Influence of the anthropogenic stress on macrophytobenthic communities

Kristina H. Dencheva

Institute of Oceanology, Bulgarian Academy of Sciences, PO Box 152, 9000 Varna, Bulgaria, e-mail: dencheva@io-bas.bg

Received: July 24, 2008 ⊳ Accepted: November 05, 2008

Abstract. As a biological quality element from the Water Frame Directive, macrophytes, are strongly indicative of the negative changes in the marine coastal ecosystem, because they directly penetrate the biogenic elements with their surface and react to influence from the land. The aim of this paper is to estimate with the help of macrophytobenthos the state of coastal ecosystems and to differentiate them into the corresponding ecological status classes as accorded in the Water Frame Directive. The final results obtained by the new approach of application of morpho-functional parameters have revealed a good status in the southern part of the Bulgarian Black Sea Coast, from Maslen Nos to Sinemorets, and a bad status in the Burgas Bay.

Key words: active surface parameters, Ecological Evaluation Index, ecological status classes, eutrophication, macrophytobenthos, Water Frame Directive

---

Introduction

For the purposes of the European Water Frame Directive, ecological water quality is an overall expression of the structure and function of the biological community, taking into account the geographical and climatic factors, as well as the physical and chemical conditions, including those, resulting from human activities. The coastal waters that concentrate most life forms and productivity are severely threatened by the anthropogenic pressure. The management of these ecosystems requires a special approach that could assess the intensity of anthropogenic stress or the ecological status. However, it is often difficult to diagnose the ecological status because of spatial and temporal variability in the community features resulting from changes in the physical and chemical parameters (Orfanidis & al. 2001). This problem could be solved by studying the communities from a functional viewpoint (groups of functionally similar species). When estimating the specific surface of macrophytes, the same approach is used (Minicheva & al. 2003). The species are differentiated into morpho-functional forms. At a functional level, communities appear to be much more temporally stable and predictable than when examined at the species level (Steneck & Walting 1982; Steneck & Dethier 1994). For example, anthropogenic stress shifts the community structure towards dominance of opportunistic species (Borowitzka 1972; Regier & Cowell 1972). The same tendency is obvious when the species diversity of communities is represented by numerical series with enhanced ecological resistance (specific surface). Species with low coefficients of specific surface are at the beginning of the series. The characteristics of these seaweeds are large vulnerable forms with a long life cycle and slow growth. At the end of the series are small, quick-growing and productive species, with a short life cycle. During eutrophication of the aquatic system, the rate of metabolic processes increases. Biological structure begins to change. Species at the beginning of the series of ecological resistance disappear and are replaced by species at the end of the series. That is why under heavy eutrophication a sharp decrease in biodiversity occurs. This mechanism explains the reasons why in the past decades the species diversity has been reduced and the size and structure of biological communities has changed (Minicheva 1993). Littler& Littler have proposed a functional–form model. This model was tested and verified experimentally: the functional characteristics of plants, such as photosynthesis and nutrient uptake are related to morphology and surface area: volume (weight) ratios (Littler & Littler 1984; Minicheva & al. 2003). Marine macrophytes penetrate the biogenic elements directly with their surface from the marine environment and are sensitive indicators of its changes. A reliable signal of increasing eutrophication is the replacement of late successional, perennial seaweeds like *Cystoseira* spp., Fucus and *Phyllophora* spp. (with low values of specific surface of 5 to 10 $m^2.kg^{-1}$) by such opportunistic species with higher specific surface like *Ulva* spp., *Enteromorpha* spp., *Ceramium, Polysiphonia* spp. (Kukk 1979; Trey & al. 1987; Harlin 1995; Shramm & Nienhuis 1996; Shramm 1999).

For the purposes of WFD, some models for estimation of the ecological status were applied. One of them was proposed by Minicheva 2003 and deals with the specific surface; the other is modified by Orfanidis & al. (2001) and is based on estimation of the biomass percentage correlation between tolerant and sensitive species.

Material and methods

Seven transects were explored, two in the northern part of the Bulgarian Black Sea Coast (namely at Shabla, Byala Laguna) and five transects in the southern part: Kraimorie (Burgas Bay), Chernomorets, Varvara, Ropotamo and Sinemorets (Fig. 1).

