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Estimating the possibility of mediterranization of the marine flora of the Black Sea – a morphofunctional approach

Galina G. Minicheva

Odessa Branch Institute of Biology of Southern Seas, National Academy of Sciences of Ukraine

Abstract

A comparative assessment of the ecological activity of phytoplankton and phytobenthos in the northwestern Black Sea (NWBS) and the Mediterranean Basin is made with the help of morphofunctional analysis. It shows that the mean specific surface S/W values which illustrate the intensity of the participation of vegetative populations in the primary-production process for NWBS macrophytes are twice higher than for the Mediterranean Basin. For highly functional phytoplankton algae, average S/W values for NWBS communities are at least 30% higher than for Mediterranean. The factors forming a barrier for penetration of Mediterranean species into the NWBS have been ranked as follows: 1st factor – level of nutrients; 2nd – salinity; 3rd – temperature and 4th – stream of solar energy on the water surface. A high level of salinity and temperature is also a significant barrier. A potential pattern for possible macrophyte aliens penetration has been created for a mediterranization scenario of the NWBS. It includes a high ecological activity (S/W – 30–100 $m^2 kg^{-1}$), cold-loving species tolerant to low salinity (up to 12 ‰), tolerating significant salinity and temperature fluctuations. *Desmarestia viridis* is an exotic species for the Adriatic Sea. In the early 1990s it entered the NWBS and became the dominant winter phytocoenosis. The biological features of this macrophyte correspond to the pattern of potential aliens entering the NWBS.

Methodology of the morphofunctional approach

The founders of the morphofunctional ecology of seaweeds are Diana and Mark Littler, American researchers of the Department of Botany of the National Museum of Natural History in Washington who initiated these studies in the late 1970s. They demonstrated the relation between the morphological form and productivity of macrophyte algae in the Caribbean basin based on the functional form of macrophytes (Littler and Littler, 1980). Meanwhile the morphofunctional approach was being developed at the Institute of Biology of Southern Seas, National Academy of Sciences of Ukraine in Sevastopol, under the guidance of Dr. Kirill Khailov. The Sevastopol school studies metabolic processes as a regulation mechanism of the morphological form of macrophytes (Khailov and Parchevsky, 1983). The main objective of the morphofunctional approach for the Odessa school (Department of Morphofunctional Ecology of Aquatic Vegetation of the OB IBSS, headed by the author) is to obtain a wider possibility for evaluating phytobenthos and phytoplankton with the help of indices of active algal surfaces (Minicheva, 1998).

Methodology of morphofunctional approach of estimation of water vegetation underlies a holistic approach. The main idea is that quantitative dependence exists between morphological parameters of aquatic vegetation and abiotic factors influencing the production process. For example, if there is an increase in nutrients in the ecosystem, small thinly branched filamentous algae will replace a large forms with thick laminated thallus. The principal methodical achievement of the morphofunctional approach is that the morphofunctional structure of the species, which is expressed in the specific surface (S/W), serves as its ecological activity (EA) coefficient. That index illustrates the intensity of the primary production process for species with different morphological structure. The EA of marine flora expressed quantitatively is one of the paths of solving the issue of ecological identification of biological diversity (Table 1).

Table 1. Stages in biological and ecological identification of species diversity.

Species diversity	**System of binary nomenclature** (K.Linnaeus, 1761)	**Theory of «r» and «k» selection** (P. MacArthur, E. Wilson., 1967)	**Coefficient of ecological activity of species** (G. Minicheva, 1990)
•	*Spirulina tenuissima*	r - species	1200
⅄	*Oscillatoria viridis*	r - species	424
✦	*Kylinia virgatula*	r - species	270
★	*Pilaiella littoralis*	r - species	140
✶	*Urospora penicilliformis*	r - species	110
✸	*Cladophora albida*	r - species	85
✹	*Polysiphonia denudata*	k - species	56
❈	*Ceramium elegans*	k - species	26
●	*Cystoseira barbata*	k - species	9
❁	*Fucus serratus*	k - species	3

The concept of EA of species is useful to understand how the floristic structure of aquatic vegetation reacts to changes in the fluxes of matter and energy passing through the ecosystem. For example under high nutrient input, only those species with a high EA will remain in the community structure. Therefore, in a eutrophic ecosystem the seaweeds with the highest S/W values (small, short cycle, thinly branched species) will dominate. Vice versa the species with lower S/W values (large, perennial forms with a thick thallus) will be inhibited and will be the first to disappear from the structure of plant communities.

