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New Statistical Approach to Spatial Analysis of Ecosystem of the Sasyk Reservoir, Ukraine

Sophia Barinova[1, *], Olena Bilous[2], Natalia Ivanova[2]

[1]Institute of Evolution, University of Haifa, Haifa, Israel
[2]Institute of Hydrobiology of NAS of Ukraine, Kiev, Ukraine

Email address:
barinova@reserch.haifa.ac.il (S. Barinova), bilous_olena@ukr.net (O. Bilous), ivanova_N_A@ukr.net (N. Ivanova)
[*]Corresponding author

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Abstract: This study represents a new statistical mapping approach in surface ecological mapping on the basis of environmental and phytoplankton data of the Sasyk Reservoir, formerly an estuary of the Black Sea coast. Ecological maps were constructed with the help of new tools in Statistica 12.0 Program. Bioindication groups and environmental variables in data mapping helped us to characterize the studied reservoir in summer 2013 as moderate temperature, fresh water, low acid and low alkaline, standing – low-streaming water, with medium amounts of oxygen, medium pollution, Class III of water quality, eutrophic, mainly with moderate concentrations of organic bounded nitrogen. The impact of coming elements affecting the reservoir ecosystem were revealed as the Sarata and Kogylnik rivers for water pH and organic pollution, and the Danube canal as the source of water salinity and available nitrogen. The central part of the reservoir was indicated as having the most unstable community with a large phytoplankton biomass and the lowest Shannon index. A new approach to surface mapping is so easy that we can recommend it for monitoring the Sasyk Reservoir ecosystem in combination with bioindication.

Keywords: Phytoplankton, Environment, Bioindication, Water Quality, Pollution, Statistics, Estuarine Reservoir

1. Introduction

The Sasyk reservoir is represented as a freshwater area with long history of anthropogenic transformation from the Black Sea estuary from 1990th [1]. Hydrobiological investigations for the purpose of assessing the ecological state of the reservoir were started in 1990 [1] and the continued assessment was made in saprobiological characteristics, macrozoobenthos, and bacteriobenthos [2-4] but has become more sporadic.

The first attempt in spatial distribution of the bioindication results was undertaken only recently based on phytoplankton found in the Sasyk Reservoir [5]. Spatial distribution analysis continues because it can give some correlation between phytoplankton and environmental data in future monitoring and can influence in making decisions on water quality regulation.

The ecological mapping approach was employed to reveal the targets and power of impacts on the freshwater riverine ecosystems. The data for the map is based on the assessments of bioindication and chemical variables. A comparison of the density/diversity indices and distribution of pollutants over the reservoir basin monitoring stations, as well as a statistic approach and modeling, were used to reveal the risk factors for the reservoir ecosystem.

Not only are the chemical variables in the water determined with equipment, but bioindication results can also be correlated with the real geographic contour of the studied aquatic objects, such as lakes and other lentic water bodies.

Surface type ecological maps are required for the purpose of comparing surface distribution of different variables, especially chemical and biological. Up till now, there are still many difficulties in constructing special data mining and programs. Usually the data of variables in lakes-type of object coming from different sampling stations are found in the lakes' surface. Therefore, each surface station can be positioned with its geographical coordinates. A table of bioindication results, chemical data, and other climatic variables can therefore be represented with coordinates of the sampling stations. The table data can be placed on the geographically outlined surface projection if the sampling stations are rather high in number.

The aim of the present study is to assess the reservoir's water quality by bioindication methods and the use of the statistical approach as a new instrument for assessment for the purpose of finding the water pollution sources and determining the major variables of its water quality regulation.

2. Material and Methods

2.1. Description of Study Site

The Sasyk reservoir is situated near the Black Sea coast in Ukraine on the far southwest of Danube–Dniester interfluves close to the Kiliyskaya delta of the Danube River (Figure 1). It is 35 km long, with a width of 3 to 12 km and is so shallow that in the deepest part there is a maximal depth of 3.2 to 3.6 m [6]. The water surface is approximately 200–215 km^2, and has an average volume of about 500 mln. m^3. Formerly, the Sasyk was a marine estuary, which formed as a result of the Black Sea transgression to the lower reaches of the Kogylnik and the Sarata rivers [7]. In 1978, the estuary separated from the sea with the help of a man-made dam (14.5 km in length and 6 m in height) connecting it with the Danube River using the Danube–Sasyk Canal, which is 13.5 km in length with a capacity up to 250 m^{3}s^{-1}. Thus, the estuary was transformed into the freshwater reservoir's Danube–Dniester irrigation system and became the first transit link in the water transfer project of the Danube–Dnieper water economic complex [8].

Figure 1. *Scheme of the Sasyk Reservoir with the sampling stations.*

Total dissolved solids (TDS) of water have decreased from 2.4-20.3‰ in 1978 up to 0.3-2.7‰ in 2013 [5]. Nevertheless, the water did not become suitable for irrigation [1, 8, 9].

