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RUBRICS

A Decade of Observations of Intertidal Benthic Communities at the Water Area of Vitino Specialized Marine Oil Port (Northern Part of Kandalaksha Bay, White Sea): A Methodological View

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Abstract—Studies of the intertidal benthos of the water area of the Vitino Specialized Marine Oil Port using typical hydrobiological methods were carried out for more than ten years. From the analysis of the structure of intertidal communities using different mathematical methods, a quasi-cyclic dynamics of their biomasses was found. The dynamics of the main features of the intertidal blue mussel bed was found at one particular sampling site. In addition, some analytical approaches to the expert assessments of the state of sea floor ecosystem are discussed specifically regarding the diagnostics of the anthropogenic influence. It was shown that a single sampling cannot serve as reliable assessment due to permanent quasi-cyclic processes taking place in the intertidal communities, and the applied methods based on a sampling taking into account the shifting alongside *K*-, *r*-axis should be used only with great precaution. Long-term monitoring is needed to make the proper conclusions. The number of samplings at each station should be set in a way that can help outweigh the aggregated distribution of particular species.

Keywords: intertidal marine benthos, long-term monitoring, quasi-cyclic dynamics, White Sea, bioindication
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INTRODUCTION

The state of the marine benthos is a fairly reliable indicator of the water purity, but a particular question arises with regard to the methodological approaches and the possibility of obtaining an unambiguous result through expert assessments based on single-time sampling. Obviously, such an approach is based on *a priori* hypothesis of the invariability of the structure and functioning of benthic communities, when the state of the environment is stable. Meanwhile, a few observations over many years give us a reason to believe that there are very long-lasting processes that take place in a number of marine (and other) communities and that are caused by various autogenous reasons (see, for example, Maksimov, Erdakov, 1985; Lukanin et al., 1986a, 1986b, 1989, 1990; Ibanez, Dauvin, 1988; Maksimovich et al., 1991; Oshurkov, 2000; Naumov et al., 2009, etc.).

It should be noted that testing fresh water for chronic pollution has been developed much better in comparison to testing saline water due to a number of both objective and subjective reasons. This is caused both by its greater importance as a drinking source and by a number of features of marine water bodies and the organisms inhabiting them, as well as by significant differences in the faunistic composition of the marine and freshwater basins (Rosenberg et al., 1993).

The importance of direct chemical analysis of water, so reliable for lakes, is markedly reduced in the analysis of pollution of rivers and, especially, of tidal seas. Dissolved in a thin surface layer of water, a pollutant that is readily detectable analytically may have no effect on the intertidal bottom inhabitants if this pollutant is brought by a tidal current, since its action is neutralized by protective mechanisms that prevent moisture loss during drying out at low tide during the brief moment of its contact with benthic organisms, and then they are covered again by a layer of more pure water. Conversely, a pollutant brought by an overflowing current, which has a destructive effect on the intertidal fauna and flora, may not be detected analytically during the high tide if the tidal current comes from an uncontaminated place. The velocities of tidal currents, especially in the areas with numerous islands and narrow strait tide gates, are very high, and this may transfer the water over many kilometers.

In such a situation, bioindication becomes extremely relevant, as the intertidal community, constantly washed by the waters coming from different parts of the water area, reflects the net effect of all the substances contained in it.

It should also be kept in mind that, on the one hand, many indices of the ratios of different groups of freshwater aquatic organisms were mainly developed for evaluation of domestic wastewater, but not industrial gray water; on the other hand, in some cases, these indices may not work for marine waters due to the physiological differences of the representatives of freshwater and marine fauna and flora (Smith, 2003).

Freshwater organisms live in an osmotically aggressive environment and are constantly forced to maintain their water–salt balance in a variety of ways. These include the active transport of water and various ions against the concentration gradient and (or) the use of a variety of isolation mechanisms. The latter also contribute to protection against pollution. As a result, in the case of an anthropogenic impact on fresh water, the abundance ratio of various taxonomic groups of marine organisms shifts in one direction or another, depending on the way various taxonomic groups maintain ionic equilibrium.

Marine organisms are mostly transparent to their environment, and their water–salt balance is largely maintained by seawater, which has very powerful buffer properties. Therefore, the differential displacement of proportions in the abundance of different groups of organisms often does not occur in marine waters. All the reasons given above explain why many researchers seek for reliable criteria based on the other principles that would make it possible to determine the state of marine biota under the integrated characteristics of bottom communities (Tomlinson et al., 1980; Andrade, Renauld, 2011).

To date, two fairly reliable methods have been developed that allowed us to estimate the level of the shift in the structure of communities from a stable state. The first of these, widely used by Russian researchers, is the *k*-dominant, or *ABC*, analysis (Warwick, 1986, Warwick et al., 1987) and its various modifications; it is based on the assumption that a few large specimens predominate in an intact community. This means that species in such a community are mainly subjected to *K*-selection, which indicates the stability of the conditions. The second approach uses a modification of the known indicator of the information diversity of C. Shannon (Shannon, 1948); it is proposed by S.G. Denisenko (2006) and represents the difference in leveling of the biomass and density of the community of benthic organisms. Both methods give similar results, but the method of Denisenko seems to be more correct for a number of reasons, both mathematical and biological. Both methods, by their very nature, do take into account the role of modular organisms; therefore, if data on intertidal ecosystems are used, the abundance of algae is ignored, which is a serious drawback of both approaches.

For more than 10 years, we have been carrying out hydrobiological monitoring of the state of intertidal benthic communities (see next section) potentially affected by petroleum products. Thus, it was possible to evaluate the applicability of the indices mentioned above and to test some other indices and approaches to be used in the analysis of the bioindication properties of the intertidal macrobenthos.

DATES AND AREA OF RESEARCH

This study was carried out in the water area of Vitino Specialized Marine Oil Port (the top of Kandalaksha Bay, White Sea) at the end of July and beginning of August from 2003 through 2013, in order to monitor the state of the intertidal benthos near the oil terminals; they were terminated due to the shutdown of the port and, as a result of this termination, of the primary funding.

From the very beginning of the study, the three sampling points were studied in the inland water area of the port:

Station 1 is located north of the oil terminal (67°04.93′ N, 32°19.00′ E); the average summer salinity during the observation period was 17.5 ppt, and the average temperature of the bottom surface at low tide was 15.4°C (original data). Here and below data on the temperature of the bottom and the salinity of the surface water are available only for the last few years of study, so they are indicative and are given in the text without statistical errors.

Station 2 is located south of the oil terminal (67°04.72′ N, 32°19.88′ E); the average summer salinity during the observation time was 19.0 ppt, and the average temperature of the bottom at low tide was 16.4°C (original data).

Station 3 is located in the intertidal zone of Korov'ya Inlet of Olenii Island, on the opposite side of Olen'ya Salma Strait (67°05.59′ N, 32°22.14′ E). The average summer salinity during the study period was 17.3 ppt, and the average temperature of the bottom at low tide was 15.3°C (original data).

Station 4 was selected as the control point in the external water area of the harbor. It is located on the intertidal zone of the mainland part of the Zapadnaya Ryazhkova Salma Strait (67°00.71′ N, 32°31.31′ E), about 13 km away from the oil terminals. The average summer salinity during the study period was 19.5 ppt, and the average temperature of the bottom at low tide was 14.0°C (original data). At this point, observations were conducted until 2015.

Through the monitoring activities, it became clear that the selected points were not sufficient to reach the goal and the studies were extended to the water area of the ZAO "Belomorskaya Neftebaza" tank farm, adjacent to Vitino Specialized Marine Oil Port water area.

