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Review **Derleme**

Aquatic Macrophyte Indices for Running Waters: Basic Components, Assessment and Evaluation

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Abstract: Aquatic plants, known as macrophytes, are used in many areas, such as agricultural fertilizer, animal feed, cosmetics industry, pharmaceutical raw material, furniture-decoration and human food. Beyond these uses, macrophytes are used as indicators to estimate the trophic state of water bodies, and to monitor the ecologic changes in aquatic ecosystems because most of them are steady in the locations, can be observed with the naked eye and are relatively easy to collect.

Macrophytes are fundamental components of lakes and running waters. Their presence, abundance, community formation and continuity are the best indicators of the health of the ecosystems in which they are found; water quality and pollution, trophic status. As such, the EU Water Framework Directive has introduced macrophyte indices as a requirement for the "good ecological status" of water bodies. Some studies on macrophyte indices have recently begun in Türkiye, and the IBMR index was evaluated as the most appropriate one. This study focuses on worldwide used river macrophyte indices. The development and implementation of indices specific to Türkiye's water resources, along with an increase in field studies and the expansion of research in this area, are essential. This study aims to explain the macrophyte indices used for ecological status determination of running waters of Europe and Türkiye, and to create scientific data for the studies to be carried out in this field by proposing a suitable index.

Keywords

- Macrophyte indices
- IBMR
- MMI
- RMI
- RI

1. INTRODUCTION

Photosynthetic organisms, which can be seen with the naked eye and spend a part or all of their life cycle in water, are referred to as "Aquatic Plants" also known as macrophytes, (Bronmark and Hansson, 2017; Çetinkaya, 2020).

Macrophytes are classified ecologically into four categories as submerged, emergent, rooted floating-leaved, and free-floating. They play a cricial role in maintaining the health of aquatic ecosystem. Through photosynthesis, they use the CO_2 in water to produce oxygen, which is essential for aquatic animals and bacteria. Additionally, aquatic plants provide shelter for aquatic organisms, attachment substrates (microhabitats) for epiphytic algae, and hiding and protection places for many vertebrates and invertebrates. They also contribute significantly to the stabilization of riverbanks and shores (Kumar 2015, Malaiya 2015).

Macrophytes such as *Eichhornia crassipes* (Mart) and *Hydrilla verticillata* (L.f.) Royle, which have effective root systems, absorb nutrients and thus improve water quality, playing a critical role in maintaining ecological balance (Paul, 2022).

However, the death and decomposition of macrophytes can lead to undesirable consequences in aquatic systems, such as eutrophication and anoxic condition. Certain aquatic plants such as water hyacinth (*Eichhornia crassipes* (Mart), water fern (*Salvinia molesta* D.

Mitch.), and water lettuce (*Pistia stratiotes* L.), known also as Nile cabbage, can cover surface of aquatic environments, posing a threat to organisms inhabiting benthic and pelagic zones (Paul, 2022).

As an essential part of aquatic biodiversity (Tasleem, 2016), macrophytes play key roles in biogeochemical cycles through organic carbon production, phosphorus mobilization, and the transfer of other nutrients (Jeppesen et al., 2009).

In addition to their ecological roles, macrophytes also are of economic importance due to their various uses. They are used as food for human and animal, raw materials for herbal medicine, construction materials, furniture, household items, and cellulose sources (Çepel, 1990; Tasleem, 2016).

Macrophytes are widely used as ecological indicators for assessing the trophic (oligotrophic, mesotrophic, eutrophic) status of water bodies (Bronmark and Hansson, 2017) and monitoring changes in aquatic ecosystems (Othman et al., 2014).

Aquatic macrophytes are widely distributed across the globe. Studies indicate that factors such as latitude, altitude, and environmental conditions affect the diversity and distribution of macrophytes. Additionally, evapotranspiration, hydrological regimes, alkalinity/acidity, floodplains, migratory birds, and agricultural and industrial waste are other factors influencing the diversity and distribution of macrophytes (Cook, 1985; Santamaría, 2002; Murphy et al., 2019).

Globally, a total of 3,457 macrophyte species belonging to 456 genera and 93 families have been identified (Murphy et al., 2019). Of these, 2,614 species (approximately 75%) are found in inland waters (Chambers et al., 2007). According to the most recent data from 2008, there are 697 species from 61 families in Türkiye’s inland waters (Seçmen and Leblebici, 2008). Türkiye is among the countries rich in macrophytes due to the presence of numerous rivers, lakes, and dam lakes, its diverse climatic characteristics, geological and topographical differences, and the intersection of various phytogeographical regions (Cirik et al., 2011).

The concept of index in surface waters involves making quantitative and qualitative observations using specific organisms to determine the trophic status of aquatic systems. An index is based on the presence of organisms that can be used as indicators of the flora and fauna of aquatic systems. Indices are used to determine the trophic status of aquatic ecosystems, identify necessary measures for ecosystem sustainability, and provide predictions about the future of the system.

This study aims to comprehensively examine macrophyte indices used in running waters worldwide, to identify a macrophyte index suitable for conditions in Türkiye, and to highlight the strengths and weaknesses of the selected index.

2. THE MACROPHYTE INDICES AND THEIR HISTORICAL DEVELOPMENT

Understanding the contributions of aquatic macrophytes to wetland ecosystems is of great importance. Investigating the relationship between macrophytes and wetlands not only highlights the individual significance of species but also allows for various perspectives on their interactions with habitat parameters, thereby offering insight into why they exist in specific habitats (Wiegleb, 1988).

Due to their sensitivity to changes in light and nutrient regimes, alterations in the habitats, physical characteristics and organic matter dynamics influenced by anthropogenic influences, aquatic macrophytes are considered excellent indicator species in freshwater ecosystems (Murphy, 1998).