Samples were taken by the method of squares and scuba diving technique (Morozova-Vodianitskaija 1936). The method of hydrobotanical transects was used (Kalugina-Gutnik 1975). On rocky and gently sloping natural shores formed by hard ores or sediments, in layers from supra- to lower sublittoral, *the method of linear transects* or *cuts* was applied. Cuts were laid perpendicular to the relief of shores towards the sea. Using the natural borders of growth of the characteristic associations of macrophytes, the layers in the cut were defined for sampling. The following layers were selected: [+1 m – 0 m]; [0 m – 0.5 m]; [0.5 m – 1.5 m]; [1.5 m – 3.0 m]; [3.0 m – 5.0 m]. In each layer at 10–15 meters, aside from the conditional line of the cut, visual evaluation of the phytocoenoses was made. Percentage of the projected bottom coverage of macrophytes was determined. Information was recorded under water by a diver, on special plastic plates. Depending on the structure of phytocoenoses and heterogeneity of the spatial distribution of macrophytes on each of the layers, 3–10 frames of quantitative accounting were made.

Coordinates of sample sites were determined with GPS. Two hundred and fifty-seven quantitative samples were analyzed from the littoral, up to 5 m deep.

The species structure was established with the help of Zinova (1967) and Dimitrova-Konaklieva's (2000) guide books. The biomass was calculated in wet weight, in $g.m^{-2}$.

The sampling sites were chosen by the following criteria. Burgas Bay was expected to be the transect with very bad conditions. It is well documented in literature that this region is very hazardous because of the high concentrations of biogenic ele-

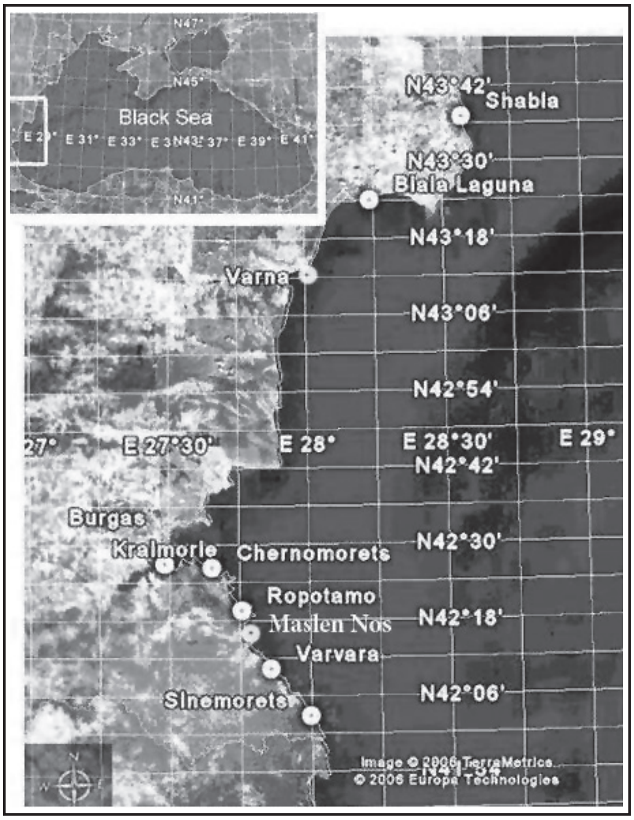

Fig. 1. Map of the investigated transects: 1. Maslen Nos; 2. Sinemorets; 3. Varvara; 4. Ropotamo; 5. Chernomorets; 6. Kraimorie (Burgas Bay); 7. Varna Bay; 8. Byala Laguna; 9. Shabla.

ments (phosphates and nitrates) and the low values of dissolved oxigen (Rojdestvenskij 1986, 1993) and phytoplancton blooms (Atanasova & al. 1995). Varvara and Sinemorets transects were chosen as sites in very good condition, owing to their hydrochemical parameters (Rojdestvenskij 1986). A higher biodiversity of macrophyte species – 102 sp. (Dimitrova-Konaklieva 1978, 2000) was established in that region, and high biomass of the olygosaprobic indicator *Cystoseira barbata* (Petrova-Karadzhova 1975) was estimated. The Ropotamo transect was chosen for the established high biomass (2414 $g.m^{-2}$) of *Zostera marina* and *Zostera noltii* (Petrova-Karadzhova 1982). The other transects were expected to have in-between ecological status among the others. The reference conditions were estimated according to the parameters of specific surface and biomass of the phytocoenoses and the biomass of *Cystoseira* spp. The bay near Maslen Nos was chosen because of its undisturbed conditions and lack of human activity. Conditions were close to pristine there. The samples from the Maslen Nos transect were taken in 1995, in summer. Samples from Varna Bay were taken in 2002, in summer, and were included to complete the ecological status classes.