Station 5 is located in the mouth of a stream flowing from the treatment facilities of the harbor, the oil

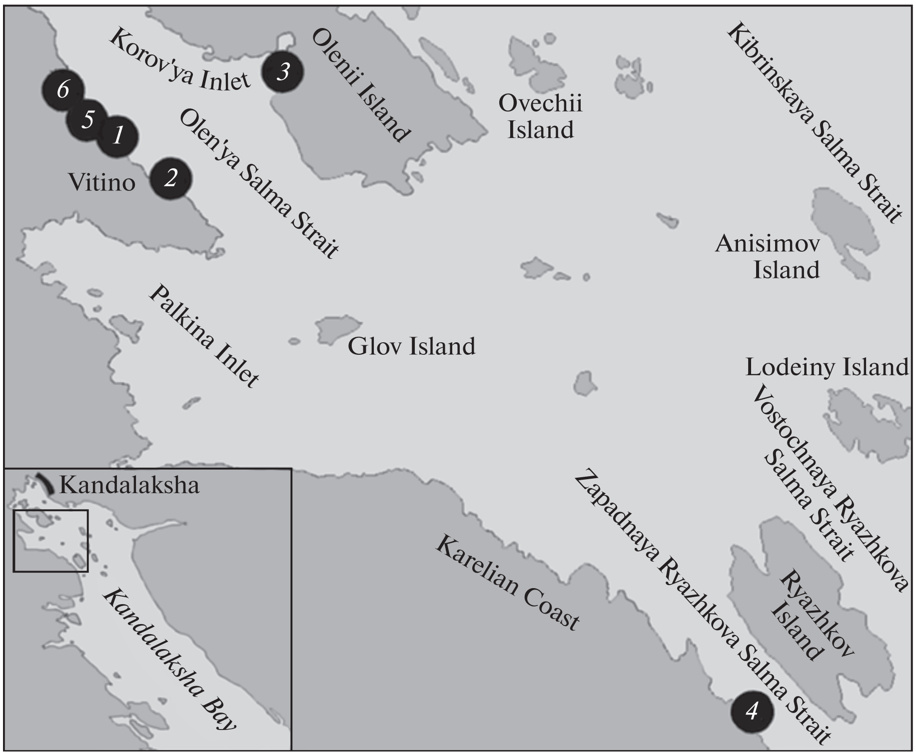

Fig. 1. Schematic map of the sampling sites. Black circles with numbers indicate intertidal benthic stations. In the cutaway in the lower left corner, a black rectangle indicates the area of the Vitino Specialized Marine Oil Port. Cartographic basis of the scheme: navigation map no. 639 Kandalaksha Port with approaches, ed. 1969 (basic scheme) and the general map of the White Sea no. 10306, ed. 1999 (cutaway).

depot, and the Beloe More village (67°05.00′ N, 32°18.69′ E). The average summer salinity during the observation period was 11.5 ppt, and the average temperature of the bottom at low tide was 15.0°C (original data). Observations at this station were conducted from 2008 to 2013.

Station 6 was added to the observation scheme in 2009 in order to compare the data obtained in the water area of the Vitino Specialized Marine Oil Port with a deliberately contaminated site (67°05.10′ N, 32°18.44′ E). The pollution of this point took place due to its geomorphological structure. A small bight, where the study site was located, is connected to the territory of the tank farm by a local depression, so a significant part of the spilled oil went into the sea even when the spills of petroleum products were small.

The average summer salinity during the study period at this point was 18.3 ppt, and the average temperature of the bottom at low tide was 16.5°C. It is located to the northwest of the previous station, about 200 m apart from it. Here, the observations were conducted from 2009 through 2013.

A map of the sampling site is presented in Fig. 1.

The content of hydrocarbons of petroleum origin over the study period is shown in Fig. 2 (the methodology is described in the next section). It is obvious that, in the known cases, the pollution of the water in the harbor water area was generally very moderate, but in 2011 at station no. 6, an accidental spill of approximately 80 kg of oil products occurred, and a significant amount of it fell into the sea. The place of the spill was immediately blocked by a double boom containment. In 2011, in some places on the inner side, there were quite significant accumulations of oil products that were not registered for the next two years of observations. From the seaward side of the boom containment, the content of the petroleum organic compounds at low tide was 0.07 mg/kg. This value exceeds the maximum permissible concentration for fishery reservoirs by 0.02 mg/kg. However, in general, the pollution of the water area increased significantly and slightly exceeded the MPC for the reservoirs for general sanitary purposes. By 2013, the situation had improved and the concentration of petroleum hydrocarbons did not exceed the MPC for fishery water bodies.

This study was carried out annually, however, due to the working environment of the harbor, there were omissions at almost all the studied stations, except station no. 4.

At all stations, except station no. 5, the intertidal is of the same type and is represented by a more or less rarefied boulder deposit on a gravel–sand base lined with clay material. At station no. 5, located at the

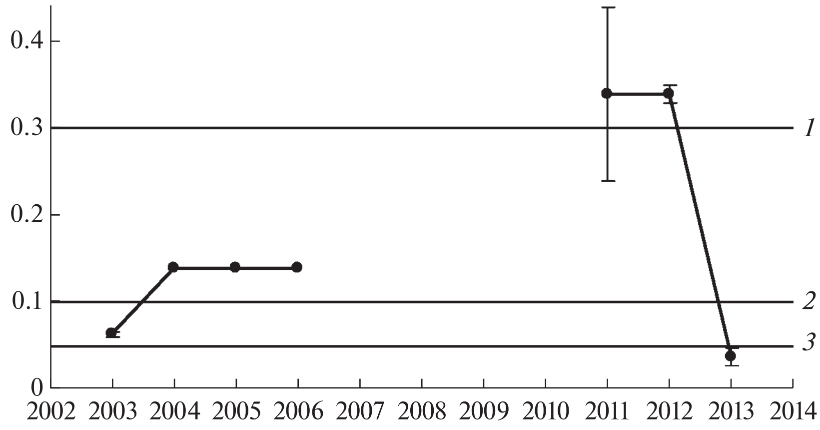

Fig. 2. Pollution of the water area of Vitino Specialized Marine Oil Port by petroleum products for the entire observation period. Data for 2003–2006 are given in accordance with Koryakin, Yurchenko, 2007, 2011, 2012; data for the period of 2011–2013 are original observations. The upper horizontal line is MPC for reservoirs of general economic purpose; the middle horizontal line is MPC for drinking water reservoirs; the lower horizontal line is MPC for fishery reservoirs (levels of MPC are given under: "Rukovodstvo...", 1977). The X-axis refers to time, years; and the Y-axis, the concentration of petroleum products, mg/L; vertical lines indicate the statistical error.

mouth of the stream flowing from the treatment facilities of the port, the oil depot, and the village of Beloe More, the bottom is presented by gravel–sandy sediments with individual stones. At station no. 6, after an emergency oil spill of about 80 kg of oil products in 2011, the containment dike was set in the inlet; the material for the protective dam was taken at the intertidal zone; this led to a significant change in its bionomic type of intertidal. The proportion of boulders has decreased noticeably; coarse clastic rock, represented mainly by small stones, was then located as ridges oriented perpendicularly to the shoreline. The sand bed was largely exposed. At present, due to the termination of the work of the tank farm, these works have been stopped.

