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ECOLOGY

Determination Analysis in Ecosystems: Contingencies for Biotic and Abiotic Components

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Abstract—Relationships between physicochemical variables and between abundance of zooplankton species, as well as dependence of the species abundance on abiotic factors, were studied by determination analysis in the ecosystems of the Sura River and Surskoe Reservoir. Marker hydrochemical variables (BOD_5 and concentration of dissolved oxygen) were revealed; their oscillations indicate increases or decreases in concentration of most pollutants. A set of species with correlated abundance was recognized in the zooplankton community. The ecologically tolerable levels of the environmental factors providing for high abundance of zooplankton species were calculated.

INTRODUCTION

The analysis of ecological publications within recent years (Budilova *et al.*, 1995) indicates that multidimensional data on natural ecosystems are usually processed by either classical statistical methods (such as analysis of variance or regression analysis) or the methods only formally attributed to statistics (factorial and cluster analyses and multivariate scaling). At the same time, applicability of these methods to processing the data of ecological observation (monitoring), which can be assigned to "passive experiments," is quite problematic.

For instance, analysis of variance and regression analysis impose a number of stringent prerequisites, including the three most important: (1) Observation data should be independent random variables with normal distribution. (2) Sample estimates of the observation variance should be uniform, i.e., should not depend on the value of observation result. (3) Errors of independent variable determination should be zero or at least negligible relative to the error of observation result determination.

Many years of experience in processing ecological monitoring data convinces us that neither of these prerequisites is satisfied. In addition, statistical models in general, and regression models in particular, cannot be used to establish or prove causalities in the studied system. As early as 1928, Azzi warned against thoughtless interpretation of correlation coefficient values as proofs of causality between the correlated variables (Azzi, 1928).

Standard correlation analysis has a restricted effect for studying variables with an abnormal distribution, as demonstrated by the example of the abiotic properties of the Surskoe Reservoir (Maksimov *et al.*, 1999). This publication also exemplifies that missing data on biotic properties, such as abundance or biomass of particular water organism groups, affect the efficiency of correlation analysis.

The traditional statistical approaches are often inapplicable to the data combining numeric and nonnumeric (qualitative) variables; to combined processing of data by objects of different characters and with different levels of description; and to processing nonlinear relationships between variables, although such relationships predominate in real ecosystems.

Determination analysis (DA) lacks the above limitations of traditional statistics and can establish relationships (contingencies) between various variables, both numeric and nonnumeric (qualitative). DA technology allows introduction of any new quantitative and qualitative variables. At the same time, a researcher controls the properties of the introduced qualitative variables and can correct them at any moment. Hence, DA becomes indispensable to finding a relationship between changes in variables if at least one of them is qualitative.

DA operates only with conditional frequencies of multivariate events with no reference to coefficients of correlation or covariance and measures of proximity and connection, i.e., the usual tools of statistics placing too stringent requirements on the initial data.

Now we have significant experience in using determination analysis in human sciences and community studies in particular (Chesnokov, 1982). In addition, we are breaking ground in adapting the method to biological studies (Zamolodchikov *et al.*, 1992; Bulgakov *et al.*, 1992; Levich *et al.*, 1996; Maksimov *et al.*, 1999a).

In this work, using the example of the Sura River ecosystem in the region of Sura Water Reservoir, we studied (1) dependences of marker abiotic variables of the ecosystem indicating its ecological condition (oxygen concentration, BOD, and pH) on pollution factors; (2) possible recognition of stable zooplankton groups

Table 1. Determinations for explaining variable BOD in classes 1–3 (79 observations) (see text for variable explanation)

Explaining variable	Class of quality	Accuracy, %	Completeness, %	Number of observations	Number of coincidences with the explaining variable
Fe	II	41	57	111	45
O_2	II	55	22	31	17
Mn	I	45	58	102	46
NH_4	IV	38	58	121	46
NO_2	III	46	14	24	11
NO_3	V	58	9	12	7
Carbohydrates	I	42	23	43	18
pH	III	52	30	46	24
Phenols	III	57	5	7	4
PO_4	IV	45	49	86	39
Suspended matter	I	54	47	69	37

with a set of coexisting species usually absent from other groups, which brings to light understanding of the changes in zooplankton species composition within various time periods; and (3) the ranges of abiotic factor values decreasing the abundance of zooplankton species.

