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Using macrophytes as trophic state indicators in upland river waters: a case study of the Czarna Maleniecka River

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Abstract

The study was conducted on the upper reach of the Czarna Maleniecka River from Furmanów to the ford at Piekło. Nine sampling sites were selected along this 20-km section. Detailed studies of flora and the physicochemical water parameters were performed in the 2004-2006 period. Data on macrophytes were collected with the Mean Trophic Rank (MTR) method. The results of physicochemical measurements were analyzed in reference to the water quality classification of the Polish Ministry of the Environment. Based on the results of these studies, the authors recommend adding two species, *Utricularia intermedia* and *Glyceria fluitans*, to the list of bioindicators.

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INTRODUCTION

The possibility of using macrophytes as indicators of the physicochemical state of river waters has been described previously in many publications (e.g., Dawson and Szoszkiewicz 1999, Thiebaut et al. 2002, Kohler&Schneider 2003). In many countries, tests are performed to choose indicatory plants and, based on them, to develop reliable methods of qualifying the degree of surface water eutrophication (Szoszkiewicz et al. 2006). Such studies are performed to meet the requirements of the binding Water Framework Directive (WFD) that requires using bioindicators to estimate the quality of flowing waters (European Commission, 2000).

The geographical range of species renders it impossible to adopt directly bioindication methods applied in other countries (Brik et al. 2006, Szoszkiewicz et al. 2006, Schneider 2007). Efforts to select indicatory taxa for Poland began on a wide scale in the late 1990s (Szoszkiewicz et al. 2002, 2005; Zbierska et al. 2002, 2004; Staniszewski 2001; Staniszewski et al. 2004). These studies, which utilized the British bioindication system known as Mean Trophic Rank (Holmes et al. 1999), were conducted mainly on lowland streams. The main aim of the present study was to verify the applicability of the MTR method to assess the trophic states of Polish upland rivers.

MATERIALS AND METHODS

The study was conducted on the upper reach of the Czarna Maleniecka River from Furmanów to the ford at Piekło. Nine sampling sites were chosen along this 20-km section (Table 1); each was representative of varying degrees of anthropogenic river-bed and river valley transformation. Detailed studies of the flora and measurements of physicochemical parameters were conducted in the 2004-2006 period.

Table 1

Description of sampling points

sampling point	kilometers from sources	place description
2	7.5	Furmanów – above the bridge
3	10.0	Niekłań Wielki – above the bridge
6	14.5	Błaszki – below the bridge
8	18.5	Stąporków – below the bridge for national road no. 42
9	20.0	Grzybów – above the wooden bridge for the Grzybów-Czarniecka Góra local road
10	22.5	below Czarniecka Góra, near the cemetery
11	24.0	Janów – 100 meters below the bridge
12	26.0	Wąsosz – 100 meters below the bridge
13	32.0	Piekło – above the ford for the Piekło-Miedzierza road

Data on macrophytes were collected using the MTR method (Holmes et al. 1999), by preparing a checklist of all the flora species regularly present in the water. The MTR system is based on establishing the presence and abundance of aquatic plants and determining their cover on a nine-grade scale (SCV – Species Cover Value) along 100-m river sections. A Species Trophic Rank (STR) ranging from 1 (eutrophic species) to 10 (species occurring in oligotrophic water only) is ascribed to particular species and to their habitat preferences (Holmes et al. 1999). Additionally, taxa proposed by Szoszkiewicz (Szoszkiewicz et al. 2002) were used to calculate MTR'. To calculate MTR'', the STR value was changed for four species proposed by Szoszkiewicz, and two more were added (Table 2). The final values of MTR, MTR', and MTR'' were calculated using the following formula:

$$MTR = \frac{\sum\left(STR \times SCV\right)}{\sum SCV} \times 10 \qquad (1)$$

where: *MTR* – Mean Trophic Rank, *STR* - Species Trophic Rank, *SCV* – Species Cover Value.

The data obtained concerning the flora were used to calculate other biological indexes, including the numbers of species, the Shannon diversity index (Shannon, Weaver 1949), and the Ellenberg index (2), based on Ellenberg nitrogen and acidity values for plants and calculated using the following formula:

$$EL = \frac{\sum(SCV \times EVP)}{\sum SCV} \qquad (2)$$

where: *EL* – Ellenberg index, *EVP* – Ellenberg values of plants (nitrogen and acidity). *SCV* – Species Cover Value.

