State of macrophytobenthic communities and ecological status of the Varna Bay, Varna lakes and Burgas Bay

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Abstract: Marine macrophytes absorb the biogenic elements with their surface directly from the marine environment and thus represent sensitive indicators of its changes. They are very important biological elements for estimation of the ecological status, because, growing in the nearest coastal zone, macrophytobenthic communities are the first to react to pollution from land sources. The aim of this paper is to estimate the present trophic level and to asses the ecological status according to the European Water Frame Directive. The operative solution of this problem is possible with the help of new, original and cost-effective expert approaches to the state of marine coastal zones, with a set of morpho-functional parameters.

The values of biomass, specific surface and Ecological Evaluation Index indicate a high level of eutrophication for the Varna Bay, Beloslav lakes, Treta Buna and Burgas Bay. They are classified as zones with a bad ecological status. It has been proved that concentrations of biogenic elements and phytoplankton blooming are higher in these zones. This fact just confirms the results obtained from macrophytobenthic metrics. The best values of the estimated metrics at Maslen Nos could be explained with the good ecological conditions in that zone and the absence of pollution sources close to that transect.

Key words: Ecological Evaluation Index, eutrophication; specific surface of macrophytes

Introduction

For the purposes of the EU Water Frame Directive, ecological water quality is an overall expression of the structure and function of a biological community, taking into account the geographical and climatic factors, as well as the physical and chemical conditions, including those resulting from human activities (Orfanidis & al. 2001). Coastal waters concentrating the greatest number of life forms and productivity are severely threatened by anthropogenic pressure. Management of these ecosystems requires a special approach that can assess the intensity of anthropogenic stress, or the ecological status.

Human activities in the last decades have greatly accelerated eutrophication by increasing the rate at which the nutrients and organic substances enter the aquatic ecosystem from the surrounding watersheds in the Varna and Burgas Bays (Rojdestvenski 1986, 1993; Stojanov 1991). These substances overstimulate the growth of algae, thus creating conditions that interfere with the recreational use of coastal ecosystems and the health of indigenous fish, plant and animal populations (Dencheva 1996; Moncheva & al. 2001; Prodanov & al. 2001; Stefanova & al. 2005). Degradation of biological structures of the ecosystem, with parallel worsening of the marine water quality decrease the resource value of the ecosystem, and affect recreation, fishing, hunting and aesthetic enjoyment. Health-related problems can occur too. Under such conditions plants are the first to react to the eutrophication factor. Ecologically, this results in decrease of biodiversity, substitution of some species with other filamentous and lamellar ones, with a shorter life cycle and high specific surface (Minicheva 1993).

The aim of this paper is to estimate the present trophic level and to asses the ecological status according to the European Water Frame Directive. The operative solution of this problem is possible with the help of new, original and cost-effective expert approaches to the state of the marine coastal zones, with complex of morpho-functional parameters.

Marine macrophytes absorb the biogenic elements directly with their entire surface from the marine environment and thus represent sensitive indicators of its changes. They are very important biological elements for estimation of the ecological status, because, growing in the nearest coastal zone, macrophytobenthic communities are the first to react to the pollution from land sources.

Material and methods

Nine transects were explored in the Varna Bay (Galata, Treta Buna, Trakata) Varna lake, Beloslav lake and the Larger Burgas Bay (Maslen Nos, Lesser Burgas Bay, Sveti Vlas) (Fig. 1).

Fig. 1. Map of investigated transects: **1**. Beloslav lake; **2-3**. Varna lake; **4-6**. Varna Bay (Galata-**4**; Treta Buna-**5**; Trakata-**6**); **7-9**. Larger Burgas Bay (Sveti Vlas-**7**; Lesser Burgas Bay-**8**; Maslen Nos-**9**).

Coordinates of the sampling sites were processed with JPS and are presented in Table 1.

A total of 257 samples were collected during the summer season in 2008 from the littoral zone, at a depth up to 5 m, with the help of a diving technique and according to the method of squares (Morozova-Vodianitskaya 1936). The method of hydrobotanical transects was used (Gutnik 1975).

