Ecological status assessment of lakes using macrophytes

Elżbieta Chilińska

Department of Hydrobiology, Faculty of Biology and Environmental Protection, Nicolaus Copernicus University in Toruń, Toruń, Poland
E-mail: ela.chilinska@gmail.com

ABSTRACT

Harmonisation of the laws of the Member States regarding the protection of the environment is one of the tasks of the European Union. Poland joined EU in 2004 and took on various commitments for the improvement of water status. In particular, the Water Framework Directive was a major breakthrough in the assessment of aquatic ecosystems. For the classification of stratified and non-stratified lakes Ecological State Macrophyte Index (ESMI) has been used. In Poland, the method for assessing the ecological status of lakes based on macrophytes has been developed for routine water monitoring shortly after joining the European Union. This index is one of the biological elements in the assessment of ecological status. It considers the whole plant communities in the reservoir. The key factor that ESMI reacts to is anthropopressure, which manifests itself as eutrophication. However, it is crucial that the lakes are also subject to different pressures. In this situation, the ESMI rating becomes only an indicative method. The article describes the role, process of evaluation and the most common problems related to ESMI.

KEY WORDS: Water Framework Directive, water quality, ecological status, ESMI, lakes

Introduction

For years, environmental monitoring using macrophytes in Poland and Europe was not playing a significant role. Several countries, e.g. the Netherlands, Belgium, Denmark, Germany and Estonia researched vegetation lake ecosystems in their territories. However, these works were merely intended to present the perennial macrophytes changes using simple methods (Ciecierska & Dynowska 2013). Only the European Union Directive 2000/60/EC of 23 October 2000, also known as Water Framework Directive (WFD), turned out to be a milestone in the evaluation of water ecosystems.

In Poland, the method for assessing the ecological status of lakes based on macrophytes was developed for routine water monitoring in 2005–2006. In this process 156 Polish lakes larger than 1 ha were used, including 78 larger than 50

ha.Water reservoirs have been grouped under the terms of the multiplicity of vegetation and abiotic parameters. Among them four groups of macrophyte lakes were distinguished: I - soft water lakes (lobelia), II - lakes with water rich in calcium (deep charales lakes), III - lakes with water rich in calcium (shallow charales lakes) as well as IV - lakes of łęczyńsko-włodawskie lakeland. A separate classification, assessed by the Ecological State Macrophyte Index, has been proposed for the second and third type, respectively stratified and non-stratified lakes. The macrophytes

indication method proposed by Prof. Marian Rejewski was the basis of its study (Rejewski 1981). Unlike other indicators, ESMI does not include the same plant taxa, but syntaxon, or their communities. In hydrobotanics this difference, however, is of little importance, due to the fact that aquatic plants tend to create almost single-species communities, and therefore the degree of coverage of the plant community is close to the degree of coverage of its dominant species (Tomaszewicz 1979, Panek 2011).

The method of assessment of ecological status of lakes based on macrophytes

Ecological State Macrophyte Index includes vegetation studies carried out in the field with a preparatory phase, some involving the calculation of the macrophyte indicators and classification of lakes to the appropriate abiotic types. ESMI has a value from 0 (meaning bad ecological status) to 1 (reflecting high water quality). This index takes into account parameters such as phytocenotic variety, maximum phytocoenotic diversity, colonization index, phytolittoral surface calculated as the sum of the areas of all plant groups and the area of the lake.

Research should be carried out in July and the first half of August because of the growing season optimum, then water vegetation is most representative and observation results are void of significant abberations. Macrophyte assessment of lakes in the basic monitoring network is done once for each lake, while for the benchmark lakes it should be performed every three years, indicating the studies done in subsequent years on the same transects (Dz.U. nr 162, poz. 1008). Studies should be carried out by two inspectors.