2.2. Materials

Materials for analysis come from our investigation in 2013 [5], Table 1 indicates data of hydrobiological and bioindication results based on phytoplankton research.

2.3. Methods

We used Program Statistica 12.0 for the construction of spatial maps of hydrobiological and chemical data that resulted from our previous research [5]. The major requirement for the data mapping was the GIS coordinates of sampling points that were measured in 2013. The surface type of ecological map construction does not require any further instrument data than what was revealed by the Statistica 12.0 program. This modern version of the program can help scientists construct the ecological maps.

3. Results

The surface type of ecological maps of variables in the Sasyk Reservoir was constructed in the Statistica 12.0 program as wafer plots based on GIS-coordinated sampling points.

Our previous investigations [5] revealed high homogeneity of the water and of phytoplankton variables. Assessment of the reservoir's ecosystem with the help of the first ecological maps in the Statistica 12.0 program (Figure 2) on the basis of bioindicator groups of phytoplankton showed that water temperature has high heterogeneity and slightly decreases near the dam (Figure 2a). Bioindication of the water temperature reveals three groups of indicators in which eurythermic species increased in the Kogylnik River input as well as near the Danube canal input (Figure 2b). The temperature indicators are slightly higher in the southern part of the reservoir where the Danube canal waters are flow in to the reservoir (Figure 2c). Nevertheless, the most affected distribution of warm-water indicators (Figure 2d) reveal the water area is the warmest near the shoreline of the Sasyk Reservoir.

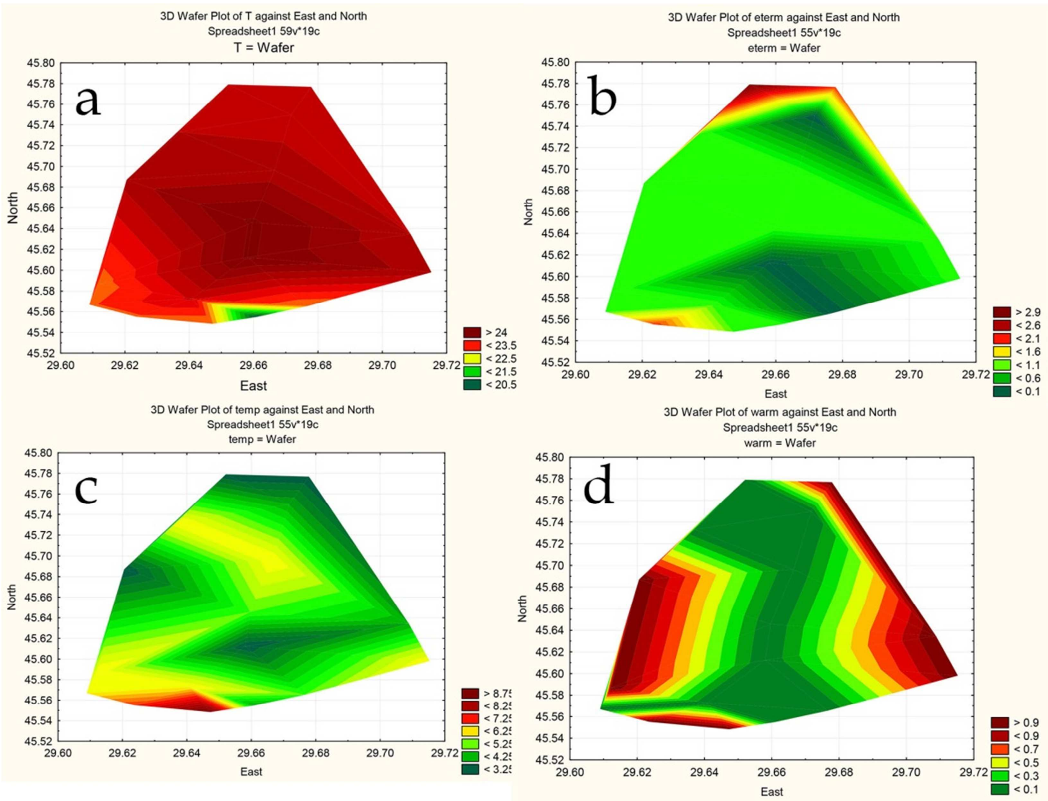

Figure 2. *Statistically mapped variables in the Sasyk Reservoir surface in 2013: Water temperature (a), Eurythermic indicators (b), Temperate-temperature indicators (c), and Warm-water indicators (d).*

The major productivity-related variable, such as oxygen saturation (Figure 3a), shows mostly oxygenated waters near the dam. Phytoplankton abundance (Figure 3b) was highest in the center of the reservoir. Phytoplankton biomass (Figure 3c) was highest near the western coast of the reservoir where agricultural fields are located. The oxygen-related stream-water indicators (Figure 3d) demonstrate oxygenated waters near the Kogylnik and Sarata rivers input in the northern part of reservoir as well as near the Danube canal water input in the south.