The Ecological Evaluation Index (EEI) proposed by Orfanidis & al. (2001) was calculated, but modified on the basis of algae biomass assessment. The biomass percentage correlation between ESG II group (tolerant species) and Ecological Status Group I – ESG I (sensitive species) was measured. EEI ranged from 2 to 10, indicating the overall ecological status of marine waters.

Index **A** was applied too. Index A = log S + {(sens – toller.)/(sens + toller.), where S is the number of species. This index was proposed by the Norwegian Institute for Water Research, (Lyche Solheim & al. 2004).

A set of new morpho-functional parameters of the algae surface was employed in the phytocoenotic analysis, as described by Minicheva & al. (2003), based on relationship between the specific surface ratio (S/W) of the macrophyte species and their photosynthetic rates, metabolic and catabolic processes (Haylov & Parchevskij 1983; Firsov 1984). Initially, the structure and functioning of the species composition depended on the eutrophication level: a high eutrophication level is associated with species of higher specific surface. The S/W ratio [m^2/kg] was estimated according to Minicheva (1993), by dividing the macrophytes into two major structural types: lamellar and cylindrical. For the lamellar type, the specific surface (S/W) was proportional to the thickness of the thallus S/W = f(h), while for the cylindrical type, correlation between S/W and the diameter of the plant is established S/W = f(d). The diameters and thickness of thalluses were measured with the help of a microscope, and S/W was calculated with the above-mentioned formulae.

The complete strategy in macrophyte investigations (field and laboratory) was the guide complied by Minicheva (2003) proposed to the Black Sea Commission.

So far the specific surface for the Bulgarian Black Sea Coast was predominantly studied in the Varna Bay (Dencheva 2006).

Results

Thirty-two species were established at the investigated transects in the summer of 2006 (including Maslen Nos and Varna Bay). Of these, 13 species belong to the *Chlorophyta*, six to *Phaeophyta* and ten were from *Rhodophyta*. One angiosperm (*Zostera noltii*) was found and two species from other groups. Ten species belonged to sensitive, or **k**-strategies (ESG I), and 20 were tolerant or **r**-strategies, or belonged to the second Ecological Status Group – ESG II as defined by Orfanidis & al. (2001), (Table 1). Species from *Bacillariophyta* and *Cyanobacteria* were not included in the ESG groups because of their insignificant biomass.

Index **A** was estimated on the basis of the species structure (Table 2). The highest index was established for Maslen Nos (1.31) and the lowest for the Burgas Bay.

Figure 2 shows the biomass percentage correlations between the two ecological status groups for the investigated transects.

Evidently, the value of tolerant species is the lowest at Maslen Nos (9 %) and the highest in the Burgas Bay (100 %). The transects have been arranged according to the model of Orfanidis & al. (2001): the high ecological status class is at Maslen Nos, followed by Varvara, Shabla, Sinemorets, and Byala Laguna. Chernomorets is in good condition. Varna Bay is rated in the moderate ecological status class. Ropotamo is in a bad and Burgas Bay is in a very bad condition.

Table 1. Species structure and ecological status groups of macrophytes from the investigated transects: 1. Maslen Nos; 2. Sinemorets; 3. Varvara; 4. Ropotamo; 5. Chernomorets; 6. Kraimorie (Burgas Bay); 7. Varna Bay; 8. Byala Laguna; 9. Shabla.