Macrophytes are recognized as effective indicators for lakes due to their sensitivity to environmental changes, such as water quality-particularly nutrient concentrations- and hydrology. By absorbing nutrients through their root systems and storage organic material produced via photosynthesis, they form a biomass, thereby serving as effective biological indicators of their habitats (Büke, 2019).

In the European Union Water Framework Directive, macrophytes are recognized as one of the fundamental biological index groups used for the biological monitoring of freshwater bodies and for achieving ecological classification objectives.

Due to these properties, many macrophyte species are widely used as bioindicators to evaluate ecological changes and in assessing the trophic status of lakes and rivers over the long term (Lehmann & Lachavanne, 1999; Kohler & Schneider, 2003).

Macrophytes were first used in Europe as biological indices for evaluating rivers and lakes in 1999. These indices were developed for specific countries or regions within Europe (Kızılırmaklı, 2020).

3. MACROPHYTE SAMPLING FOR INDICES

The determination of macrophyte indices fundamentally requires representative sampling of the water source during critical periods specifically, when the macrophyte's entire vegetative structure is fully developed. Thus, proper sampling methodology is essential. To ensure standardization in macrophyte sampling, it is first necessary to correctly select the sampling tools and equipment.

3.1. Equipment Used in Macrophyte Sampling

The following equipment is typically used for macrophyte sampling in lakes and rivers (Kayaalp, 2014):

- High-resolution maps of the study area,
- Various plastic containers,
- Waterproof labels,
- Waterproof field notebooks or data sheets, indelible pens, and a clipboard,
- Measuring tape, marking rods, or a mallet,
- Field data recording system,
- Identification keys, floras, and plant illustrations,
- Protective clothing,
- Grapnel (plant sampling rake),
- Diving suit,
- Inflatable boat or motorboat (with appropriate safety gear),
- Bathymetric data or maps,
- Laser or echo sounder for depth measurement,
- Single or double-sided rakes,
- Multi-pronged hook,
- GPS device,
- Polarized binoculars,
- Underwater viewing device (bathyscope or aquascope),
- Magnifying camera,
- Waterproof camera,
- Binocular microscopes,
- Secchi disk.

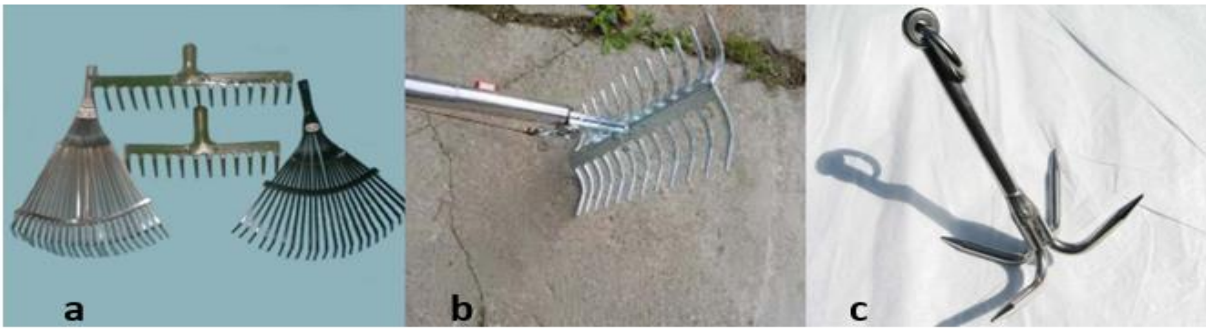

Figure 1. Equipment used for plant collection during macrophyte sampling (Kayaalp, 2014). (a. Single-sided rake, b. Double-sided rake, c. Multi-tipped hook).

Figure 2. Equipment used for plant search in macrophyte sampling (Kayaalp, 2014). (a. Binoculars Polarized glasses, b. Underwater imaging apparatus (bathyscope)-aquascope).

3.2. Macrophyte Sampling in Running waters

In macrophyte sampling to be conducted in running waters, the first step is to carry out taxonomic observations specific to the region in order to determine the floristic composition of the area. Examining and/or comparing visual materials such as photographs or satellite images taken at different times from the study area facilitates the identification of plants and provides insight into the general status and changes in the local plant flora. This method is applied in countries such as Denmark and Finland (Demir et al., 2020).

3.2.1. Determination of Macrophyte Sampling Sites

In river macrophyte sampling, the first step is to identify artificial modifications (such as slope or flow regulation) within the riverbed where the research will be conducted, as well as land use changes. It is also necessary to determine whether these modifications are related to human activities, if applicable. This information can be useful for future studies and is crucial for understanding the historical transformation of the region from past conditions up to the sampling period (Demir et al., 2020).

When selecting a sampling site factors such as the distance from the source, bank slope, and altitude should be taken into account. In addition to these factors, land use within the river basin (or sub-basin) must also be assessed. Furthermore, the region’s geomorphological structure and physical barriers such as levees and drainage channels that may influence the distribution of macrophyte communities should be examined. Potential pollution sources around the sampling area that could affect water quality such as settlements, agricultural fields, and wastewater treatment plants must also be identified. To achieve this, a site visit should be conducted prior to selecting the sampling point in order to assess the presence of these influencing factors (Demir et al., 2020).

Once all this data has been collected and preliminary fieldwork has been completed, sampling areas and transects can be selected. Additional sampling sites may be added and the number of samples increased based on factors that may influence macrophyte distribution during field studies. The main goal is to collect samples that represent the entire river water body (Demir et al., 2020).

3.2.2. Macrophyte Sampling Period in Rivers

Sampling in rivers should be carried out during periods when the flow velocity is low and species density is increasing typically in late spring (late May to early June) and early autumn (late August to early September). The number of sampling points should be proportional to the vegetation density in the area. If sampling is to be conducted once a year, it is recommended to do so in early summer; if conducted twice a year, early summer and early autumn are appropriate periods (Kayaalp, 2014; Demir et al., 2020).