MATERIALS AND METHODS

In this work, we used the data on hydrochemistry, hydrology (data array I), and hydrobiology (abundance of zooplankton species; data array II) of three Sura River regions: the river, Surskoe Reservoir, and the reservoir region near the dam. The samples were collected for five years (1993–1997) in the river and reservoir only in summer (several samples a month) and once a month all year long in the region near the dam. The total number of observations was 215 on hydrochemistry and hydrology and 199 on hydrobiology.

Each abiotic variable in data array I was divided into classes according to a six-point quality classifier by hydrochemical variables (Oksiyuk *et al.*, 1993), where class I corresponds to the safest value and class VI corresponds to the most unsafe one. Next, 13 variables ranging within at least four quality classes were selected, including BOD_5, concentrations of iron (Fe), manganese (Mn), ammonium (NH_4), nitrites (NO_2), nitrates (NO_3), phosphates (PO_4), carbohydrates, phenols, dissolved oxygen (O_2), suspended matter, and pH.

DA procedures determined the efficiency of a given rule. The rule is a conventional statement relating possible cause and effect in the studied phenomenon; for instance, "if temperature value (explaining variable) corresponds to class I, BOD value (explained variable) also corresponds to class I." Value of a rule is determined by "accuracy" and "completeness" criteria. Accuracy (A) is the proportion of cases when the rule is observed in all applied cases (proportion of cases when both variables are assigned to class I among all cases when the *explaining* variable is assigned to class I). Completeness (C) is the proportion of cases when the rule is observed in all cases when the explained variable occurs (proportion of cases when the both variables are assigned to class I among all cases when the explained variable is assigned to class I). Let us consider a specific example. The number of observed BOD and temperature values assigned to class I is 73 and 79, respectively. The number of coinciding cases is 40. Hence, BOD was assigned to class I (< 2 mg O_2/l) in 40 out of 79 cases when temperature was below 20°C and T = 40/79 = 51%. In the studied data array, BOD took this value 73 times; i.e., C = 40/73 = 55%. A numeral variable can be explained as well. DA can easily produce a range of this variable, most reliably explaining a particular quality class of an explained variable. In this case, completeness does not suffice to validate the rule significance due to great difference in the quality class volume between the variables; hence, we primarily relied on the accuracy criterion for estimating the significance of particular contingencies.

A similar preliminary procedure was carried out for the hydrobiological data array. Eleven species and three larval stages of zooplankton were selected occurring in at least 20% of the observations: *Bosmina coregoni*, *Bosmina longirostris*, *Chydorus sphaericus*, *Daphnia cucullata*, *Daphnia longispina*, *Epistylis* sp., *Euchlanis dilatata*, *Eudiaptomus* sp., *Eudiaptomus gracilis*, *Keratella quadrata*, *Mesocyclops leuckarti*, *Copepoda* larvae, other larvae, and nauplii. Each of the 14 groups was divided into two classes: "few" (low abundance or absence) and "many" (high abundance).

RESULTS

Abiotic variables. We analyzed abiotic variables to reveal a possible contingency between marker variables of the general reservoir condition (BOD, O_2, and pH), on the one hand, and other factors, primarily pollutants, on the other hand. Here, we mean verification of the following rule for each marker variable: if a pollutant concentration is unsafe (in the sense defined in the previous section), the marker variable also appears unsafe. The benefit of this investigation is quite clear: if the above statement is true, measurement of a marker variable alone will suffice to determine if toxic conditions of the reservoir are safe or unsafe. Initially, we selected the first explained variable (BOD). The BOD classes I, II, and III (i.e., the most safe ones), combined in a single qualitative variable, were sequentially related to all classes of other (explaining) variables and checked for the most accurate contingency between the explaining variable and explained ones of unsafe (II–VI) classes

Table 2. Significant contingencies between abiotic variables (see text for variable explanation)

Explained variable in safe classes	Explaining variables (quality class, accuracy, and completeness of determination are given sequentially in parentheses)	
	safe quality classes	unsafe quality classes
BOD (classes I–III)	Fe (2, 41, 57), O_2 (2, 55, 22), Mn (1, 45, 58), NO_2 (3, 46, 14), Carbohydrates (1, 42, 23), Suspended matter (1, 54, 47)	NH_4 (4, 38, 58), pH (3, 52, 30)
O_2 (classes I–III)	BOD (3, 62, 34), Mn (1, 52, 50), NH_4 (2, 63, 19), Carbohydrates (2, 74, 24), PO_4 (3, 61, 29)	NO_2 (4, 53, 65), NO_3 (4, 54, 48), pH (5, 88, 14)
pH (classes I–II)	Fe (2, 57, 54), NH_4 (2, 69, 19), NO_2 (3, 88, 18), NO_3 (2, 65, 19)	BOD (4, 57, 59), O_2 (5, 84, 23), Mn (2, 56, 53), carbohydrates (5, 63, 21), phenols (4, 54, 92), PO_4 (5, 64, 29), suspended matter (2, 57, 47)

(Table 1). Only the rules with the highest accuracy relative to other rules and completeness of the explaining variable being at least 10 observations were taken as true. In this case, when the accuracy difference for the rules was below 5%, a rule with higher completeness was preferred. The maximum mismatch of BOD classes was observed with concentrations of NH_4 (class IV), PO_4 (class IV), and pH (class III).