Species	Sample sites									ESG
	1	2	3	4	5	6	7	8	9	
Chlorophyta										
1. *Cladophora vagabunda* (L) Van Hoek			+	+		+		+	+	II
2. *Cladophora vadorum* (Aresch.) Kütz.		+	+		+					II
3. *Cladophora albida* (Nees) Kütz.									+	II
4. *Cladophora coelothrix* Kütz.		+					+			II
5. *Ulva linza* L.							+			II
6. *Ulva intestinalis* L.			+				+	+	+	II
7. *Ulva prolifera* O.F. Müller						+		+		II
8. *Ulva flexuosa* Wulfen	+						+			II
9. *Chaetomorpha linum* (O.F. Müll.) Kütz.		+	+					+	+	II
10. *Chaetomorpha ligustica* (Kütz.) Kütz.					+		+			II
11. *Ulva rigida* C. Agardh	+	+	+		+		+	+	+	II
12. *Rhizoclonium riparium* (Roth) Harv.						+			+	II
13. *Ulothrix implexa* (Kütz.) Kütz.							+			II
Phaeophyta										
14. *Cystoseira barbata* (Stackh.) C. Agardh	+	+	+		+			+	+	I
15. *Cystoseira crinita* Duby	+	+	+		+		+	+	+	I
16. *Ralfsia verrucosa* (Aresch.) Aresch.		+			+					I
17. *Zanardinia prototypes (*Nardo) Nardo	+									I
18. *Feldmania irregularis* (Kütz.) Hamel				+						II
19. *Sphacelaria cirrhosa* (Roth) C. Agardh		+								II
Rhodophyta										
20. *Ceramium rubrum* C. Agardh		+	+		+		+	+	+	II
21. *Ceramium diaphanum* var. *elegans* (Roth) Roth	+	+	+				+			II
22. *Polysiphonia subulifera* (C. Agardh) Harv.		+	+							II
23. *Corallina officinalis* L.	+	+	+		+		+		+	I
24. *Osmundea pinnatifida* (Huds.) Stackh.	+	+	+							I
25. *Callithamnion corymbosum* (Smith) Lyngb.							+			II
26. *Gelidium latifolium* Bornet ex Hauck	+	+	+		+		+	+		I
27. *G. crinale* (Hare ex Turner) Gailon		+	+		+					II
28. *Nemalion helminthoides* (Velley) Batters	+									I
29. *Phyllophora crispa* (Huds.) P.S. Dixon	+									I
Magnoliophyta										
30. *Zostera noltii* Hornem.				+				+		I
Cyanbacteria										
31. *Lyngbya confervoides* C. Agardh ex Gomont						+	+			
Bacillariophyta										
32. *Berkeleya rutilans* (Trentep. ex Roth) Grunov							+			

Table 2. Values of Index A.
1. Maslen Nos; 2. Sinemorets; 3.Varvara; 4. Ropotamo; 5. Chernomorets; 6. Kraimorie (Burgas Bay); 7. Varna Bay; 8. Byala Laguna; 9. Shabla.

Index A	1	2	3	4	5	6	7	8	9
	1.31	0.95	1.00	0.14	1	–0.4	0.86	0.75	0.6

Figure 3 presents the average values of phytocoenose biomass in the investigated transects. The highest biomass is estimated at Maslen Nos and Byala Laguna (3457.9 and 3696,2 g.m^{-2}). These transects are in a very good condition in terms of the biomass. The lowest values are registered at Ropotamo, Burgas Bay and Varna Bay.

Figure 4 shows the average values of the specific surface of macrophytes. The lowest value of the specific surface is calculated at Maslen Nos (15.8 m^2.kg^{-1}). The highest is characteristic of the Burgas Bay (120 m^2.kg^{-1}), followed by the Ropotamo transect.

Table 3 shows the values of specific surface and the borders of these values for different ecological status classes. The referent value is 15 m^2.kg^{-1}.The ecological status classes, according to the specific surface, are the following: Maslen Nos – high, Varvara, Sinemorets, Chernomorets, and Byala Laguna – good. Shabla and Varna Bay have moderate ecological status, Burgas Bay and Ropotamo have a bad status.