The plant species nomenclature was taken from *A Checklist of the Flowering Plants and Pteridophytes of Poland* (Mirek et al. 2002), while the acidity and nitrogen values for species were based on Ellenberg (Lindacher 1995).

The quality of water in Czarna Maleniecka River was determined by evaluating the following parameters: temperature, odor, color, pH, conductivity, general and mineral acidity, general alkalinity, general hardness, chemical

Table 2

List of macrophytes noted in the Czarna Maleniecka River used in calculating the MTR, MTR' and MTR''

species name	STR	STR'	STR''	species name	STR	STR'	STR''
Acorus calamus L.	2	2	2	*Potamogeton natans* L.	5	5	5
Alisma plantago-aquatica L.	3	3	3	*Rorippa amphibia* (L.) Besser	3	3	3
Batrachium aquatile (L.) Dumotr.	5	5	5	*Rumex hydrolapathum* Huds.	3	3	3
Batrachium peltatum Schrank	4	4	4	*Sagittaria sagittifolia* L.	3	3	3
Carex acutiformis Ehrh.	3	3	3	*Schoenoplectus lacustris* (L.) Palla	3	3	3
Carex gracilis Curtis	5	5	5	*Sparganium erectum* L. Emand. Rchb.	3	3	3
Carex rostrata Stokes	7	7	7	*Sparganium emersum* Rehmann	3	3	3
Carex vesicaria L.	6	6	6	*Spirodela polyrrhiza* (L.) Schleid.	2	2	2
Ceratophyllum demersum L.	2	2	2	*Typha angustifolia* L.	2	2	2
Eleocharis palustris (L.) Roem.& Schult.	6	6	6	*Typha latifolia* L.	2	2	2
Elodea canadensis Michx.	5	5	5	*Callitriche cophocarpa* Sendtn.	-	5	5
Equisetum fluviatile L.	5	5	5	*Hottonia palustris* L.	-	5	5
Equisetum palustre L.	5	5	5	*Utricularia vulgaris* L.	-	6	7
Fontinalis antipyretica L.	5	5	5	*Oenathe aquatica* (L.) Poir.	-	3	4
Glyceria maxima (Hartm.) Holmb.	3	3	3	*Carex pseudocyperus* L.	-	5	4
Hydrocharis morsus-ranae L.	6	6	6	*Cicuta virosa* L.	-	5	4
Iris pseudacorus L.	5	5	5	*Utricularia intermedia* Hayne	-	-	10
Juncus bulbosus L.	10	10	10	*Glyceria fluitans* (L.) R.Br.	-	-	3
Lemna minor L.	4	4	4	*Calla palustris* L.	-	-	-
Lemna trisulca L.	4	4	4	*Mentha aquatica* L.	-	-	-
Menyanthes trifoliata L.	9	9	9	*Lycopus europaeus* L.	-	-	-
Nuphar lutea (L.) Sibth. & Sm.	3	3	3	*Lysimachia thyrsiflora* L.	-	-	-
Nymphaea alba L.	6	6	6	*Carex lasiocarpa* Ehrh.	-	-	-
Phragmites australis (Cav.) Trin. ex Steud.	4	4	4	*Scutellaria galericulata* L.	-	-	-
Potamogeton crispus L.	3	3	3	*Veronica beccabunga* L.	-	-	-
Potamogeton lucens L.	3	3	3				

oxygen demand (COD_{Mn}), ammonium ions, nitrate, nitrite, phosphates, dissolved oxygen, concentrations of metal ions such as calcium, magnesium, and iron. The water used in physicochemical analyses was sampled in spring, summer, and fall 2006, and all study procedures were performed according to Polish Standards (Hermanowicz et al. 1999). Spectrophotometric measurements of ammonium ions, nitrate, nitrite, phosphates, and iron were performed with a VIS Metertech SP830, and potentiometric measurements were taken with a Eurosensor ESAg - P-301WM combination electrode coupled with a TELEKO N - 5172 pH analyzer. Conductivity was analyzed using a TELEKO N -5772 conductometer with a HYDROMET CD-2 sensor. The results are discussed in reference to the water quality classifications of the Ministry of the Environment (2004).

The data collected were subjected to statistical analysis using the STATISTICA 6.0 software package (StatSoft, Inc. 2003). Firstly, numerical data conformity was tested with Gaussian distribution using Shapiro-Wilk's W-test (Shapiro et al. 1968). Then correlations between the values of the macrophyte index and chemical variables of water quality were tested using Pearson's correlation coefficient r.