For practical application of the morphofunctional approach when studying aquatic vegetation, the estimation algorithms of the indices based on parameters of the active surface of unicellular and multicellular algae have been elaborated (Minicheva *et al.*, 2003). The main indices are:

- Population specific surface (S/W)p – gives the area of the surface through which the population to carry out metabolism with the aquatic environment ($m^2.kg^{-1}$), used for estimating the EA of species with a difference morphological structure;
- Community surface index SIcm – reflects the area of the vegetation developing per square meter of sea bottom (for phytobenthos – unit) or per a cubic meter of the water column (for phytoplankton – m^{-1}), used for estimating the intensity of the production process in ecosystems of different trophic status.

Possibilities of the morphofunctional approach:

- On the basis of the morphological portrait of aquatic vegetation it is possible, to compare the EA of the autotrophic link and the trophic status of ecosystems with different floristic composition (Minicheva, 1996; 1998a). In 2004 in Odessa an international workshop (Black Sea Ecosystem Recovery Project) was conducted where the methods of evaluating the trophic status were passed on to participants of six Black Sea riparian states. A unified evaluation was carried out for assessing the comparative state of eutrophication along the Black Sea coast.
- Using the numerical EA species coefficients it is possible to predict changes in the floristic composition and in the structural-functional organization of communities of benthic vegetation during changes in the trophic status of the ecosystem. It is quite possible in the new conditions to determine species which may become potential alien species or perspective resources. For the northwestern Black Sea the time necessary for restoring the *Cystoseira* and *Phyllophora* communities that were degraded under eutrophication, the corridors of EA for possible alien species and the potential resource species for creating processing technology has been determined (Minicheva, 1990; 1993; 1996; 2007b).
- Using the morphofunctional parameters it is possible to describe quantitatively the response of the phytobenthos community and phytoplankton to **local** (coastal hydrotechnical constructions, recreation, discharges, etc.), **regional** (changes in water quality in the aquatic basin) and **global** (climatic) influence of factors. The optimum exposure of phyto-overgrowths on coastal hydrotechnical constructions for restoring water quality in the coastal zones with a high anthropogenic load has been revealed. The potentiel force of response of autotrophic communities to climatic changes has been also determined. The high stability of communities of coastal macrophytes and phytoplankton in the northwestern Black Sea to possible fluctuations of climatic factors is also shown (Minicheva, 2005; 2006; Minicheva *et al.*, 2008b).

Comparative analysis of factors of the Black and Mediterranean Seas production processes

The variability of both geographical-climatic and anthropogenic factors influence the development of the floristic structure, biomass, production characteristics and morphological portrait of the vegetation. To compare the window of conditions in which the flora of the Black and Mediterranean seas develops, the mean values and variability of temperature, light, salinity and nutrients in different areas were analyzed (Figure 1). The mean values and variability (oscillation coefficient, VR, %) of these factors were estimated according to published data (Marine Atlas of the Atlantic and Indian oceans, 1950-1966; Mediterranean Targeted Project II, 1997-1998) and statistical methods (Vasnev, 2001). A preliminary comparative analysis of different areas of the Mediterranean-Black Sea basin showed the following laws governing the production processes:

- the smallest difference of mean values and oscillation between Black and Mediterranean Seas was noted for light (stream of solar energy) (see Figure 1a);
- the northwestern Black Sea (NWBS) is the coldest for comparative areas, with a 3 fold higher oscillation of sea water temperature (see Figure 1b);
- the salinity is 2 fold lower of the Black Sea in contrast to the Mediterranean. In its northwestern part which receives the runoff of three large European rivers (Danube, Dniester, Dnieper) the oscillation is on two orders higher than in the Mediterranean (see Figure 1c);
- in the NWBS the level of nutrients is 6-7 fold higher, but the oscillation, related not only to geographical and climatic factors but also to biological processes, is similar for both (see Figure 1d).