Table 1. *The phytoplankton variables with an average data on abundance, biomass and number of species and its ecology over the Sasyk Reservoir sampling stations in summer 2013 [5].*

Stations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Ecological categories																	
Temperature																	
temp	5	4	9	7	6	6	6	6	4	6	4	3	3	6	3	5	3
eterm	–	1	1	2	1	1	1	1	1	1	–	2	3	1	1	1	–
warm	–	–	1	1	–	1	–	1	1	–	–	1	–	–	1	–	–
Salinity																	
hb	1	1	1	2	1	1	2	1	1	1	2	2	1	1	1	1	1
i	23	22	31	22	24	23	23	28	22	24	25	23	15	28	16	14	22
hl	5	6	8	7	8	5	8	6	7	5	7	7	5	4	5	5	7
mh	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–
pH																	
acf	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
ind	9	8	11	9	8	7	10	8	9	7	7	9	7	10	4	4	6
neu	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
alp	6	9	15	8	11	11	8	10	7	9	8	8	4	8	6	5	7
alb		1	1	1	1	–	–	–	–	1	1	2	–	–	–	–	–
Water mass dynamics and oxygenation																	

Stations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Ecological categories																	
st	5	5	6	6	8	4	2	6	4	4	4	8	4	5	5	2	4
st–str	30	32	39	28	30	32	34	35	32	33	32	26	22	36	24	26	26
str	–	1	1	1	1	2	–	–	–	1	1	2	–	–	1	–	1
Organic pollution according Watanabe																	
sx	2	2	4	1	1	1	3	2	1	2	1	1	–	3	–	–	1
es	3	7	10	8	9	10	5	7	5	6	6	4	3	3	5	4	5
sp	2	1	2	2	3	1	2	1	1	1	1	3	1	2	1	2	1
according Pantle-Buck in Sládeček modification																	
a	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	1	–
a–b	3	2	2	2	3	1	1	1	1	1	2	2	1	3	2	–	2
b	21	17	22	18	20	18	18	21	19	20	20	19	13	22	16	16	16
b–a	1	4	1	2	3	3	2	3	2	1	2	2	2	2	–	3	1
b–o	3	2	3	3	2	4	2	3	3	3	2	3	1	3	2	1	2
b–p	1	1	1	–	1	1	1	1	1	1	–	–	–	–	1	–	–
o	–	1	2	–	1	–	2	1	1	3	1		1	3	1	–	1
o–a	6	7	12	10	9	8	11	11	9	8	8	7	9	8	5	6	9
o–b	3	4	5	3	2	2	2	5	3	5	5	3	3	5	3	2	2
o–x	1	–	1	1	1	1	1	–	–	–	–	1	–	–	–	1	–
x	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–
x–b	–	1	1	–	1	1	–	1	–	–	1	2	1	1	–	–	1
x–o	–	1	2	1	2	1	–	–	–	1	1	–	–	–	1	–	1
Water quality class																	
I	–	1	2	1	2	2	1	–	–	1	1	–	–	–	1	–	1
II	4	6	9	4	5	4	5	7	4	8	7	6	5	9	4	3	4
III	31	30	38	33	34	33	33	38	33	32	32	31	25	35	23	26	28
IV	1	1	1	1	1	1	1	1	1	1	–	–	–	–	1	1	–
V	3	2	2	2	3	1	1	1	1	1	2	2	1	3	2	–	2
Trophic state																	
o–m	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
m	1	1	–	1	1	–	–	–	1	–	1	1	–	–	1	–	1
me	–	2	3	1	1	2	1	1	1	3	1	1	–	1	1	–	1
e	4	6	10	3	7	7	5	5	4	5	6	4	3	6	3	3	4
he	2	1	2	2	2	1	1	2	–	1	1	2	–	1	1	1	1
o–e	–	1	1	3	1	2	1	1	1	1	–	–	1	–	1	2	–
Nitrogen uptake metabolism																	
ats	–	–	2	1	1	1	2	2	–	1	–	2	–	1	–	–	–
ate	4	9	11	6	8	7	5	5	6	7	7	4	3	4	5	4	5
hne	2	2	2	2	2	3	1	2	1	2	2	2	1	2	2	1	2
hce	1	–	1	1	1	1	1	–	–	–	–	1	–	1	–	1	–
Saprobity index	2.15	1.99	1.99	2.15	2.02	2.05	2.04	2.00	2.03	1.93	1.94	2.00	2.17	2.00	2.29	2.19	1.97
Abundance (10^6 cellsL^{-1})	56.2	24.0	30.8	86.3	36.3	14.9	24.2	21.9	22.6	25.5	32.4	22.5	35.3	18.1	48.7	126.1	24.2
Biomass (mg·L^{-1})	6.55	3.96	5.45	4.95	4.43	3.77	3.40	3.47	2.56	3.83	4.51	3.64	1.95	2.98	8.20	4.79	4.07
No. of Species	50	48	64	49	53	50	53	59	48	51	50	46	36	54	40	36	47
Shannon index (Bites/specimens)	2.38	2.55	2.58	2.03	2.56	2.63	2.61	2.67	2.31	2.50	2.32	2.53	2.00	2.53	2.68	1.86	2.62
Cell average mass (B/N, 10^{-6} mg cell^{-1})	0.12	0.16	0.18	0.06	0.12	0.25	0.14	0.16	0.11	0.15	0.14	0.16	0.06	0.16	0.17	0.04	0.17

