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RESPONSE OF AUTOTROPHIC COMMUNITIES OF THE NORTHWESTERN BLACK SEA TO THE VARIABILITY OF CLIMATIC FACTORS

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Abstract. The issue on the response of aquatic vegetation to possible climatic changes is considered in the study of seaweeds and phytoplankton communities in the north-western Black sea (NWBS). It has been shown that the variability of temperature and illumination has a great effect on the restructuring of autotrophic communities in relation to the tendency of changes in their average annual values. On the basis of empirical data, the values of daily interseasonal and interannual variability for temperature, light flux, and structural-functional parameters of phytobenthos and phytoplankton communities for the past ten-year period were estimated. The conclusion is natural flexibility of seaweeds and phytoplankton communities of moderate latitudes guarantees from 2 to 6 times a high stability to contemporary tendencies of climatic changes. The most vulnerable are seaweeds on the shelf developing in stable conditions at depths of 25–50 m. Unstable weather conditions may cause anomalies, to which sensitivity of vegetative communities is higher than for the tendency to change the average annual temperature. Anomaly according to absolute unit is greater than standard deviation it causes significant changes 2 and more fold in the level of the production process and disturbance in the floristic structure of communities. In the past 10-year period in NWBS the greatest temperature anomalies with significant response of vegetative communities were recorded in 2002–2003 years.

Keywords: seaweeds, phytoplankton, temperature, illumination, variability.

AIMS AND BACKGROUND

The aim of the present paper is to make a qualitative evaluation of the temporal (daily, interseasonal, interannual) and spatial (shallow water, deep water) variability of some climatic factors (temperature, solar energy flow), to compare the given values with analogous parameters of changes in the structural-functional organisation of phytobenthos and phytoplankton communities in the north-western Black sea (NWBS), and to assess the degree of natural flexibility of communities with different living forms of autotrophs which are resistant to possible climatic changes.

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The intensity in climate changes today has become one of the challenging issues of modern civilisation. Today the most significant occurring climate changes are revealed through increasing mean average temperatures and rise in weather instability (heavy rainfall deposits, squalls, cyclones) caused by disturbances in the hydrological cycle[1].

A special part in this issue is attributed to seas and oceans. On the one hand, the hydrosphere is an important element in the formation of climatic conditions, on the other, oceanic and marine ecosystems contain a large part of the planetary biological resource which as a result of climatic transformations can change its quality and quantity significantly.

In the context of the issue, the Black sea ecosystem is an important ecological and social facility as its highly productive ecological resource is used by 6 densely populated riparian countries. The NWBS area is limited by a line extending from the cape Tarkhankut (Crimean Peninsula) to the Zmeiny island making up the economic zone of waters of Ukraine. The NWBS includes the coastal zone and the wide shelf platform into which 3 large European rivers (Danube, Dniester, Dniepr) cast their runoff of 270 km^3/year (Ref. 2). Situated in moderate latitudes with a marked seasonal fluctuation of climatic factors, the ecosystem of this area undergoes significant changes in abiotic conditions due to relative shallow water (maximum depth of 60 m) and variations in volume and quality of river runoff. In these natural instable conditions autotrophic communities develop. They are represented by planktonic and benthic forms of unicellular and multicellular algae which are characterised by a certain natural flexibility as a result of adaptation to conditions of the ecosystem. For the NWBS region there is a large empirical material which reflects the more than 50-year dynamics of the main hydrological-hydrochemical and biological parameters, including data on floristic diversity and production processes of communities of aquatic vegetation[3].

The reaction of autotrophic communities to changes in climatic factors is a particular case in the fundamental ecological mechanism which provides dynamic balance between abiotic and biotic components of the ecosystem. The new complex of parameters based on those of the surface of multicellular and unicellular algae allowed to describe quantitatively the reorganisation of the structural-functional organisation of the plant communities under the influence of changes in the intensity of the energy flow passing through the aquatic ecosystem[4]. Taking into consideration that climatic changes are besides changes in absolute average annual values, the variability of abiotic factors rises. The question arises: what is the reserve of natural flexibility of autotrophic NWBS communities to resist possible climatic changes without disturbing recently the intensity of the production process and floristic diversity.