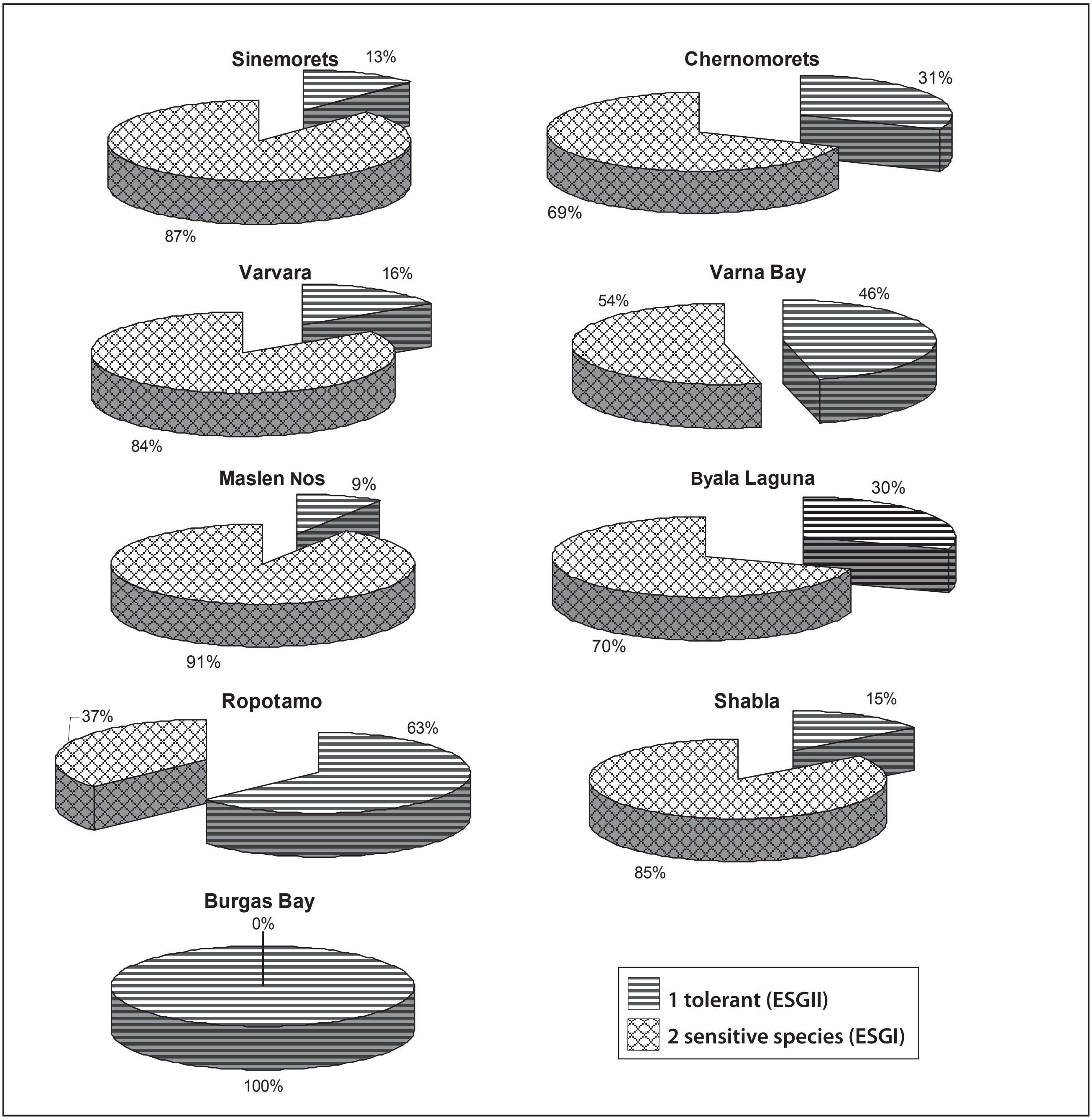

Fig. 2. Biomass percnetahe correlation between two ecological status groups – tolerant and sensitive species – from the investigated transects.

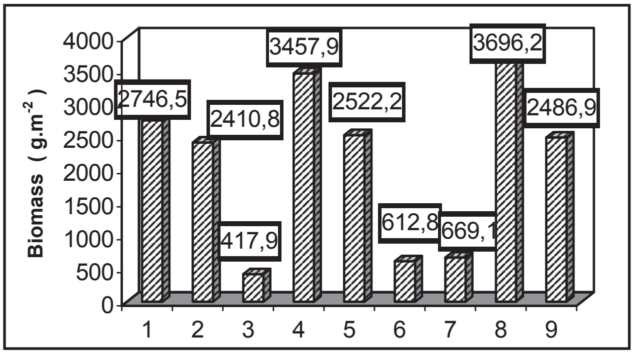

Fig. 3. Average biomass values from the investigated transects: 1. Sinemorets; 2. Varvara; 3. Ropotamo; 4. Maslen Nos; 5. Chernomorets; 6. Burgas Bay; 7. Varna Bay; 8. Byala Laguna; 9. Shabla.

