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USE OF THE MACROPHYTES' MORPHOFUNCTIONAL PARAMETERS TO ASSESS ECOLOGICAL STATUS CLASS IN ACCORDANCE WITH THE EU WFD

Use of a complex of macrophytes' morphofunctional parameters has been proposed for coastal ecosystems Ecological Status Class (ESC) assessment in accordance with the EU Water Framework Directive (WFD). Benefits of switching from quantitative to qualitative expression of submerged aquatic vegetation ecological properties to express Ecological Evaluation Index have been considered. In accordance with the WFD requirements, formulas for calculation and classification schemes are presented for the four morphofunctional parameters: Three Dominants Ecological Activity (S/W_{3Dp}); Average Species Ecological Activity (S/W_x); Phytocenosis Ecological Activity (S/W_{ph}); Phytocenosis Surface Index (SI_{ph}). Advantages and disadvantages of the four proposed parameters used for marine coastal ecosystems monitoring have been discussed. Results of spatial assessment of the Ukrainian Black Sea water areas' ESC and their long-term dynamics for Odessa coast in 1980-2011 have been presented. The results received have demonstrated similar structure of the ESC categories correlation for the Ukrainian Black Sea coast and Catalan Mediterranean coast, as well as current tendency towards the Ukrainian Black Sea coast environmental status improvement, which in the last years was broken as the result of abnormal climatic conditions.

Key words: macrophytes, morphofunctional parameters, Ecological Status Class, Water Framework Directive, Black Sea

Search for new indicators, unification of assessment methods and increase of environmental forecast precision are the important tasks of marine ecosystems monitoring. Successful resolving of those tasks would enable us to get comprehensive picture of current state and determine directions of environmental processes development in the coastal zones of Europe. This task is being successfully solved on the international level due to ratification of a number of important environmental EU Directives. Among them are Water Framework Directive (WFD, 2000/60/EC) and Marine Strategy Framework Directive (MSFD, 2008/56/EC), which hold prominent place when it comes to elaboration of universal and efficient methods for assessment and management of European coast.

Macrophytes fulfil basic environmental function in coastal ecosystems – create primary organic matter with which the cycle of matter and energy transformation in trophic chains begins. Depending on intensity of environmental processes in marine coastal systems structural & functional organization of submerged aquatic vegetation (SAV) varies significantly. Accordingly, Macroalgae and Angiosperms in line with the MSFD are considered as Biological Quality Elements. High indicative properties of the SAV have been confirmed in the course of a simple method for confidence rating of eutrophication status classification development. For marine coastal ecosystems average confidence of SAV (0.64) is higher than physicochemical conditions (0.57) and benthic invertebrates (0.30) [2].

The task of the WFD ideology practical implementation by means of marine coastal ecosystems Ecological Status Classes (ESC) development using SAV as indicator is being actively solved during last decade by experts in European countries. Greek researchers have proposed an original approach – when expressing Ecological Evaluation Index (EEI) using structural indicators of macrophytes (floristic composition, coverage, biomass), their environmental properties should be taken into account in accordance with the theory of *r*-spices and *k*-spices selection [31]. For the purposes of the ESC assessment Greek and Slovenia coast of the Mediterranean began to use broadly method of macrophytes division into two Ecological Status Groups (ESG): ESG I – latesuccessional and ESG II – opportunistic and consideration of their input into the structure of benthic phytocommunities [24, 25, 26, 28, 30]. Later, as the result of Greek and Norwegian researchers' work this approach was improved and it was proposed to divide them into five sub-clusters [27]. Alternatively CARLIT and BENTOS methods to use a macroalgae as biological key element for the assessment of the ecological status of coastal waters in the frame of the WFD was proposed by Spanish experts [4]. The CARLIT (cartography of littoral and upper-sublittoral rocky-shore communities) method uses the knowledge in the value of species/communities as bioindicators obtained from BENTOS procedure to obtain a quick assessment of water quality based on cartographical surveys [3, 32]. Combination of the ESG method based on the functional-form groups of macroalgae and CARLIT method based on cartographical surveys of benthic community was applied to Bulgarian coast of the Black Sea [5].

Based on studies of the functional-form groups of benthic marine macroalgae [14, 15] and peculiarities of the metabolism influencing forming of structure and functions of marine macrophytes [7], the new direction – morphofunctional ecology of macrophytes started in Ukraine in the 90th of the last Century [8, 18, 20]. Complex of parameters based on specific surface (S/W) of algae having different morphological configuration was used to diagnose trophic level of marine coastal ecosystems' correspondence to phytobenthos morphofunctional organisation [16, 19] and for quantitative forecasting of changes in floristic composition under the Black Sea ecosystem eutrophication [17]. High level of connection between macrophytes' morphofunctional parameters and quality of aquatic environment became the basis for using of S/W values of different species as the characteristics of their ecological activity. An attempt to use macroalgae specific surface for ESC assessment in line with the WFD requirements has been made for the Black Sea coast of Bulgaria [9].

The objective of the paper is to demonstrate high performance of the complex of macrophytes' morphofunctional parameters in assessment of marine coastal ecosystems' Ecological Status, as well as to produce the first results of spatial and long-term assessment of the Ukrainian Black Sea coast's ESC in accordance with the WFD requirements based on the bottom vegetation state.

Materials and Methods. Structural & functional organisation of macroalgae and angiosperms population and communities in the Ukrainian Black Sea coastal area growing from the Danube Delta to the Strait of Kerch including shelf zone (Zernov's Phyllophora Field), the North-Western Black Sea bays and the North-Western Black Sea limans has been analysed coming out of author's own data and the data from literature.

Assessment of macrophytes populations and communities has been done using a complex of hierarchic morphofunctional indices based on the parameters of surface aquatic vegetation [18]. Calculation of these parameters has been done using specially elaborated algorithms [23]. Two parameters of this complex, namely: Specific Surface of the Population (S/W_p) and Community Surface Index (SI_{cm}), have been used as the basic ones, on the ground of which four morphofunctional indicators for marine coastal and shelf ecosystems' ESC assessment were proposed in this paper.

To analyse the response of the proposed morphofunctional parameters to temperature regime and illumination the material received from the stations of monitoring polygon located on Odessa coast has been used. During 2011, 12 surveys have been carried out for underwater macrophytobenthos counts on the natural and artificial substrata; 580 frames collected for quantitative control of macrophytes, over 2500 morpho-dependent parameters measured. The solar outputs to surface of macroalgae biotopes were calculated with consideration of the basic astronomical, geographical and meteorological factors [6]. Information on temperature regime of marine water in the polygon area was received from regional offices of the Ministry of Environment and Natural Resources of Ukraine.

To assess the ESC of 26 different water areas in Ukrainian sector of the Northern Black Sea the author's own data and the data from published literature have been used on macrophytobenthos dominant species, which were re-calculated using the known regional S/W_p values [23]. Database of the IBSS (Institute of Biology of Southern Seas, Odessa Branch) on macrophytes' species composition and biomass for the period of 1980 – 2011 has been used to assess the ESC long-term dynamics for Odessa coast.

Results and Discussion. During assessment of marine coastal ecosystems' ESC based on the state of macrophyte communities the key stage of experts work would be proper selection of parameters and indices to express the EEI proposed by Greek experts [25]. Assessment of ESC of coastal ecosystems using macrophytobenthos would be efficient if the EEI's indicators have the following properties: to reflect intensity of primary production process; to be sensitive to the most common human pressures on coastal ecosystems (eutrophication, transformation of biotopes, changes in hydrodynamics etc.); to have connection with standard monitoring parameters of macrophytes – species composition, projective bottom coverage, biomass of submerged vegetation.

Appropriate approach to selection of SAV indicator characteristics is the prerequisite of elaboration of objective and practical methods to assess marine coastal ecosystems' ESC. At the moment there are different concepts of benthic communities' parameters selection to assess ecological status. The MSFD (Annex III), for example, recommends a number of classical hydrobiological characteristics for Angiosperms and Macroalgae. At that, it should be noted that these parameters reflect only the structural properties of benthic vegetation.