For the purpose of WFD, some models for estimation of the ecological status were applied. One of them was proposed by Minicheva & al. (2003) and consisted of calculation of the specific surface of macrophytes, while the other is the Ecological Evaluation Index of Orfanidis & al. (2001), modified by us for the estimation of biomass percentage correlation between tolerant and sensitive species.

In the analysis of phytocoenoses, a set of new morpho-functional parameters of algae surface was used (Minicheva & al. 2003). Here is its essence put concisely:

The relationship between the specific surface (S/W) of macrophyte species and their photosynthetic rates and metabolic and catabolic plant processes is well known and proven in literature. Consequently, S/W is applied as a structure-functional characteristic of the species and provides information about the intensity of functioning of the species. The structure and functioning of the species composition depends on the eutrophication level. When the level of eutrophication is higher, the species with higher specific surface prevail. S/W is the correlation between the entire surface of the species and its biomass. This parameter is estimated by the method of Minicheva (1993) according to which the macrophyte species are divided into two basic groups: with lamellar and cylindrical type of structure. In the first group the specific surface (S/W) is proportional to the thickness of the thallus S/W = f(h), while for the cylindrical type correlation between S/W

Table 1. Coordinates of the investigated transects.

Transect	Coordinates	
Beloslav lake1	43°11.643' N	027°43.027' E
Varna lake 2	43°11.937' N	027°48.515' E
Varna lake3	43°11.135' N	027°50.217' E
Galata 4	43°10.245' N	027°56.607' E
Treta Buna 5	43°12.432' N	027°57.558' E
Trakata 6	43°13.114' N	027°58.826' E
Sveti Vlas 7	42°42.536' N	027°43.920' E
Lesser Burgas Bay 8	42°30.231' N	027°32.047' E
Maslen Nos 9	42°19.970' N	027°45.566' E

and the diameter of the plant is used S/W = f(d). The thickness, or diameter of the thalluses, is measured in microns by microscope, with the help of an eyepiece micrometer (250 measurements are needed for a reliable result). The specific surface of macrophytes is estimated in m^2/kg according to the above-mentioned formulae (Minicheva 1993). The parameters-specific surface of populations (S/Wp) gives an account not only of the species morphological peculiarities, but of the structure of their populations. In this method (Minicheva 1993) S/Wp is proposed for indirect functional assessment of populations. For a reliable estimation of S/W of the populations, the method comprises a preliminary calculated number of plants needed for processing.

Estimation of the Ecological Evaluation Index (EEI) of Orfanidis (2001) was modified and based on biomass estimation. The biomass percentage correlation was measured between the Ecological Status Group (ESG) II (tolerant species) and ESG I (sensitive species).

The sampling sites were chosen according to the criteria and aim of this paper. The Burgas and Varna Bays are the largest ports on the Bulgarian Black Sea Coast. They play a very important role in international communications and are economically valuable zones. That is why, monitoring and maintenance of a good ecological status is very important.

The Lesser Burgas Bay was regarded as transect with very bad conditions. It was well documented in literature that it is a very hazardous region because of the high concentrations of biogenic elements (phosphates and nitrates) and the low values of dissolved oxygen (Rojdestvenski 1986, 1993) and phytoplankton blooming (Atanasova & al. 1995).

The situation in the Varna Bay is similar. As reported in literature, the concentrations of nutrients and the intensity and frequency of phytoplankton blooming were higher at cape Galata (Stoianov 1991; Velikova & al.1999), which is related mainly to the impact of Varna and Beloslav lakes and the channel current entering the Bay (Stojanov 1991; Dencheva 1996; Moncheva & al. 2002; Doncheva & al. 2003).

Svety Vlas (the north part of Larger Burgas Bay) and Maslen Nos (the south part) are more distanced from the basic sources of pollution.

Results and discussion

From the investigated transects in the summer season of 2008 year, 32 species were established. Twelve species belonged to *Chlorophyta* type, four to *Phaeophyta* and 13 were from *Rhodophyta*. One angiosperm *Zostera noltii* was defined and two species from other groups. Nine species belonged to the sensitive group, or K-strategic, and 21 were tolerant, or r-strategic, belonging to the second ESG II, as defined by Orfanidis & al. (2001) (Table 2).

