecosystems play a particularly important role in the conservation of biological diversity due to the special role of water on the planet and the extreme importance of the fundamental water-land ecological boundary (Madsen & Wersal, 2017).

The main adverse factors affecting aquatic plants can be natural or anthropogenic. Natural factors include climate change, changes in the water regime, successional change of phytocenoses, and displacement of some plant species by others. Anthropogenic factors include changes in the habitat conditions due to pollution and eutrophication, changes in the water regime of reservoirs as a result of hydro-reclamation activities; damage to macrophyte thickets caused by motor transport, harvesting of protected species, economic activities (extraction of plant raw materials, etc.). There are four main anthropogenic causes of species extinction: 1) habitat loss, fragmentation and modification; 2) over-exploitation of resources; 3) pollution of the environment; 4) the displacement of native species by introduced species (Fatimata, 2020).

As a result of anthropogenic impacts on natural ecosystems, many rare and economically valuable plant species, including those listed in the international and national Red books, are under threat of extinction. (Red Book, 1981; Safarov, 2003; Fourth national report, 2009; Fifth national report, 2013; Red Book, 2014; Sherimbetov *et al.*, 2018) Conservation strategy for rare, endangered and economically valuable plant species should include the protection of specific populations of these species as well as their habitats.

To ensure the protection, rational use and reproduction of aquatic and semi-aquatic plants, it is necessary to preserve populations of rare and endangered plant species listed in international, national and regional Red Books. It is necessary to cultivate the most valuable and rare species, create protected areas and reserves to promote rational use, restoration, and reproduction of plant resources. This will increase the number of not only rare and endangered plant species, but also economically valuable plants. Cultivation of aquatic and semi-aquatic plants is necessary to increase the cleaning capacity and food resources of reservoirs, create shelters for mammals and waterfowl, and to strengthen banks and protect them from erosion.

The main methods of protecting specific populations of rare, endangered and also economically valuable plant species and their communities in natural conditions are legal, ecological, biological, biotechnical, preventive and awareness building, of which practical ones play the main role.

Protection of plant populations should combine the following activities:

- Limiting anthropogenic pressures on populations of rare, endangered, and economically valuable plants;
- Cultivation of protected and economically valuable plants in natural conditions (polyculture method);
- Inventory and mapping of rare and endangered species habitats;
- Periodic revision and mapping of rare and endangered species locations;
- Assessment of the number, productivity, and operational reserves of protected species;
- Creation of special botanical, biological, and landscape reserves (micro-reserves) (Jain, 1990; Guo, 2019).

By observing the above conditions, it is possible to preserve the existing reserves of economically useful wild aquatic and semi-aquatic plants. If these conditions are not observed, there will be continuous degradation extending to complete disappearance within a few years, even of thickets that are initially large.

Thus, the monitoring, protection and rational use of aquatic ecosystems, the development and implementation of new methods of biodiversity information accumulating and processing, the structural and functional organization and the main types of anthropogenic impact on the ecosystems of reservoirs, the keeping of regional inventories of hydrobionts remain the main methods for controlling and preserving the hydrosphere biodiversity.

Conclusion

Aquatic and semi-aquatic plants are an integral part of aquatic ecosystems, including saline and soda lakes. Interest in higher aquatic plants (macrophytes) is due to their role in aquatic ecosystems. Higher aquatic vegetation plays a dual role. Positive impacts include the direct or indirect provision of food and shelter to many aquatic organisms, protection against erosion, the enrichment of water with oxygen, organic and mineral substances; this vegetation type can also act as an indicator of the state and trophic capacity of a reservoir. The negative impacts include the accumulation of easily oxidizing organic and toxic substances in the water and shading of reservoirs, etc.

The distribution of aquatic and semi-aquatic plants and their abundance and growth depend on abiotic (transparency, temperature, light, pH value, water movement, dissolved oxygen and macro- and micronutrient amount), biotic (presence of other organisms and the interaction with them) and anthropogenic factors (pollution of reservoirs by household wastewaters, industrial and agricultural runoff).

Aquatic and semi -aquatic plants can grow in a wide variety of conditions: they are able to live in both fresh and mineralized water, in an aquatic environment and on land, in damp places or along the sea coast. However, one of the main features of aquatic and semi- aquatic plants of soda and saline lakes is their persistence and ability to adapt to extreme environments. Yet, the soda and salt lake flora is not very diverse.

To control the diversity of aquatic and semi-aquatic plants of soda and salt lakes, it is necessary to monitor abiotic, biotic, and anthropogenic changes in aquatic ecosystems. The plants of these types of reservoirs attract attention because they are adapted to extreme conditions (high pH and unique chemical composition of soda and salt lakes). Due to the special role of water on the planet and the extreme importance of the fundamental water-land ecological boundary, these ecosystems play a particularly important role in biological diversity conservation and have potential for future practical applications.

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