Species composition is a characteristic of communities' floristic structure. This structural parameter is inefficient for comparison of geographically distant ecosystems that differ drastically in their floristic composition. Assessing the ESC based on macrophytobenthos species composition one would need additional information on ecological and indicator role of species. Biomass is also one of phytocenosis structure characteristics. Without information about the time of its growth, parameters of seasonal or perennial macrophyte species' biomass would not reflect intensity of benthic vegetation participation in production process. There is a danger of partial loss of macrophyte biomass in the upper horizons of coastal zone due to storm dynamics. Annual/seasonal variability is an indicator describing only the character of temporal dynamics of structural parameters. Besides, annual/seasonal variability characterizes more the state of coastal ecosystem connected with natural climate conditions than with ecological status, which in majority of cases is formed under the influence of man-caused factors. At that, it should be pointed out that recommendations to use the above mentioned parameters have objective reason, which is connected with the international tradition of hydrobiological studies. Species composition and biomass of benthic hydrobionts are at present the most widespread monitoring parameters, for which significant databases are accumulated. Besides, at present a new methodology of CARLIT method developed for the implementation of the European WFD increases significantly informativeness of hydrobiological structural parameters due to information about the value of the communities as indicators of water quality and using GIS technology [4].

The proposal to use for macrophytes ecological labelling based on functional group of macroalgae (*r*-spices и *k*-spices) has become a significant step towards transfer from structural to functional methodology of the ESC assessment improving. The recent result of this approach is the proposal to use five sub-categories for the ESG for functional characteristics of macrophytes [27]. Taking into account inputs of the species having different environmental activeness into plant community enables us to come over in determination of an ecosystem's ecological status from structural to functional approach.

Peculiarity of morphofunctional properties, which is based on the macrophytes surface's capacity to reflect the intensity of populations and communities realization of production process, could be used for further improvement of marine ecosystems state ecological assessment methods. The value of parameter 'Specific Surface of the Population' (S/W_p) is an individual marker of environmental activeness of a species. The value of 'Community Surface Index' (SI_{cm}) reflects the intensity of autotrophic process ensured by phytobenthos communities. When the level of primary production process grows in an ecosystem (the most common cases – man-induced eutrophication of coastal ecosystems) species having higher S/W_p parameters receive preferential development effort, at that, values of SI_{cm} increase. Thus, use of not only sub-categories, but also morphofunctional parameters for macrophytes' ecological labelling enables us to come over from qualitative to quantitative concept of ESC assessment based on SAV functional properties (Table 1).

Table 1 Comparison of possibilities provided by different concepts of marine coastal ecosystems' ESC assessment
Табл. 1 Сравнение возможностей различных концепций при оценке экологического статус класса (ESC) морских прибрежных экосистем

Concept	Classical hydrobiology	Ecological Status Groups	Morphofunctional approach
Source	[11]	[24, 25, 27]	[18, 23]
Indices	Characteristic for angiosperm and macroalgae: - species composition; - biomass; - annual/seasonal variability.	Ecological marks for macrophytes: - ESG I (k-selected species), (IC, IB, IA); - ESG II (r-selected species), (IIB, IIA).	Morphofunctional parameters of macrophytes: - Specific Surface of the Population $(S/W)_p$; - Community Surface Index SI_{cm}.
Capabilities	• Reflecting the biological structure	• Reflecting the ecological function on a high-quality level	• Reflecting the ecological function on a quantitative level

Practical convenience of the S/W_p parameter use is due to the fact that once calculated value for a species in a certain habitat could be further used as a coefficient if its ecological activity in regional monitoring. Big perennial macrophyte forms having thick laminar thalloma are characterized by minimal values of S/W_p. Ecological activity of those species is low; they are indicators of Good Ecological Status. They are dominants of phytocenosis receive maximal development under Reference conditions. Small seasonal forms with thin filamentous thalloma are, on the contrary, characterized by maximal S/W_p values. Such species with high ecological activity receive preferential development effort under eutrophic conditions at high specific speed of production process. As a rule, they dominate in ecosystems whose ESCs are estimated as Bad and Poor. Comparison between two approaches to ecological labelling of macrophytes indicates similarity of results received using ESG and S/W_p (Table 2).

At that, significant difference lies in the fact that macrophytes' ecological labelling carried out using morphofunctional parameters has a numerical expression for each species, which enables us to perform mathematical operations with communities' species composition.

Table 2 Ecological labelling of macrophytes using different approaches: determination the Ecological Status Group; calculation of morphofunction indices
Табл. 2 Экологическая маркировка макрофитов с использованием различных подходов: определение экологических статус групп (ESG); расчёт морфофункциональных показателей

Macrophytes	Ecological Status Group [27]	Ecological activity (S/Wp, $m^2.kg^{-1}$)
Chondrus	IC	3.2
Litophyllum	IC	4.1
Phyllophora	IIA	7.5
Cystoseira	IA	9.5
Zostera	IB	10
Dillophys	IIA	11
Gelidium	IIA	14
Padina	IB	16
Corallina	IIB	24
Ceramium	IIB	26
Chaetomorpha	IIB	32
Ulva	IIB	36
Bryopsis	IIB	47
Cladophora	IIB	75
Bangia	IIB	85
Callithamnion	IIB	130
Ectocarpus	IIB	160
Acrochetum	IIB	280
Cyanobacteria	IIB	300 – 1200

Besides, values of S/W_p are received not by subjective expert assessment, but using objective method of mathematical calculation of the morphological parameters measured according to unified algorithms [23].

The S/W_p parameter is beneficial not only for the EEI expression but also for other approaches to macrophytes ecological labelling. Polish experts are using Macrophyte Quality Assessment Index (MQAI) which constitutes a ratio between the total biomass of "positive" taxa and the total biomass of "negative" taxa [13]. Assessment using S/W_p coefficients of species referred to as "positive" and "negative" taxes [29] transforms information on ecological status of species from qualitative to quantitative level. For example, using the values of ecological activity we could make calculations and conclude that S/W_p of the species presented in "positive" group varied within the limits 5 – 25 $m^2 \cdot kg^{-1}$, while for the species representing "negative" group – 40 – 160 $m^2 \cdot kg^{-1}$.

Morphofunctional approach explains also numerous examples describing changes in phytobenthos structural organization, which happen under the influence of eutrophication and degradation of ecological situation in many European seas. At that, different floristic composition of geographically distant ecosystems does not complicate comparative assessment done with the use of S/W_p. For example, in the Baltic Sea species belonging to *Fucus* genus are being replaced by epiphytic green algae under influence of eutrophication [12]. Range of values of S/W_p for species belonging to *Fucus* genus varies within 2-5 $m^2 \cdot kg^{-1}$. Epiphytic filamentous algae replacing the *Fucus* communities are characterized by S/W_p values ranging from 60 to 120 $m^2 \cdot kg^{-1}$. Thus, eutrophication processes and ESC changes for the Baltic Sea could increase macrophytes' ecological activity up to 30 times. Four stages of replacement of dominant algae species under the increase of the organic matter and nutrients concentrations along the North-Western Mediterranean coast [32] also reflect consequent growth of macrophytes' ecological activity under decreasing of ESC. Replacement of *Cystoseira* ($S/W_p \sim 10$) with the *Corallina* ($S/W_p \sim 20$) and then complex of green (*Ulva* ~35 – 40; *Enteromorpha* ~ 35 – 50; *Cladophora* ~ 40 – 80) and blue-green algae (*Oscillatoria, Lyngbya* ~ 200 – 800) ($m^2 \cdot kg^{-1}$) shows that with decrease of aquatic environment quality ecological activity of benthic algae could increase consequently 2, 10 and 50-fold.

The following example shown for the Black Sea is demonstrating a similar mechanism, under which growth of the ecosystem's trophic status creates the conditions for better development of the algae having high S/W_p coefficients. Secondary eutrophication of Zernov's Phyllophora Field located in the North-Western Black Sea shelf, as the result of previously accumulated nutrients' entering water column from bottom sediments stimulated rough development of small filamentous algal forms. Specific surface of previously dominant species *Phyllophora crispa* and *Ph. truncata* made up an average 7.34 ± 0.31 and 10.16 ± 0.33 $m^2 \cdot kg^{-1}$, correspondingly. The values of specific surface of mass algal filamentous species growing on phyllophora thalloma have 10 – 40 fold higher ecological activity than the phyllophora itself, and for *Polysiphonia sanguinea* 80.00 ± 1.36; for *Desmarestia viridis* – 78.25 ±2.3; for *Feldmania irregularis* – 303.2 ±16.2 $m^2 \cdot kg^{-1}$ [21].