The preparatory phase

In this phase the preparation for field research begins. Starting with the standard equipment used for field monitoring studies of lakes, such as a vessel, protective clothing or life jackets for both inspectors and, finally, specialist equipment. For the macrophyte study it is important to collect additional equipment, which includes a GPS device, an echo sounder, bathymetric and topographic maps, ropes and poles used to determine the length and width of the transect, hook for collecting underwater

vegetation, a research protocol, a Secchi disk, as well as plastic bags with a line or dryers with tissue paper for collecting botanical taxa difficult to gather which require identification in a laboratory.

Before starting field studies, it is required to calculate the smallest possible number of transects, which is necessary for the macrophytes research and to determine their layout on bathymetric maps of the lake, taking into account representativeness and diversity of vegetation. Factors that should also be

taken into account include morphometry and usage of coastal catchment of a reservoir, in order to arrange them relatively equally over the entire surface of the reservoir. The minimum number of transects depends on the surface of the lake and the shoreline development, but it cannot be less than six. The number of transects is a minimal value and reducing it is possible only in strictly justified cases, such as severe weather conditions, the lack of elodeids or when the calculated number of transects considerably exceeds 30 (Kolada & Ciecierska 2009). It is calculated using the Jensen's formula for the lakes with a surface smaller than 0.2 km² (Jensen 1977):

$$MLT = \frac{L}{\sqrt{\pi * P}}$$

and larger than or equal to 0.2 km²:

$$MLT = \left(\frac{T_{min}}{2} + \frac{P - P_{min}}{P} * \frac{L}{\sqrt{\pi * P}}\right)$$

where:
MLT - the least (total) number of transects;
L - the length of shoreline (km);
P - the lake surface area (km²);
P_{min} - the lower limit of the size of the lake in a particular size class (Tab. 1);
T_{min} - the smallest number of transects required for the lake in a particular size class.

Table 1. Classification of lake sizes indicating the minimum number of transects required for the lake in a particular size class (Ciecierska & Dynowska 2013).

Size class	P [km²]	T_{min}
I – II	< 0.20	2
III	0.20 – 0.39	2
IV	0.40 – 0.79	4
V	0.80 – 1.59	6
VI	1.60 – 3.19	8
VII	3.20 – 6.39	10
VIII	6.40 – 12.79	12
IX	12.80 – 25.59	14
X	25.60 – 51.19	16
XI	51.20 – 102.39	18

The investigation of macrophytes in the field

Investigation of macrophytes on a certain transect includes the designation of its area with a width of not less than 30 m and length which reflects the colonization zone, from the lake shore to a maximum depth of occurrence of vegetation. The percentage of plant coverage of the entire transect is estimated and all the occurring plant communities on the transect with the estimated percentage of the coverage in relation to the total area occupied by the plants is identified based on the seven stage Braun-Blanquet scale (Golub *et al.* 2006).

During the studies it is important to include all the environmental groups starting from reed bed proper and reed bed of sedge (helophytes), through plants with floating leaves (nympheids), vascular submerged plants (elodeids), Charetea (charophytes) and mosses. It is never allowed to miss the transect where there were no macrophytes, except for the situation described above, because it will disturb the final ESMI evaluation. It is also important to make additional observations of the type of the bottom or the inclination of the littoral.

Table 2. Loliolide and its derivatives in marine organisms.

Braun-Branquet scale	Percentage of communities in the total area occupied by plants	The average coverage [%]
5	100 – 75	86
4	75 – 50	61
3	50 – 25	34
2	25 – 5	15
1	5 – 1	3
+	1 – 0.1	0.5

Calculation of macrophyte indicator

To determine the final value of the ESMI index it is necessary to average the data collected in transects and identify individual indicators containing information on the qualitative and quantitative state of macrophytes.

One of the most important indicators is the phytocoenotic diversification (H), calculated from the Shannon-Weaver Index (Panek 2001), which takes the form:

$$H = \sum \frac{n_i}{N} * \ln \frac{n_i}{N}$$

where: H - phytocenotic diversification index;
n_i - area of specific plant community in the percentage of the total phytolittoral area;
N - total area of phytolittoral (100%).