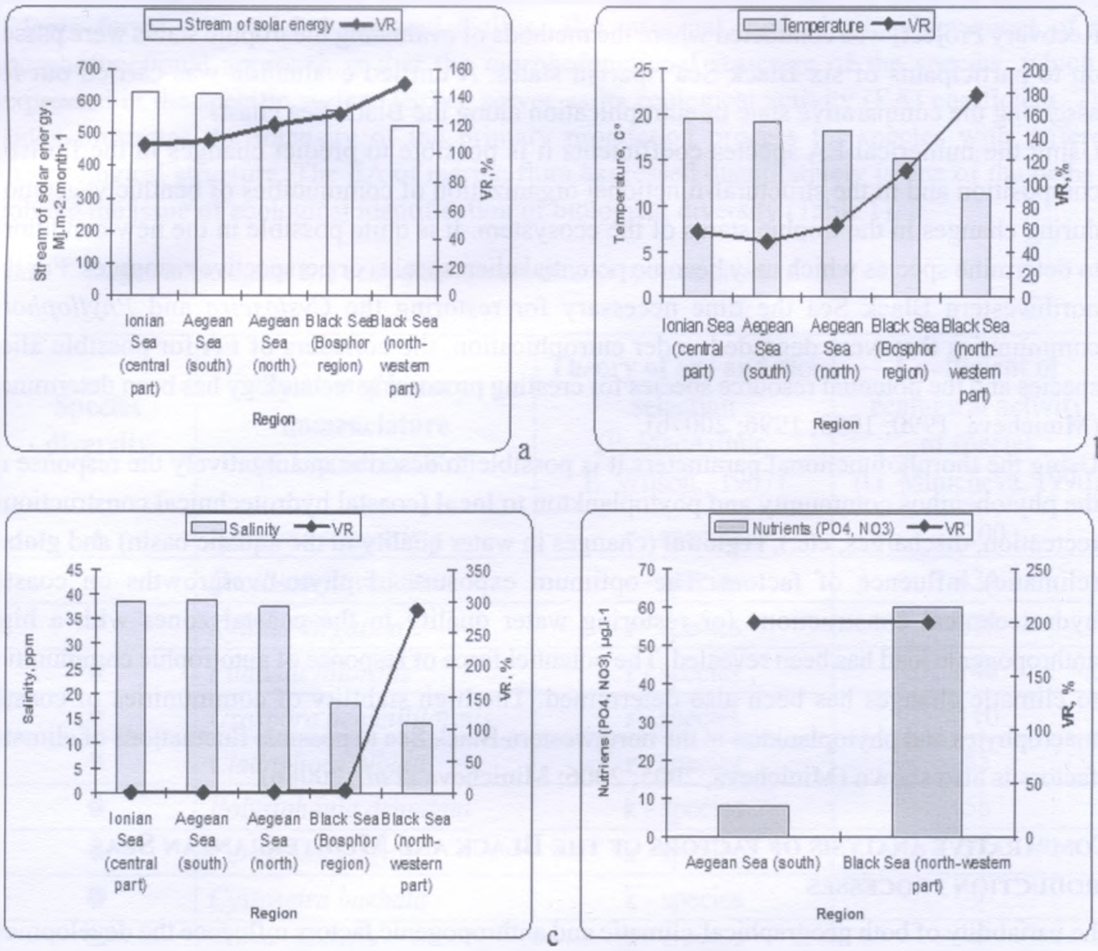

Figure 1. Comparative analysis of mean values and oscillation (VR) of factors determining the development of vegetation in different parts of the Mediterranean and Black Seas basins.

These relations allow to make a ranking of factors determining the corridors of conditions of development of aquatic vegetation in both basins and the possibility of mediterranization or vice versa "pontization" (Pontus Euxinus, ancient name of Black Sea) of the marine flora. For determining the ratios of mean values and oscillation of factors influencing the aquatic vegetation, the southern Aegean Sea and the northwestern Black Sea were selected. The first factor determining the barrier of penetration of Mediterranean vegetation into the NWBS is a significantly higher level of nutrients (1:7,5). The second factor – a lower salinity (2,7:1) and third – a lower temperature (1,7:1) (Figure 2). The mean values of the stream of solar energy on the water surface are almost similar for both areas (1,2 :1) (see Figure 2). In this way it is possible that during mediterranization of the NWBS, small, short cycled, thinly branched (high S/W values) cold loving algal species of the Mediterranean Basin, tolerant to low salinity (up to 12‰), can enter the NWBS.