Sampling sites should consist of transects approximately 1–5 meters wide and 100 meters long, depending on the river width. In shallow areas, a zigzag (Z-shaped) pattern should be followed along the channel to observe the existing species more thoroughly. Sampling points must be selected based on typological characteristics, and shaded areas, as well as locations near bridges or levees, should be avoided as much as possible (Kayaalp, 2014; Demir et al., 2020).

4. MACROPHYTE INDICES

Among the indices used for rivers in Mediterranean countries, the River Macrophyte Index (RMI) is employed only in Slovenia, whereas the IBMR (Biological Macrophyte Index for Rivers) is used in Spain, Portugal, France, Greece, Southern Cyprus, and Türkiye. While other countries use the original version of the IBMR method, the index has been adapted for use in Türkiye by assigning species scores to taxa that are present in Turkish rivers but not included in the original index, thus making it applicable to the country's watercourses (Demir et al., 2020).

Table 1. Assessment methods applied for aquatic macrophytes in rivers under the Water Framework Directive in European countries (Demir et al., 2020).

Country	Applied Method / Index
Austria	Austrian macrophyte index (AIM)
Belgium (Flanders)	MAFWAT
Belgium (Wallonia) France Greece Italy Portugal Spain Türkiye	Biological Macrophyte Index for Rivers (IBMR)
Cyprus	Multimetric Macrophytes Index (MMI)
Germany	Reference Index (RI)
UK	(LEAFPACS)
Netherlands	Maatlatten
Slovenia	River Macrophyte Index (RMI)
Poland	Macrophyte Index for Rivers (MIR)

4.1. The IBMR Used in Turkish Rivers

The IBMR, developed by Haury et al. (2003) and employed by several Mediterranean countries (Greece, France, Portugal, Spain, and Southern Cyprus), is an index that assesses trophic degradation and severe organic pollution in rivers by using macrophyte taxa as indicators to determine the trophic status of rivers. In ecological assessments of running waters, the IBMR index is also preferred in Türkiye. For the sampling procedure required to calculate this index, river segments of 50–100 meters are selected during periods of both fast and slow seasonal flow using a boat, and macrophytes are collected using a grapnel.

The IBMR calculation is based on 355 aquatic macrophyte taxa, including macroalgae, bryophytes, and vascular plants, along with the use of each taxon's Trophic Score (Csi) and Stenotopy Index (Ei) values (Table 2). To draw conclusions regarding the ecological status of the river based on the IBMR index, the criteria outlined below are used, and the formula for the calculation is provided accordingly (Afnor, 2003; Haury et al., 2006; Kızılırmaklı, 2020).

Table 2. CSi and Ei Values of Macrophytes Used in the IBMR Index (Afnor, 2003).

No	Taxa	CSi	Ei
1	*Acorus calamus* L.	7	3
2	*Adiantum capillus-veneris* L.	12	2
3	*Agrostis gigantea* subsp. *gigantea* L.	10	1
4	*Alisma lanceolatum* With.	9	2
5	*Alisma plantoga-aquatica* subsp. *plantoga aquatica* L.	14	3
6	*Alisma plantago-aquatica* L.	8	2
7	*Alisma* sp.	10	2
8	*Amblystegium fluviatile* Hedw.	11	2
9	*Amblystegium riparium* Hedw.	5	2
10	*Amblystegium sp.*	10	2
11	*Amblystegium tenellum* Cardot & Broth.	15	2
12	*Aneura pinguis* L.	14	2
13	*Anomodon attenuatus* Hedw.	12	3
14	*Apium inundatum* (Synonym *Helosciadum inundatum* L.)	17	3
15	*Apium nodiflorum* (Synonym *Helosciadum nodiflorum* L.)	10	1
16	*Apium* sp.	13	2
17	*Arundo donax* (Synonym *Phragmites australis*)	9	2
18	*Asplenium adianthum-nigrum* L.	12	2
19	*Asplenium trichomones* L.	12	2
20	*Audouinella* sp.	13	2
21	*Azolla filiculoides* Lam.	6	3

22	*Bangia atropurpurea* Roth.	10	2
23	*Bangia* sp.	10	2
24	*Batrachospermum* sp.	16	2
25	*Berula erecta* (Huds.) Coville	14	2
26	*Binuclearia* sp.	14	2
27	*Brachythecium plumosum* Huds.	18	3
28	*Brachythecium reflexum* (Starke) Schimp.	14	2
29	*Brachythecium rivulare* Schimp.	15	2
30	*Brachythecium* sp.	16	3
31	*Brachythecium starkei* (Brid.) Schimp.	16	3
32	*Breidleria pratensis* (W.D.J. Koch ex Spuce) Loeske	12	2
33	*Butomus umbellatus* L.	9	2
34	*Callitriche hamulata* Kütz. ex W.D.J.Koch	12	1
35	*Callitriche obtusangula* Le Gall	8	2
36	*Callitriche platycarpa* Kütz.	10	1
37	*Callitriche* sp.	10	2
38	*Callitriche stagnalis* Scop.	12	2
39	*Callitriche truncata* subsp. *occidentalis*	10	2
40	*Carex paniculata* subsp. *paniculata*	13	2
41	*Carex binervis*	13	2
42	*Carex diluta*	13	2
43	*Carex vesicaria* L.	13	2
44	*Carex rostrata* Stokes	15	3
45	*Carex* sp.	13	2
46	*Carex vesicaria* L.	12	2
47	*Catabrosa aquatica* (L.) P.Beauv.	11	2
48	*Ceratophyllum demersum* L.	5	2
49	*Ceratophyllum* sp.	3	2
50	*Ceratophyllum submersum* L.	2	3
51	*Chaetophora* sp.	12	2
52	*Chara globularis* Thuill.	13	1
53	*Chara hispida* L.	15	2
54	*Chara* sp.	14	1
55	*Chara vulgaris* L.	13	1
56	*Chiloscyphus pallescens* (Ehrh. ex Hoffm.) Dumort.	14	2
57	*Chiloscyphus polyanthos* (L.) Corda	15	2
58	*Chiloscyphus polyanthos* var. *polyanthos*	15	2
59	*Chiloscyphus* sp.	15	2
60	*Cinclidotus aquaticus* (Hedw.) Bruch & Schimp.	15	2
61	*Cinclidotus danubicus* Schiffn. & Baumgartner	13	3
62	*Cinclidotus fontinaloides* (Hedw.) P.Beauv.	12	2
63	*Cinclidotus riparius* (Host ex Brid.) Arn.	13	2
64	*Cinclidotus* sp.	13	2
65	*Cirriphyllum crassinervium* (Taylor ex Wilson) Loeske & M.Fleisch.	14	2
66	*Cladophora* sp.	6	1
67	*Collema fluviatile* (Huds.) Steudel	17	3
68	*Conocephalum conicum* (L.) Dumort.	14	2
69	*Cratoneuron commutatum* Synonym *(Palustriella commutata* (Hedw.) Ochyra)	15	2
70	*Cratoneuron filicinum* (Hedw.) Spruce	18	3
71	*Cratoneuron* sp.	16	2
72	*Dermatocarpon weberi* (Synonym of *Dermatocarpon luridum* (Dill. ex With.) J.R.Laundon)	16	3
73	*Diatoma* sp.	12	2
74	*Draparnaldia* sp.	18	3
75	*Drepanocladus aduncus* (Hedw.) Warnst.	15	3