Symbols of Ecological categories: Temperature: temp – temperate, warm – warm–water, eterm – eurythermic. Salinity: hb – oligoholobious–halophobe, i – oligoholobious–indifferent, hl – oligoholobious–halophile, mh – mesohalobous. pH: acf – acidophilic; ind – indifferent, neu – neutrophiles (correspond to pH–indifferent species), alp – alkaliphilic; alb – alkalibiontic. Water mass dynamics and oxygenation: st– standing low oxygenated water, str – streaming high oxygenated water, st–str – standing–streaming moderate oxygenated water. Organic pollution on the Pantle–Buck's in Sládeček modification: x – xenosaprobes, x–o – xeno–oligosaprobes, o–x – oligo–xenosaprobes, x–b – xeno–betamesosaprobes, o – oligosaprobes, o–b – oligo–betamesosaprobes, b–o – beta–oligosaprobes, o–a – oligo–alphamesosaprobes, b – betamesosaprobes, b–a – beta–alphamesosaprobes, b–p – beta–polysaprobes, a – alphamesosaprobes, a–b – alpha–betamesosaprobes. Water quality class (according to saprobity indices ranks): I – 0–0.5, II – 0.5–1.5, III – 1.5–2.5, IV – 2.5–3.5, V – 3.5–4.0. Organic pollution according Watanabe's: sx – saproxen, es – eurysaprob, sp – saprophil. Trophic state: o–m – oligo– to mesotraphentic, m – mesotraphentic, me – meso–eutraphentic, e – eutraphentic; he – hypereutraphentic, o–e, oligo– to eutraphentic (hypereutraphentic). Nitrogen uptake metabolism: ats – nitrogen–autotrophic taxa, tolerating very small concentrations of organically bound nitrogen, ate – nitrogen–autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen, hne – facultative nitrogen–heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen, hce – obligatory nitrogen–heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen. slightly below or slightly above the conventional stage boundary.

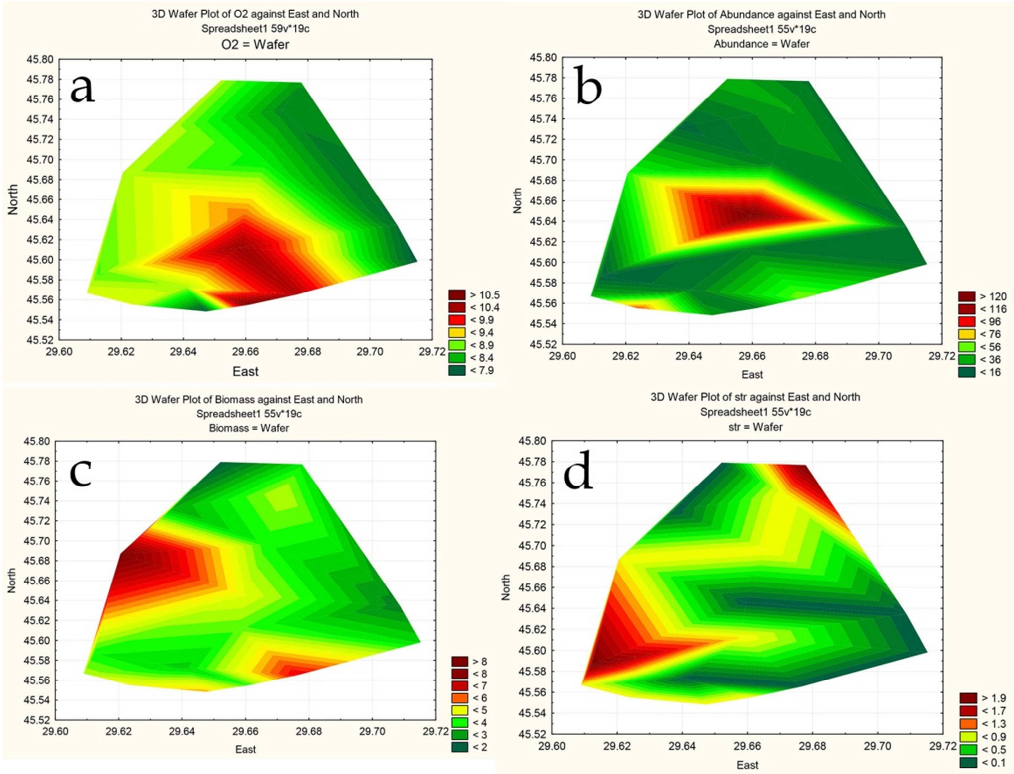

Figure 3. Statistically mapped variables in the Sasyk Reservoir surface in 2013: Oxygen saturation (a), Phytoplankton abundance (b), Phytoplankton biomass (c), and Stream-water indicators (d).