So, it becomes evident that morphofunctional parameters reflect quantitatively the indicator properties of SAV; explain and could predict the direction of changes in aquatic vegetation of different floristic structure under the changes of ecosystem's ecological status.

It is proposed to consider the possibilities of four macrophytes' morphofunctional indicators, which could be proposed for expressing the EEI when assessing coastal ecosystems' ecological status based on phytobenthos state (Table 3).

Table 3 Macrophytes' morphofunctional indicators proposed for assessment of marine coastal ecosystems' ESC
Табл. 3 Морфофункциональные индикаторы макрофитов, предлагаемые для оценки экологического статус класса (ESC) морских прибрежных экосистем

Indices	Calculation formula
Three Dominants Ecological Activity , **S/W_{3Dp}**	$S/W_{3DP} = \frac{\sum 3(S/W)_{pi}}{3n}$ where: S/W_{pi} – specific surface of populations of three first phytobenthos dominants
Average Species Ecological Activity, **S/W_x**	$S/W_x = \frac{\sum (S/W)_{pi}}{ni}$ where: S/W_{pi} – specific surface of all populations in the community
Phytocenosis Ecological Activity, **S/W_{ph}**	$S/W_{ph} = \sum (\frac{B_{pi} \times 100\%}{\sum B_{pi}} \times (S/W)_{pi})$ or $S/W_{ph} = \sum (\frac{P_{pi} \times 100\%}{\sum P_{pi}} \times (S/W)_{pi})$ where: S/W_{pi} – specific surface of phytocenosis populations; B_{pi} – biomass of populations; P_{pi} – projective cover of populations
Phytocenosis Surface Index, **SI_{ph}**	$SI_{ph} = \sum (B_{pi} \times (S/W)_{pi})$ where: S/W_{pi} – specific surface of phytocenosis populations; B_{pi} – biomass of phytocenosis populations

Three Dominants Ecological Activity (S/W_{3Dp}) has high indicator sensitivity of eutrophication level of an ecosystem. This is due to the existing regularities connecting minimal possible values of S/W_p of macrophytes with the certain intensity of primary production process [18]. In case of autotrophic process intensification, increase of limiting barrier takes place for ecological activity of species. The species, whose S/W_p becomes less than a certain value, move into suppressed state and at the stages of more intensive eutrophication disappear from communities' structure. The lowest S/W_p, coefficients are characteristic of the biggest perennial forms of macrophytes. As a rule, those forms dominate in phytobenthos. Thus, the dominating macrophyte species are the most sensitive in an ecosystem to environmental state aggravation and are the most vulnerable elements of vegetation communities. Monitoring of their state is the reliable method to control changes in ecological status of marine environment. Recording of the first three dominant species' S/W_p average values could be considered as an express-method for quick determination of aquatic vegetation ecological activity and operative assessment of the ecosystem's environmental state. Receiving of information for the S/W_{3Dp} parameter is a simple mathematical procedure, as it would be enough to determine the dominant macrophytobenthos species and use the available regional S/W_p coefficients.

Average Species Ecological Activity (S/W_x) takes into account average value of specific surface of all phytobenthos species in the coastal area being assessed. Such recording of complete floristic structure of macrophytobenthos communities is traditional for classical hydrobiological studies. However, identification of complete floristic composition including small epiphytic species is quite complicated technical task for monitoring. Besides, there are some restrictions from the side of morphofunctional regularities in phytobenthos floristic structure forming. Small short-cycle species having high S/W_p values do not have high indicative sensitivity to habitat. In the ecosystems assessed as 'Bad – ESC' they are mass species and show explodes, though their presence in small quantities could be found in floristic composition of the communities, which develop under reference conditions.

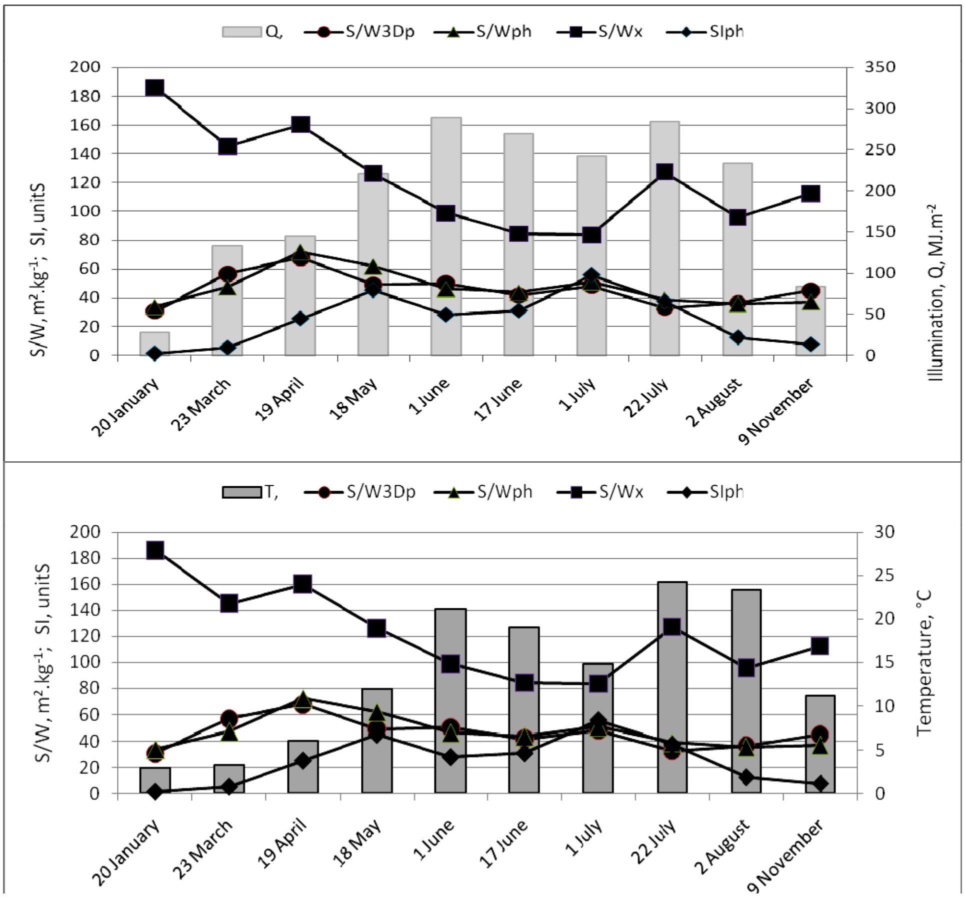
Calculation of Phytocenosis Ecological Activity (S/W_{ph}) and Phytocenosis Surface Index (SI_{ph}) parameters require taking into account of the entire complex of phytobenthos structural indicators: floristic composition, bottom cover and biomass. The difference between these parameters lies in the fact that the S/W_{ph} parameter takes into consideration ecological activity of species (S/W_p) and relative input of their populations into phytocenosis biomass or bottom cover. For the SI_{ph} parameter coefficients S/W_p of the populations included into the phytocenosis and the sum of absolute values of their biomass are used. The SI_{ph} parameter is the standard indicator of macrophytes' morphofunctional complex [21]. The benefit provided by this parameter is that its values could be recalculated based on the available historical databases on macrophytobenthos floristic composition and biomass for any monitored area. The benefit of the S/W_{ph} parameter, being suggested for the first time, is that for its calculation not the absolute, but the relative values of structural parameters are used. Such a recording method reflects only the real morphofunctional portrait of a community and is protected from the influence of other factors, which are not connected directly with the intensity of autotrophic process. For example, changes in biomass or bottom cover decrease as the result of active hydrodynamics could be the reason for significant errors in the parameters calculated on their basis.

In order to test the properties of the indicators proposed analysis of annual dynamics has been performed of the four proposed macrophytes' morphofunctional indicators for the monitoring test site on Odessa coast in 2011.