76	*Drepanocladus fluitans* (Synonym of *Warnstorfia fluitans* (Hedw.) Loeske)	14	2
77	*Drepanocladus* sp.	14	2
78	*Dryopteris filix-mas* (L.) Schott	14	2
79	*Dryopteris pallida* (Bory) Maire & Petitm.	14	2
80	*Eleocharis palustris* (L.) Roem. & Schult.	12	2
81	*Eleocharis* sp.	12	2
82	*Eleogiton fluitans* (Synonym of *Eleogiton fluitans* (L.) Link)	18	3
83	*Elodea canadensis* Michx.	10	2
84	*Elodea nuttallii* (Planch.) H.St.John	8	2
85	*Elodea* sp.	9	2
86	*Enteromorpha intestinalis* (L.) Link	3	2
87	*Enteromorpha* sp.	3	2
88	*Equisetum arvense* L.	11	2
89	*Equisetum fluviatile* L.	12	2
90	*Equisetum palustre* L.	10	1
91	*Equisetum ramosissimum* (Synonym of *Equisetum ramosissimum* Humb. & Bonpl. ex Willd.)	11	2
92	*Equisetum* sp.	11	1
93	*Equisetum telmateia* Ehrh.	11	2
94	*Eurhynchium hians* (Synonym of *Oxyrrhynchium hians* (Hedw.) Loeske)	14	2
95	*Fimbristylis bisumbellata* (Forssk.) Bubani	14	2
96	*Fissidens crassipes* Wilson ex Bruch & Schimp.	12	2
97	*Fissidens gracilifolius* Brugg.-Nann. & Nyholm	14	3
98	*Fissidens grandifrons* Brid.	15	3
99	*Fissidens minutulus* Sull.	14	3
100	*Fissidens polyphyllus* Wilson ex Bruch & Schimp.	20	3
101	*Fissidens pusillus* (Wilson) Milde	14	2
102	*Fissidens rufulus* Schimp.	14	3
103	*Fissidens* sp.	14	3
104	*Fissidens viridulus* (Sw.) Wahlenb.	11	2
105	*Fontinalis antipyretica* Hedw.	10	1
106	*Fontinalis duriaei* (Synonym of *Fontinalis hypnoides var. duriaei* (Schimp.) Husn.)	14	3
107	*Fontinalis hypnoides* var. *duriaei*	14	3
108	*Fontinalis* sp.	13	2
109	*Fontinalis squamosa* Hedw.	16	3
110	*Glyceria fluitans* (L.) R.Br.	14	2
111	*Glyceria notata* Chevall.	14	2
112	*Groenlandia densa* (L.) Fourr.	11	2
113	*Gymnostomum calcareum* Nees & Hornsch.	14	2
114	*Hildenbrandia rivularis* (Liebman) J.Agardh	15	2
115	*Hippuris vulgaris* L.	12	2
116	*Homalothecium sericeum* (Hedw.) Schimp.	14	2
117	*Hottonia palustris* L.	12	2
118	*Hydrocharis morsus-ranae* L.	11	3
119	*Hydrocotyle vulgaris* (Synonym of *Hydrocotyle verticillata* Thunb)	14	2
120	*Hydrodictyon reticulatum* (L.) Lagerh.	6	2
121	*Hydrurus foetidus* (Villars) Trevisan	16	2
122	*Hygroamblystegium fluviatile* (Hedw.) Loeske	11	2
123	*Hygroamblystegium* sp.	13	2
124	*Hygroamblystegium tenax* (Hedw.) Jenn.	15	2
125	*Hygrohypnum dilatatum* (Synonym of *Platyhypnum duriusculum* (De Not.) Ochyra)	19	3
126	*Hygrohypnum duriusculum* (De Not.) Ochyra	19	3