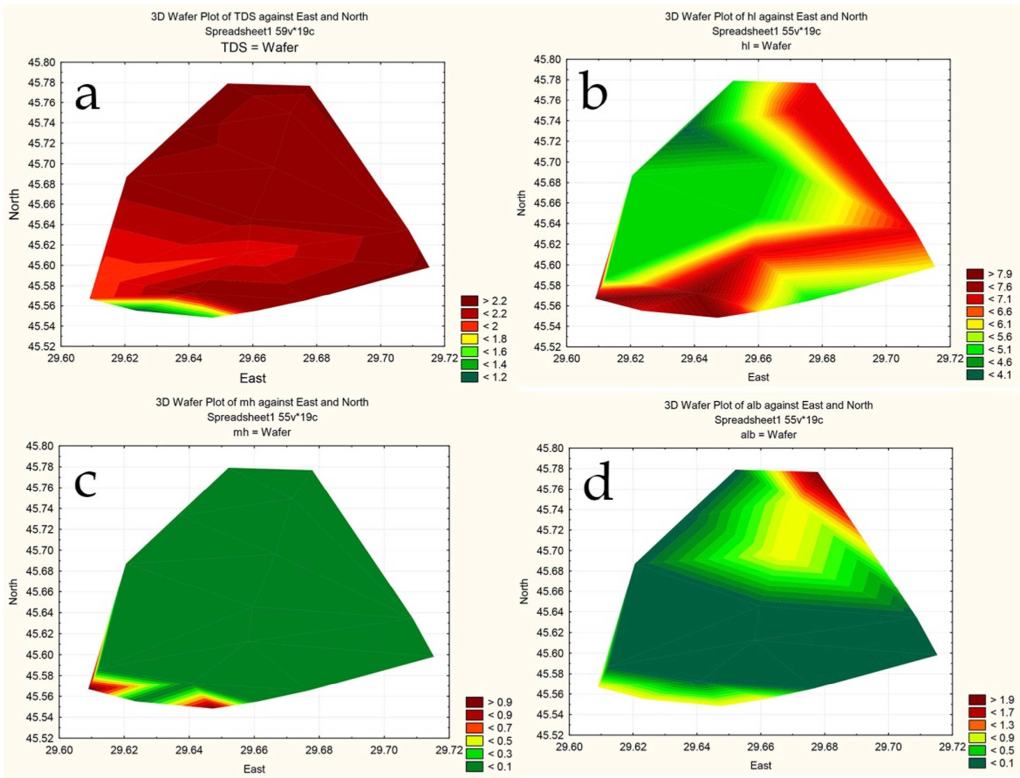

Figure 4. Statistically mapped variables in the Sasyk Reservoir surface in 2013: Water Total Dissolved Solids (TDS) (a), Halophiles indicators (b), Mesohalobe indicators (c), Alkalibiontes indicators (d).

Water TDS (Total Dissolved Solids) is mapped on Figure 4a and show high levels of homogeneity in the reservoir surface. However, in the southern part of reservoir, we can see decreases of TDS in the place where the Danube fresh water is flows into the reservoir. The halophilic species-indicators of salinity reveal an impact of sea waters in the southwestern part near the dam and near the eastern coast of the reservoir (Figure 4b). Mesohalobes, which are indicators of brackish water, show saline water influence in the southern part only near the dam (Figure 4d).