Figure 2 shows the biomass of macrophytobenthic communities from the investigated transects.

The lowest biomass was registered in Varna (270,4±50,7 $g.m^{-2}$; 375,8±44,7 $g.m^{-2}$) and Beloslav lakes (255,5±33,7 $g.m^{-2}$), which is explained by the high nutrient loads and pollution from industrial complexes near the lakes (Stojanov 1991; Moncheva & al. 2002; Doncheva & al. 2003). The highest biomass was registered at Maslen Nos (1207,5±179,3 $g.m^{-2}$), because that zone had the purest waters (Rojdestvenski 1993).

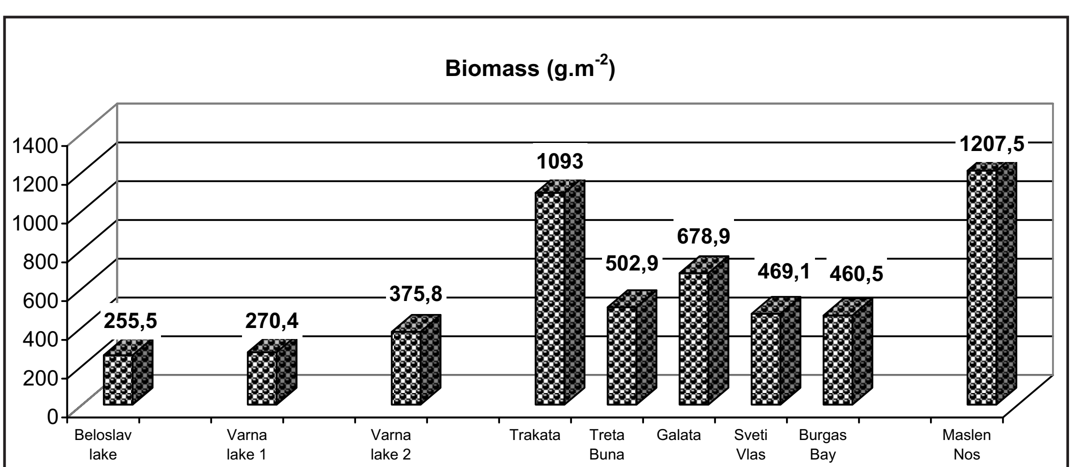

Fig. 2. Biomass of the macrophytobenthic communities ($g.m^{-2}$) from the investigated transects: **1**. Beloslav lake; **2**. Varna lake 1; **3**. Varna.

Table 2. Floristic structure of algae from the investigated transects and Ecological Status Groups (ESG): 1. Beloslav lake; 2. Varna lake 1; 3. Varna lake 2; 4. Galata; 5. Treta Buna; 6. Trakata; 7. Sveti Vlas; 8. Lesser Burgas Bay; 9. Maslen Nos.

Species	Sampling sites									ESG
	1	2	3	4	5	6	7	8	9	
Chlorophyta										
1. *Cladophora vagabunda* (L.) Hoek	+	+	+	+	+	+	+	+	+	II
2. *C. albida* (Nees) Kütz.				+						II
3. *C. coelothrix* Kütz.						+				II
4. *Ulva linza* L.					+	+				II
5. *U. intestinalis* L.	+	+	+	+	+	+	+	+	+	II
6.*U. prolifera* O.F. Müll.								+		II
7. *U. compressa* L.	+	+	+							II
8. *U. flexuosa* Wulfen					+	+				II
9. *U. rigida* C. Agardh			+	+	+	+	+	+	+	II
10. *Chaetomorpha linum* (O.F. Müll.) Kütz.							+		+	II
11. *Ch. ligustica* (Kütz.) Kütz.	+			+						II
12. *Ulothrix implexa* (Kütz.) Kütz.			+				+	+		II
Phaeophyta										
13. *Cystoseira barbata* (Stackh.) C. Agardh	+					+			+	I
14. *C. crinita* Duby	+					+	+		+	I
15. *Zanardinia prototypus* (Nardo) P.C. Silva	+								+	I
16. *Sphacelaria cirrosa* (Roth) C. Agardh									+	II
Rhodophyta										
17. *Ceramium rubrum* C. Agardh			+	+	+	+	+	+	+	II
18. *C. diaphanum* var. *elegans* (Roth) Roth				+	+	+				II
19. *Polysiphonia subulifera* (C. Agardh) Harvey							+		+	II
20. *P. denudata* (Dillwyn) Grev. ex Harv.					+		+			II
21. *P. elongata* (Huds.) Spreng.					+	+			+	I
22. *Corallina officinalis* L.	+				+				+	I
23. *Osmundea pinnatifida* (Huds.) Stackh.	+								+	I
24. *Callithamnion corymbosum* (Smith) Lyngb.				+	+		+			II
25. *Gelidium latifolium* Bornet ex Hauck	+								+	I
26. *G. crinale* (Hare ex Turner) Gaillon						+	+			II
27. *Goniotrichum* elegans (Chauv.) Zanardini					+	+				II
28. *Acrochaetium virgatulum* (Harv.) Batters	+		+	+	+		+	+		II
29. *Phyllophora crispa* (Huds.) P.S. Dixon									+	I
Anthophyta										
30. *Zostera noltii* Hornem.						+		+		I
Cyanobacteria										
31. *Calothrix aeruginea* (Kütz.) Thuret								+		
32. *Lyngbya majuscula* (Dillwyn) Harv.	+	+				+				
Bacillariophyta	+	+	+							