Maximally similar character of seasonal dynamics has been revealed between the following indices: Three Dominants Ecological Activity (S/W_{3Dp}), Phytocenosis Ecological Activity (S/W_{ph}) and Phytocenosis Surface Index (SI_{ph}) (Fig. 1). Besides, the S/W_{3Dp} index has high level of invert with temperature regime ($R = -0.80$). This could form the basis for broad use of S/W_{3Dp} for aquatic ecosystems monitoring, as collection of primary data for its calculation during underwater studies is a simpler procedure than collection of the information required to calculate S/W_{ph} and SI_{ph} indices.

Average Species Ecological Activity index (S/W_x) also correlates well with temperature ($R = -0.72$) and illumination ($R = 0.71$). However, collecting of information on this index is connected with technical difficulties in underwater studies requiring complete recording of all bottom vegetation floristic composition in the monitoring test site.

As all the proposed morphofunctional indicators have their advantages and disadvantages (Table 4) expert decision on each specific morphofunctional indicator choice as the EEI should be taken depending on specific task of a study. Evidently, the next methodological stage should be to search for or to select out of suggested parameters one universal indicator, which would reflect ecological status of coastal ecosystems the best way irrespective of the type of spatial or temporal assessment.



a

b

Fig. 1 Seasonal dynamics of morpho-functional parameters and abiotic factors: a – illumination; b – temperature (2011)

Рис. 1 Сезонная динамика морфофункциональных параметров и абиотических факторов: а – освещённость; b – температура (2011 г.)

Table 4 Comparison of advantages and disadvantages of macrophytes' morphofunctional indicators proposed for coastal ecosystems' ESC assessment

Табл. 4 Сравнение преимуществ и недостатков морфофункциональных индикаторов макрофитов, предлагаемых для оценки экологического статус класса (ESC) прибрежных экосистем

Indicator	Advantages	Disadvantages
Three Dominants Ecological Activity, **S/W_{3Dp}**	- Efficient for comparative express-assessment of ecosystems with different floristic composition. - Low level of labour input. - Low probability of computation error. - Low level of user's qualification.	- Characteristics of artificial phytosystem (only first three dominants). - Low sensitivity for short-period (seasonal) monitoring of ESC for water bodies with perennial dominants.
Average Species Ecological Activity, **S/W_x**	- High sensitivity for temporal (seasonal, long-period) monitoring of ESC in water bodies with simplified species composition.	- High level of labour input. - High probability of computation error. - High level of user's qualification.
Phytocenosis Ecological Activity, **S/W_{ph}**	- Characteristics of natural phytosystem (phytoconosis – basic unit of vegetation). - High sensitivity for spatial and temporal monitoring.	- High level of labour input. - Lack of databases (impossibility of recalculation of historical databases on structural parameters).
Phytocensis Surface Index, **SI_{ph}**	- Characteristics of natural phytosystem (phytocenosis – basic unit of vegetation). - High sensitivity for spatial and temporal monitoring. - Possibility of historical databases recalculation on structural parameters.	- High level of labour input. - High probability of computation error (loss of biomass on upper horizons).

The next stage of use of macrophytes' morphofunctional parameters for ESC assessment in aquatic ecosystems is connected with proceeding to expression of EEI empirical values in the scale of [1 – 0] and five standard classes (High, Good, Moderate, Poor, Bad) with respective colour characteristics (blue, green, yellow, orange, red).

Proceeding from EEI to Ecological Quality Ratio (EQR) requires solution of the most complicated expert task – identification of the values of EEI parameters for Reference Conditions (RC) or Good Ecological Status (GES) of aquatic ecosystem.

The WFD identifies four options for deriving reference conditions: (i) comparison with an existing undisturbed site or a site, with only very minor disturbance; (ii) historical data and information; (iii) models; or (iv) expert judgment (Annex II, 1.3 (iii)).

Deficit or complete absence in some regions of the sites free from any human impact is one of the problems in RC identification for water bodies. Morphofunctional indicators of macrophytes reflect integral intensity of primary production process caused by both human influence and natural factors.

High-productive (eutrophic) ecosystems are to higher extent susceptible to negative phenomena connected with high speed and instability of environmental processes, such as: phytoplankton blooms, hypoxia, mass mortality, depleted composition and simplified structure of biological communities etc. At that, such phenomena are not always caused by human impact, as primary production process intensity depends also on a number of natural conditions (water body depth and connected with it temperature regime and intensity of bottom layers illumination, character of hydrodynamics, volume and quality of basic discharge entering the ecosystem etc.).

Even under completely no human influence, the natural level of primary production process in the shallow North-Western Black Sea shelf, which is the sink for big rivers discharge, would be higher compared to, for example open and deep-water Crimean or Caucasus coast. Besides, specific climate conditions of a year could contribute to changing of natural level of primary production, hence – change (increase or decrease) the ESC of an ecosystem irrespective of changes in intensity of direct or indirect human impact.

Based on the many years' database of phytobenthos morphofunctional parameters in different parts of the Ukrainian Black Sea sector that differ in their natural conditions and level of human pressure, quantitative connections between universal index EQR [1 – 0] and three morphofunctional indicators (S/W_{3Dp}, S/W_x, SI_{ph}) have been received, which could be used as the EEI (Fig. 2).

At present, such dependence cannot be received for the indicator S/W_{ph}, as there is not enough empirical data collected on this parameter.

In EQR's scale the entire spectrum of empirical values of morphofunctional parameters has been introduced: from reference water areas characterized by the lowest trophic level, complex structure of phytocenoss, high floristic diversity and big number of perennial big forms of macrophytes with minimal S/W_p coefficients; to highly eutrophic sites with extreme degradation of bottom vegetation structure, represented by small number of little short-cycle species with maximal S/W_p values.

The proposed EEI classification schemes could be used to assess the ESC of water bodies in Ukrainian sector of the Black Sea ecosystem, as for determination of their parameters we have used the data on macrophytes' morphofunctional organization from the Danube Delta to the Strait of Kerch, including limans ecosystems (Table 5).

In future these classification schemes would require intercalibration taking into account the values of macrophytes' morphofunctional indicators for other National coasts of the Black Sea.