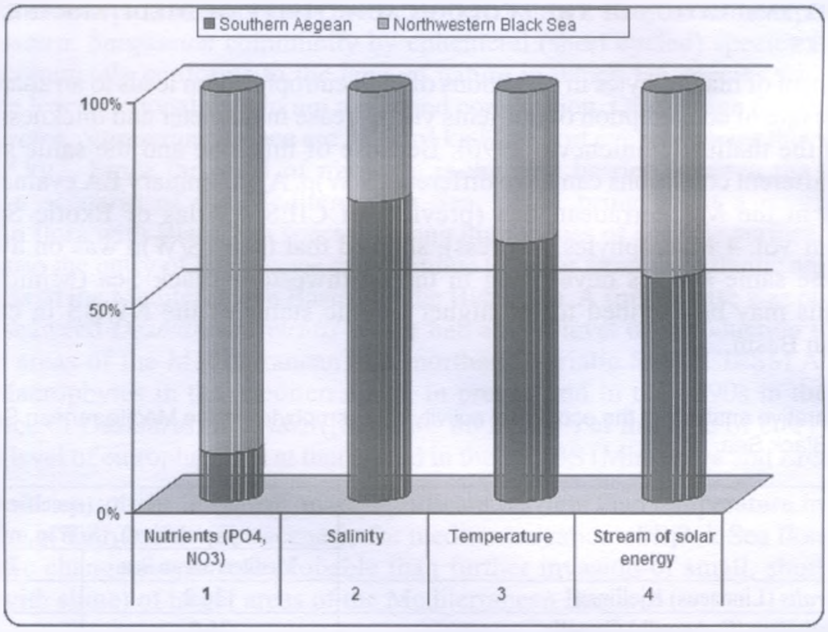

Figure 2. Ratio of average values of abiotic factors for the southern Aegean Sea and northwestern Black Sea.

The degree of oscillation of factors for developing vegetative communities is as significant as their mean values (Minicheva *et al.*, 2008b). On degree of oscillation the salinity is the first factor for determining the entry of new species in the NWBS – 1:572 (Figure 3). The ratio of temperature oscillation in the southern Aegean Sea and NWBS is 1:3,6. In the northwestern area the fluctuations of light on the water surface and of nutrients are not much higher than in the Aegean Sea (see Figure 3). A mediterranization scenario for the aquatic vegetation of the northern Black Sea, can only involve species sustaining low levels of salinity and temperature and with a very high tolerance to salinity and temperature oscillations.

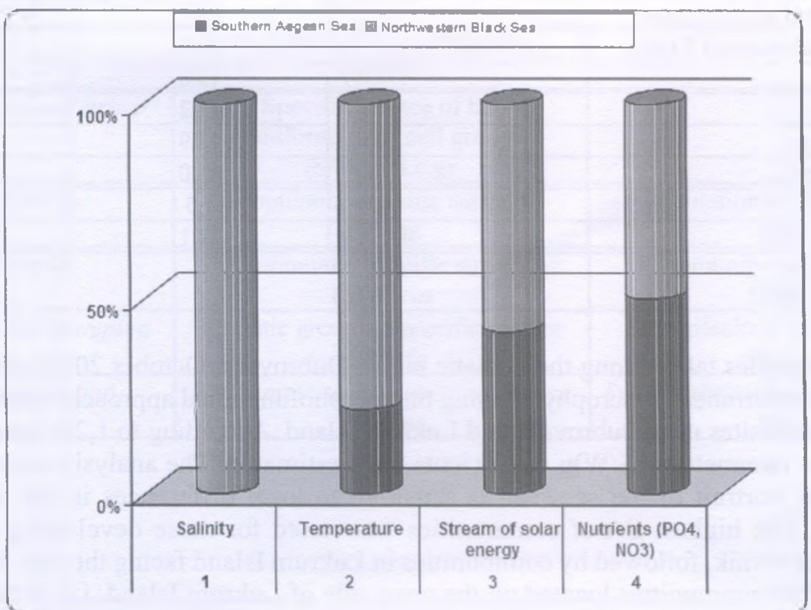

Figure 3. Ratio of oscillation coefficients (VR) of abiotic factors for the southern Aegean Sea and the northwestern Black Sea.