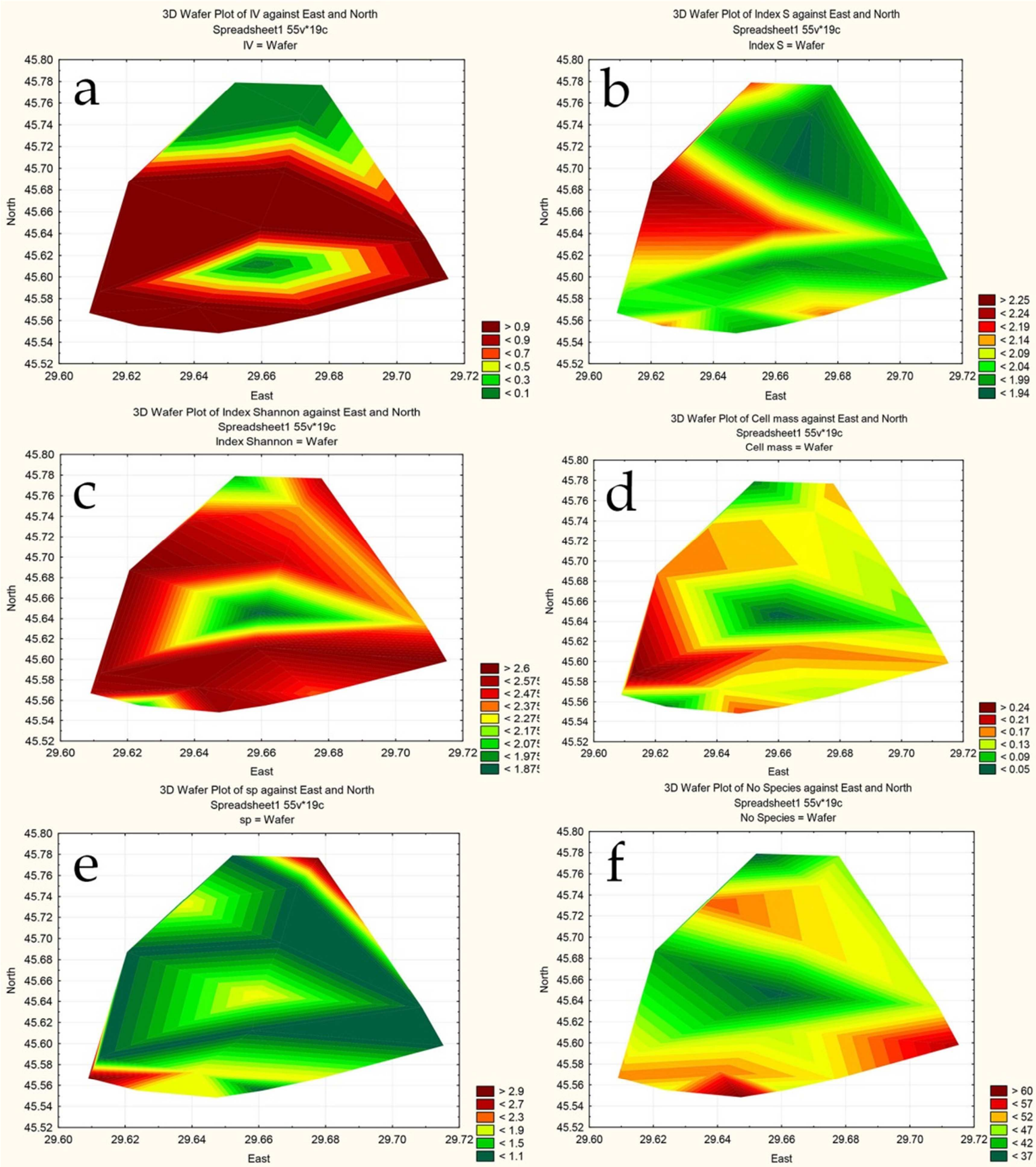

Figure 5. *Statistically mapped variables in the Sasyk Reservoir surface in 2013: Water quality Class IV indicators (a), Index saprobity S (b), Shannon Index (c), Average cell mass (d), Saprophiles taxa according to the Watanabe system (e), No. of algal species in phytoplankton community (f).*

The water pH indicators in the community were rather heterogenic but the map (Figure 4d), on the basis of high pH alkalibiontes indicators, shows input of alkaline waters from the Kogylnik and Sarata rivers' basin.

Water quality Class IV indicators (Figure 5a) and Index saprobity S (Figure 5b) show that organic pollution comes mostly from the western coastal agricultural fields. Averaged cell volume of phytoplankton and Shannon Index were correlated (Figure 5 c, d) and indicate that the ecosystem in the peripheral part of the reservoir is most stable. Indicators of high pH water are represented mostly in the upper part of the reservoir in the Kogylnik River input (Figure 3e). At the same time, diatom species indicators (Figure 5e) of high organic pollution (saprophiles taxa according to Watanabe system) revealed the Kogylnik underground waters' flow in the northern part of the Sasyk Reservoir, and also in the southwestern part in the place of the Danube canal input. As a result of the ecosystem's sustainable assessment, the number of algal species in the phytoplankton community (Figure 5f) is revealed at the dam as a place where species richness increases.

It is very important to know how organic pollution stimulates the trophic sustainability in the reservoir and which taxa are preferable. In this case, we analyzed the distribution of trophic level indicators (Figure 6 a, b).