127	*Hygrohypnum luridum* (Hedw.) Jenn.	19	3
128	*Hygrohypnum ochraceum* (Synonym of *Hygrohypnella ochracea* (Turner ex Wilson) Ignatov & Ignatova)	19	3
129	*Hygrohypnum* sp.	19	3
130	*Hyocomium armoricum* (Brid.) Wijk & Margad.	20	3
131	*Hyocomium flagellare* (Synonym of *Hyocomium armoricum* (Brid.) Wijk & Margad.)	20	3
132	*Hyocomium* sp.	20	3
133	*Hypericum elodes* L.	17	3
134	*Iris pseudacorus* L.	10	1
135	*Juncus acutus* L.	12	2
136	*Juncus articulatus* L.	12	2
137	*Juncus bulbosus* L.	16	3
138	*Juncus conglomeratus* L.	12	2
139	*Juncus effusus* L.	12	2
140	*Juncus fontanesii* J.Gay ex Laharpe	12	2
141	*Juncus fontanesii* subsp. *pyramidatus*	12	2
142	*Juncus heldreichianus* T.Marsson ex Parl.	12	2
143	*Juncus inflexus* L.	12	2
144	*Juncus obtusiflorus* (synonym of *Juncus subnodulosus* Schrank)	17	3
145	*Juncus* sp.	17	3
146	*Juncus subnodulosus* Schrank	17	3
147	*Jungermannia atrovirens* Dumort.	19	3
148	*Jungermannia gracillima* (Synonym of *Solenostoma gracillimum* (Sm.) R.M.Schust.)	20	3
149	*Jungermannia* sp.	19	3
150	*Lemanea fluviatilis* (L.) C.Agardh	15	2
151	*Lemanea* sp.	15	2
152	*Lemanea torulosa* (Synonym of *Paralemanea torulosa* (Roth) Sheath & Sherwood)	15	2
153	*Lemna gibba* L.	5	3
154	*Lemna minör* L.	10	1
155	*Lemna* sp.	9	2
156	*Lemna trisulca* L.	12	2
157	*Leptodictyum riparium* (Hedw.) Warnst.	14	2
158	*Leptomitus* sp.	0	3
159	*Littorella uniflora* (L.) Asch.	15	3
160	*Luronium natans* (L.) Raf.	14	3
161	*Lycopus europaeus* L.	11	1
162	*Lyngbya* sp.	10	2
163	*Marchantia polymorpha* L.	14	2
164	*Marsupella aquatica* (Lindenb.) Schiffn.	19	2
165	*Marsupella emarginata* (Ehrh.) Dumort.	20	3
166	*Marsupella emarginata* var. *aquatica*	19	2
167	*Marsupella emarginata* var. *emarginata*	20	3
168	*Marsupella* sp.	19	2
169	*Melosira* sp.	10	1
170	*Mentha aquatica* (Ehrh.) Dumort.	12	1
171	*Mentha longifolia* (L) L.	12	1
172	*Mentha* sp.	12	1
173	*Mentha spicata* L.	12	1
174	*Mentha suaveolens* Ehrh.	12	1
175	*Menyanthes trifoliata* L.	16	3
176	*Metzgeria furcata* (L.) Corda	14	2
177	*Microspora* sp.	12	2
178	*Monostroma* sp.	13	2
179	*Montia fontana* L.	15	2

180	*Mougeotia* sp.	13	2
181	*Myosotis gr. Palustris* L.	12	1
182	*Myosotis scorpioides* L.	12	1
183	*Myosotis* sp.	12	1
184	*Myriophyllum alterniflorum* DC.	13	2
185	*Myriophyllum* sp.	11	2
186	*Myriophyllum spicatum* L.	8	2
187	*Myriophyllum verticillatum* L.	12	3
188	*Najas major* All.	5	3
189	*Najas marina* L.	5	3
190	*Najas minor* All.	6	3
191	*Najas* sp.	5	3
192	*Nardia acicularis* (Gmelin, 1791)	20	3
193	*Nardia compressa* (Hook.) Gray	20	3
194	*Nardia scalaris* Gray	20	3
195	*Nardia* sp.	20	3
196	*Nasturtium officinale* W.T.Aiton	11	1
197	*Nitella flexilis* (L.) C.Agardh	14	2
198	*Nitella gracilis* (Sm.) C.Agardh	14	2
199	*Nitella mucronata* (A.Braun) Miq.	14	2
200	*Nitella* sp.	14	2
201	*Nostoc pruniforme* C.Agardh ex Bornet & Flahault	14	2
202	*Nostoc* sp.	14	2
203	*Nostoc zetterstedtii* Aresch. ex Bornet & Flahault	14	2
204	*Nuphar lutea* (L.) Sm.	9	1
205	*Nymphaea alba* L.	12	3
206	*Nymphoides peltata* (S.G.Gmel.) Kuntze	10	2
207	*Octodiceras fontanum* (Synonym of *Fissidens fontanus* (Bach.Pyl.) Steud.)	7	3
208	*Oedogonium* sp.	6	2
209	*Oenanthe aquatica* (L.) Poir.	11	2
210	*Oenanthe crocata* L.	12	2
211	*Oenanthe fluviatilis* (Bab.) Coleman	10	2
212	*Oenanthe* sp.	11	2
213	*Orthotrichum rivulare* Turner	15	3
214	*Oscillatoria* sp.	11	1
215	*Osmunda regalis* L.	14	2
216	*Pachyfissidens grandifrons* (Brid.) Limpr.	15	3
217	*Persicaria amphibia* (L.) Delarbre	9	2
218	*Persicaria hydropiper* (L.) Delarbre	8	2
219	*Persicaria* sp.	8	2
220	*Phalaris arundinacea* L.	10	1
221	*Philonotis calcarea* (Bruch & Schimp.) Schimp.	18	2
222	*Philonotis fontana* (Hedw.) Brid.	18	3
223	*Philonotis* sp.	18	2
224	*Phormidium* sp.	13	2
225	*Phragmites australis* (Cav.) Trin. ex Steud.	9	2
226	*Plagiomnium undulatum* (Hedw.) T.J.Kop.	14	2
227	*Plantago lanceolata* L.	9	2
228	*Plantago majör* L.	9	2
229	*Platyhypnidium riparioides* (Synonym of *Rhynchostegium riparioides* (Hedw.) Cardot)	12	3
230	*Platyhypnidium rusciforme* (Synonym of *Rhynchostegium riparioides* (Hedw.) Cardot)	12	1
231	*Polygonum amphibium* (Synonym of *Persicaria amphibia* (L.) Delarbre)	9	2
232	*Polygonum aviculare* L.	9	2