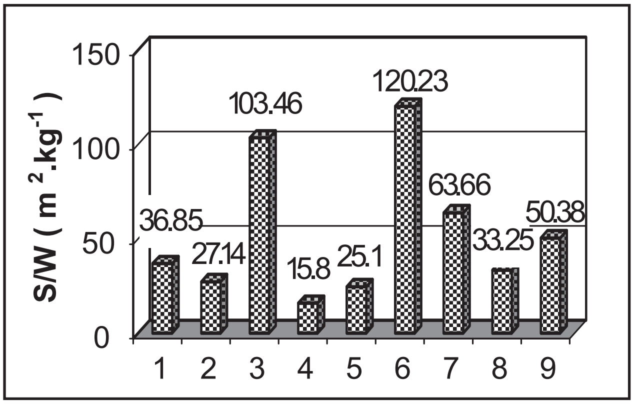

Fig. 4. Average specific surface values of the macropytobenthic communities from the investigated transects: 1. Sinemorets; 2. Varvara; 3. Ropotamo; 4. Maslen Nos; 5. Chernomorets; 6. Burgas Bay; 7. Varna Bay; 8. Byala Laguna; 9. Shabla.

Table 3. Values of the specific surface for different ecological status classes.

Indicator	Ecological state classes				
	(high)	(good)	(moderate)	(poor)	(bad)
	I	II	III	IV	V
	Hard substrate				
S/W	15–25 m^2/kg	25–45 m^2/kg	45–75 m^2/kg	75–100 m^2/kg	>100 m^2/kg

Conclusions

The models for estimation of the ecological status classes based on morpho–functional groups are more reliable and sensitive (Orfanidis & al. 2001; Minicheva & al. 2003) than those using the structural characteristics of the communities, and allow express assessment of any environmental conditions. Furthermore, the method of estimation of the specific surface index, allows a more sensitive and precise grading of the bad ecological status class and of the benefit of microphytobenthic communities, which is important, especially in transitional waters and modified water bodies.

These initial results are the first stage of future monitoring, that will help decision-makers to solve problems related to the restriction of contaminants inflow from land and to the improvement of recreation conditions and aesthetical view of our beautiful seaside.

Acknowledgements. The author is indebted to the unknown reviewer for the valuable critical comments and should pay special attention in next publications.

References

Atanasova, B., Velikova, V. & Manasieva S. 1995. Dynamics of abiothic factors and structure of planctocoenosis in the Burgas Bay. – Izv. Inst. Ribni Resursi (Varna), **23**: 80-108 (in Bulgarian).

Borowitzka, M.A. 1972. Intertidal algal species diversity and the effects of pollution. – Austral. J. Mar. Freshwater Res., **25**: 73-84.

Dencheva, K. 2006. Macrophytobenthic coenoses as indicators of the eutrophication level in the Varna Bay (Bulgarian Black Sea Coast). – Phytol. Balcan., **12**(3): 339-343.

Dimitrova-Konaklieva, S.1978.Geografical analysis of marine algae of the Black Sea in Achtopol region. – Fitologiya, **18:** 22-35 (in Bulgarian).

Firsov, K. 1984. Hierarchic structure – functional analysis of marine multicellular algae *Cystoseira barbata*. *PhD Thesis*. Inst. Biol. S Seas, Sevastopol (in Russian, unpubl.).

Dimitrova-Konaklieva, S. 2000. Marine Algae of Bulgaria (*Rhodophyta*, *Phaeophyta*, *Chlorophyta*). Pensoft, Sofia (in Bulgarian).

Harlin, M.M. 1995. Changes in major plant groups following nutrient enrichment. – In: **McComb, A.J.** (ed.), Eutrophic Shallow Estuaries and Lagoons. Pp. 173-187. CRC Press, Murdoch.

Haylov, M. & Parchevskij, N. 1983. Hierarhic Regulation of Marine Plants Structure and Function. Naukova Dumka, Kiev (in Russian).