PRELIMINARY EVALUATION OF THE ECOLOGICAL ACTIVITY OF MEDITERRANEAN MACROPHYTES

The development of macrophytes in conditions of high eutrophication leads to an adaptive response increasing the rate of consumption of nutrients via decrease in diameter and thickness of laminated structures of the thallus (Minicheva, 1996). Because of this, one and the same species which develops in different conditions can have different (S/W)p. A preliminary EA evaluation of exotic macrophytes in the Mediterranean Sea (preview of CIESM Atlas of Exotic Species in the Mediterranean Vol. 4 Macrophytes, in press), showed that their (S/W)p was on average 5-25% lower than the same species developing in the northwestern Black Sea (Minicheva, 1998b) (Table 2). This may be ascribed to the higher trophic status of the NWBS in contrast to the Mediterranean Basin.

Table 2. Comparative analysis of the ecological activity of macrophytes in the Mediterranean Sea and species inhabiting the Black Sea.

Species	Ecological activity (specific surface of population), (S/W)p, $m^2.kg^{-1}$	
	Mediterranean Sea	Black Sea
Pylaiella littoralis (Linnaeus) Kjellman	136,2	157,5
Punctaria tenuissima (C. Agardh) Greville	25,0	22,7
Desmarestia viridis (O.F. Müller) J.V. Lamouroux	72,7	78,0
Padina sp.	18,0	19,4
Ectocarpus siliculosus var. *hiemalis* (P.L. Crouan & H.M. Crouan) Foslie	187,9	178,9
Scytosiphon dotyi M.J. Wynne	11,1	27,04
Acrochaetium sp.	404,5	496,2
Porphyra yezoensis Ueda	55,0	63,1
Antithamnion sp.	92,6	116,2
Ceramium sp.	25,0	26,0
Apoglossum gregarium (E.Y. Dawson) M.J. Wynne	26,2	28,9
Gracilaria arcuata Zanardini	11,2	14,4
Grateloupia sp.	6,2	8,2
Hypnea sp.	6,0	17,9
Nemalion vermiculare Suringar	5,04	4,6
Lomentaria hakodatensis Yendo	10,9	9,3
Chondria sp.	13,8	28,6
Laurencia sp.	11,2	13,9
Polysiphonia sp.	17,9	60,0
Cladophora sp.	45,0	47,8
Codium sp.	7,5	8,5
Ulva sp.	21,1	36,3

Macrophyte samples taken along the Adriatic coast (Dubrovnik, October 2003) allowed the first analysis of Mediterranean macrophytes using the morphofunctional approach. Macrophytes were sampled at seven sites near Dubrovnik and Lukrum Island. According to 1,200 measurements of morphological parameters, (S/W)p coefficients were estimated. The analysis confirmed that the morphological portrait of the seaweed is sensitive to local differences in the conditions for development. The highest EA of communities was noted for those developing on the public beaches of Dubrovnik, followed by communities in Lukrum Island facing the city. The lowest EA was observed in communities located on the open side of Lukrum Island, i.e. in its cleaner area which was less subject to anthropogenic eutrophication.

According to preliminary evaluation the functional activity of NWBS macrophytes communities exceeds more than twice that of the Adriatic Sea. This is due to the higher level of eutrophication.

Similarly, recent eutrophication episodes in the northern Adriatic Sea, led to the replacement of the *Fucus, Cystoseira, Sargassum* community by ephemeral (short cycled) species (Munda, 1993; 2008). This completely conforms to the laws of nature in which EA species with high (S/W)p values replace low functional that do not withstand competition. On average the species of genus *Fucus, Cystoseira, Sargassum* surface are 3-12 $m^2.kg^{-1}$. In short cycled species this value may rise to 50-150 $m^2.kg^{-1}$. Since the level of nutrients is the first barrier between the two basins, a eutrophication scenario of the Mediterranean Sea, could bring about a pontization of the Mediterranean flora with Black Sea species having high values of specific surface. According to another scenario the entry of EA species can continue to occur from the Atlantic and Indo-Pacific in trophic areas of the Mediterranean Basin and the Black Sea. A similar case was observed for the alien brown seaweed *Desmarestia viridis* which had a high level of introduction in the northern most trophic areas of the Mediterranean Sea (northern Adriatic Sea) (CIESM Atlas of Exotic Species of Macrophytes in the Mediterranean, in press), and in the 1990s in the NWBS. The specific surface of *Desmarestia viridis* ((S/W)p = 80 $m^2.kg^{-1}$) at the time of entry corresponded ideally to the level of eutrophication at that period in the NWBS (Minicheva and Eremenko, 1993).