233	*Polygonum hydropiper*(Synonym of *Persicaria hydropiper* L.)	8	2
234	*Polygonum lapathifolium (Synonym of Persicaria maculosa* var. *maculosa)*	9	2
235	*Polygonum* sp.	8	2
236	*Porella pinnata* L.	12	2
237	*Potamogeton acutifolius* (Synonym of *Potamogeton compressus* L.)	12	3
238	*Potamogeton alpinus* Balb.	13	2
239	*Potamogeton berchtoldii* Fieber	9	2
240	*Potamogeton coloratus* Hornem.	20	3
241	*Potamogeton compressus* L.	6	3
242	*Potamogeton crispus* L.	7	2
243	*Potamogeton densus* (Synonym of *Groenlandia densa* (L.) Fourr.)	11	2
244	*Potamogeton fluitans* Roth	4	3
245	*Potamogeton friesii* Rupr.	10	1
246	*Potamogeton gramineus* L.	13	2
247	*Potamogeton lucens* L.	7	3
248	*Potamogeton mucronatus* (Synonym of *Potamogeton friesii* L.)	10	1
249	*Potamogeton natans* L.	12	1
250	*Potamogeton nodosus* Poir.	4	3
251	*Potamogeton obtusifolius* Mert. & W.D.J.Koch	10	2
252	*Potamogeton panormitanus* (Synonym of *Potamogeton pusillus* L.)	9	2
253	*Potamogeton pectinatus* (Synonym of *Stuckenia pectinata* L.)	2	2
254	*Potamogeton perfoliatus* L.	9	2
255	*Potamogeton polygonifolius* Pourr.	17	3
256	*Potamogeton praelongus* Wulfen	13	2
257	*Potamogeton pusillus* L.	9	2
258	*Potamogeton* sp.	10	2
259	*Potamogeton trichoides* (Synonym of *Potamogeton confervoides* Rchb.)	7	2
260	*Potentilla palustris* (Synonym of *Comarum palustre* L.)	16	3
261	*Pteridium aquilinum* (L.) Kuhn	14	2
262	*Pteris cretica* L.	14	2
263	*Pteris vittata* L.	14	2
264	*Pterogonium gracile* (Synonym of *Nogopterium gracile* (Hedw.) Crosby & W.R.Buck*)*	14	2
265	*Racomitrium aciculare* (Synonym of *Codriophorus acicularis* (Hedw.) P.Beauv.)	18	3
266	*Racomitrium canescens* (Synonym of *Niphotrichum canescens* (Hedw.) Bedn.-Ochyra & Ochyra)	18	3
267	*Ranunculus aquatilis* L.	11	2
268	*Ranunculus circinatus* Sibth.	10	2
269	*Ranunculus divaritacus* (Schrank) Schur	10	2
270	*Ranunculus flammula* L.	16	3
271	*Ranunculus fluitans* Lam.	10	2
272	*Ranunculus hederaceus* L.	12	3
273	*Ranunculus ololeucos* J.Lloyd	19	3
274	*Ranunculus omiophyllus* Ten.	19	3
275	*Ranunculus peltatus* (Synonym of *Ranunculus aquatilis* L.)	12	2
276	*Ranunculus penicillatus* subsp. *calcareus*	13	2
277	*Ranunculus penicillatus* subsp. *penicillatus*	12	1
278	*Ranunculus penicillatus* var. *calcareus*	13	2

279	*Ranunculus penicillatus* var. *penicillatus*	12	1
280	*Ranunculus repens* L.	13	2
281	*Ranunculus* sp.	13	2
282	*Ranunculus trichophyllus* Chaix	11	2
283	*Rhacomitrium aciculare* (Synonym of *Codriophorus acicularis* (Hedw.) P.Beauv.)	18	3
284	*Rhizoclonium* sp.	4	2
285	*Rhynchostegium riparioides* (Hedw.) Cardot	12	1
286	*Riccardia chamaedryfolia* (With.) Grolle	15	2
287	*Riccardia multifida* (L.) Gray	15	2
288	*Riccardia pinguis* (Synonym of *Aneura pinguis* (L.) Dumort.)	14	2
289	*Riccardia sinuata* (Synonym of *Riccardia chamedryfolia* (With.) Grolle)	15	2
290	*Riccardia* sp.	15	2
291	*Riccia fluitans* L.	8	3
292	*Rorippa amphibia* (L.) Besser	9	1
293	*Rorippa nasturtium-aquaticum* (Synonym of *Nasturtium officinale* W. T. Ation)	11	1
294	*Rorippa* sp.	10	1
295	*Sagittaria sagittifolia* L.	6	2
296	*Scapania paludosa* (Müll.Frib.) Müll.Frib.	20	3
297	*Scapania* sp.	18	3
298	*Scapania undulata* (L.) Dumort.	17	3
299	*Schistidium rivulare* (Brid.) Podp.	15	3
300	*Schizomeris* sp.	1	3
301	*Schoenoplectus lacustris* (L.) Palla	8	2
302	*Scirpoides holoschoenus* (L.) Soják	12	2
303	*Scirpus fluitans* (Synonym of *Isolepis fluitans* (L.) R. Br.)	18	3
304	*Scirpus lacustris* (Synonym *Schoenoplectus lacustris* (L.) Palla)	8	2
305	*Scirpus* sp.	12	2
306	*Scirpus sylvaticus* (Synonym of *Scirpus radicans* Schkuhr)	10	2
307	*Sirogonium* sp.	12	2
308	*Sium erectum* (Synonym of *Berula erecta* (Huds.) Coville)	14	2
309	*Sium inundatum* (Synonym of *Helosciadium inundatum* (L.) W.D.J.Koch)	17	3
310	*Sium nodiflorum* (Synonym of *Helosciadium nodiflorum* (L.) W.D.J.Koch)	10	1
311	*Sium* sp.	14	2
312	*Solenostoma crenulatum* (Synonym of *Solenostoma gracillimum* (Sm.) R.M.Schust.)	20	3
313	*Solenostoma* sp.	19	3
314	*Solenostoma triste* (Synonym of *Jungermannia atrovirens* Dumort.)	19	3
315	*Sparganium angustifolium* (Synonym of *Sparganium subglobosum* Morong)	19	3
316	*Sparganium emersum* Rehmann	10	1
317	*Sparganium emersum* Rehmann *(< 20 cm)*	13	2
318	*Sparganium emersum* Rehmann *(> 20 cm)*	7	1
319	*Sparganium erectum* L.	10	1
320	*Sparganium minimum* (Synonym of *Sparganium natans* L.)	15	3
321	*Sparganium* sp.	13	2
322	*Sphaerotilus* sp.	0	3
323	*Sphagnum denticulatum* Brid.	20	3
324	*Sphagnum inundatum* Russow	20	3