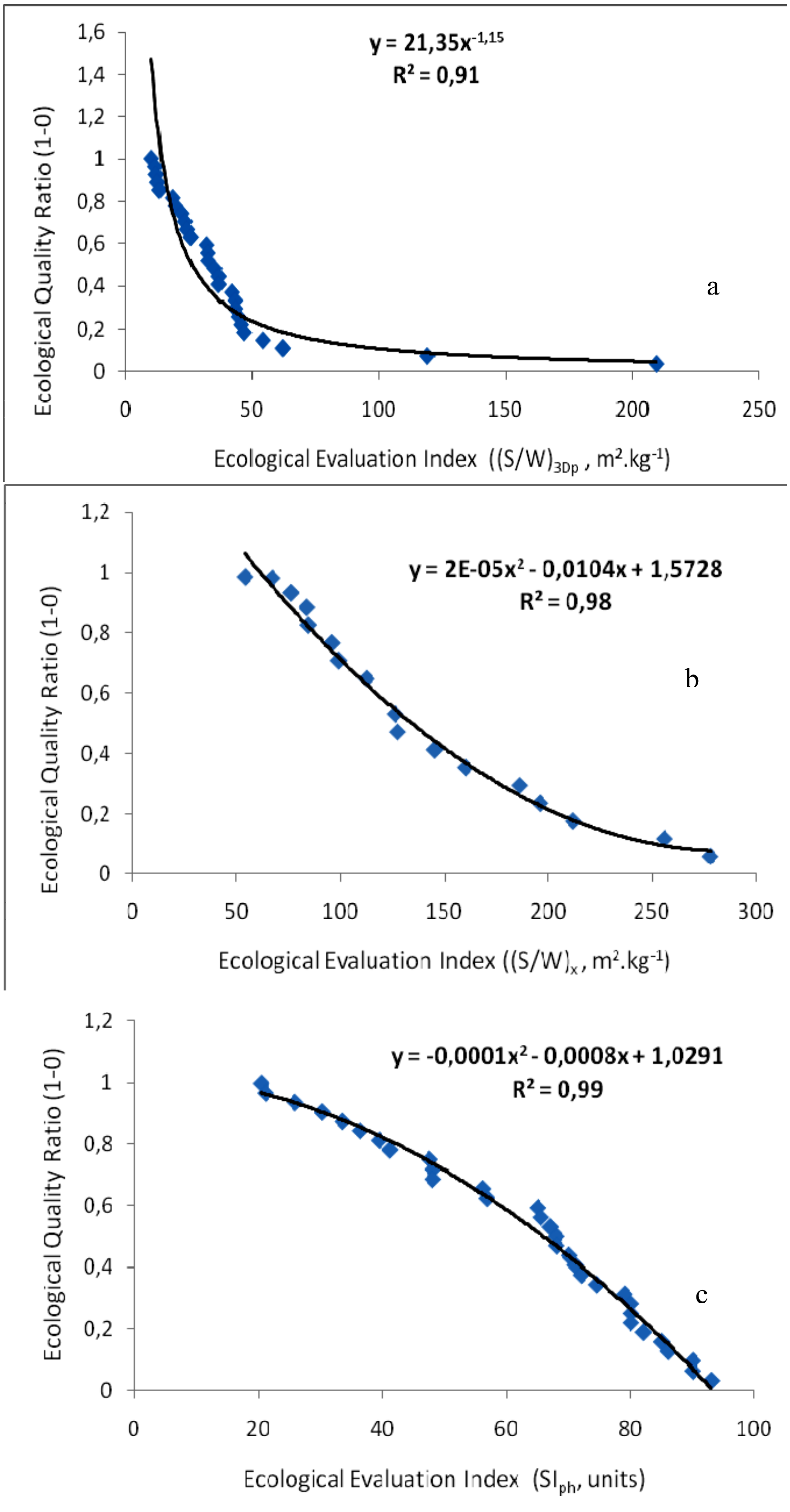


Fig. 2 Approximations of the different EEIs to the EQR's scale: a – $(S/W)_{3Dp}$; b – $(S/W)_{x}$; c – SI_{ph}

Рис. 2 Аппроксимация различных индексов экологи-ческой оценки (EEI) к шкале относительного экологического качества (EQR): a – $(S/W)_{3Dp}$; b – $(S/W)_{x}$; c – SI_{ph}

Classification scheme of the $(S/W)_{3Dp}$ index has been used for spatial assessment of the ESC for 26 water bodies in Ukrainian sector of the Northern Black Sea in the current period (Table 6, Fig. 3). The picture received shows that maximal number of water bodies having the lowest ecological status classes is located in the north-western area. «Bad» status class (EQR: 0.11 – 0.07) correspond to ecosystems of the Kujalnitskiy and Hadzhibey-skiy Limans. Low ecological status of those sites has resulted from combination of unfavorable natural conditions and human impact: limans are shallow ecosystems having no free water exchange with the sea. Besides, they are situated within the boundaries of Odessa – the city with million population. These water bodies suffer all kinds of municipal pressures, including sewer discharge into the Hadzhibeyskiy Liman. On the other side, 5 sates having «High» status class (EQR: 0.98 – 0.85) enjoy combination of favourable natural conditions and minimal human pressure: the Tendrovskiy, Karkinitskiy and Egorlytskiy bays and the Karadag coast are marine protected area of international and national significance (Biosphere and Nature Reserves).

And at least, the Donuzlav Lake had no high human pressures for a long time as it used to be out-of-bounds military site.

Table 5 EEI classification scheme for macrophytes' morphofunctional indices
Табл. 5 Схема классов экологической оценки для морфофункциональных показателей макрофитов

ESC	EEI range					
	$(S/W)_{3Dp}$, $m^2.kg^{-1}$	EQR	$(S/W)_x$, $m^2.kg^{-1}$	EQR	SI_{ph}, units	EQR
High	$(S/W)_{3Dp} < 15$	≥ 0.82	$(S/W)_x < 60$	≥ 0.98	$SI_{ph} < 25$	≥ 0.95
Good	$15 \leq (S/W)_{3Dp} \leq 30$	0.54	$60 \leq (S/W)_x \leq 80$	0.79	$25 \leq SI_{ph} \leq 40$	0.84
Moderate	$31 \leq (S/W)_{3Dp} \leq 45$	0.37	$81 \leq (S/W)_x \leq 120$	0.58	$41 \leq SI_{ph} \leq 65$	0.55
Poor	$46 \leq (S/W)_{3Dp} \leq 60$	0.25	$121 \leq (S/W)_x \leq 200$	0.17	$66 \leq SI_{ph} \leq 90$	0.15
Bad	$(S/W)_{3Dp} > 60$	≥ 0	$(S/W)_x > 200$	≥ 0	$SI_{ph} > 90$	≥ 0

Table 6 Ukrainian water bodies' ESC assessment
Табл. 6 Оценка экологического статус класса (ESC) водных объектов Украины

Water Body	Ecological Status Class	EEI, $(S/W)_{3Dp}$, $m^2.kg^{-1}$	Ecological Quality Ratio
Tendrovskiy Bay	High	11.2	0.98
Karkinitskiy Bay	High	11.7	0.96
Donuzlav Lake	High	11.9	0.92
Egorlytskiy Bay	High	12.5	0.89
Karadag coast	High	13.4	0.85
Tiligul Liman	Good	18.6	0.81
FeodosijaBay	Good	19.7	0.78
Sebastopol Bay	Good	22.3	0.74
Dnister Liman	Good	23.4	0.70
Kerchenskiy Channel	Good	24.2	0.67
Zmiinyi Island coast	Good	25.7	0.63
Dofinovskiy Liman	Moderate	32.0	0.59
Zernov's Phyllophora Field	Moderate	32.5	0.56
Tuzlopvskie Limans	Moderate	32.6	0.52
Zhebrijanovskiy Bay	Moderate	35.2	0.48
Grigorievskiy Liman	Moderate	36.7	0.42
Odessa Bay	Moderate	36.7	0.42
Kalamitskiy Bay	Moderate	41.9	0.37
Dnipro-Bugskiy Liman	Moderate	43.3	0.33
Berezanskiy Liman	Moderate	44.7	0.30
Shabolatskiy Liman	Poor	45.7	0.26
Suhoy Liman	Poor	46.8	0.22
Danube Delta Front	Poor	54.2	0.18
Sasyk Lake	Poor	62.1	0.15
Kujalnitskiy Liman	Bad	119.0	0.11
Hadzhibeyskiy Liman	Bad	209.4	0.07