A similar comparison with the same verification was carried out for O_2 and pH (Table 2). Negatively contingent variables (unsafe quality classes) for O_2 included concentrations of NO_3, phenols, and pH. High content of dissolved oxygen (class II) is most significantly related to low BOD (classes I–III), indicating decreasing organic matter in the reservoir. On the other hand, a decrease in water quality indicated by pH and concentration of nitrogen- and phosphorus-containing mineral salts is not accompanied by increased organic matter (BOD) or decreased content of dissolved oxygen. As concerns pH, acidity of the environment does not depend on most other indices, including the other two marker variables.

The data obtained indicate that the available hydrochemical and hydrological data are not quite suitable for DA of qualitative explaining variables due to low volume of certain quality classes. That is why we searched for the ranges in the numeric scale of the above chemical factors and water temperature most reliably explaining the best and worst quality classes according to the three marker variables. DA allows us to determine such ranges using an optimization procedure, i.e., defining the optimal combination between accuracy and completeness of determination for a particular rule. In this case, accuracy was set between 50 and 70% depending on the explaining variable; however, it was the same for the explaining variable during the search for determinations of the best and worst classes of the explained variable. Calculation results are presented in Fig. 1. In the case of BOD, the worst quality class (the highest of all presented in the available data array) was joint classes V and VI (Fig. 1a), while the worst classes for O_2 and pH were joint classes IV and V (Fig. 1b) and classes III, IV, and V (Fig. 1c), respectively. Completeness of determinations were too low (below 10%) to verify them for five (concentrations of NO_2, NH_4, phenols, and carbohydrates, as well as pH) and two (concentrations of NO_2 and phenols) explaining variables at a given accuracy level in the case of BOD and O_2, respectively. Thus, we excluded these variables from further analysis. The best BOD classes corresponded to safer values of most variables (except NO_3) as compared to the worst classes. An inverse relationship was revealed for O_2 relative to NO_3, Mn, and pH. In turn, pH negatively correlated with O_2, Fe, PO_4, Mn, and carbohydrates. Hence, the transition from qualitative characters to numeric variables confirmed the obtained results. In general, biochemical-oxygen demand and concentration of dissolved oxygen can be used in DA as markers of degrading of the ecological condition of a reservoir by chemical variables, since unfavorable quality classes of BOD and O_2 usually correlate with evenly unfavorable classes of pollutants included in the analysis (carbohydrates, phenols, suspended matter, and iron). At the same time, increased concentrations of nutrients (nitrates, nitrites, ammonium salts, and phosphates) do not affect the marker properties. In the case of the pH variable, we managed to demonstrate that increased environmental alkalinity most accurately correlates with increased concentration of nitrogen-containing salts. Hence, pH can serve as a specific marker of changes in these chemical properties.

Zooplankton species. Studies of natural species distribution, as well as the similarity between particular species by the volume of their econiches and, hence, by the time and mode of nutrition through the responses to environmental biotic and abiotic influences, are linked to revealing stable population groups with synchronous population oscillations depending on the season, levels of chemical and physical environmental factors, etc. In this section, we applied DA to study possible recognition of stable groups with a set of coexisting species usually absent from other groups of zooplankton of the Sura River and Surskoe Reservoir.