MATERIALS AND METHODS

Hydrobiological and hydrological studies

All hydrobiological and hydrological studies were carried out at the maximum ebb close by the low water line. At stations nos. 1, 2, 3, 4, and 6, where kelp was growing (brown algae *Fucus vesiculosus* Linnaeus, 1753 and *Ascophyllum nodosum* (Linnaeus) Le Jolis, 1863, further, fucoids), a sample frame of $1/40$ m^2 was placed randomly near the hydrographic tidal plane and samples were taken on the kelp cover. Then, either under this sample or in close proximity to it, a column of sediment (about 15 cm high) was extracted using a tube sampler with an area of $1/131$ m^2. The projective cover of the intertidal zone with fucoids was assessed visually as fractions of a unit. At each station, samples were taken in triplicate. Washing of the material was carried out on a steel sieve U1-ESL-P with a rim diameter of 200 mm and a mesh size of 1 mm (the side of the square). Before returning to the shore laboratory, the material was stored in the ship refrigerator and sorted in the laboratory immediately after the end of the cruise. All the organisms found were determined up to species level (except for a number of filamentous algae Chlorophyta, Rhodophyta and Phaeophyta, Nemertini, oligochaetes of the Enchytraeidae family, and also the species of amphipods from the genus *Gammarus*, juvenile gastropods of the genus *Littorina*, and bivalve mollusks of the genus *Musculus*) and weighed wet on Adventurer Pro RV313 electronic scales with an accuracy of 0.001 g; in addition, single organisms were counted. The data obtained on the biomass and population density of the collected organisms from both subsamples of each replication were recalculated per square meter and added, and the population density and the biomass of the benthos found in the kelp were multiplied by the coefficient of the projective cover of fucoids. At station no. 5, where a continuous cover of significant intertidal sites with fucoids was absent during the entire observation period, only a tube sampler was used. Later, the data obtained by arithmetic averaging of the three replications from each station was used for analysis.

In total, during the study period, 159 samples were taken at the Vitino Specialized Marine Oil Port and the Belomorskaya Neftebaza, and 87 forms of plants and animals were found.

The sediment temperature was measured with an accuracy of 0.1°C by a TMC 1510-02-11 digital thermometer, where the probe was buried approximately to 10-cm depth in the sediment. The salinity was measured in the immediate vicinity of the sampling points at the low water line by a WY-100 refractometer with an accuracy of 1 ppt.

All the data obtained were entered into the "Benthos of the White Sea" database implemented by Naumov in 1990 in the algorithmic language Clipper 5.0, and into the integrated information system "Marine Benthos 2.1" developed by some of the authors of this article.

During the processing of the material, the results of rapid analyses built into both systems were used.

Water samples for the content of petroleum hydrocarbons were collected at high tide and low tide in order to exclude the influence of tidal movements. The samples were fixed with CCl_4. The concentration of petroleum products was determined by the extraction-photometric method with column chromatography on Al_2O_3 and IR spectroscopic termination (Metodicheskie Ukazaniya..., 1995) at the Laboratory of Hydrochemistry, Institute of Water Problems of the North, Karelian Science Center, Russian Academy of Sciences, Petrozavodsk, Russia.

Statistical analysis

For the mathematical processing of the collected material, common methods of linear statistics, cluster analysis, ANOVA, singular spectrum analysis, the phase portrait method, and also some other methods described below were applied. The significance level at which the null hypothesis was rejected was set as $P_1 = 0.05$ in all cases.

The current state of the intertidal communities was estimated by the modified index *difference of evenness* of S.G. Denisenko (2006), when the Shannon diversity index (or rather Pielou, 1977) was replaced by the oligomixness index (Naumov, 1991); this makes it possible to avoid some shortcomings when using the Shannon index for the ecological data (Pesenko, 1982) and allows us, if a comparison is necessary, to use the common methods of linear statistics. The index of oligomixness is a statistical indicator, calculated by the formula

$$I_o = \frac{\sigma_A}{A}\sqrt{S},$$

where I_o is the oligomixness index; σ_A is the mean square deviation of the abundance parameter of all species in the community; A is total abundance of species, which can be expressed by any parameter (total biomass or total population density of all individuals found); and S is the number of species found. The index falls into the range $0 \le I_o \le 1$, and for $S = 1$ it makes no sense. It has no demands on the form of distribution, since it is not an interval, but a point estimate. Its standard error is defined as

$$m_{I_o} = \frac{I_o}{\sqrt{2S}},$$

where m_{I_o} is the statistical error of the oligomixness index.

Therefore, the measure of stability of the benthic communities applied in this paper may be called *the difference of oligomixness* (Naumov, 2013), by analogy with that proposed by Denisenko, and is calculated by the formula

$$R_o = I_{oB} - I_{oN},$$

where R_o is the difference of oligomixness; I_{oB} and I_{oN} are the indexes of oligomixness, calculated for biomass and population density, respectively.

The oligomixness difference, as well as the evenness difference, is defined in the range of $-1 \le R_o \le 1$. Its statistical error is

$$m_{R_o} = \sqrt{m_{I_{oB}}^2 + m_{I_{oN}}^2},$$

where m_{R_o} is the error of the oligomixness difference. For the convenience of presentation in the present study, both the index and its error are multiplied by 100; i.e., they are expressed not in fractions of one, but in percentage. The positive values of this indicator correspond to the stable state of the community.

ANOVA is used in the study as the implementation of two single-factor complexes: analysis of the total variance over the years (changing the biomass of communities in time) and the total variance by species (community structured, measured by the biomass of individual species). The fraction of the explained variance was used to estimate the contribution of individual factors to variability of dispersion complexes (Plokhinskii, 1970, Lakin, 1980, Winer et al., 1991).

Statistical significance was assessed using the F-test of Fisher for variance analysis and Student's t-test in all other cases.

Cluster analysis was carried out by the k-nearest neighbor method. The fractions of logarithms of species biomass in individual communities were used as primary data; this allows comparing communities by species structure regardless of their total biomass (Naumov, 2013). The index of the percentage similarity of J. Czekanowski (Czekanowski, 1909) was applied as a measure of similarity

$$I_{cz} = \sum_i^S \min\left(\frac{a_{i,j}}{A_j}, \frac{a_{i,j}}{A_k}\right),$$

where I_{cz} is the index of the percentage similarity of Czekanowski, S is the total number of species, A is the total abundance of species in the jth and kth descriptions, and a_i is the abundance of the ith species.

Singular spectral analysis was used in the original version of *eigenvector filtering* proposed by J. Colebrook; in Russian papers, it also appears as *component filtration* (Colebrook, 1978; Ibanez, Dauvin, 1988; Naumov et al., 2009; Khalaman, Naumov, 2009). The method was described in detail earlier (Ibanez, Dauvin, 1988; Naumov, 2006).

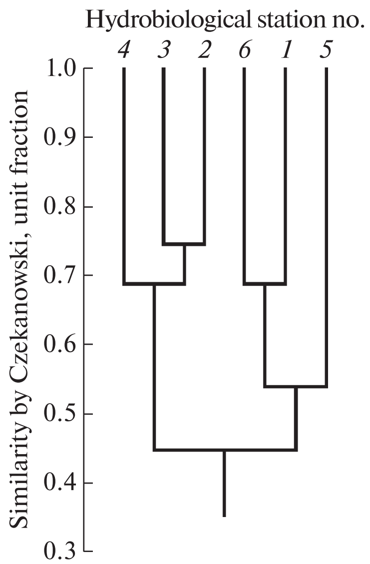

Fig. 3. Cladogram of the similarity of the communities studied at the stations. Numbers on the top indicate the numbers of the hydrobiological stations.

To identify quasi-cyclic processes, dynamic phase portraits of interannual variations of different parameters of benthic communities were built. In order to do this, the graphs of the dependence of differentiated time series on the initial data series were plotted (for method substantiation and references, see Tereshchenko, 2009). Differentiation was performed by representing the original series in finite differences.