This paper is a first attempt to compare fluctuations in climatic factors and the corresponding reaction force of autotrophic communities for a concrete area in the Black sea ecosystem.

EXPERIMENTAL

For assessing NWBS temperature changes, rows of average monthly temperatures of coastal waters for the period of 1997–2007 (Hydrophysical laboratory, Odessa Ecological University) were used. The evaluation of solar energy flux was carried out on the basis of estimated data of changes in the height of the sun above the horizon in daily and annual cycles for the latitude of the Odessa coast. For the shelf zone the illumination of the bottom was done according to the transparency index by the Secchi disk.

For bottom vegetation, samples of coastal phytobenthos of the Danube–Dnieper interfluve (0–10 m) were taken including monitoring stations on the Odessa coast for 1997–2007. The dynamics of deepwater communities of seaweeds of the shelf zone (25–50 m) were analysed on the basis of international cruises within the framework of the Black Sea Ecological Program (r/v 'Akademik', Bulgaria, September–October 2004, July 2006; r/v 'Poseidon', Germany, March 2008). The dynamics of communities of coastal phytoplankton were analysed for 2000–2007 by the structural-functional parameters of deep water communities (Ukrainian Centre of Ecology of the Sea, r/v 'Vladimir Parshin', Ukraine, May 1999, December 2004, January 2005). For analysis of changes in the daily production of phytoplankton, literature data were used[5].

For quantitative evaluation of structural-functional parameters of planktonic and benthic communities besides the classic parameters – species composition, abundance, biomass, additionally were used parameters based on those of the surface of unicellular and multicellular algae – specific surface (S/W) of the floristic composition of communities, surface index (SI) of phytoplankton and phytobenthos community[6].

The main methodological technique was used for statistical evaluation of the degree of changes in climatic and biological indices applying the same universal coefficients. The biological rows of observations in contrast to hydrometereological ones, as a rule, have a lower frequency and periodicity of primary data. At the same time they have a wavy character of dynamics. In this connection the most universal index – the coefficient of oscillation – was selected. This coefficient is estimated as the relation of range of deviation to average value of the row expressed in % (V_R) (Ref. 7). V_R for the abiotic factors and structural-functional parameters of autotrophic communities was calculated for analogous temporal intervals (daily, interseasonal, interannual) and spatial zones of NWBS (coastal – 0–10 m and shelf – 25–50 m).

For the temperature rows for 1997–2007 the annual anomalies were calculated by average monthly anomalies after excluding the annual cycle and linear temperature trend.

RESULTS AND DISCUSSION

One of the most widespread indices of evaluation of changes in climatic conditions is the average annual temperature. The analysis of this index for sea water near the NWBS Odessa coast showed that in the past decades, a tendency was observed for an increase in the average annual temperatures by 1.7 C°. This can be explained by the not large time interval analysis and specific conditions in the NWBS related with shallow water and large volume and transformations of the river runoff. The absolute values of the average annual temperatures show a characteristic, sufficient stability. Maximum difference between the warmest and coldest year is 2°C (Fig. 1). V_R of average annual water temperature for this period was 17%. A significant absence of relation between the average annual temperature and average annual values of ecological activity of the floristic composition of communities S/W, abundance, biomass, SI of coastal communities of plankton and phytobenthos has been observed.

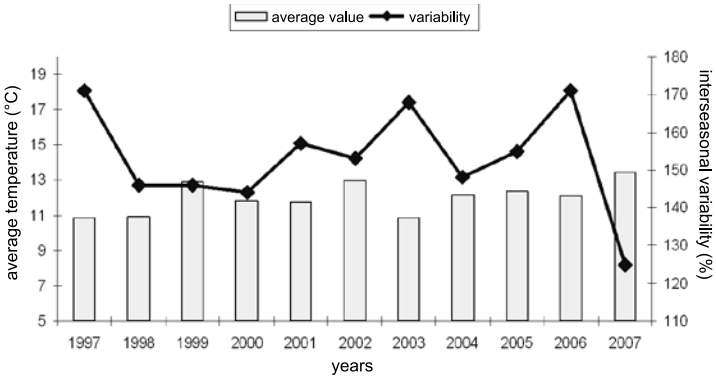

Fig. 1. Dynamics of average annual temperature and interseasonal variability of sea water along the Odessa coast in 1997–2007