The maximum value of phytocenotic diversity is also calculated (H_{max}) (Ciecierska & Dynowska 2013), according to the formula:

$$H_{max} = \ln S$$

where: H_{max} - the theoretical maximum rate of phytocenotic diversity;
S - the number of communities forming phytolittoral.

The structural simplifications of vegetation under anthropopressure (J) are reflected by the rate of the actual phytocenotic diversity (H), the theoretically possible maximal diversity (H_{max}) (Pielou 1966), calculated from the formula:

$$J = \frac{H}{H_{max}}$$

As a quantitative benchmark of macrophytes applied settlement rate (Z), expressing area actually occupied by the macrophytes (phytolittoral surface) and the surface potentially available to them, considered as the area of littoral limited by isobath 2.5 m (lake area, where the water is shallower than 2.5 m). Settlement rate should be calculated as follows (Ciecierska & Dynowska 2013):

$$Z = \frac{N}{P - \text{isob.}\, 2.5}$$

where: Z – settlement rate;
N - total area of phytolittoral (ha);
P - the lake surface area (ha);
isob. 2.5 - area limited by isobath 2.5 (ha).

The quantitative and qualitative indicators described above, included in a single formula, are used to calculate the Ecological State Macrophyte Index, which takes the form (Kolada & Soszka 2004, Ciecierska 2008, Ciecierska & Kolada 2013):

$$\text{ESMI} = 1 - \exp\left[-\frac{H}{H_{max}} * Z * \exp\left(\frac{N}{P}\right)\right]$$

where: H - phytocenotic diversification index;
H_{max} - the theoretical maximum rate of phytocenotic diversity;
Z - settlement rate;
N - total area of phytolittoral (ha);
P - the lake surface area.

Interpretation of the results

Until now ESMI index limit values have been determined only for stratified and non-stratified lakes with calcium-rich waters (Tab. 3).

Table 3. ESMI values defining water quality class according to the guidelines of the Minister of Environment of 2011

Ecological State*	Ordinanceof the Minister of Environment	
	Lower limit for ESMI values forstratified lakes	Lower limit for ESMI values for non-stratified lakes
High	0.68	0.68
Good	0.34	0.27
Moderate	0.17	0.11
Poor	0.09	0.05
Bad	<0.09	<0.05

*According tothe ordinanceof the Minister of Environment Journal of Laws of 2008. No. 162, pos. 1008

Classification of surface water according to the Ecological State Macrophyte Index is based on the biological indicator. It depends on many environmental and anthropogenic factors. That does not always facilitate interpretation of the data (Kłosowski & Kłosowski 2007). Therefore, during assessing the ecological status of lakes, next to biological elements such as phyto-plankton, phytobenthos, ichthyofauna, benthic macroinvertebrates and macrophytes, it is important to take into account the elements verifying the former (physicochemical), and, in the case of lakes, hydromorphological features (Soszka 2007, Kolada 2008). So:

- if the ESMI index value indicates good condition, but the participation of Charetea in phytolittoral is higher than 25% and higher than 3% in the Braun-Blanquet scale (in accordance with the agreed reference conditions), it is reasonable to increase the class by one level, that is, to a high water quality;

- when there is a situation that the value of the ESMI index indicates a state high or good, but more than 75% of phytolittoral take phytocenoses

of invasive species such as *Ceratophyllum demersum* or *Elodea canadensis*, it is reasonable to decrease the class by one level.

- if in the lake there are no submerged plants at all but only a well-developed reed, then regardless of the value of the ESMI index the lake should be classified to bad ecological status;

- if the value of the ESMI index indicates a poor or bad water status, and/or there are almost no macrophytes in the lake, but the physico-chemical parameters indicate a higher status of water quality and there is no identified pressure of anthropogenic origin in the catchment, it is time to acknowledge that macrophytes are inappropriate to assess the ecological status of the water ecosystem.