RESULTS AND DISCUSSION

Lists of taxa found at the stations are given in Table 1 together with the average biomass for the entire period of observation.

The number of taxa found at each station in different years is presented in Table 2; the average annual biomass, in Table 3. Obviously, the maximum number of species and the largest biomass were found at control station no. 4, and the lowest values of these parameters were observed at station no. 5, located at the mouth of the stream flowing from the treatment facilities. It can be assumed that this is due to differences in the average salinity of the surface water layer. This assumption is also supported by differences in the species composition of the intertidal organisms at these points: at station no. 5, the species composition (Table 1) is quite typical for the desalinated areas of the White Sea intertidal zone. Such signs include the weak development of fucoids, the high biomass of *Ulva intestinalis* Linnaeus, 1753, and the absence of *Arenicola marina* (Linnaeus, 1758) and *Semibalanus balanoides* (Linnaeus, 1767).

The cluster analysis (Fig. 3) quite clearly divides the communities studied into three groups. The first group includes stations nos. 2 and 3, to which control station no. 4 adjoins. All of them are located either close to the entrance to Olen'ya Salma Strait or outside it. The second group comprises stations nos. 1 and 6, in spite of the fact that at the latter station the biomass of the benthos was significantly lower than at other sites studied due to permanent, although not very strong (until 2011), but noticeable oil pollution (Table 3). This pollution was detected even visually by the distinctive brown coating on the stones, small spots of the oil film on the surface of the water, and the smell of oil under the clay sheet. Both stations are located in the central part of Olen'ya Salma Strait.

Station no. 5 differs from all other stations by desalination, as was mentioned above.

The difference in oligomixness for all stations for each year of observations is presented in Table 4. Only high positive values of this parameter appear to be significantly different from zero (meaning the state of the community, intermediate between stable and disturbed). This is not surprising. The biomass and population density of individual species in the community may differ by several orders of magnitude, which leads to huge variances in the corresponding series. To even this dispersion, it makes sense to use logarithmic data (Table 5). The authors do not know the publications in which such a technique would be used for plotting *ABC* diagrams or calculating the difference of evenness, i.e., methods based on the hypothesis of the predominance of *K*-selection in stable and *r*-selection in disturbed communities, so it is interesting to compare the results obtained on the primary data and log-transformed series.

First of all, regard must be paid to the average difference in oligomixness: calculated under primary data, it is 25.31 ± 3.11%, using log-transformed data, 25.61 ± 1.24%. This difference is statistically insignificant, indicating that, on average, both approaches lead to similar results.

At the same time, after evening the dispersion of species biomass in the community by log-transformation, the statistical error is generally reduced, which leads to an increase in the number of reliable results. Almost all of the obtained results are statistically different from the intermediate state (expressed by the zero difference of oligomixness), and negative values (few and statistically insignificant) obtained during processing of the nontransformed data were not found at all (Table 5). This last result is surprising: the material studied represents communities that are not just affected by oil pollution, but that are practically destroyed by it. In particular, these are cases when the difference in oligomixness is not only positive but also very high (see Tables 4 and 5, for 2012 and 2013). This, apparently, can be explained by the fact that, with a strong effect of petroleum on the organisms, smaller individuals die earlier than larger ones, which leads to high index values. In particular, this behavior of the

Table 1. List of species found during the entire observation period, given by stations. Average biomasses are given with the statistical error, g/m^2

Species	Station nos.					
	1	2	3	4	5	6
Phaeophyta						
Ascophyllum nodosum	4341.092 ± 860.239	5399.608 ± 1252.914	4253.720 ± 657.515	2293.154 ± 604.627		150.673 ± 75.052
Chaetopteris plumosa	0.003 ± 0.003	1.014 ± 0.571		0.817 ± 0.335		0.001 ± 0.001
Chorda filum				2.170 ± 1.593		
Chordaria flagelliformis				1.891 ± 1.138		
Desmarestia aculeata		0.320 ± 0.320		10.633 ± 10.614		
Dictyosiphon foeniculaceus	6.164 ± 3.490	2.955 ± 2.955		89.498 ± 63.120		
Dictyosiphon sp.	0.039 ± 0.027	0.039 ± 0.039	0.398 ± 0.396	8.048 ± 4.509		0.421 ± 0.399
Ectocarpus sp.	0.536 ± 0.403	0.064 ± 0.064	0.521 ± 0.513	2.758 ± 1.691	8.457 ± 6.919	0.957 ± 0.625
Elachista fucicola	4.200 ± 3.109		0.001 ± 0.001	1.795 ± 0.691		0.015 ± 0.008
Fucus distichus			89.540 ± 50.274			
Fucus serratus			18.396 ± 18.396	76.743 ± 76.743		47.396 ± 27.917
Fucus vesiculosus	3923.975 ± 545.874	1381.157 ± 288.683	2374.932 ± 473.233	4930.215 ± 1447.719	65.263 ± 36.229	1065.674 ± 601.705
Mesogloia vermiculata				0.002 ± 0.002		
Pylaiella littoralis				0.090 ± 0.089		
Petalonia fascia	0.052 ± 0.052					
Scytosiphon lomentaria	0.163 ± 0.163	0.391 ± 0.371				
Stictyosiphon sp.	0.057 ± 0.053	0.345 ± 0.292	0.210 ± 0.210	1.065 ± 0.958		0.087 ± 0.075
Rhodophyta						
Ahnfeltia plicata		0.015 ± 0.015		1.552 ± 1.093		
Ceramium sp.				1.084 ± 0.942		
Cystoclonium purpureum				1.308 ± 0.954		
Devaleraea ramentacea				0.050 ± 0.050		
Ilea zostericola				0.021 ± 0.021		
Coccotylus brodiei				1.836 ± 1.813		
Odonthalia dentata				0.046 ± 0.046		
Palmaria palmata		0.181±0.130		0.023 ± 0.023		
Polysiphonia nigrescens				0.215 ± 0.215		
Polysiphonia sp.		0.190±0.181	0.197±0.197	0.370 ± 0.274		
Stictyosiphon sp.	0.057 ± 0.053	0.345±0.292	0.210±0.210	1.065 ± 0.958		0.087 ± 0.075
Polysiphonia urceolata				0.037 ± 0.030		
Chlorophyta						
Acrosiphonia sp.				1.320 ± 1.320		
Chaetomorpha sp.		3.851 ± 3.826	0.197 ± 0.197	0.264 ± 0.185		0.001 ± 0.001
Cladophora rupestris		0.068 ± 0.068		44.193 ± 38.524		0.003 ± 0.003
Cladophora sericea	2.912 ± 2.900	145.001 ± 44.267	9.282 ± 3.701	319.315 ± 78.844	0.022 ± 0.022	8.451 ± 5.188
Monostroma grivellei					0.015 ± 0.015	

Table 1. (Contd.)