The index of interseasonal temperature variability illustrates the thermogradients in which metabolism of hydrobionts takes place all year round. Changes in climatic factors determine the movement of the energy flux passing through the autotrophic communities. As a result of the responses of aquatic vegetation, interseasonal fluctuation of the level of the primary production process takes place and the floristic structure of the community is restructured. The interseasonal temperature variability for different years in the study area for the past decade was almost twofold higher in comparison to V_R of average annual water temperature, making

up 30%. Maximum changes in the interseasonal temperature regime were noted for 1997, 2003 and 2006 (see Fig. 1). It has been revealed that the community of unicellular plankton algae and coastal macrophytes is more sensitive to the interseasonal temperature variability in contrast to its mean annual values. The correlation coefficient between the interseasonal changes in structural-functional parameters of communities of phytoplankton and phytobenthos makes up 0.87±0.3.

Parallel analyses of V_R daily, interseasonal and interannual temperatures, solar energy flux and structural-functional parameters of phytoplankton and phytobenthos communities showed the following regularity. For temperature, maximum variability is noted for the interseasonal period. For phytobenthos the most significant changes take place in seasonal restructuring of the floristic structure of communities. Interseasonal values of V_R for both of these components of the dynamic system are equal to 156 and 190%, correspondingly. The light flux changes markedly during the day (V_R – 225%). Also the intensity of the primary production process changes greatly in small-cycled unicellular forms of phytoplankton (V_R – 500%), bearing rapid physiological response. The smallest change in climatic factors and parameters of autotrophic communities of the NWBS ecosystem is characteristic for interannual dynamics (Fig. 2).

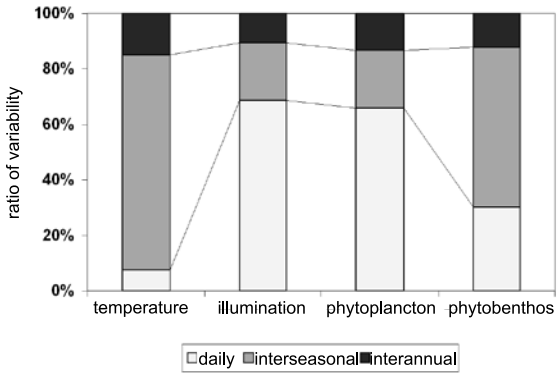

Fig. 2. Ratio of daily, interseasonal and interannual variability of temperature (°C), illumination (MgJ m^{-2}), parameters of communities of phytoplankton (abundance, biomass, S/W of floristic composition, SI of community) and phytobenthos (S/W of floristic composition, SI of community) in NWBS ecosystem in 1997–2007

When the structural-functional parameters of vegetative communities begin to leave the borders of the range of natural fluctuation characteristics for the concrete area, these responses are qualified as deviations. They occur in changes in floristic diversity, transformation of the structure of communities replacing dominant species, in significantly increasing or decreasing the intensity of the production process. Climatic changes belong to long-periodic processes which first occur at the level of interannual dynamics. It is clear that there is a necessity to evaluate

natural flexibility (cyclic fluctuations without deviation) for interannual changes in autotrophic communities having quick (unicellular algae) and more protracted responses (seasonal and perennial macrophytes).

The degree of natural flexibility can be evaluated as the relation of V_R of the plants community to the V_R of abiotic factors. These relations are important to evaluate for factors which cause maximum flexibility in different types of aquatic plants. For example, the greatest change in photosynthesis in short-cycle forms of phytoplankton causes the factor of illumination. For long-cycle macrophytes this factor is temperature, which causes maximum interseasonal restructuring of the floristic structure of the phytobenthic community. However, the assessment of this relation for different types of vegetative communities of NWBS has shown that all kinds of V_R (daily, interseasonal, interannual) of phytoplankton and phytobenthos exceed the corresponding V_R factors determining their maximum flexibility (Fig. 3). Interannual flexibility of coastal phytobenthos is 2-fold greater than the interannual variability of the temperature and 1.2-fold greater than the interannual variability of the flow of solar energy. The interannual flexibility of phytoplankton exceeds 6-fold the interannual variability of the temperature and 3-fold of the flux of solar energy.