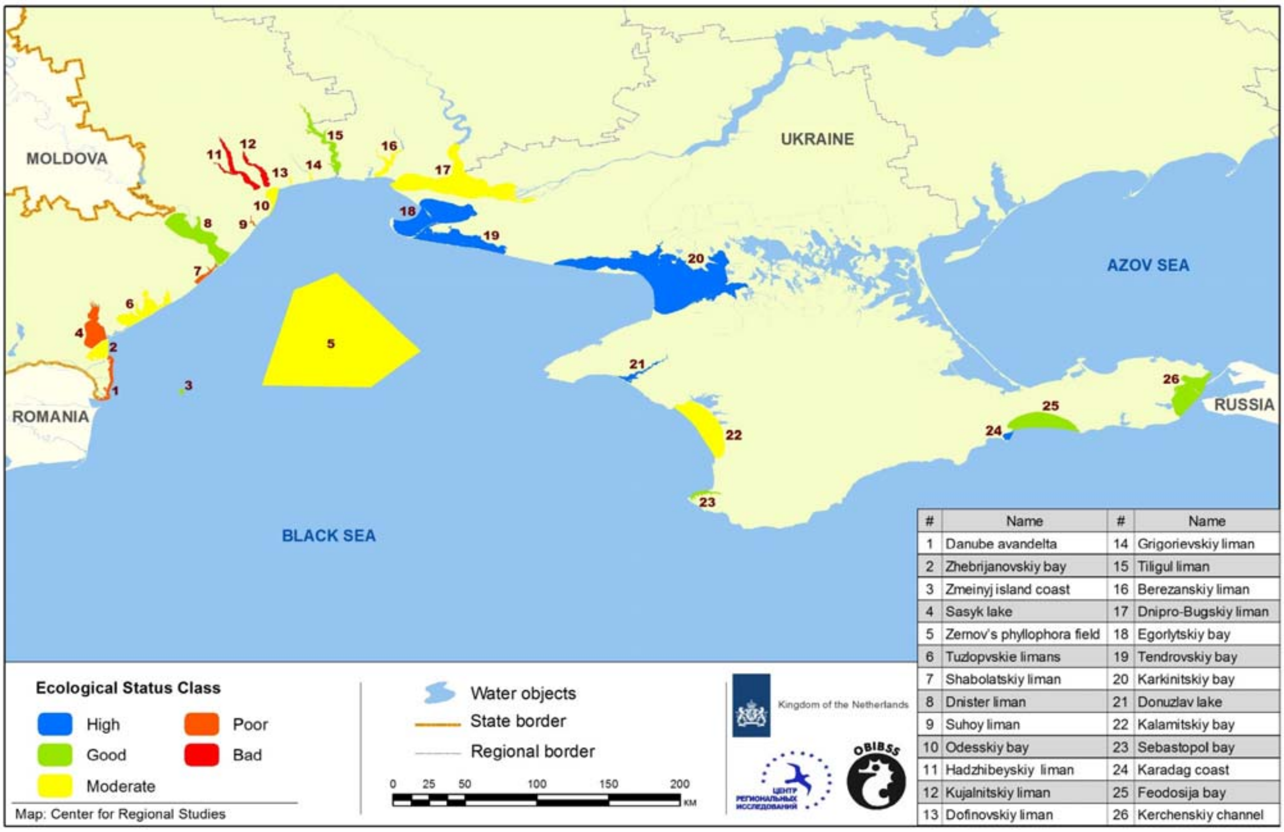


Fig. 3 Assessment of ESC of different water areas in the Ukrainian Northern Black Sea sector
Рис. 3 Оценка экологического статус класса (ESC) для различных водных объектов Украины в северном секторе Чёрного моря

Universal WFD approach using the EQR indices and standard quality classes offers the possibility to compare environmental state of water bodies in different European regional ecosystems, which are in principle different in structure of their biological component and intensity of ecological processes. The ESC assessment of the Ukrainian Black Sea water bodies performed for the first time in line with the EU standards enabled us to carry out comparative analysis with the Mediterranean areas (Fig. 4). The biggest percentage of both the Black Sea and Mediterranean areas belongs to «Moderate» and «Good» ESC. At that, percentage of water bodies belonging to «Poor» and «Bad» ecological classes in the Northern Black Sea area is somewhat higher compared with areas in Catalonia. However, this could be explained by the fact that the Black Sea is presented by water areas having higher natural level of primary production process (river delta fronts, limans, estuaries) than those in the Mediterranean region.

Availability of database for macrophytobenthos morphofunctional parameter SI_{ph} for Odessa coast for more than 30 years period enabled us to receive long-term inter-annual ESC dynamics for this segment of the Black Sea coast (Fig. 5). Long-term trend of environmental state expressed using the ESC classification coincides with the logics of eutrophication stages described for the North-Western Black Sea [22]. Intensive eutrophication stage (80^{th} - early 90^{th} of the last century) gave way to stabilization stage and trend of stable de-eutrophication (end of last century – beginning of the present century), though in recent years the trend of ecological situation general improvement in the North-Western Black Sea has been breached by anomalous climatic conditions.

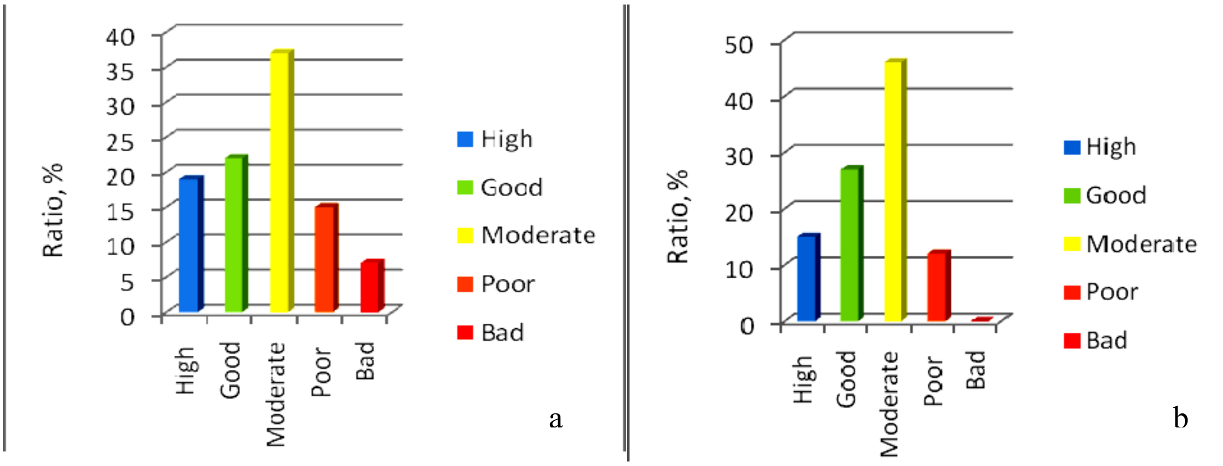


Fig. 4 Comparison of the ESC structure for water bodies of the Black Sea (a) (Northern Black Sea, 26 areas of Ukrainian part**)** and the Mediterranean Sea (b) (Western Mediterranean, 37 areas of Catalonia [4]**)**

Рис. 4 Сравнение структуры экологических статус классов (ESC) для водных объектов Черного моря (a) (северная часть Черного моря, 26 акваторий Украины) и Средиземного моря (b) (западное средиземноморье, 37 акваторий Каталонии [4]**)**

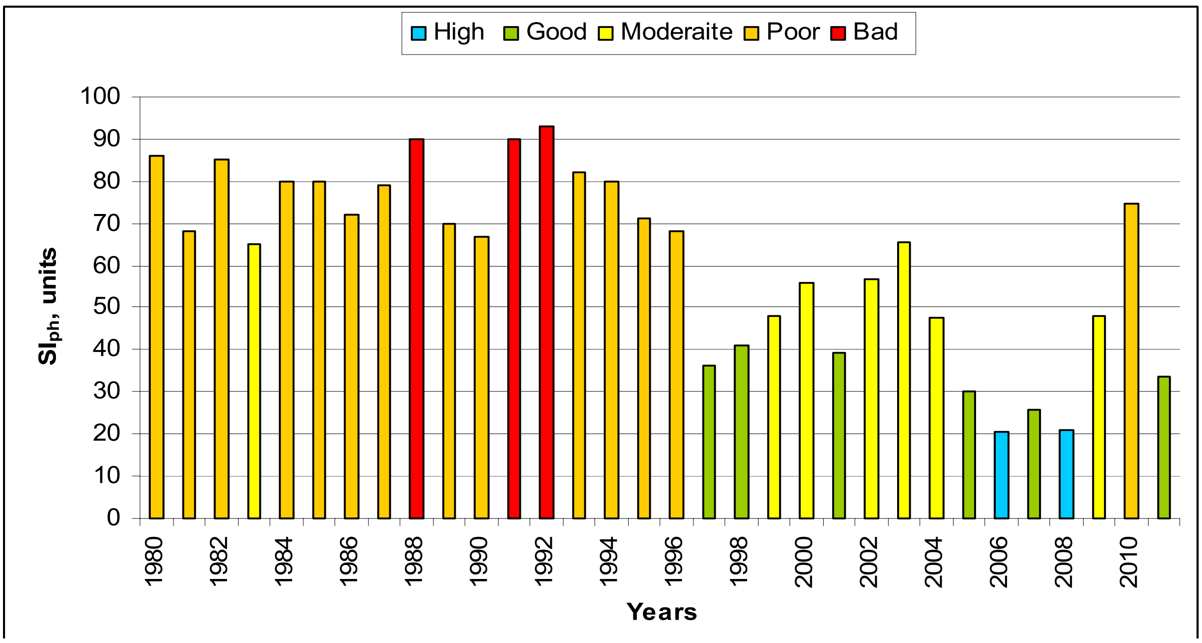


Fig. 5 Long-term dynamic of ESC value for Odessa coast (North-Western Black Sea) received using SI_{ph} index

Рис. 5 Долгопериодная динамика значений экологических статус классов (ESC) для Одесского побережья (северо-западная часть Черного моря) полученная с использованием SI_{ph} показателя

As an example we could take 2010, when big amount of precipitation and anomalous high water temperature have resulted at intensification of primary production process by several times in the North-Western Black Sea in August [1]. The picture received using ESC classification based on the macrophytes' morphofunctional indicators similarly illustrates the situation based on the WFD standards: prevalence of ecological classes «Poor» and «Bad» in the 80th and early 90th; transition from late 90th to «Moderate», «Good» and even «High»; exception – «Poor» – was anomalous from climatic viewpoint 2010 (see Fig. 5).