Species	Station nos.					
	1	2	3	4	5	6
Rhizoclonium riparium			0.202 ± 0.197	0.024 ± 0.017		
Spongomorpha sp.		1.441 ± 1.441		1.612 ± 1.202		
Ulva intestinalis		1.378 ± 1.378	0.119 ± 0.086	3.310 ± 1.698	60.496 ± 22.060	0.520 ± 0.271
Angiospermae						
Ruppia maritima		11.229 ± 5.959	0.415 ± 0.406			
Zostera marina		2.077 ± 1.857	12.354 ± 9.424	4.457 ± 4.433		10.652 ± 10.652
Hydrozoa						
Clava multicornis				0.002 ± 0.002		
Dynamena pumila				0.032 ± 0.032		
Anthozoa						
Bunodactis stella				1.110 ± 0.618		
Plathelmintes						
Procerodes solowetzkiana				0.109 ± 0.058		
Nemertini						
Lineus sp.				0.710 ± 0.459		
Nemertini indet.	0.032 ± 0.032		0.033 ± 0.033	5.028 ± 1.433		
Priapulida						
Halicriptus spinulosus		4.275 ± 2.609	0.314 ± 0.314	2.533 ± 1.599		
Polychaeta						
Alitta virens	1.061 ± 0.731	8.942 ± 4.927				
Arenicola marina		0.095 ± 0.095	0.819 ± 0.571			
Capitella capitata	0.004 ± 0.003		0.001 ± 0.001	0.027 ± 0.012	0.004 ± 0.004	
Eteone longa	0.021 ± 0.014	0.318 ± 0.107	0.186 ± 0.058	0.013 ± 0.011	0.058 ± 0.041	0.026 ± 0.019
Fabricia sabella	0.006 ± 0.005	0.054 ± 0.025	0.016 ± 0.007	0.086 ± 0.067		
Manayunkia aestuarina		0.005 ± 0.003				
Phyllodoce maculata			0.009 ± 0.009	0.024 ± 0.024		
Polydora quadrilobata		0.005 ± 0.005	0.004 ± 0.004	1.495 ± 1.375		
Pholoe minuta				0.003 ± 0.003		
Pygospio elegans	0.013 ± 0.010	0.220 ± 0.064	0.146 ± 0.049	0.510 ± 0.126	0.029 ± 0.029	
Scoloplos armiger	0.002 ± 0.002			0.151 ± 0.093		
Spio theeli	0.006 ± 0.005		0.021 ± 0.021			
Oligochaeta						
Clitellio arenarius		0.002 ± 0.002		0.013 ± 0.008	0.531 ± 0.531	
Enchytraeidae indet.				0.650 ± 0.419		
Limnodrillus sp.		0.016 ± 0.011		0.004 ± 0.003	0.007 ± 0.007	
Oligochaeta indet.	0.086 ± 0.060	0.055 ± 0.044		0.844 ± 0.687	0.433 ± 0.291	0.066 ± 0.061
Paranais litoralis		0.001 ± 0.001		0.002 ± 0.002		
Tubifex costatus	0.750 ± 0.385	0.035 ± 0.020	0.033 ± 0.015	0.713 ± 0.385	0.197 ± 0.099	0.001 ± 0.001

Table 1. (Contd.)

Species	Station nos.					
	1	2	3	4	5	6
Tubificoides benedeni	0.058 ± 0.023	1.674 ± 0.566	1.920 ± 0.437	9.984 ± 2.328	0.015 ± 0.015	0.169 ± 0.148
Cirripedia						
Semibalanus balanoides	0.812 ± 0.658			0.047 ± 0.028		
Isopoda						
Jaera albifrons	0.430 ± 0.093	2.148 ± 0.443	2.938 ± 0.797	0.306 ± 0.099	0.018 ± 0.011	0.036 ± 0.016
Gammaroidea						
Gammarus sp.	5.470 ± 1.447	7.220 ± 1.375	11.040 ± 2.001	5.210 ± 2.452	0.708 ± 0.288	0.737 ± 0.331
Monoculodes simplex			0.005 ± 0.005			
Orchomenella minuta					0.073 ± 0.050	
Pontoporea affinis			0.022 ± 0.022			
Insecta						
Chironomus salinarius		0.039 ± 0.018	0.001 ± 0.001	0.002 ± 0.002		
Halocladius vitripennis	0.084 ± 0.037	0.143 ± 0.065	0.008 ± 0.007	1.763 ± 0.900	0.041 ± 0.023	0.051 ± 0.030
Gastopoda						
Amauropsis islandica				6.533 ± 5.204		
Hydrobia ulvae	5.923 ± 2.058	62.372 ± 10.111	55.164 ± 10.569	60.718 ± 8.742	13.806 ± 5.411	0.846 ± 0.494
Hydrobia ventrosa			0.009 ± 0.009			
Littorina littorea	0.638 ± 0.638	0.330 ± 0.330		3.549 ± 3.549		
Littorina obtusata	10.590 ± 7.519	1.018 ± 0.786	2.120 ± 1.258	106.167 ± 23.269	0.104 ± 0.104	
Littorina saxatilis	61.199 ± 6.155	48.133 ± 8.142	41.527 ± 6.881	82.580 ±1 5.781	3.916 ± 2.099	6.345 ± 2.751
Littorina sp. juv.				0.091 ± 0.062		
Bivalvia						
Macoma balthica	69.210 ± 12.554	178.653 ± 30.389	127.934 ± 18.899	113.318 ± 14.084	173.818 ± 35.742	34.615 ± 18.587
Musculus sp. juv.	0.001 ± 0.001			0.001 ± 0.001		
Mya arenaria			8.821 ± 5.227		0.342 ± 0.342	
Mytilus edulis	573.098 ± 82.619	540.851 ± 152.450	695.965 ± 158.275	3631.654 ± 585.423	44.049 ± 43.168	323.213 ± 218.170
Bryozoa						
Electra crustulenta		0.009 ± 0.009				
Asteroidea						
Asterias rubens				0.079 ± 0.057		

Table 2. The number of species found in the water area of OOO Vitino Specialized Marine Oil Port and ZAO Belomorskaya Neftebaza in 2003–2015

Date	Station nos.					
	1	2	3	4	5	6
01.08.2003	12	20	18	22	–	–
30.07.2004	11	9		20	–	–
09.08.2005	11	15	13	17	–	–
14.08.2006	17	16	22	20	–	–
13.08.2007	13	15	16	30	–	–
25.07.2008	10	21	12	25	16	–
24.07.2009			18	40	8	13
20.07.2010	13	19	15	27	6	19
20.07.2011	15	26	20	30	3	6
22.07.2012	15	19	15	28	7	11
22.07.2013	11	–	13	29	10	9
29.07.2014	–	–	–	24	–	–
28.07.2015	–	–	–	38	–	–
Total for the period of observation	32	42	40	68	23	25
Average	12.8 ± 0.7	17.8 ± 1.6	16.2 ± 1.0	26.9 ± 1.9	8.3 ± 1.8	11.6 ± 2.2

Hereafter in similar tables, missing values indicate that there was no work conducted at the particular station in the particular year.