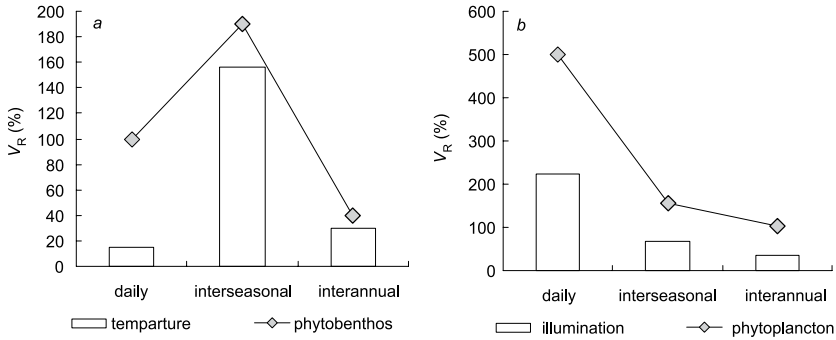

Fig. 3. Ratio of the oscillation coefficient between climatic factors and NWBS autotrophic communities: *a* – V_R illumination (MgJ m^{-2}) and V_R phytoplankton parameters (for daily dynamics – production parameters were analysed; for interseasonal and interannual – abundance, biomass, S/W of floristic composition, SI of community); *b* – V_R temperature (°C) and V_R phytobenthos parameters (for daily dynamics – production was analysed; for interseasonal and interannual – S/W of floristic composition, SI of community)

Differences have been revealed in the V_R values for attached and free floating vegetative communities, developing in zones with different variability of abiotic factors. The conditions of development of benthic macrophyte communities in the NWBS shelf zone at depths of 25–50 m are 3-fold more stable for temperature and illumination in comparison to coastal biotopes (0–10 m depths) (Fig. 4). The seaweed communities of which red algae of the *Phyllophora* G r e v. and *Polysiphonia* Grev. genera are dominant in present-day conditions have a lower magnitude of

interseasonal flexibility of ecological activity of the floristic structure in contrast to coastal phytobenthos. Development in stable conditions has significantly lowered their flexibility which makes them more vulnerable than the coastal phytobenthos, even if there is an insignificant change in their habitat. Communities of coastal and deepwater phytoplankton do not have significant changes in the variability of the structural functional parameters. It is evident that phytoplankton freely moving between the shallow and deepwater zones has no set law governing it as for attached algal species.

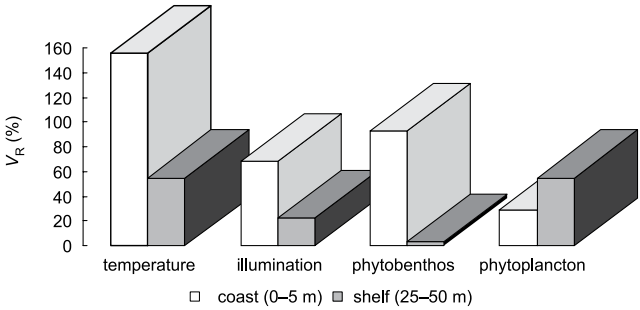

Fig. 4. Interseasonal variability of abiotic factors and autotrophic communities for NWBS coastal and shelf zones (V_R for the phytobenthos and phytoplankton communities was estimated according to S/W indices of floristic composition)

The rising instability of weather conditions during climatic changes causes a rise in variability of the temperature factor which leads to temperature anomalies. For the past decade, maximum heat anomaly was observed in 2002, and maximum cold – in 2003. The positive anomaly in 2002 according to the absolute value exceeded the standard deviation 1.7-fold, while the negative anomaly in 2003 exceeded it 2.4-fold (Fig. 5). According to the laws of dynamic equilibrium, in the winter of 2002–2003 until the end of 2003, responses occurred in NWBS communities of coastal phytobenthos which exceeded the natural flexibility characteristic for this area. A 2-fold increase in the production process was registered. The law of seasonal dynamics of floristic composition was disturbed. The period of development of winter macrophytes was shifted for 6–7 weeks. The brown algae of the cold period: *Desmorestia viridis* (O. M u l l. in H o r n e m) J. V. L a m o u r., *Punctaria latifolia* G r e v., *Ectocarpus confervoides* = *E. siliculosus* (D i l l w y n) L y n g b. developed until mid-July.