- a similar problem may also be noted in lakes where lake basin has extremely steep slopes (Kolada & Ciecierska 2009, Ciecierska & Dynowska 2013).

Conclusions

Individual indicators included in the Ecological State Macrophyte Index containing taxonomic composition and abundance of macrophytes as well as composite index clearly and directly react to anthropopressure, considered as its main but not the only sign is the process of eutrophication.

To assess the ecological status of lakes which are subjected to pressures other than accelerated eutrophication, ESMI method should not be used, because it is not sensitive to these pressures. Prof. Hanna Ciecierska claims that a similar problem, as, concerns lakes with the shape of the bottom which has an adverse impact on the expansion of macrophytes. Therefore the ESMI evaluation should be treated only as an estimate with the assumption that it can be changed, for example, after the conclusion of the conversion to the ESMI formula amendments involving lake basin shape.

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Streszczenie

W Polsce metoda oceny stanu ekologicznego jezior na podstawie makrofitów opracowana została na potrzeby rutynowego monitoringu wód w latach 2005–2006 na zlecenie ówczesnego Ministra Środowiska. Do procesu tego posłużyło 156 jezior. Zbiorniki zostały pogrupowane pod względem różnorodności roślinności oraz parametrów abiotycznych. Wśród nich wyodrębniono cztery grupy jezior makrofitowych: I – jeziora o wodach miękkich (lobeliowe), II – jeziora o wodach bogatych w wapń (ramienicowe głębokie), III – jeziora o wodach bogatych w wapń (ramienicowe płytkie), a także IV – jeziora łęczyńsko-włodawskie. Dla drugiego oraz trzeciego typu, odpowiednio jezior stratyfikowanych i niestratyfikowanych zaproponowano odrębną klasyfikację ocenianą za pomocą Makrofitowego Indeksu Stanu Ekologicznego. Podstawą jego opracowania była metoda makrofitoindykacji roślinności jezior rejonu Laski w Borach Tucholskich zaproponowana przez profesora Mariana Rejewskiego w latach 70. XX w, a udoskonalona w następnych latach przez profesor Hannę Ciecierską. Określała ona bioróżnorodność na poziomie zbiorowisk roślinnych fitolitoralu tworzonych przez makrofity.

Metoda ESMI obejmuje zarówno badania roślinności przeprowadzone w terenie z etapem przygotowawczym oraz część polegającą na wyliczaniu samych wskaźników makrofitowych. Indeks przyjmuje wartości od 0, obrazującego zły stan ekologiczny, do 1 odzwierciedlającego stan bardzo dobry. W trakcie wyliczania końcowego indeksu ESMI uwzględnia się parametry takie jak: różnorodność fitocenotyczna, maksymalna różnorodność fitocenotyczna, indeks kolonizacyjny, powierzchnia fitolitoralu obliczona jako suma powierzchni wszystkich zespołów roślinnych oraz powierzchnia samego jeziora.

Zarówno poszczególne wskaźniki wchodzące w skład ESMI uwzględniające skład taksonomiczny oraz obfitość makrofitów, jak i sam zespolony indeks, wyraźnie i w sposób kierunkowy reagują na antropopresję. Jako jej główny, ale nie jedyny przejaw przyjęto proces eutrofizacji, dlatego otrzymane wyniki klasyfikacji porównywano różnymi wskaźnikami trofii. Zatem, do oceny stanu ekologicznego jezior podlegających presjom innego typu niż przyśpieszona eutrofizacja, metoda ESMI nie powinna być wykorzystywana, ponieważ nie jest ona podatna na te presje. Podobny problem, jak zauważa profesor Hanna Ciecierska dotyczy jezior o niekorzystnym dla rozwoju makrofitów ukształtowaniu dna zbiornika. W związku z tym powinno potraktować się ocenę ESMI jako szacunkową z założeniem, iż może ona ulec zmianie, np. po zawarciu przeliczenia do wzoru ESMI poprawki na ukształtowanie misy jeziornej.