Table 3. Average biomass, g/m^2, and its statistical error of the intertidal communities found in the water area of OOO Vitino Specialized Marine Oil Port and ZAO Belomorskaya Neftebaza, 2003–2015

Date	Station nos.					
	1	2	3	4	5	6
01.08.2003	9811.77 ± 2354.82	1522.35 ± 365.36	6411.47 ± 1538.75	10808.12 ± 2593.95	–	–
30.07.2004	5751.50 ± 471.00	2196.00 ± 1034.00	–	9473.00 ± 4884.00	–	–
09.08.2005	10276.00 ± 825.00	2893.00 ± 148.00	8077.00 ± 1243.00	15000.00 ± 1841.00	–	–
14.08.2006	7053.00 ± 1912.00	6140.00 ± 3490.00	9976.00 ± 1932.00	6703.00 ± 2333.00	–	–
13.08.2007	12618.78 ± 2133.00	10545.20 ± 2672.00	11321.38 ± 1758.00	17189.18 ± 3081.00	–	–
25.07.2008	6276.86 ± 890.14	3035.59 ± 155.00	2162.54 ± 504.86	6283.37 ± 873.17	816.36 ± 77.77	–
24.07.2009	–	–	9459.99 ± 1556.60	9463.85 ± 2369.69	286.65 ± 48.02	1572.47 ± 988.76
20.07.2010	7125.46 ± 384.87	14653.44 ± 714.94	11161.92 ± 572.07	13374.03 ± 342.29	446.62 ± 50.47	6192.88 ± 274.86
20.07.2011	7941.34 ± 499.94	19344.26 ± 544.44	7572.81 ± 223.10	11809.08 ± 237.77	102.88 ± 33.73	174.33 ± 13.85
22.07.2012	10937.64 ± 501.12	10507.68 ± 467.63	7907.72 ± 318.17	29018.85 ± 672.73	388.79 ± 35.21	9.42 ± 0.56
22.07.2013	12895.49 ± 1109.55	–	3189.07 ± 145.58	9087.40 ± 173.80	193.11 ± 12.77	115.82 ± 7.12
29.07.2014	–	–	–	3559.69 ± 939.826	–	–
28.07.2015	–	–	–	13419.59 ± 1209.06	–	–
Average	9068.78 ± 820.96	7870.84 ± 2093.01	7723.99 ± 978.92	11937.63 ± 1761.69	372.40 ± 102.47	1612.98 ± 1180.25

parameters of the dimensional structure has been analyzed in the study of A.I. Azovskii (Azovskii, 2015). If this is the case, then the methods of analysis based on the hypothesis of the change from *K*-selection to *r*-selection as a consequence of anthropogenic impact, at least for the intertidal ecosystems, are questionable, and these data should be tested in other ways.

For this purpose, ANOVA was used.

Obviously, the more stable the biomass of the community through the years, the lower its interannual variance. Hence, the null hypothesis in this case says that the biomass does not change year after year.

On the other hand, the more structured the community, the higher the interspecies dispersion; therefore, in this case, the null hypothesis is reduced to the

Table 4. The difference of oligomixness in the zoobenthos, %, and its statistical error, calculated on the basis of the primary data in the water area of OOO Vitino Specialized Marine Oil Port and ZAO Belomorskaya Neftebaza, 2003–2015

Date	Station nos.					
	1	2	3	4	5	6
01.08.2003	5.21 ± 23.21	8.78 ± 16.91	13.49 ± 15.51	35.90 ± 18.17	–	–
30.07.2004	3.44 ± 24.18	–2.17 ± 21.80	–	1.73 ± 23.05	–	–
09.08.2005	*44.35 ± 19.24	–10.61 ± 17.09	21.15 ± 13.32	20.05 ± 22.21	–	–
14.08.2006	21.55 ± 18.24	*42.11 ± 18.83	*46.81 ± 16.87	15.58 ± 23.29	–	–
13.08.2007	*47.99 ± 19.71	5.94 ± 14.94	40.09 ± 19.67	40.23 ± 17.92	–	–
25.07.2008	16.28 ± 14.78	7.01 ± 10.34	–2.78 ± 18.31	10.13 ± 12.24	28.05 ± 18.33	–
24.07.2009	–		33.87 ± 16.76	32.23 ± 16.08	51.60 ± 28.02	*48.40 ± 20.88
20.07.2010	*56.05 ± 20.47	*38.60 ± 14.61	*47.26 ± 19.11	*45.29 ± 17.71	59.35 ± 33.56	*50.79 ± 21.55
20.07.2011	11.63 ± 26.33	–11.52 ± 23.26	14.80 ± 16.37	*48.21 ± 16.11	1.43 ± 1.76	0.68 ± 0.89
22.07.2012	*42.35 ± 19.99	26.21 ± 16.64	28.07 ± 16.87	*41.50 ± 16.24	26.00 ± 27.69	78.93 ± 49.42
22.07.2013	39.21 ± 19.51	–	–38.08 ± 20.47	10.51 ± 13.18	1.90 ± 28.01	14.69 ± 53.55
29.07.2014	–	–	–	*63.45 ± 17.28	–	–
28.07.2015	–	–	–	17.85 ± 22.99	–	–

Values that are significantly different from zero are indicated with an asterisk.

Table 5. The difference of oligomixness in the zoobenthos, %, and its statistical error calculated on the basis of the log-transformed data in the water area of OOO Vitino Specialized Marine Oil Port and ZAO Belomorskaya Neftebaza, 2003–2015

Date	Station nos.					
	1	2	3	4	5	6
01.08.2003	*24.93 ± 8.59	*25.91 ± 5.93	*23.59 ± 6.09	*21.99 ± 4.75	–	–
30.07.2004	*27.30 ± 10.12	*28.25 ± 9.83		*24.35 ± 5.50	–	–
09.08.2005	*25.76 ± 8.12	*22.01 ± 5.78	*21.64 ± 6.14	*17.23 ± 5.35	–	–
14.08.2006	*26.34 ± 7.02	*28.39 ± 7.59	*23.81 ± 5.10	*26.78 ± 6.83	–	–
13.08.2007	*24.30 ± 6.85	*22.22 ± 6.31	*24.30 ± 6.86	*21.55 ± 4.69	–	–
25.07.2008	*24.03 ± 8.37	*21.56 ± 4.65	*25.31 ± 7.65	*22.70 ± 4.82	*27.69 ± 7.06	–
24.07.2009	–	–	*22.28 ± 6.29	*19.94 ± 3.93	*38.28 ± 14.15	*33.83 ± 10.28
20.07.2010	*24.16 ± 7.22	*27.15 ± 6.71	*28.69 ± 8.40	*23.17 ± 4.90	*44.10 ± 20.71	*40.94 ± 11.40
20.07.2011	*27.19 ± 9.18	*22.92 ± 6.30	*25.66 ± 7.32	*22.83 ± 4.57	0.62 ± 0.54	0.80 ± 0.58
22.07.2012	*24.64 ± 6.94	*21.37 ± 6.07	*16.77 ± 4.76	*21.65 ± 5.37	29.55 ± 14.41	48.17 ± 48.51
22.07.2013	*29.35 ± 9.30	–	*15.01 ± 5.14	*22.97 ± 4.72	*31.44 ± 11.71	58.62 ± 45.51
29.07.2014	–	–	–	*23.14 ± 4.93	–	–
28.07.2015	–	–	–	*30.00 ± 7.34	–	–

Values that are significantly different from zero are indicated with an asterisk.

assertion that the community is not structured and the biomasses of all species are the same.

All calculations were performed in three versions: for the whole community, and also for the zoo- and phytobenthos separately. The results are presented in Table 6.

Apparently, in the case of studying the interannual variation, the null hypothesis can be rejected only for the phytobenthos at station no. 5, although in this case the fraction of the explained dispersion remains sufficiently low.

Thus, even for the most polluted station no. 6, where very significant changes occurred during the research, the applied ANOVA does not reveal any violations, and according to these results, the community is indistinguishable from a stable one.