Kalugina-Gutnik, A. 1975. Phytobenthos of the Black Sea. Naukova Dumka, Kiev (in Russian).

Kukk, H.A. 1979. Phytobenthic successions of the Gulf of Finland. – In: Abstracts. Third Conf. Algology – Macrophytobenthos. Pp. 83-84. Naukova Dumka, Kiev.

Littler, M.M. & Littler, D.S.1984. Relationships between macroalgal functional form groups and substrata stability in a subtropical rocky intertidal system. – J. Exp. Mar. Biol. Ecol., **74**: 13-34.

Lyche Solheim, A., Andersen, T., Brettum, P., Bækken, T., Bongard, T., Moy, F., Kroglund, T., Olsgard, F., Rygg, B.

& Oug, E. 2004. Report 4860. – In: **Lyche Solheim**, **A**. (ed.), BIOKLASS – Classification of Ecological Status in Norwegian Water Bodies: Relevant Criteria and Possible Boundary Values between Good and Moderate Ecological Status for Selected Elements and Pressures. Norwegian Inst. water Research (in Norwegian).

Minicheva, G. 1993. Structure-functional peculiarities of macrophytobenthic communities formation. – Algologiya, **3**(1): 3-12 (in Russian).

Minicheva, G., Zotov, B. & Kosenko, M. 2003. Methodical Recommendations for the Morpho-Functional Indexes Definition for Unicellular and Multicellular Forms of Aquatic Vegetation. NASU, Odessa.

Morozova-Vodianitskaja, N. 1936. Quantitative assessment of benthic plants in the Black Sea. – Trudy Sevastopol'sk. Biol. Stantsii, **5**: 133-139 (in Russian).

Orfanidis, S, Panayotidis, P. & Stamatis, N. 2001. Ecological evaluation of transitional and coastal waters: A marine benthic macrophytes-based model. – Medit. Mar. Sci., **2**(2): 45-65.

Petrova-Karadzhova, V. 1975. Quantitative distribution and resources of the brown algae *Cystoseira barbata* (Good et Wood) Ag. at the Bulgarian Black Sea Coast. – Izv. Inst. Ribni Resursi (Varna), **14**: 100-135 (in Bulgarian).

Petrova-Karadzhova, V. 1982. Distribution and stocks of sea grasses *Zostera marina* L. and *Zostera nana* L. along the Bulgarian Black Sea coast. – Izv. Inst. Ribni Resursi (Varna), **19**: 91-97 (in Bulgarian).

Regier, H.A & Cowell, E.B. 1972. Application of ecosystem theory, succession, diversity, stability, stress and conservation. – Biol. Conservation, **4**(2): 83-88.

Rojdestvenskij, A. 1986. Hydrochemistry of the Bulgarian Sector of the Black Sea. Publishing House Bulg. Acad. Sci., Sofia.

Rojdestvenskij, A. 1993. Anthropogenic influence of the hydrochemical regime of the Bulgarian Black Sea sector. – In: Third Sci. Conf. Reports. Ecology, Economic and Living Environment of Black Sea Region. Pp. 6-11. Union of Scientist, Varna (in Bulgarian).

Schramm, W. 1999. Factors influencing seaweed responses to eutrophication: some results from EU-project EUMAC. – J. Appl. Phycol., **11**(1): 69-78.

Schramm, W. & Nienhuis, P.H. (eds).1996. Marine Benthic Vegetation: Recent Changes and the Effects of Eutrophication. Ecological Studies 123. Springer-Verlag, Berlin, Heidelberg.

Steneck, R. & Dethier, M.N. 1994. A functional group approach to the structure of alga-dominated communities. – Oikos ,**69**(3): 476-498.

Steneck, R.S. & Walting, L. 1982. Feeding capabilities and lamination of herbivorous mollusks: A functional group approach. – Mar. Biol., **68**: 299-319.

Trey, T., Kukk H. & Kukk, E. 1987. Phytobenthos as an Indicator of the Degree of Pollution in the Gulf of Finland and in the Neighbouring Sea Areas. Meri, Helsinki.

Zinova, A. 1967. Guidebook of the Green, Brown and Red Algae of the Southern Seas of USSR. Nauka, Moskva (in Russian).