The level of nutrients and salinity are more significant barriers than temperature in the exchange of marine flora of both basins. The scenario for mediterranization of Black Sea flora as a result of global climatic change seems less probable than further invasion of small, short cycled algae (overgrown with slime) of larger areas of the Mediterranean Basin.

The preliminary comparative analysis of the phytoplankton structure of the Black and Mediterranean Seas

The elaboration of a number of phytoplankton indices of active surfaces allows to apply the morphofunctional approach to communities of planktonic algae (see Table 3) (Zotov, 2006). Depending on the dimensions and the geometric form of the cell, each taxonomic section of phytoplankton has a certain EA value. The sequence of EA of phytoplankton is started by dinophytes and ended by blue-green algae with maximum values of specific surface of the taxonomic section – (S/W)ts (Figure 4).

Table 3. Morphofunctional indices of phytoplankton.

Organization level	**Specific surface index**	**Surface index**
Cell	Specific surface of the cell **(S/W)c**	-
Uniform-sized cell group	Specific surface of the uniform-sized cell group **(S/W)uni.c.gr**	-
Population	Population specific surface **(S/W)p**	Population surface index **SIp**
Community	Community specific surface **(S/W)cm**	Community surface index **SIcm**
Region floristic grouping	Floristic grouping specific surface **(S/W)fg**	Phytoplankton surface index **SIphp**
Taxonomic section	Taxonomic section specific surface **(S/W)ts**	Taxonomic section surface index **SIts**

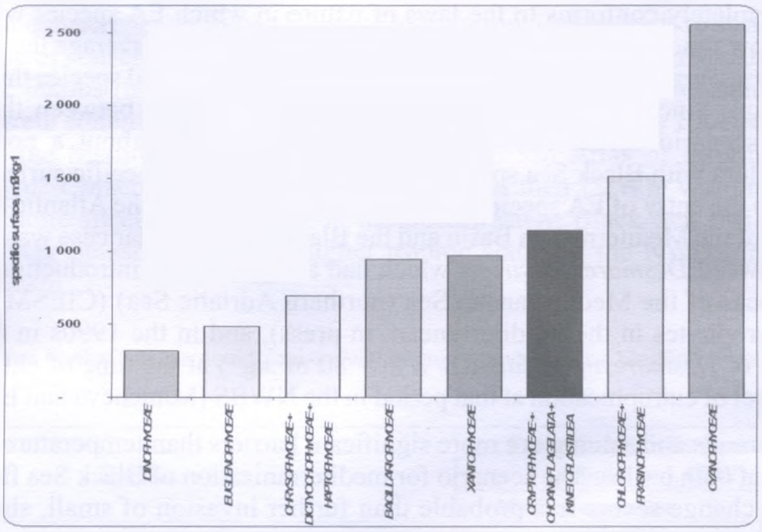

Figure 4. Main phytoplankton taxa arranged by EA.

Comparing the taxonomic structure of the phytoplankton of the northwestern Black Sea and the Mediterranean reveals a significant similarity of species diversity - 629 and 643, respectively, and of taxonomic structure (Zotov, 2006; Vadrucci *et al.*, 2007) (Figure 5).