325	*Sphagnum palustre* L.	20	3
326	*Sphagnum* sp.	20	3
327	*Spirodela polyrhiza* (L.) Schleid.	6	2
328	*Spirogyra* sp.	10	1
329	*Stigeoclonium* sp.	13	2
330	*Stigeoclonium tenue* (C.Agardh) Kütz.	1	3
331	*Stuckenia pectinata* (L.) Börner	2	2
332	*Tetraspora* sp.	12	1
333	*Thamnium alopecurum* (Synonym of *Thamnobryum alopecurum* (Hedw.) Gangulee*)*	15	2
334	*Thamnobryum alopecurum* (Hedw.) Gangulee	15	2
335	*Thorea hispida* (Thore) Desv.	14	3
336	*Thorea ramossissima* Bory	14	3
337	*Thorea* sp.	14	3
338	*Tolypella glomerata* (Desv.) Leonh.	12	2
339	*Tolypella prolifera* (Ziz ex A.Braun) Leonh.	15	3
340	*Tolypella* sp.	13	2
341	*Trapa natans* L.	10	3
342	*Tribonema* sp.	11	2
343	*Typha angustifolia* L.	6	2
344	*Typha latifolia* L.	8	1
345	*Typha* sp.	7	1
346	*Ulothrix* sp.	10	1
347	*Vallisneria spiralis* L.	8	2
348	*Vaucheria* sp.	4	1
349	*Veronica anagallis-aquatica* L.	11	2
350	*Veronica beccabunga* L.	10	1
351	*Veronica catenata* Pennell	11	2
352	*Veronica* sp.	11	2
353	*Wolffia arhiza* (L.) Horkel ex Wimm.	6	2
354	*Zannichellia palustris* L.	5	1
355	*Zygnema* sp.	13	3

The IBMR is calculated using the following formula;

IBMR = [∑(Ei*Ki*CSi)] / [∑(Ei*Ki)]

In the formula:

IBMR: The Biological Macrophyte Index for Rivers.

CSi (Trophic Score or Specific Score): A value assigned to each macrophyte taxon based on its sensitivity to organic pollution. These scores range from 0 (hypertrophic) to 20 (oligotrophic). The values are determined based on Table 2.

Ei (Stenotopy Index): A score indicating the trophic range in which a macrophyte taxon occurs. A taxon receives a score of 3 if it is found in only one trophic level, 2 if found in two trophic levels, and 1 if present across all trophic levels. Based on the calculation results, ecological status assessments are made with reference to Table 4 (Kızılırmaklı, 2020).

Ki Value (Abundance Scale): Represents the relative abundance observed during fieldwork. Estimates are made using the values provided in Table 3.

Table 3. Abundance Values (%) and Their Corresponding Grapnel-Based Plant Fragment Observations (Kızılırmaklı, 2020).

Abundance Value	Percentage Value (%)	Part Attached to Grapnel
1	< 0,1	Only one piece available
2	0,1-1	Low abundance or frequency
3	1,1-10	Average abundance or frequency
4	11-50	High abundance or frequency
5	>50	Too much abundance or frequency

Table 4. IBMR Assessment Chart (Afnor, 2003; Haury et al., 2006).

Ecological class	IBMR value
Bad	IBMR≤ 8
Poor	8 < IBMR ≤ 10
Medium	10 < IBMR ≤ 12
Good	12 < IBMR ≤ 14
Very Good	IBMR > 14

4.1.1. An Applied Case Study in the Context of Turkish River Systems

The IBMR values obtained from the macrophyte sampling conducted by Topaldemir (2021) as part of a doctoral dissertation in the Miliç Coastal Wetland located in the Terme district of Samsun, Türkiye, are as follows:

Table 5. Macrophyte Composition Data from the Miliç Wetland (Topaldemir, 2021).

Taxa	Ei	Ki	CSi	Ei*Ki*CSi	Ei*Ki
Alisma plantago-aquatica L.	2	2	8	32	4
Azolla filiculoides Lam.	1	5	6	30	5
Butomus umbellatus L.	2	1	9	18	2
Callitriche stagnalis Scop.	2	3	12	72	6
Ceratophyllum demersum L.	2	3	5	30	6
C. submersum L.	3	5	2	30	15
Chara globularis Thuill.	1	2	13	26	2
C. hispida L.	1	2	15	30	2
Hydrocharis morsus-ranae L.	3	2	11	66	6
Iris pseudocorus L.	1	3	10	30	3
Lemna gibba L.	3	3	5	45	9
L. minör L.	1	2	10	20	2
L. trisulca L.	2	2	12	48	4
Myriophyllum spicatum L.	2	1	8	16	2
Nasturtium officinale W. T. Ation	1	2	11	22	2
Nymphaea alba L.	3	1	12	36	3
Phragmites australis (Cav.)Trin.ex Steud.	1	5	9	45	5
Potamogeton crispus L.	2	2	7	28	4
Ranunculus trichophyllus Chaix.	2	3	11	66	6
Sparganium erectum L.	1	5	10	50	5
Spirodela polyrhiza (L.) Schleid.	2	3	6	36	6
Stuckenia pectinata (L.) Börner	2	4	2	16	8
Typha latifolia L.	1	3	8	24	3
Wolffia arhiza (L.) Horkel ex Wimm.	2	1	6	12	2
Zannichellia palustris L.	2	2	5	20	4