RESULTS

The flora of Czarna Malenicka River valley is comprised of 51 species of aquatic macrophytes (Table 2). The number of species at one sampling site ranged from 15 to 32 at an average of 23.7. The mean value of the Shannon diversity index was 3.00 (SD 0.31). Small differences were noted in the acidity index based on Ellenberg numbers (average 6.56, SD 0.14). A greater range of values was observed in the second Ellenberg index, nitrogen abundance, at an average value of 6.03 (SD 0.20). The differences among MTR, MTR', and MTR'' at particular sampling sites was not considerable (maximum 5%) and change classification only for one sampling site (No. 6) into different eutrophication categories. In the three band system, sampling sites 8-12 located near Stąporków were classified as band IIb (advanced eutrophication), while the rest were band IIa (medium-degraded; Table 3). The average trophic index for MTR was 44.01 for MTR' – 44.67, while for MTR'' it was 44.71.

Table 3

Compression between water classification based on physicochemical parameters and macrophyte indexes

sampling station	MTR''		$N\text{-}NO_2$ [$mg \cdot dm^{-3}$]		BOD_5 [$mg \cdot dm^{-3}$]		PO_4 [$mg \cdot dm^{-3}$]	
	value	band[b]	value	class[a]	value	class[a]	value	class[a]
2	58.85	**IIa**	0.011	**I**	0.79	**I**	0.163	**I**
3	48.38	**IIa**	0.015	**I**	1.84	**I**	0.154	**I**
6	47.07	**IIa**	0.008	**I**	2.21	**II**	0.170	**I**
8	36.43	**IIb**	0.052	**II**	3.95	**III**	0.621	**III**
9	43.22	**IIb**	0.067	**II**	2.43	**II**	0.599	**III**
10	43.96	**IIb**	0.051	**II**	2.35	**II**	0.478	**III**
11	41.70	**IIb**	0.034	**II**	2.68	**II**	0.423	**III**
12	46.76	**IIa**	0.026	**I**	2.61	**II**	0.292	**II**
13	54.14	**IIa**	0.010	**I**	1.46	**I**	0.436	**III**

[a] - according to water quality classification by the Ministry of the Environment (2004);
[b] - band: IIa (45-65). IIb (25-45) (Holmes et al. 1999)

According to physicochemical measurements, the Czarna Maleniecka River was designated as class V water quality. The low final water classification (class V) was due to the low value of parameters such as color, ammonia nitrogen, and iron. These were related to each other and came from natural sources. Low concentrations of dissolved oxygen (water quality classes III and IV) were observed at the Czarna Maleniecka River measuring sites in Stąporków and below the city at stations 8, 9, and 10. At the same sites, there were higher concentrations (class III) of nitrate (III) and nitrites and phosphates (V).

The Shapiro-Wilk's W-test indicated that the variables were normally distributed. The analyses of correlations between the physicochemical parameters of water and the macrophyte indexes (Table 4) show that the number of species at the sampling sites and the Shannon diversity index were not considerable indicators of trophic state.

Table 4

Correlations between water classification based on physicochemical parameters and macrophyte indexes