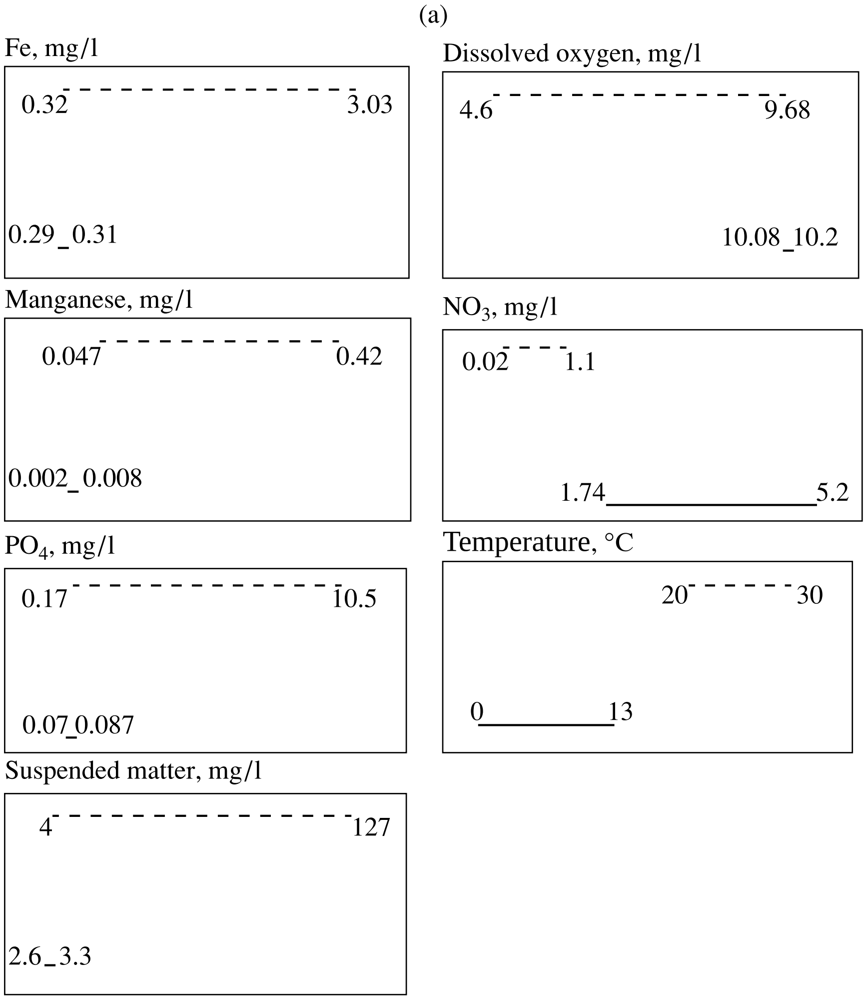

Fig. 1. Ranges of abiotic variables describing ecological safety and nonsafety by integral indices: (a) BOD; (b) O_2; and (c) pH; solid and dotted lines indicate ranges corresponding to class I and unsafe class, respectively.

During grading the species abundance into "few" and "many" classes, the zero samples were not discarded but rather assigned to the "few" class. Indeed, zero abundance does not necessarily indicate its absence in the sample. It is quite possible that not a single specimen of a species with low abundance comes into the researcher's view with existing methods for abundance measurement. Thus, the introduction of a qualitative variable in DA allows us to bypass the problem of zero variables—whether to equate them to zero or consider them as missed. In our case, volumes of the "few" and "many" classes significantly differed, since the proportion of observations with zero abundance exceeded 50% for almost all species. Since abundance values below 0.15×10^3 cells/l, in addition to the zero ones, were assigned to the "few" class, the number of observations in it appeared three times that in the "many" class. That is why we considered species abundance in the "few" class as an explaining character; otherwise, the accuracy of the studied rules will be too low to distinguish the most valuable rule from the other ones.

Contingency analysis presented in Table 3 indicated three organisms (*Epistylis* sp., *Euchlanis dilatata*, and *Eudiaptomus gracilis*) with high abundance correlating with low abundance of almost all other species and larval stages and being negatively contingent with one another at the same time. The remaining eight species and three larval stages form a relatively stable group with a mutually contingent decrease in the abundance of all organisms. The analysis indicates that abundances of the first three species are contingent on the abundances of neither other species, nor one another.

Relationship between species abundance and values of abiotic factors. After independent investigation of abiotic and zooplankton components of the Sura River ecosystem, we studied the relationship between them; i.e., we tried to find out if oscillations in hydrochemical and hydrological indices affect the abundance of a particular species. First, we established the interval