The higher biomass count in the Trakata transect (1093±117,8 g.m^{-2}) was due to the better ecological conditions in that zone, where the influence of lakes through channel waters is restricted (Stojanov 1991).

The next important index that characterizes the macrophytes as reliable indicators is the specific surface (S/W). Figure 3 shows that specific surface has the highest values in Beloslav (240,23±98,76 m^2.kg^{-1}) and Varna lakes (198,77±74,33 m^2.kg^{-1}; 206,89±99,63 m^2·kg^{-1}), followed by the investigated transect in the Lesser Burgas Bay (121,36±41,78 m^2.kg^{-1}), the southern part of the Larger Burgas Bay. The specific surface increases with the higher level of eutrophication. As the Lesser Burgas Bay and Varna and Beloslav lakes are the most polluted zones on the Bulgarian Black Sea coast (Stojanov 1991; Rojdestvenski 1993; Moncheva & al. 2002; Doncheva & al. 2003), the registered values of the specific surface are high. The lowest values of S/W (32,79±9,65 m^2.kg^{-1}) were recorded at the Maslen Nos transect.

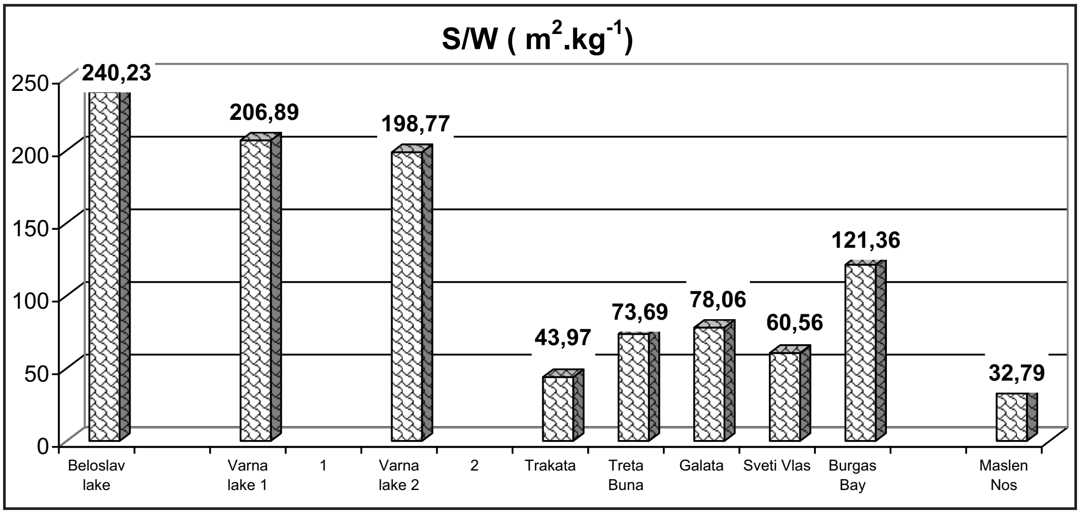

Fig. 3. Specific surface values (S/W) of the macrophytobenthic communities in the investigated transects.