Variable	Number of species	Shannon diversity index	Ellenberg plant index		MTR	MTR'	MTR''
			nitrogen	acidity			
PO_4 [mg·dm^{-3}]	0.4882	0.2191	0.6402	-0.0719	-0.6235	-0.5728	**-0.6529**[a]
N-NO_3 [mg·dm^{-3}]	0.0645	-0.2224	**0.7736**[a]	-0.4078	-0.3953	-0.4300	-0.5344
N-NO_2 [mg·dm^{-3}]	-0.5496	0.3252	0.5901	-0.0635	**-0.7231**[a]	**-0.6881**[a]	**-0.7311**[a]
N-NH_4 [mg·dm^{-3}]	0.6493	-0.3281	0.1433	-0.5549	0.2187	0.2465	0.1268
Temperature [°C]	0.6535	-0.0012	**0.8204**[b]	0.3506	**-0.7637**[a]	**-0.7883**[a]	**-0.7899**[a]
pH	0.1942	-0.3645	**0.8304**[b]	-0.1058	-0.4430	-0.4800	-0.5566
Dissolved oxygen [mg·dm^{-3}]	-0.2878	-0.4785	0.5194	-0.0697	-0.0122	-0.0838	-0.1487
Fe [mg·dm^{-3}]	0.1222	0.4772	-0.4456	0.3338	0.1068	0.1341	0.2147
BOD_5 [mg·dm^{-3}]	**0.7045**[a]	0.2890	**0.8288**[b]	0.4798	**-0.9493**[c]	**-0.9557**[c]	**-0.9563**[c]
Alkalinity [mmol·dm^{-3}]	0.5315	0.0060	**0.8338**[b]	-0.0297	**-0.7559**[a]	**-0.7514**[a]	**-0.8124**[b]
Acidity [mmol·dm^{-3}]	0.5391	**0.7721**[a]	-0.0353	0.2565	-0.4478	-0.3829	-0.3562
$CaCO_3$ [mg·dm^{-3}]	0.4588	-0.0871	0.8270[b]	-0.1132	**-0.6862**[a]	**-0.6889**[a]	**-0.7578**[a]
Ca [mg·dm^{-3}]	0.4378	-0.1324	0.8778[b]	-0.0956	-0.6505	-0.6596	**-0.7276**[a]
Mg [mg·dm^{-3}]	0.3460	0.1761	0.4336	-0.1466	-0.5384	-0.5082	-0.5490
Conductivity [µS·cm^{-3}]	0.4128	-0.1234	**0.8342**[b]	-0.1542	-0.6560	-0.6592	**-0.7356**[a]
COD_{Mn} [mg·dm^{-3}]	0.3318	0.3208	0.0031	-0.2577	-0.2504	-0.2135	-0.2216

[a]) $p<0.05$, n=9; [b]) $p<0.01$, n=9; [c]) $p<0.005$, n=9.
MTR – Mean Trophic Rank; MTR' – Mean Trophic Rank with corrections (Szoszkiewicz et al. 2002); MTR'' – Mean Trophic Rank with authors' corrections

Two indexes analyzed based on Ellenberg numbers showed that the nitrogen richness index had more significant correlations with more physicochemical water parameters. The MTR and the MTR' indexes had statistically significant correlations with the concentrations of half of the nutrient compounds. MTR'', improved by the authors, was correlated with most of the investigated water parameters, including nitrate concentration and pH.

DISCUSSION

Among the parameters analyzed, acidity and the MTR, MTR', and MTR'' indexes have considerable indicative characteristics. The value of the Mean Trophic Rank, calculated based on macrophytes, was, on average, lower than the mean value calculated for other Polish lowland rivers (Staniszewski 2001, Zbierska et al. 2004).

The analysis of physicochemical parameters indicated that water quality in the Czarna Maleniecka River was satisfactory in comparison with other rivers of the Świętokrzyskie area (http://www.kielce.pios.gov.pl). The majority of the tested parameters ranged from water quality class I to III in the upper river section. Significant water quality deterioration occurred in Stąporków, where the concentrations of a majority of nutrient parameters increased (classes III and IV). Chemical measurements carried out below Stąporków indicated that self-purification processes were functioning and water quality was improving in the Czarna Maleniecka River.

The results of nutrient determinations fully confirmed the conclusions drawn from the analysis of coefficients MTR, MTR', and MTR" (Table 4). The high correlation between all types of MTR and BOD_5 and nitrite (III) and phosphates (V) are the most important as it proves that this bioindication method is useful for estimating the trophic states of upland rivers in Poland. Moreover, correlations between MTR and MTR' with nutrient compound concentrations and other trophic coefficients are low. There is no relationship between MTR and concentrations of nitrate (V), nitrate, ammonia nitrogen, dissolved oxygen, which have been determined in lowland polish rivers (Szoszkiewicz et al. 2002; Zbierska et al. 2002, 2004) and same French rivers (Thiebaut et al. 2002). The correction introduced by the authors (MTR") increased correlation significance and revealed new relationships with nitrate (V) and pH.

Since the study was conducted only at nine sampling sites, the results are not necessarily representative of all Polish upland rivers. This means it is imperative to perform further studies to adapt the MTR method to upland river conditions. The list of 127 plant species published by British authors (Holmes et al. 1999) must be modified. Current Polish research is focused on enriching the original list of macrophytes with indigenous species that can replace indicator species that are not present in Polish flora. The results of the current studies indicate that two new species, *Utricularia intermedia* and *Glyceria fluitans*, can be added to the bioindicator list.

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