According to Formula 4.1, the IBMR value was calculated as 7.13 based on the equation 848/116. As indicated in Table 4, this indicates that the ecological status of the wetland is classified as "bad" based on the IBMR index assessment (Topaldemir, 2021).

5. FACTORS LIMITING THE APPLICATION OF MACROPHYTE INDICES

The primary factors limiting the effectiveness of macrophyte indices are environmental factors that constrain the survival of aquatic plants, such as water temperature, water quality, light availability, nutrient levels, water depth, turbidity, and flow velocity. Since these factors directly affect the growth and sustainability of aquatic plants, they indirectly influence index calculations as well.

In macrophyte index assessments, the absence of index-specific species in the study area may lead to inaccurate results. Therefore, before applying an index to assess trophic status, the suitability of the index for the specific aquatic environment should be determined.

Another limiting factor is the identification of macrophyte species. Inaccurate species identification decreases the reliability of results. For this reason, researchers responsible for index calculations should be well-versed in aquatic plant taxonomy or consult a specialist in aquatic vegetation.

The selection and correct use of sampling tools and equipment (e.g., grapnels, rakes) are also crucial. Inappropriate tool use or the absence of necessary equipment can directly affect the outcome of the index calculations.

6. SUITABLE MACROPHYTE INDICES FOR USE IN INLAND WATERS OF TÜRKİYE

As in many regions worldwide, lake ecosystems in Türkiye are under pressure due to intensive anthropogenic activities such as agriculture and irrigation around lakes, as well as significant natural and/or artificial fluctuations in water levels caused by Mediterranean climatic characteristics and water abstraction for irrigation. Furthermore, climate change projections predict a 25–30% decrease in precipitation and increased evaporation in arid and semi-arid Mediterranean regions. Therefore, the protection of lake ecosystems is a critical priority for Türkiye.

In this context, following the Helsinki Summit, Türkiye began reforming its water management policies in the early 2000s to align with the EU Water Framework Directive (WFD). Several projects were initiated to support this alignment process, including MATRA (2002–2004), which focused on the Büyük Menderes River Basin, and EU-TWINNING (2008–2009), which identified 25 River Basins across the country. Additionally, after the launch of the EU Environmental Chapter negotiations, the number of WFD-related projects increased.

For instance, under the "Technical Assistance Project for Capacity Building in Water Quality Monitoring (TR2009/0327.02-02/001)," an initiative was launched in the Büyük Menderes River Basin to determine the ecological status of Turkish lakes using macrophyte-based indices. The LEAFPACS index, developed in the United Kingdom, was used for this purpose. Another index, the Macrophyte Index, was applied to Lake Mogan and revealed that the lake's ecological status was "moderate" in 2003 and had deteriorated to "poor" by 2013 (Levi, 2016).

Since improving macrophyte presence and abundance is considered a vital component of lake restoration projects, assessing the ecological status of lakes through macrophytes is crucial (Levi, 2016). According to Erkan (2014) and Bakır (2015), the LEAFPACS index (WFD-UKTAG, 2014) is currently the most suitable method for trophic status assessment in Turkish lakes, while the IBMR index is recommended for rivers.

7. DISCUSSION AND CONCLUSION

Water resources are among the most critical elements that must be sustainably managed to ensure the continuation of human life. With increasing population, industrialization, agricultural activities, and domestic waste, pollution in water bodies has escalated, leading to the degradation and shortening of their lifespans. Therefore, it is essential not only to monitor the water budgets of these resources but also to assess their ecological status.

Across the world and in Türkiye, various ecological assessment indices have been developed to determine the trophic status of aquatic environments. In these assessments, multiple biological indicators are used. Among them, macrophytes are considered particularly reliable due to their visible presence and high sensitivity to nutrient pollution, which makes them effective indicators of water quality.

For lakes in Türkiye, the LEAFPACS2 index, an updated version of the LEAFPACS index developed in the United Kingdom, is considered the most appropriate. For rivers, the IBMR index is regarded as more accurate in reflecting ecological conditions.

Macrophytes are crucial components of aquatic ecosystems, especially in rivers and riparian zones. Their presence, abundance, ability to form communities, and persistence serve as strong indicators of the health of aquatic ecosystems, water quality, pollution levels, and trophic status. Therefore, the EU Water Framework Directive mandates the use of macrophyte indices as part of the requirements for achieving “good ecological status” in water bodies.

In Türkiye, preliminary studies on macrophyte indices have begun. This study focused on macrophyte indices used for rivers both globally and within Türkiye. To improve the management of water resources, it is essential to develop macrophyte indices tailored to the ecological characteristics of Turkish aquatic systems, to increase the number of field studies in this area, and to expand the scope of research.

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CONFLICT OF INTEREST

The authors declare that there are no financial interests or personal relationships that may have influenced this work.

AUTHOR CONTRIBUTIONS

Study design: OÇ; Manuscript writing: İÖ. Final revision OÇ, İÖ All authors approved the final draft.

ETHICAL STATEMENTS

Local Ethics Committee Approval was not obtained because experimental animals were not used in this study.

DATA AVAILABILITY STATEMENT

The data used in this study are available from the corresponding author upon reasonable request.

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