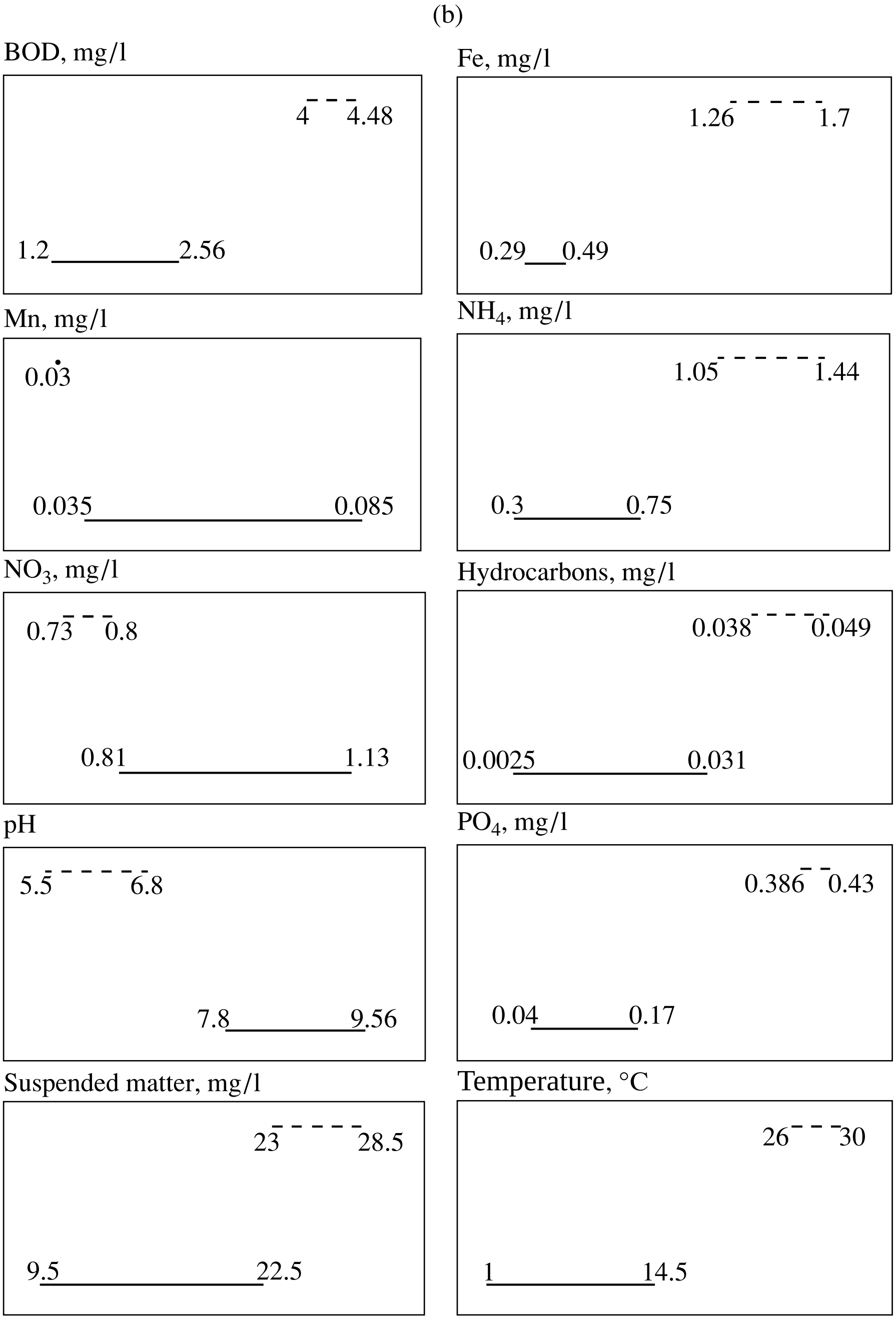

Fig. 1. (Contd.)

at the scale of abiotic variables most precisely and completely explaining the high abundance of the species. We assumed that only high values of BOD, concentrations of Fe, Mn, carbohydrates, phenols, and suspended matter can decrease the abundance; and, hence, the upper level of the unknown range was fixed during optimization. The reverse situation is specific for oxygen content—only an decrease in this index can have unfavorable consequences for zooplankton; so we fixed the lower limit of the range. In the case of concentrations of ammonium, nitrites, nitrates, and phosphates, as well as temperature and pH, no constraints were set on their possible limits, since both too high and too low values of these variables can affect favorable conditions of the organisms. Since the desired classes of the explained variables (high species abundance) appeared underloaded (25–30% of the total number of species for the majority of species), and, conversely, the number of