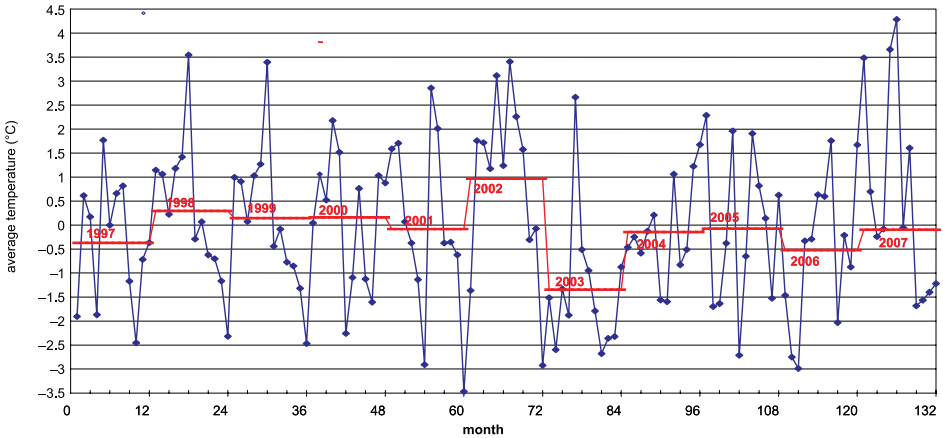

Fig. 5. Monthly and annual temperature anomalies in the Odessa coast

CONCLUSIONS

Analysis of the response of NWBS autotrophic communities to changes in climatic factors allows to make the following conclusions:

• In marine ecosystems of moderate latitudes the variability of climatic factors mostly is linked with restructuring responses of vegetative communities when comparing with mean values. For NWBS phytoplankton and phytobenthos a significant relation has not been revealed between the average annual temperatures and structural-functional parameters of communities. The correlation between the oscillation coefficients of these parameters is 0.87 ± 0.3.

• The variability of climatic factors and parameters of autotrophic communities for different time intervals has significant differences. Maximum values of variability for the NWBS ecosystem are characterised by daily dynamics of illumination (225%) and interseasonal temperature dynamics (156%). Minimum values – interannual are 35 and 30%, correspondingly. In unicellular short-cycle algae the highest variability of functional processes occurred during daily fluctuations (500%). For long-cycle macrophytes the highest change in the community structure occurred in the interseasonal dynamics (190%).

• The high natural flexibility of moderate latitudes guarantees a sufficiently high stability for this group of aquatic vegetation to modern tendencies of climatic changes. At present all types of variability (daily, interseasonal and interannual) of NWBS phytoplankton and phytobenthos are higher than the variability of climatic factor. Interannual flexibility of NWBS coastal phytobenthos is 2-fold higher than the interannual temperature variability and 1.2-fold higher than the solar energy flow. The interannual flexibility of phytoplankton 6-fold exceeds the interannual temperature variability and 3-fold the solar energy flow.

• Attached communities of aquatic vegetation developing in stable conditions have lower natural flexibility. On the shelf at 25–50 m depths, the variability abiotic factors in 3-fold lower than in coastal biotopes (0–10 m). Correspondingly, the most vulnerable to climatic changes of seaweeds communities develop, the natural flexibility of which is a magnitude less than in coastal phytobenthos. This is not evident for the free-floating NWBS phytoplankton communities.

• The unstable weather conditions characteristic for climatic changes can cause a rise in the temperature factor to an anomalous level. Anomalies in absolute units exceeding standard deviations 2-fold and more cause disturbances in the level of the production process and floristic structure. For the past decade 2002 was an anomalous warm and 2003 an anomalous cold year. During this period the coastal phytobenthic production rose 2-fold and there was a 6–7 week shift in seasonal development of floristic composition.

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