The northern part of the Varna Bay (Trakata transect) has characteristically a lower degree of pollution (Stereva & al. 2004) than the southern one of Galata. That is the reason for the lower values of specific surface in the Trakata transect (43,97±15,01 $m^2.kg^{-1}$), than in Galata (78,06±32,28 $m^2.kg^{-1}$).

The higher values of the specific surface in Treta Buna transect (73,69±22,81 $m^2.kg^{-1}$) are probably due to the point sources of pollution and the high concentration of tourists in that zone.

The different boundaries of the ecological status classes developed for the Specific Surface Index on the Bulgarian Black Sea coast are presented in Table 3.

According to the boundary values of S/W defined for the different ecological status classes and presently estimated values, we can determine the following ecological status for the investigated transects (Table 4).

Beloslav lake, Varna lake and the Lesser Burgas Bay transects have characteristically poor ecological conditions, according to the calculated S/W values. According to S/W values, Treta Buna and Svety Vlas transects are classified as zones with moderate ecological conditions and Maslen Nos and Trakata zones are shown to be in a good state. The hydrochemical analysis of these zones has confirmed the results of the ecological status obtained from S/W values. Trakata, Ttreta Buna and Galata transects situated in the Varna Bay had different ecological status classes and S/W values. That was probably due to the local point sources of pollution and hydrophysical parameters.

Table 3. Boundaries of the Specific Surface Index (S/W).

	High	Good	Moderate	Poor	Bad
S/W	15 ≤ S/W < 25	25 ≤ S/W < 45	45 ≤ S/W < 75	75 ≤ S/W < 100	100 ≤ S/W

Figure 4 presents the percentage correlations of biomass between the macrophyte species from the two ecological status groups defined by Orfanidis & al. (2001).

The biomass percentage values of the sensitive species are high in the Maslen Nos transect (75 %), followed by those in Trakata (50 %) and Svety Vlas (45 %). The biomass percentage of sensitive taxons in these zones was mostly formed by the *Cystoseira crinita* species, a good indicator of pure waters. The lowest percentage values for the tolerant species were estimated at Maslen nos (25 %), Trakata (50 %) and Svety Vlas (55 %). The calculated values of the two ecological groups have indicated better ecological conditions in these regions. The highest biomass percentage values of the tolerant representatives was registered in Varna lake (100 %), Beloslav lake (100 %), and the Lesser Burgas Bay (100 %), followed by Treta Buna (10 %) and Galata (37 %). A total lack of biomass of any sensitive species in Varna, Beloslav lakes and the Lesser Burgas Bay indicated the high level of pollution in these zones, which was proved in literature (Rojdestvenski 1993).

Table 4. Ecological status based on the Specific Surface Index.

Transect	Values of the specific surface of macrophytes (S/W)	Ecological status
Maslen Nos	32.79	Good
Lesser Burgas Bay	121.36	Bad
Svety Vlas	60.56	Moderate
Galata	78.06	Poor
Treta Buna	73.69	Moderate
Trakata	43.97	Good
Varna lake 2	198.77	Bad
Varna lake 1	206.89	Bad
Beloslav lake	240.23	Bad