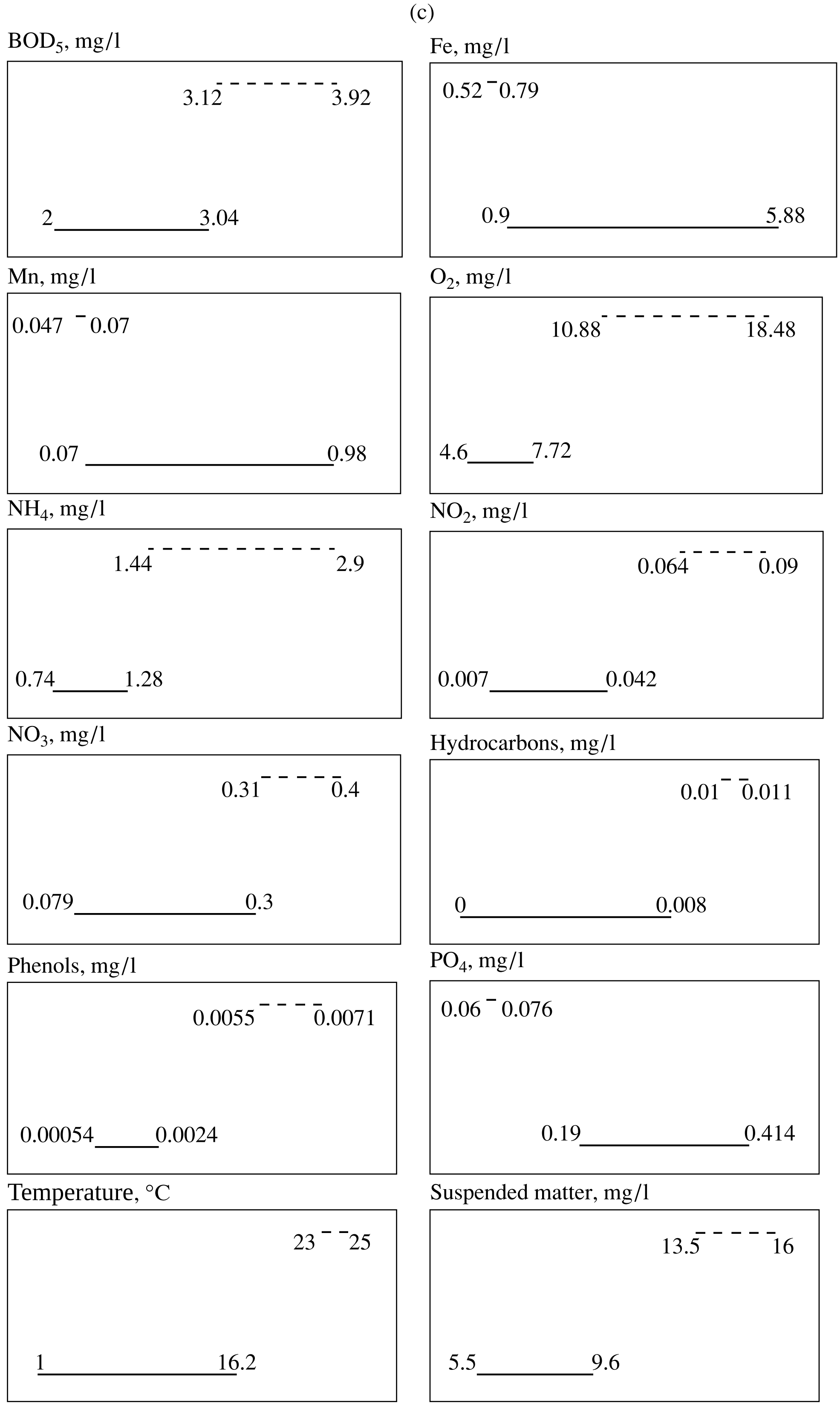
(c)
BOD5, mg/l
3.12
3.92
2
3.04
Fe, mg/l
0.52
0.79
0.9
5.88
Mn, mg/l
0.047
0.07
0.07
0.98
O2, mg/l
10.88
18.48
4.6
7.72
NH4, mg/l
1.44
2.9
0.74
1.28
NO2, mg/l
0.064
0.09
0.007
0.042
NO3, mg/l
0.31
0.4
0.079
0.3
Hydrocarbons, mg/l
0.01
0.011
0
0.008
Phenols, mg/l
0.0055
0.0071
0.00054
0.0024
PO4, mg/l
0.06
0.076
0.19
0.414
Temperature, °C
23
25
1
16.2
Suspended matter, mg/l
13.5
16
5.5
9.6

Fig. 1. (Contd.)