The proposed ESC classification built on the basis of macrophytes' morphofunctional indicators reflects environmental status of an ecosystem connected with primary production process intensity and comprises such basic components as: - natural conditions (geographic location, morpho-physiological parameters of aquatic ecosystem, hydrodynamics etc.); - human pressures (eutrophication, pollution, transformation of biotope etc.); - climatic anomalies (temperature, light conditions, precipitation etc.) Comparison of the ESCs of Odessa region and the Danube Delta Front confirms this statement and illustrates the fact that natural conditions providing for higher production level, like, for example, in river deltas, estuaries and limans, bring down ecological status of sites. At that, climatic anomalies might decrease or increase the ESC depending on direction tendency of the factor. It is hence logical that in the period of 2006 – 2011 higher ESCs prevailed in Odessa region compared with the Danube Delta Front. During the anomalous 2010 sharp degradation of ecological status took place for each site due to intensification of primary production process in the North-Western Black Sea because of high water temperature (Fig. 6).

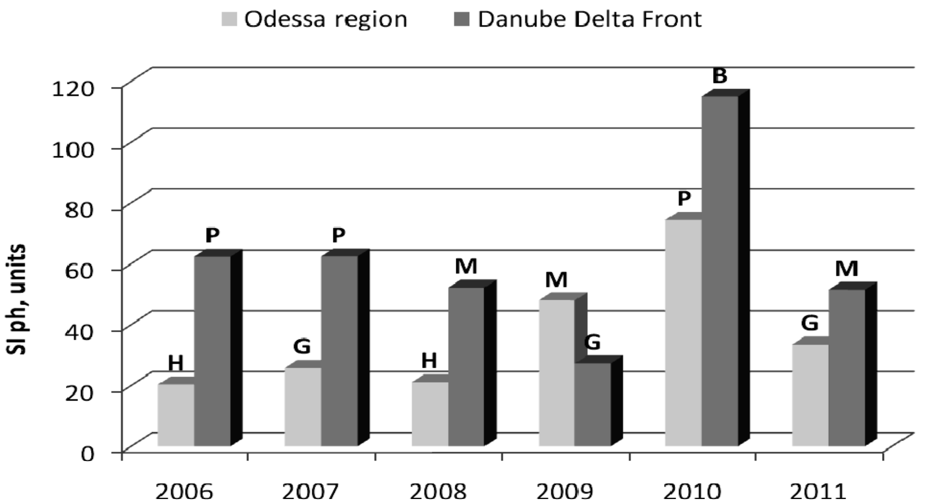


Fig. 6 Comparative characteristics of ESC between Odessa region and the Danube Delta Front: H – High; G- Good; M – Moderate; P – Poor; B –Bad
Рис. 6 Сравнительная характеристика экологических статус классов (ESC) Одесского региона и авандельты Дуная: H – высокий ; G – хороший ; M – средний; P – недостаточный; B – плохой

Conclusions.

- Use of macrophytes populations' ecological activity (S/W_p) coefficients for aquatic ecosystems' Ecological Status Class assessment according to the EU WFD requirements enables us to proceed from qualitative to quantitative assessment of bottom vegetation indicator role.
- The proposed morphofunctional indicators: Three Dominants Ecological Activity (S/W_{3Dp}); Average Species Ecological Activity (S/W_x)**;** Phytocenosis Ecological Activity (S/W_{ph}) and Phytocenosis Surface Index (SI_{ph}) for EEI quantification have differences in possibilities for spatial and temporal assessment of coastal ecosystems ecological status. In this regard, experts should choose this or that morphofunctional indicator depending on monitoring aims and peculiarities of submerged vegetation organisation.
- Categories of aquatic ecosystems' Ecological Status Classes received based on macrophytes' morphofunctional indicators are connected with intensity of primary production process, respectively – with water bodies' trophicity and biodiversity level. Accordingly, the results received using this method would reflect not only the strength of human pressure, but also the source natural conditions of the site being assessed, as well as climatic anomalies.
- Assessment of 26 water bodies in the Ukrainian Black Sea area carried out for the first time in accordance with the EU WFD requirements has shown that the structure of ratio between the ESC categories for the Ukrainian

Black Sea area and the Catalonian Mediterranean coast are similar.

- Long-term ESC dynamics for Odessa coast for the period 1980-2011 demonstrates the current trend of general improvement of the North-Western Black Sea coast ecological status, which has been significantly breached only in 2010 because of anomalous climatic situation.

Acknowledgments. The work has been performed under the State financial support to the fundamental project of the National Academy of Sciences of Ukraine «Use of Aquatic Vegetation for Indication and Environmental Management of the Azov and Black Seas Coastal Ecosystems». Stage: «Development of Ecological Parameters for Phyto-Indicators in Accordance with Water Frame Directive (WFD, 2000/60/EC) [10], Marine Strategy Framework Directive (MSFD, 2008/56/EC) [11] Requirements Based on Morphofunctional Methodology». The author would like to express her sincere gratitude to the staff of Morphofunctional Ecology of Aquatic Vegetation Department, Institute of Biology of Southern Seas, Odessa Branch (National Academy of Sciences of Ukraine) for many years' collaboration and assistance in collecting and discussing of the materials used in preparation of this paper.

1. *Adobovskiy V., Alexandrov B., Bogatova Yu.* et al. Reactions of aquatic ecosystems of northwestern Black Sea region on the climate anomalies // 3rd Bi-annual BS Scientific and UP-GRADE BS-SCENE EC Project Joint Conference (Odessa, Ukraine, Oct. 31 – Nov. 4, 2011): Abstr. – Odessa, 2011 – P. 164 - 165.
2. *Andersen J. H, Murray C., Kaartokallio H.* et al. A simple method for confidence rating of eutrophication status classification // Marine Pollution Bulletin. – 2010. – 60. – P. 919 – 924.
3. *Arevalo R., Pinedo S., Ballesteros E.* Change in the composition and structure of Mediterranean rocky-shore communities following a gradient of nutrient enrichment: descriptive study and test of proposed method to asses water quality regarding macroalgae // Mar. Poll. Bull. – 2007. – 55. – P. 104 – 113.
4. *Ballesteros E, Torras X., Pinedo S.* et al. A new methodology based on littoral community cartography dominated by macroalgae for the implementation of the European Water Framework Directive // Mar. Poll. Bull. – 2007. – 55. – P. 172 – 180.
5. *Berov D, Karamfilov V., Vasilev V.* et al. Benthic macroalgal communities as Ecological Quality Indicator of Bulgarian Black Sea coastal water // J. Balkan Ecology. – 2010. – **13**, No 2. – P. 161 – 171.
6. *Bolshakov V., Bolshakov M.* The streams of solar energy for different orientated surface of hydrotechnical constructions // Ukr. Hydro-meteorol. J. – 2010. – 7. – P. 220–231. (in Russian).
7. *Chaylov K., Parchevskiy V.* Hierarchical regulation of the structure and function of the marine plant. – Kiev: Pub. Naukova dumka, 1983. – 253 p. (in Russian).
8. *Chaylov K., Prazukin A., Kovardakov S.* et al. Functional morphology of marine macroalgae. – Kiev: Pab. Naykova Dumka, 1992. – 280 p. (in Russian).
9. *Dencheva K.* State of macrophytobenthic communities and ecological status of the Varna Bay, Varna lakes and Burgas Bay // Phytologia Balcanica. – 2010. – **16**, No 1. – P. 43 – 50.
10. *DIRECTIVE 2000/60/EC* of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, 23 October 2000. (WFD, 2000/60/EC)
11. *DIRECTIVE 2008/56/EC* of the European Parliament and of the Council establishing a framework for Community action in the field of marine environmental policy, 17 June 2008. (MSFD, 2008/56/EC)
12. *HELCOM* Development of tools for assessment of eutrophication in the Baltic Sea Balt // Sea Environ. Proc. – 2006. – No 104. – 62 p.
13. *GIOS* (2009) Development of measurement and classification method of biological quality elements used in the procedure of ecological status assessment of marine transitional and coastal water bodies including participation the European intercalibration exercise NFOZ, IM and IMGW 2009, mimeorg.. – 100 p. (in Polish).
14. *Littler M., Littler D.* The evaluation of tallus form and survival strategies in benthic marine macroalgae: field and laboratory test of a functional form model // American Naturalist. – 1980. – **116**. – P. 25 – 43.
15. *Littler M., Littler D., Taylor P.* Evaluation strategies in a tropical barrier reef system: functional-form group of macroalgae // J. Phycol. – 1983. – **19**. – P. 223 – 231.
16. *Minicheva G.* Responses of macroalgae under eutrophycaton of the ecosystems // Algology. – 1996. – **6**, No 3. – P. 250 – 257. (in Russian).
17. *Minicheva G.* Prediction changes of the marine vegetation in the conditions of euthrofication of the coastal ecosystems / Partnership in Coastal Zone