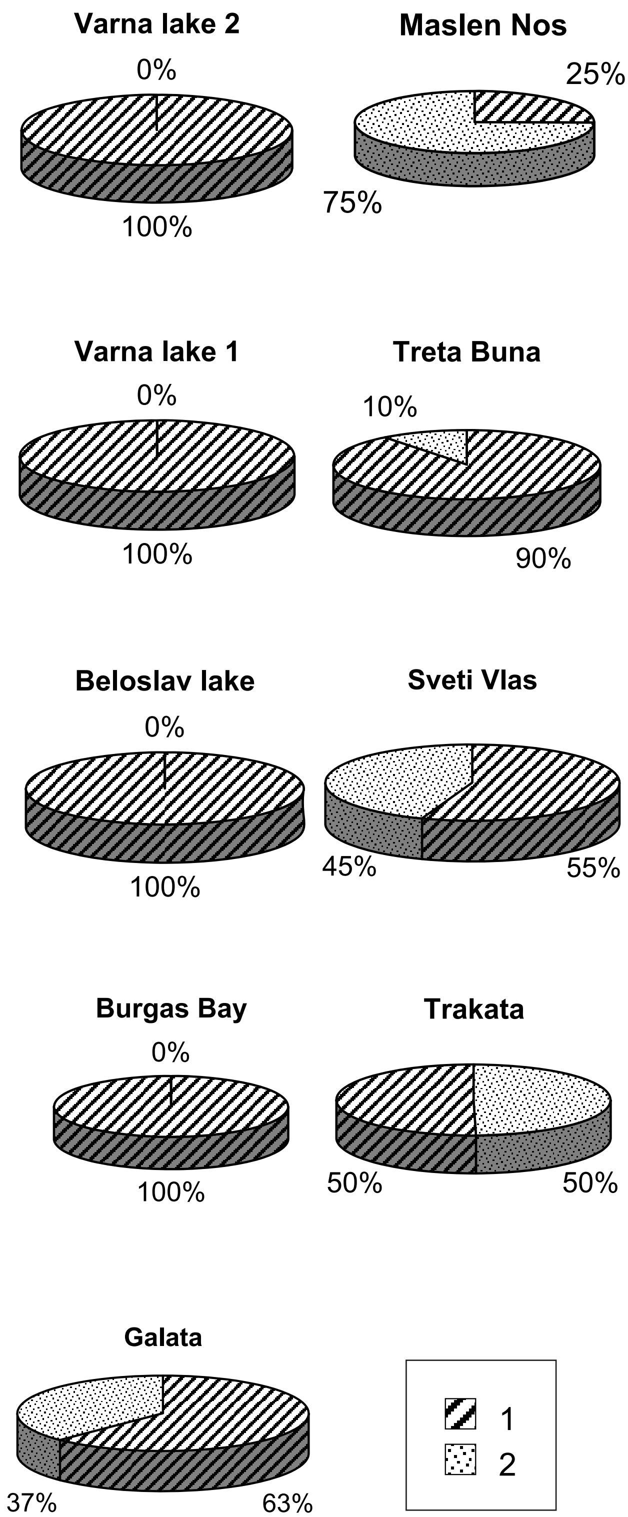

Fig. 4. Percentage correlation of biomass between the macrophyte species from the two ecological status groups, ESG I and ESG II: **1**. ESG II – biomass of tolerant species; **2**. ESGI – biomass of sensitive species.

Table 5 shows the values and boundaries of the ecological status classes of the Ecological Evaluation Index for the Bulgarian Black Sea coast accepted by the Bulgarian Basin Directorate.

According to these values defined for the ecological status classes, we can determine the following status of the investigated transects (Table 6).

Table 5. **Values and boundaries of the Ecological Evaluation Index (EEI) of the different ecological status classes.**

	High	Good	Moderate	Poor	Bad
EEI	10 ≥ EEI > 8	8 ≥ EEI > 6	6 ≥ EEI > 4	4 ≥ EEI > 2	2 ≥ EEI > 0

Table 6. **Ecological status based on the Ecological Evaluation Index (EEI) and correlation ratio of the biomass between the ecological status groups (%).**

Transect	Ecological evaluation index – EEI	Percentage correlation ratio of the biomass between the ecological status groups ESGI:ESGII (%)	Ecological status
Maslen Nos	7.5	75 : 25	Good
Lesser Burgas Bay	0	0 : 100	Bad
Svety Vlas	4.5	45 : 55	Moderate
Galata	3.7	37 : 63	Poor
Treta Buna	1	10 : 90	Bad
Trakata	5	50 : 50	Moderate
Varna lake 2	0	0 : 100	Bad
Varna lake 1	0	0 : 100	Bad
Beloslav lake	0	0 : 100	Bad

In agreement with EEI values, Maslen Nos was defined as transect with a good ecological status. This corresponded to the hydrochemical parameters in that zone (Rojdestvenski 1993) and the distance from basic sources of pollution. The same factors have determined the moderate status of Sveti Vlas and Trakata transects. The poor conditions in Varna lake, Beloslav lake, Treta Buna and the Lesser Burgas Bay have been confirmed by the hydrochemical parameters (nutrients, dissolved oxygen), status of the phytobenthic communities (high S/W values, and lowest values of EEI indices), and other biological elements (Stojanov 1991; Rojdestvenski 1993; Stefanova 2001; Moncheva & al. 2002; Doncheva & al. 2003).