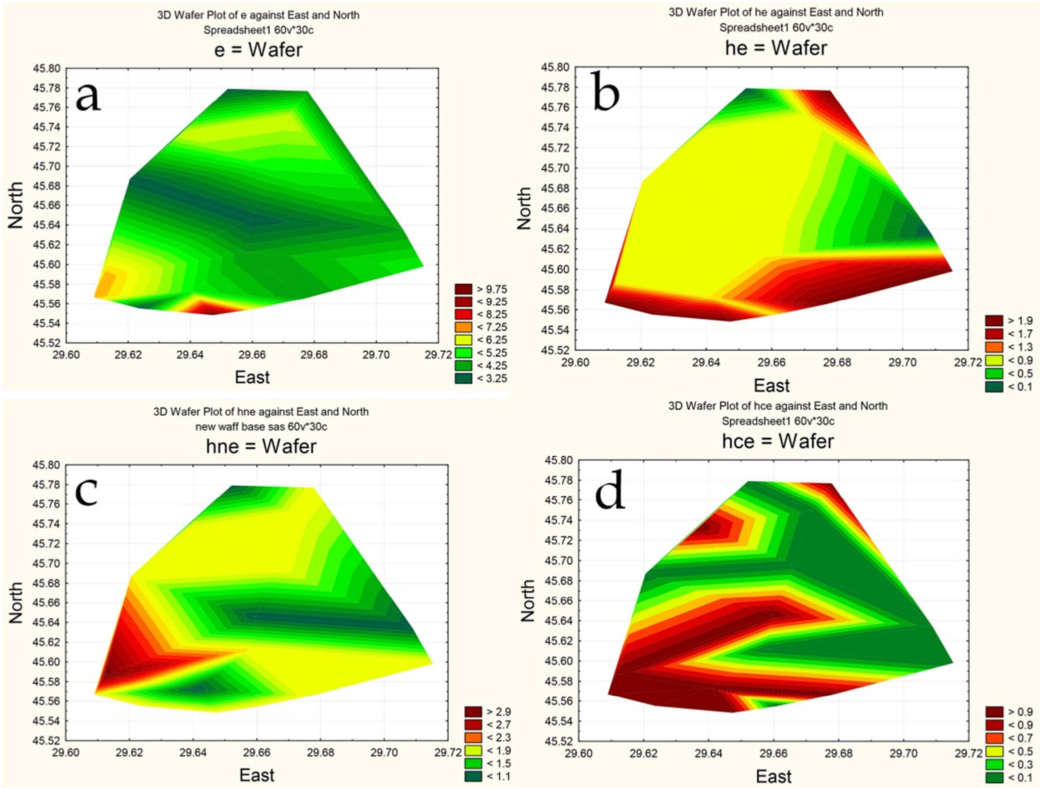

Figure 6. *Statistically mapped variables in the Sasyk Reservoir surface in 2013: eutrophic species indicators (a), hypereutrophic species indicators (b), facultative nitrogen-heterotrophic taxa (c), obligatory nitrogen-heterotrophic taxa (d).*

It can be seen that the beginning of the eutrophication process is presented in communities near the southwestern coast (Figure 6a), whereas hypertrophic indicators are distributed mostly in the saline-water filtration input across the dam and the Danube canal in the southern part of reservoir, as well as in the northern part where the Kogylnik River water also enters (Figure 6b). This situation is correlated with the indicators of the photosynthetic way of proteins synthesis when the autotrophic algae in phytoplankton are usually presented. The distribution of some groups of heterotrophic taxa can reveal in which station the algal community has affected the photosynthetic process. Usually this situation is generated by some toxicants that are presented in the reservoir water. Therefore, we can observe areas on the reservoir surface which have some substances that are toxic for the first level of the trophic pyramid. The distribution of the facultative nitrogen-heterotrophic taxa (Figure 6c) is accumulated in the southwestern part of reservoir, whereas the map of obligatory nitrogen-heterotrophic taxa distribution (Figure 6d) pointed not only to the southwestern part, but also to the western and northern parts of the reservoir in which the algal community was stressed.

4. Discussion

The reservoir is shallow, about 3 m deep with a very large water surface that provokes the water variables' homogeneity. In this case, we have tried to find some instruments for revealing the variables that can mark some importance for analyzing the ecosystem in future monitoring of the Sasyk Reservoir. Earlier, hand-made mapping on the base of some biological variables were implemented across the water surface of this large reservoir. In this way, not only were species richness, abundance, and algal mass of the phytoplankton revealed but also the methods of bioindication were implemented [5]. Bioindication methods were also very informative in the analysis of ecosystems of several other regional large water bodies [10]. Therefore, it is very important not only in monitoring water quality but also in trying to find new cost-effective methods for its assessment.

Ecological conditions of large regional water bodies have a large range. As can be seen in a recent study, the environment of south-boreal province lakes and reservoirs salinity varied from 0.5 g l^{-1} such in the Great Lota in Turkey [11] up to 0.9 g l^{-1} and in northern Kazakhstan lakes up to 30 g l^{-1} [12]. The Balkhash Lake, even in its western freshened part, is brackish [13], but the Kolsay lakes are fresh [14]. The southern subtropical province in India is also fresh (Lake Santragachi [15] with 0.3 g l^{-1} and the Shibpukur Lake with 4 g l^{-1} [16]). In Israel, in the arid zone, the water bodies' salinity varied from 0.9 to 30 g l^{-1} [12] as in northern Kazakhstan [12]. This information helps us to conclude that the Sasyk Reservoir in Ukraine [5] occupies the intermediate position in this range with 2.2 g l^{-1}.