Table 6. Proportion of the explained dispersion of biomass, %, of the intertidal communities and its statistical error in the water area of OOO Vitino Specialized Marine Oil Port and ZAO Belomorskaya Neftebaza in 2003–2015 for the entire observation period

Types of dispersion complexes	Station nos.					
	1	2	3	4	5	6
Interannual variance (level of instability over time)						
Total community	0.35 ± 2.50	1.51 ± 2.75	0.63 ± 2.49	0.90 ± 1.35	3.37 ± 3.53	4.80 ± 3.07
Zoobenthos	0.84 ± 2.49	2.96 ± 2.70	1.73 ± 2.46	2.01 ± 1.33	1.96 ± 3.58	11.45 ± 2.86
Phytobenthos	2.00 ± 2.46	3.17 ± 2.70	1.45 ± 2.47	2.28 ± 1.33	*13.37 ± 3.16	10.04 ± 2.90
Interspecies variance (level of community structuring)						
Total community	*67.63 ± 2.23	*36.06 ± 5.35	*70.04 ± 2.25	*45.47 ± 2.28	*44.03 ± 6.94	*20.36 ± 7.71
Zoobenthos	*89.89 ± 0.70	*48.98 ± 4.27	*64.50 ± 2.67	*40.14 ± 2.51	*60.46 ± 4.91	*33.25 ± 6.46
Phytobenthos	*64.42 ± 0.89	*35.51 ± 3.60	*71.18 ± 1.26	*54.26 ± 1.50	*17.99 ± 2.39	*19.98 ± 7.10

Values that are significantly different from zero are indicated with an asterisk.

Meanwhile, the biomass of the community at station no. 6 has increased markedly from 2009 to 2010 due to *Fucus vesiculosus*, a common species of brown algae inhabiting the intertidal zone, but by 2011, it had decreased dramatically due to an accidental oil spill, and it did not differ statistically from zero until the end of observations.

Consequently, this method does not give an unambiguous answer to the question posed.

The second reason why the results of such monitoring observations may be erroneous is that intertidal benthic organisms are generally distributed unevenly, in aggregations, and the size of the aggregation of different species differs (Chertoprud, Azovskii, 2000, Azovsky et al., 2000). This leads to such large errors in the parameters being measured that in most cases all the differences obtained are statistically unreliable. The implication is that it is necessary to take a certain number of replicates at each station, so this number of replicates would level the mosaic distribution of individual species when averaging the data. On the available material, it is difficult to make reasonable assumptions about how many replicates are necessary in order to avoid this. One thing is clear: three replicates at one intertidal station are not enough for this.

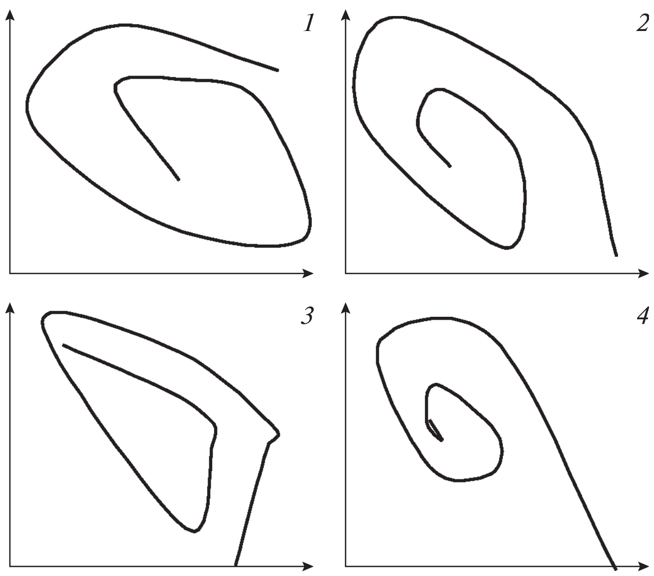

Fig. 4. Dynamic phase portraits of quasi-cyclic oscillations of the biomass of the studied intertidal communities revealed by the filtration component. *1–4* are the station numbers. The X-axis refers to the identified temporal variables; the Y-axis, to the same parameter presented as finite differences. The dimension of scales is given in conventional units (see explanations in the text).

Another difficulty is that quasi-cyclic processes are found at all stations except nos. 5 and 6, where the observation series are too short (Fig. 4). In addition to the fact that the changes in total biomass are observed in different years in such cases, which is clearly seen in Fig. 4, this also leads to cyclical changes in the indicators of stability of the whole community (see below).

Station no. 4 is the only station where there are no gaps in observations. This allows us to relate the difference of oligomixness to the dynamics of a dense mussel bed (Fig. 5).

As is seen in Fig. 5A, quasi-cyclic oscillations at this station are also characteristic for the difference of oligomixness and for the population density and biomass of *Mytilus edulis* Linnaeus, 1758, as well as for the average weight of individuals of this species. The extraction of time variables from the corresponding series by means of eigenvector filtering reveals several curvilinear trends in the dynamics of the stability index. Two of them are statistically reliable: the main trend and a quasi-cycle of an approximate duration of four years (Fig. 5B). The rest are statistically insignificant and should be considered as white noise; i.e., they are stochastic components. The main trend reflects cyclicity of a long duration, about 20–25

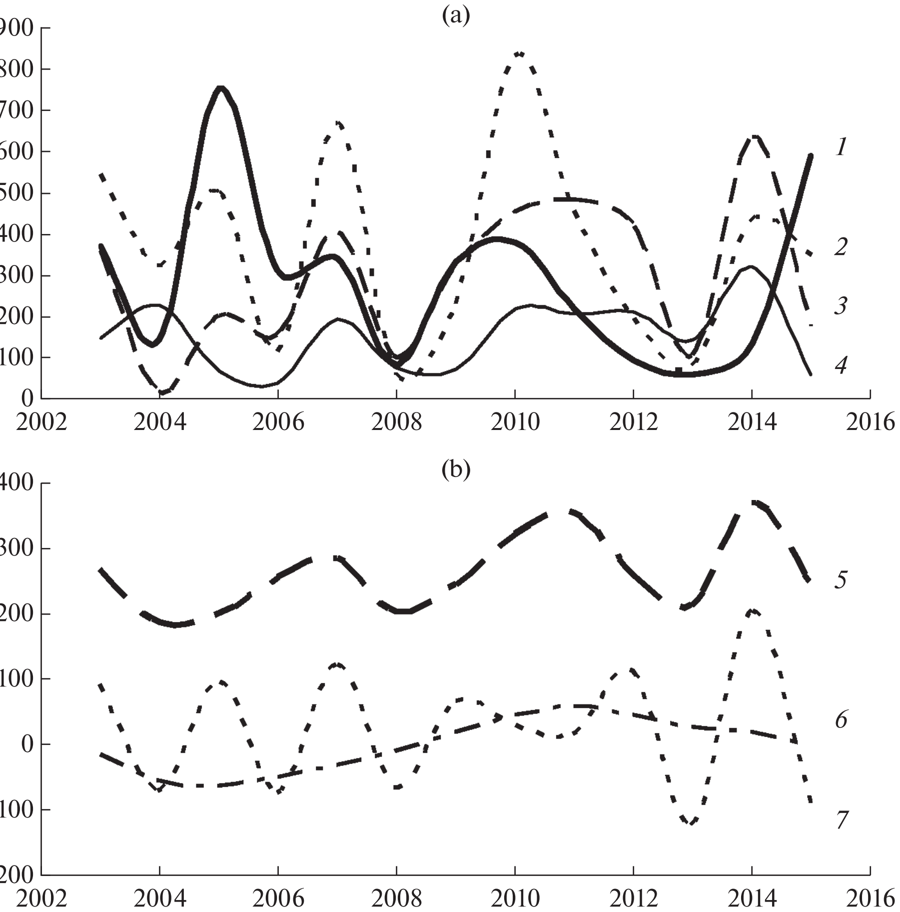

Fig. 5. Dynamics of the intertidal mussel bed of *Mytilus edulis* and the difference in oligomixness in the zoobenthos at station no. 4 (the outer water area of the port). (a) is the raw data. The X-axis refer to time, years; on the Y-axis the solid bold line is the population density, ind./m^2; the dashed line is biomass, g/m^2; the solid thin line is the average weight of one specimen, g; and the dashed line is the difference of oligomixness, %. The data are reduced to a comparable scale, so the digitization of the Y-axis is conditional. In order to facilitate the perception of the graph, statistical errors are not given. (b) is the curvilinear trends of the difference of oligomixness, found by eigenvector filtering. The solid bold line is the main trend; and the dashed bold line is the four-year quasi-cycle; the thin solid line is the 2-year quasi-cycles; dashed and dotted thin lines are stochastic trends. The X-axis refer to time, years; the Y-axis is the difference in oligomixness (the Y-axis scale is arbitrary for the reasons described above). All trends are given as deviations from the previous axis of maximum variation.

years, which significantly exceeds the time of observation, so it is impossible to make any reliable conclusions about it. For careful consideration there is only a four-year quasi-cyclic component of all the processes mentioned above (Fig. 6).