In general, there is a good agreement between the assessments based on the different metrics (EEI and S/W) for all stations (Table 7).

The final ecological status based on the lower value of different metrics is presented in Table 8. Maslen Nos was determined as a zone in a good ecological sta-

Table 7. Comparison of the results of different metrics per transect.

Transect	Ecological evaluation index – EEI	Ecological status	Values of the specific surface of macrophytes (S/W)	Ecological status
Maslen Nos	7.5	Good	32.79	Good
Lesser Burgas Bay	0	Bad	121.36	Bad
Svety Vlas	4.5	Moderate	60.56	Moderate
Galata	3.7	Poor	78.06	Poor
Treta Buna	1	Bad	73.69	Moderate
Trakata	5	Moderate	43.97	Good
Varna lake 2	0	Bad	198.77	Bad
Varna lake 1	0	Bad	206.89	Bad
Beloslav lake	0	Bad	240.23	Bad

Table 8. Final ecological status based on macrophyte metrics.

	Transect	Final ecological status
Coastal waters	Maslen Nos	Good
	Lesser Burgas Bay	Bad
	Svety Vlas	Moderate
	Galata	Poor
	Treta Buna	Bad
	Trakata	Moderate
Coastal lakes (Varna)	Varna lake 1	Bad
	Varna lake 2	Bad
	Beloslav lake	Bad

tus class. The positive values of the estimated metrics at Maslen Nos are explained by the good ecological conditions in that zone and the absence of pollution sources close to that transect (Rojdestvenski 1986, 1993). The Sveti Vlas transect was put in the moderate ecological status class.

Urbanisation, tourism, coastal protection constructions, and shipping possibly add significant pressure and worsen the ecological status of the coastal waters in the Varna Bay. Three ecological status classes were established for the Varna Bay. The difference was due to the intensity of action and distance from the point sources of pollution.

As bodies at risk, Varna and Beloslav lakes and the Lesser Burgas Bay have characteristically poor ecological conditions on the basis of the lack of sensitive species, high specific surface values and low EEI values.

Conclusions

From the analysis above, it became clear that Varna and Beloslav lakes and the Lesser Burgas Bay are zones with the worst ecological conditions owing to:

- very high specific surface values;
- lack of species sensitive to pollution, with high specific surface and very short life cycle (microphytes are important in lakes);
- very low biomass; and
- reduced depth (due to a very low transparency and a high level of eutrophication and phytoplankton blooming (Rojdestvenski 1986; Stojanov1991; Velikova & al. 1999).

The most positive values of the estimated metrics (highest biomass volume, lowest specific surface, highest EEI volume, highest percentage of biomass of the sensitive species) at Maslen Nos are explained by the good ecological conditions in that zone and the absence of sources of pollution close to that transect (Rojdestvenski 1986, 1993).

Varna Bay, the adjacent lakes, and the Burgas Bay are characteristically water bodies at risk and special attention should be paid to them, so as to develop adequate measures for restoration of these ecosystems.

The models for estimation of the ecological status classes based on the morpho-functional groups are more reliable and sensitive (Orfanidis & al. 2001; Minicheva & al. 2003) than those which use structural characteristics of the communities and allow express assessment of any environmental conditions. The specific surface of macrophytes is a very sensitive metric and allows a more sensitive and precise grading of the poor ecological status class and the benefit of microphytobenthic communities particularly important in the transitional and modified water bodies. The results obtained for Varna and Beloslav lakes have proved that the values of these metrics indicate over three times higher eutrophication than in the Varna Bay and twice higher eutrophication than in the Burgas Bay.

These initial monitoring results will help decision-makers in undertaking relevant action for the improvement of ecological conditions.

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