Methods of bioindication were implemented in the abovementioned lakes and reservoirs on the basis of its algal species diversity. Studied reservoir algal species richness of phytoplankton was represented by a total of 130 species, which varied between 36-64 taxa in the community of the sampling stations [5] as in other similar water bodies [11, 17, 18]. It is remarkable that species richness in the abovementioned lakes decreased with salinity increases as was demonstrated in the groups of lakes with high amounts of salinity [12, 18]. Therefore, algal diversity of the Sasyk Reservoir with large algal species richness confirms its freshwater sustainability at the present time in the scale of the studied lakes of region.

The domination of Chlorophyta species in the Sasyk Reservoir phytoplankton [5] characterizes its ecosystem as effective, like the subtropical lakes in India [15, 16] or summer community in the Neot HaKikar in Israel [19]. The regional norm is different with prevailing diatom species in diverse waterbodies' phytoplankton [18, 20].

Bioindication methods were implemented first for the Sasyk Reservoir water quality analysis as in the abovementioned hot-region lakes [11, 12, 14]. Bioindication analysis characterizes the Sasyk Reservoir as moderate temperature, freshwater, low acid and low alkaline, with standing or low-streaming water mass, medium amounts of oxygen, medium pollution, Class III of water quality, eutrophic, mainly with moderate concentrations of organic bounded nitrogen. The impact of the Sarata and Koglynik rivers on the reservoir ecosystem influenced water pH and organic pollution levels; the Danube canal influenced water salinity and available nitrogen.

In comparison with other regional lakes, the bioindication of the Sasyk Reservoir environment represented a similar tendency in the water quality process with salinity as a regulating factor like in Northern Kasakhstan and Kolsay lakes [14, 17], as well as in Turkey [11] and Israel [12]. The bioindication assessment results were different from the Indian subtropics lakes, where water temperature is the major regulating factor [11, 15].

In the Sasyk Reservoir ecosystem, we implemented not only an integral bioindication method [5] for assessment but also a new statistical method of surface mapping.

Yes, of course, the algal abundance and biomass can show the parts of reservoir that have the most suitable environment for phytoplankton development. The first step of map construction should determine which variables or indicator groups are significant for constructing the map. Earlier [5], they were chosen mostly intuitively. So, for example, the warm-water indicators or alkalibiontes indicator groups were selected for the mapping of temperature and water-pH differences. The most apparent difficulties previously for mapping were in species richness because it was necessary to calculate the standard deviation and after dividing our data for the stations into two parts – above and below of SD, and only after that could the data be mapped.

Some environmental data, such as water temperature, Total Dissolved Solids (TDS), and oxygen saturation, were included in our map construction as well. Figure 2a shows water temperature distribution. The gradient between parts of the studied reservoir can be observed on the map even in the case of a very small range in the data. The indicator species of warm-water habitats' (Figure 2d) distribution is similar to our earlier analysis [5], but the hand-made surface map does not give a clear picture for prognostic distribution. Moreover, the statistically constructed maps of closely related temperature indicators, such as eurythermic and temperate water temperature taxa, reveal consistent indications for the lake areas in relation to water surface warming (Figure 2b, c).

It is well known that water oxygenation represents one very important variable for the functioning of the algal community. The oxygen saturation of the Sasyk Reservoir water was mapped (Figure 3a) for the first time. The mapping of closely related biological parameters, such as phytoplankton abundance and algal biomass, were presented by the community response to oxygen saturation. Whereas algal abundance distribution map was correlated with oxygen saturation, the algal biomass displays different distribution which is mostly related for areas of the dam and on the western coast. In comparison with hand-made maps [5], our maps are more representative of and related to the environment.

5. Conclusion

The new statistical approach in surface mapping of biodiversity and phytoplankton productivity was used with help of Statistica 12.0 program in parallel with bioindication methods.

The spatial analysis of the ecosystem's relationship to environmental variables can be improved with the help of ecological maps only.

A very important property of our maps is the continuation of parameter distribution that can be used for future analysis in prognostic properties. In any case, the previously constructed maps are similar to the study done here in respect to phytoplankton abundance and biomass. The same situation is with the analysis of water salinity environment and indication assessment of which is very important in future use of the Sasyk Reservoir.

It is not necessary to choose some parts of data for this approach of mapping now. It gives us the total view for all data spatial analysis. In our analysis a very small range of data can be implemented to point out the gradients between parts of the studied reservoir. As a new surface mapping method, we can conclude that statistical maps are more representative of and related to the environment.

As a result, we observe that the surface mapping method is recommended to assess the ecological conditions of the water body − not for individual stations but for the whole reservoir. This study confirms the conclusion from our previous work about the correlation of water temperature and total dissolved solids, which is strongly related to chloride concentration.

Statistical mapping also confirms that the bioindication method shows a more detailed picture than the standard physico-chemical analysis.

Thus, bioindication and chemical data surface mapping represent easy tools for data comparison that can be included in the monitoring of the Sasyk Reservoir.

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