Because the temporal rows of biomass are plotted along the X-axis and the analogs of their first derivative (the rate of change of the system is $\Delta B/\Delta t$, where B is the biomass and t is the time with a one-year lag) are plotted along the Y-axis, each subsequent shift of the point generator in the graphs reflects the results of quasi-cyclic processes passing through the year. It is clearly seen that in all four cases the trajectory of the point generator makes spiral turns in the vicinity of an ellipse, periodically approaching it, then moving away. This type of dynamics is characteristic of self-oscillating systems (Andronov et al., 1981), and the mussel bed is one such example together with some others (see below for an explanation). The trajectory of the system fluctuates within a certain region, periodically changing direction, and, therefore, experiencing a change in stable and unstable states, but not deviating from the ellipse, which designates the limit cycle, as far as to pass to a qualitatively different state. Thus, the system of the mussel bed is unstable itself, because it constantly changes, but it is stable in time.

It is obvious that the self-oscillations of the system are determined by the features of the long-term dynamics of the abundance of mussels. There are good reasons to believe that in a dense settlement of this species, mature mollusks suppress the settling of spat (Lukanin et al., 1986a, 1986b, Lukanin, 1990; Naumov, 2006); as a result, mussels can be represented mainly by one or more cohorts close in age. When they

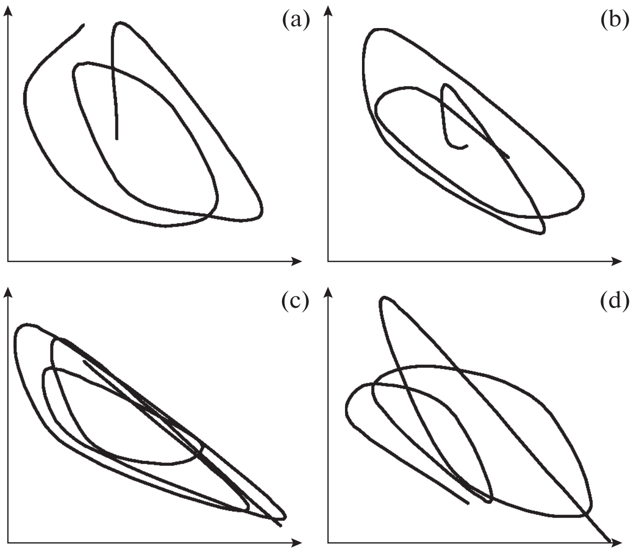

Fig. 6. Dynamic phase portraits of various characteristics of the mussel bed at station no. 4. (a), population density, ind./m^2; (b), biomass, g/m^2; (c), average weight of one specimen, g; (d), community difference of oligomixness, %. The X-axis refers to the identified temporal variables; the Y-axis refers to the same parameter presented as finite differences. The dimension of scales is given in conventional units (see explanations in the text).

begin to grow old and die out, the conditions arise for replenishing the bed with young specimens. As a result, the dynamics of the population density turns out to be phase-shifted relative to the biomass dynamics, and the dynamics of the average weight of one specimen is shifted in phase relative to both of them (Fig. 5A). Since the mature population of mussels by biomass exceeds the rest of the zoobenthos together by orders of magnitude, it is the mussel that regulates the significance of the difference of oligomixness in the community. Consequently, this indicator in such assemblages should have a pronounced quasi-cyclicity, which we actually observe (Fig. 6d).

Therefore, the mussel bed at station no. 4 (Figs. 6a–6c) is subject to the usual quasi-cyclicity (Lukanin et al., 1986a, 1986b; Naumov, 2006) and, therefore, due to its high biomass, largely determines the structure of the entire community and significantly affects the difference of oligomixness. Consequently, a single expert evaluation cannot give anything to assess the state of such an intertidal ecosystem. In fact, in one phase of the cycle, the expert will consider the community to be safe, and thus not affected by anthropogenic impact, and contrary conclusions may be made in a couple of years during the other phase. Our conclusion refers to any known methods of expert assessment, based on determination of the state of the community with regard to the shifting of natural selection in the *K*- or *r*-direction.

Previously, it was shown that it was the quasi-cyclic dynamics of a dense mussel bed that led to a massive outflow of sea stars on the Letnii Coast of Dvina Bay in 1990 (Naumov, 2011). Conducting only several single observations and ignoring the inherent cyclicity of the ecosystem led to a multitude of errors.

The inference should be drawn that in order to estimate reliably the degree of anthropogenic impact on such intertidal ecosystems, one needs to know the phase of the mussel bed cycle (or, in general, of any edificator), which is impossible without long-term regular monitoring observations, and the duration of the expected quasi-cycles is such that for some a reasonable answer can be obtained only after 10–15 years of studies. Under continual monitoring, it is already possible to identify the changes in the development trends of the system by constructing dynamic phase portraits.

One has also to keep in mind that, as was shown above, quite stable communities can develop under mild chronic pollution, although they may be unusual for healthy biotopes. At the same time, the existence of a regular cyclical development of the community, which is quite successful (from the point of view of the influence of the anthropogenic press) due to intensive succession processes, leads to its appreciable instability, which is reflected in the distortion of the *k*-dominant curves and the low difference of oligomixness in some quasi-cycle phases. All of these bring additional difficulties to analysis of the anthropogenic press on marine biota. It is possible that the presence of cyclicity can influence the assessment of the state of the community when using other approaches to solve the problem.

As a result, at the current state of analysis of disturbances to marine intertidal bottom communities, at least in the case of communities encountered in the water area of Vitino Specialized Marine Oil Port, the visual assessment proves to be more reliable than the analytical one.

CONCLUSIONS

(1) The intertidal communities in the water area of the Vitino Specialized Marine Oil Port have a natural quasi-cyclic dynamics, and they depended little (or were entirely independent of) on the activities in the harbor and oil depot. An exception is the intertidal community at station no. 6, which was directly affected by the petroleum from emergency oil spills, but this has not been demonstrated by the mathematical methods used.

(2) Methods developed for the bioindication of pollution based on comparing the evenness of biomass and population density of species in the community (Warwick, 1986, Warwick et al., 1987; Denisenko, 2006; Naumov, 2013) should be applied with extreme caution. The same applies to ANOVA.

(3) Express analysis of data obtained from single observation does not give anything for bioindication of marine pollution.

(4) For a reliable solution to the problem, it is necessary to look for other methods. Constant monitoring and processing of the data using dynamic phase portraits may appear as one approach. Such monitoring, as our original data show, should be conducted annually, and its first results can be obtained only after the time necessary for at least three quasi-cycles to have taken place. It is better to use log-transformed data to even the dispersion of biomass and of population density during processing of the obtained material. The number of necessary replications at one station in each individual case must be set experimentally. In any case, three replications are not enough.

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