Table 3. Positive contingency between low and high abundance of species in samples

Explained variable (low abundance)	Explaining variables (high abundance); accuracy and completness are given in parentheses
Bosmina coregoni	*Epistylis* sp. (68–20), *Euchlanis dilatata* (79–24)
Bosmina longirostris	*Epistylis* sp. (89–23), *Eudiaptomus gracilis* (78–23)
Chydorus sphaericus	*Epistylis* sp. (97–26), *Euchlanis dilatata* (72–20)
Daphnia cucullata	*Epistylis* sp. (74–19), *Euchlanis dilatata* (87–23), *Eudiaptomus gracilis* (78–24)
Daphnia longispina	*Epistylis* sp. (71–19), *Euchlanis dilatata* (79–22)
Epistylis sp.	*Bosmina coregoni* (83–37), *Bosmina longirostris* (92–29), *Chydorus sphaericus* (98–34), *Daphnia cucullata* (81–26), *Daphnia longispina* (80–27), *Euchlanis dilatata* (92–22), *Eudiaptomus* sp. (84–22), *Eudiaptomus gracilis* (93–26), *Keratella quadrata* (88–32), *Mesocyclops leuckarti* (83–31), Copepoda larvae (84–61), Diaptomus larvae (87–37), Copepoda nauplii (85–62)
Euchlanis dilatata	*Bosmina coregoni* (89–39), *Chydorus sphaericus* (80–28), *Daphnia cucullata* (90–29), *Daphnia longispina* (85–29), *Epistylis* sp. (92–22), *Eudiaptomus* sp. (92–26), *Eudiaptomus gracilis* (87–24), *Keratella quadrata* (91–33), *Mesocyclops leuckarti* (90–34), Diaptomus larvae (93–39), Copepoda nauplii (82–61)
Eudiaptomus sp.	*Epistylis* sp. (82–20), *Euchlanis dilatata* (97–24), *Eudiaptomus gracilis* (100–29)
Eudiaptomus gracilis	*Bosmina longirostris* (80–26), *Daphnia cucullata* (81–27), *Epistylis* sp. (92–23), *Euchlanis dilatata* (85–21), *Eudiaptomus* sp. (100–28), *Mesocyclops leuckarti* (77–30), Copepoda nauplii (76–58)
Keratella quadrata	*Epistylis* sp. (82–22), *Euchlanis dilatata* (87–24)
Mesocyclops leuckarti	*Epistylis* sp. (74–20), *Euchlanis dilatata* (85–24), *Eudiaptomus gracilis* (69–22)
Copepoda larvae	*Epistylis* sp. (50–23)
Diaptomus larvae	*Epistylis* sp. (76–22), *Euchlanis dilatata* (87–26)
Copepoda nauplii	*Epistylis* sp. (53–25), *Euchlanis dilatata* (46–22)

observations within the limits of the optimized range of abiotic factors was high (usually over 50%), high accuracy of the studied rules could not be expected: usually, it was below 30–40%. That is why we fixed the lower limit of completeness (51%) and then maximized accuracy.

Results of the calculations (Table 4) demonstrate that the group of 11 zooplankton species with mutually contingent abundance is usually uniform relative to the values of safe ranges of abiotic factors. Here, safety is considered as an organism condition when its abundance is preserved within the selected high range. In this case, abundance of particular zooplankton species and larval stages is a marker of biocenosis ecological condition, so that the established ranges can be called ecologically tolerable levels (ETL) of the factors affecting biocenosis (Levich, 1994; Maximov *et al.*, 1999). One can note that the three species not included in the above group are more tolerant to many factors; i.e., their ETL has wider range. This applies to concentrations of Fe, Mn, O_2, ammonium (upper level), nitrites (lower level), phenols, and phosphates (upper level) for *Epistylis* sp.; to BOD; to concentrations of Fe, O_2,Mn, ammonium (upper level); to suspended matter, as well as pH (lower level) and temperature (upper level) for *Euchlanis dilatata*; and to concentrations of nitrites (lower level), nitrates (upper level), and phosphates (upper level), as well as pH (lower level) and temperature (lower level) for *Eudiaptomus gracilis*. At the same time the revealed ETL for these three species significantly differ by most characters, which is, apparently, another indication of the particular position of each of them in the zooplankton community. It is interesting to compare the revealed ETL with the State Utility and Drinking MAC also presented in Table 4. By the majority of indices (except concentrations of Mn, nitrites, nitrates, and oxygen) the revealed ranges are wider than the standards. Hence, we can propose relative resistance of the zooplankton community from the Sura River to environmental factors, while the MAC determined in laboratory conditions do not quite adequately reflect its adaptation potential.