Management. – Samora Pub. Lim,, 1996. – P. 541 – 547.
18. *Minicheva G. G.* Morphofunctional fundamentals of formation of marine phytobenthos: D. Sc. Thesis Dissertation, Sebastopol, 1998. – 32 p. (in Russian).
19. *Minicheva G.* Use of surface indexes of benthos algae for express diagnostics of the tropho-saprobiotic status of marine coastal ecosystem // Algology. – 1998. – **8**, 4. – P. 419 – 427. (in Russian)/
20. *Minicheva G.* Theoretical and practical possibilities of morphofunctional approach at research of algae community // Algology. – 1999. – **9**, No 2. – P. 89 – 90. (in Russian)
21. *Minicheva G.* Contemporary morpho-functional transformation of seaweed communities of the Zernov Phyllophora Field // Intern. J. Algae. – 2007. – **9**, No 1. – P. 1 – 21.
22. *Minicheva G., Maximova O. V., Morushkova N. A.* et al. State of the environment of the Black Sea (2001-2006/7) / State of the Environment of the Black Sea (2001-2006/7). – Istanbul, Turkey, 2008. – P 247 – 272.
23. *Minicheva G., Zotov A., Kosenko M.* Methodical recommendations on the determination of a number of morphofunctional indexes of unicellular and multicellular forms of aquatic vegetation. GEF project for recovery of the ecosystem of the Black Sea. – Odessa, 2003. – 32 p.
24. *Orfanidis S., Panayotidis P., Stamatis N.* Ecological evaluation of transitional and coastal waters: A marine benthic macrophytes-based model // Mediterr. Mar. Sci. – 2001. – **2**, No 2. – P. 45 – 65.
25. *Orfanidis S., Panayotidis P., Stamatis N.* An insight to the ecological evaluation index (EEI) // Ecological Indicators. – 2003. – **3**, 1. – P. 27 – 33.
26. *Orfanidis S., Papathanasiou V., Sabetta L.*et al. Benthic macrophyte communities as bioindicators of transitional and coastal waters: relevant approaches and tools // Transitional Waters Bulletin. – 2007. – **3**. – P. 45 – 49.
27. *Orfanidis S., Panayotidis P., Ugland K.* Ecological Evaluation Index continuous formula (EEI-c) application: a step forward for functional groups, the formula and reference condition values // Mediterr. Mar. Sci. – 2011. – 12. – P. 199 – 231.
28. *Orlando-Bonaca M., Lipej L., Orfanidis S.* Benthic macrophytes as a tool for delineating, monitoring and assessing ecological status: The case of Slovenian coastal waters // Mar. Pollut. Bull. – 2008. – **56.** – P. 666 – 676.
29. *Osowiecki A., Lysiak-Pastuszak E., Kruk-Dowgiallo L.* et al. Development of tools for ecological quality assessment in the Polish marine areas according to the Water Framework Directive. Part IV – preliminary assessment // Intern. J. Oceanography and Hydrobiology. – 2012. – **41**, 3. – P. 1 – 10.
30. *Panayotidis P., Montesanto B., Orfanidis S.* Use of low-budget monitoring of macroalgae to implement the European Water Framework Directive // J. Appl. Phycol. – 2004. – **16**. – P. 49 – 59.
31. *Pianka E.R.* On r and k selection // American Naturalist. – 1970. – **104**, No 940. – P. 592 – 597.
32. *Pinedo S., Garcia M., Satta M.P.* et al. Rocky-shore communities as indicators water quality: A case study in the Northwestern Mediterranean // Marine Pollution Bulletin. – 2007. – 55. – P. 126 – 135.

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Використання морфофункціональних параметрів макрофитів для оцінки екологічного статус-класу відповідно до Водної Директиви ЄС. Г. Г. Мінічева. Для оцінки екологічного статус-класу (ESC) морських прибережних екосистем, відповідно до вимог Водної Директиви Євросоюзу (WFD) пропонується використовувати комплекс морфофункціональних показників макрофитів. Розглядаються переваги переходу від якісного до кількісного вираження екологічного оцінного індексу. Для чотирьох морфофункціональних показників: Екологічна активність трьох доминатів (S/W_{3Dp}); Середня екологічна активність видів (S/W_x); Екологічна активність фітоценозу (S/W_{ph}); Індекс поверхні фітоценозу (SI_{ph}) приводяться формули розрахунку, класифікаційні схеми відповідно до вимог WFD. Обговорюються переваги і недоліки чотирьох запропонованих показників при використанні їх в моніторингу морських прибережних екосистем. Наводяться результати просторової оцінки ESC водних акваторій українського сектору Чорного моря і їх довготривалої динаміки для Одеського узбережжя за період 1980-2011 рр. Отримані результати демонструють схожу структуру співвідношення категорій ESC для українського узбережжя Чорного моря і каталонського узбережжя Середземного моря, а також сучасну тенденцію поліпшення екологічного статусу українського узбережжя, яка останніми роками стала порушуватися у наслідок аномальних кліматичних умов.

Ключові слова: макрофіти**,** морфофункціональні параметри, екологічний статус клас, Водна Директива ЄС, Чорне море

Использование морфофункциональных параметров макрофитов для оценки экологического статус-класса в соответствии с Водной Директивой ЕС. Г.Г. Миничева. Для оценки экологического статус-класса (ESC) морских прибрежных экосистем, в соответствии с требованиями Водной Директивы Евросоюза (WFD) предлагается использовать комплекс морфофункциональных показателей макрофитов. Рассматриваются преимущества перехода от качественного к количественному выражению экологического оценочного индекса. Для четырех морфофункциональных показателей: Экологическая активность трех доминатов (S/W_{3Dp}); Средняя экологическая активность видов (S/W_x); Экологическая активность фитоценоза (S/W_{ph}); Индекс поверхности фитоценоза (SI_{ph}) приводятся формулы расчета, классификационные схемы в соответствии с требованиями WFD. Обсуждаются преимущества и недостатки четырех предлагаемых показателей при использовании их в мониторинге морских прибрежных экосистем. Приводятся результаты пространственной оценки ESC водных акваторий украинской части Черного моря и их долговременной динамики для Одесского побережья за период 1980-2011 гг. Полученные результаты демонстрирует сходную структуру соотношения категорий ESC для украинского побережья Черного моря и каталонского побережья Средиземного моря, а также современную тенденцию улучшения экологического статуса украинского побережья, которая в последние годы стала нарушаться в результате аномальных климатических условий.

Ключевые слова: макрофиты, морфофункциональные параметры, экологический статус класс, Водная Директива ЕС, Черное море