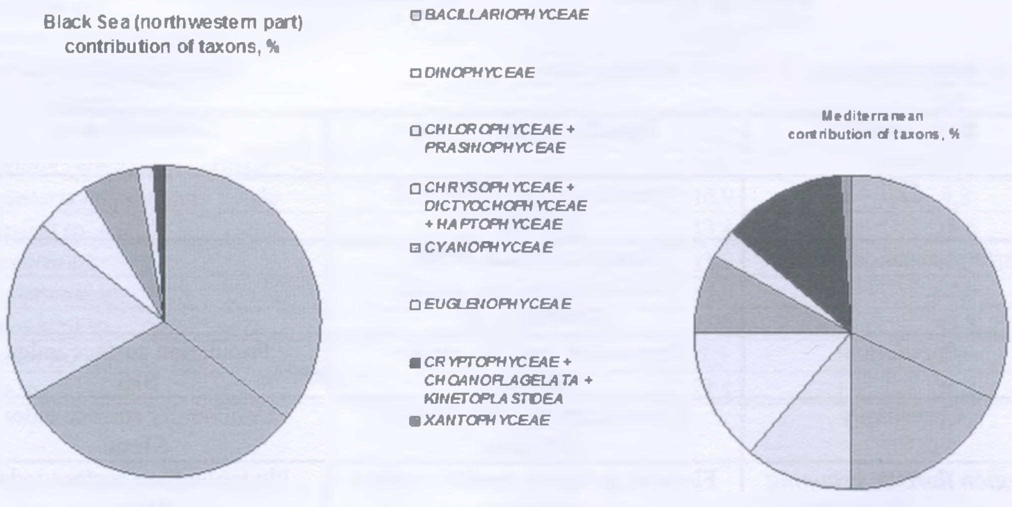

Figure 5. Comparative analysis of the taxonomic structure of the NWBS and Mediterranean phytoplankton.

When comparing the integral EA of phytoplankton of the two areas, considering the percentage contribution of each taxonomic section and average (S/W)ts value, then the laws governing the morphofunctional differences are linked with the conditions of the habitat (Figure 6). The NWBS has a more simple community structure. The first three taxonomic groups (*Bacillariophycea, Dinophycea, Chlorophycea*) make up 84% of all cells, and the cells average S/W value makes up 926,6 $m^2.kg^{-1}$. In the Mediterranean area, the taxonomic structure is smoother (see Figure 6). The same three dominating groups (*Bacillariophycea, Dinophycea, Chlorophycea*) make up 61%, with a mean S/W value of 652,5 $m^2.kg^{-1}$.

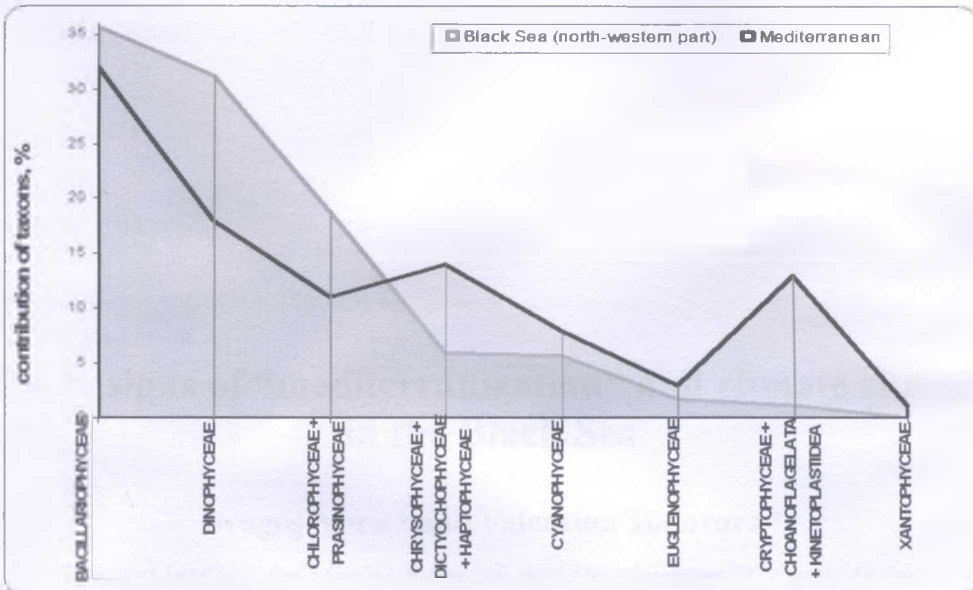

Figure 6. Comparative analysis of NWBS and Mediterranean phytoplankton EA.

The life form phytoplankton (unicellular algae) has an EA a few magnitudes greater than phytobenthos (macrophytes). Preliminary evaluation has shown that the functional activity of NWBS macrophytes more than twice exceeds that of the Mediterranean Basin (Adriatic Sea). For phytoplankton the difference does not exceed 30%.

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