Table 4. Ecologically tolerable levels of environmental factors

Species, age	Ecologically tolerable levels												
	BOD, mg/l, ul	Fe, mg/l, ul	O_2, mg/l, ll	Mn, mg/l, ul	NH_4, mg/l, ll; ul	NO_2, mg/l, ll; ul	NO_3, mg/l, ll; ul	Carbohydrates, mg/l, ul	pH, ll; ul	Phenols, mg/l, ul	PO_4, mg/l, ll; ul	Temperature, °C, ll; ul	Suspended matter, mg/l, ul
Bosmina coregoni	2.6	0.72	8	0.09	0.2; 0.555	0.034; 0.08	0.02; 0.52	0.034	8.07; 9.5	0.0058	0; 0.24	21; 27	11.5
Bosmina longirostris	3.9	0.48	8.4	0.07	0.2; 0.76	0.046; 0.36	0.02; 0.68	0.52	7.93; 9.56	0.004	0.15; 1.14	19; 30	20.5
Chydorus sphaericus	5.04	0.8	6	0.06	0.13; 0.65	0.035; 0.13	0.02; 0.49	0.122	8; 9.2	0.003	0; 0.12	22; 27	22.5
Daphnia cucullata	2.6	0.64	8.4	0.04	0.2; 0.555	0.036; 0.08	0.07; 0.68	0.35	8.05; 9.45	0.0071	0.19; 1.14	21; 27	11
Daphnia longispina	4.56	0.84	7.7	0.06	0.2; 0.75	0.042; 0.124	0.3; 0.87	0.034	8.12; 9.5	0.009	0; 0.095	20; 25	12
Eudiaptomus sp.	12.16	0.84	8.4	0.09	0.2; 0.66	0.042; 0.124	0.36; 0.97	0.036	8.2; 9.45	0.0071	0.06; 0.26	21; 25	11
Keratella quadrata	7.04	0.43	7.7	0.05	0.2; 0.555	0.029; 0.08	0.02; 0.76	0.093	7.76; 9.45	0.004	0.06; 0.26	20; 26	6.5
Mesocyclops leuckarti	4.32	1.32	8.56	0.06	0.4; 2.9	0.042; 0.13	0.16; 0.84	0.037	7.98; 9.45	0.016	0; 0.12	19; 25	14
Diaptomus larvae	2.56	0.84	8.4	0.04	0.2; 0.555	0.042; 0.196	0.27; 0.97	0.037	8.07; 9.45	0.009	0.06; 0.26	19; 25	5.8
Copepoda larvae	4.8	0.87	8.08	0.07	0.6; 2.4	0.035; 0.16	0.02; 1.03	0.52	7.7; 9.56	0.0071	0; 0.22	20; 30	19
Copepoda nauplii	3.9	0.69	8.16	0.06	0.2; 0.93	0.044; 0.36	0.02; 0.68	0.066	7.76; 9.56	0.016	0.06; 0.26	19; 26	16.5
Epistylis sp.	3.2	1.21	4.9	0.14	0.508; 0.97	0.025; 0.057	0.52; 1.04	0.053	8.07; 9.5	0.009	0.14; 0.6	20.5; 23	9.6
Euchlanis dilatata	7.44	1.5	4.8	0.42	0.83; 2.2	0.05; 0.89	0.12; 0.65	0.69	6.5; 7.8	0.0028	0.21; 2.4	20; 30	26
Eudiaptomus gracilis	1.92	0.34	7.7	0.05	0.24; 0.84	0; 0.064	0.76; 6.5	0.053	7.5; 8.36	0.0037	0; 0.194	0; 20.5	5
Maximum allowable concentrations [MAC]	3	0.3	4	0.1	0.5	3.3	45		6.5–8.5	0.001			0.25

Note: ul, upper level; ll, lower level; for other designations, see text.

The causes of particular position of the three above species are apparently due to their particular ecological status. For instance, *E. dilatata* is a euribiont species easily adaptable to a very wide range of environmental factors. This explains its tolerance limits, which are the widest by the majority of indices.

CONCLUSION

The primary analysis of the data on the Sura River ecosystem demonstrated the high efficiency of DA for establishing the relationship between various components of the ecosystem. DA allowed us to (1) reveal environmental factors responsible for changes in organic matter quantity expressed as BOD and the content of dissolved oxygen; (2) reveal the groups of zooplankton species with mutually contingent abundance; and (3) calculate the ranges of abiotic factors allowing high abundance of the organisms. Further prospective application of the method is related to investigation of integral properties of the ecosystem, such as generalized class of water quality by abiotic indices and thesaprobe index of the zooplankton community. Wider application of multiple classification is possible, for instance, for analysis of the relations between biotic and abiotic components of the ecosystem. A DA procedure called context introduction can study any relations within one of the three regions—the river, reservoir, and the region near the dam. The lower limits of accuracy and completeness validating the considered rule should be also defined.

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