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ASSESSMENT OF ACTUAL WATER QUALITY AND SEDIMENTOLOGICAL CONDITIONS OF THE CORBU I LAKE, WESTERN BLACK SEA COAST

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Abstract: Corbu I Lake, analyzed between July 24th and 29th, 2019, had a brackish water that from a physico-chemical point of view, presented oxygen supersaturation, a high degree of mineralization, a rather alkaline pH and a subunitary index of water transparency. Also, the water of Corbu I Lake corresponded to a moderate ecological status (III) at the time of taking the surface samples, due to the pointlike and local diffuse anthropogenic influences. From a chemical point of view, the biogenic elements containing nitrogen and phosphorus, sulphates and detergents, were not conforming with the maximum permitted levels specified by the Order No. 161/2006, published in the Official Journal of Romania by the Ministry of Environment and Water Management. Regarding the eutrophication degree, the indicators of total mineral nitrogen and total phosphorus corresponded to the eutro-hypertrophic and, respectively, hypertrophic stages. The $N_{T\ mineral}/P_T$ ratio ranged between 5.72 and 68.53, indicating the more pronounced incidence of eutrophication in this lake, which also had a high content of organic matter (>20 mg/l), due to the zonal diffuse sources of pollution. The ecological status of the studied aquatic environment was from good to weak classes for nitrites, ammonium and phosphates, moderate for sulphates and weak for detergents. It had a low content of silica, as well as anaerobic fermentation products (H_2S and S^{2-}) that were undetectable and quantitatively insignificant. The granulometry of the bottom-sediment samples of Corbu I Lake has identified muds, with the clay fraction subordinated to the silt. Due to the accumulated and decomposed biogenic material, black and unctuous muds with a specific odor were found. The interpretation of the data resulting from the grain size analysis highlighted the deposition of the sediments by suspensions in calm water with poor circulation, a different and poorly sorting and an excess of fine clastic material.

Keywords: limnological studies, water quality, physico-chemical parameters, brackish water, eutrophication, laser diffractometry, bottom-sediments, grain size analysis, Corbu I Lake, western Black Sea coast

1. INTRODUCTION

The southern zone of the Romanian Black Sea coast is rich in lakes, especially maritime limans. One of them, Corbu Lake (Gargalâc), is located in the southeastern part of the Central Dobrogea Plateau (Casimcei Plateau), at an altitude of 0.9 m above the Black Sea level (Gâștescu et al., 2016), with an area of 5.2 km^2 and a reception basin of 64.25 km^2 (Romanescu, 2008). The maximum depth is 1.9 m and the average depth is 1.4 m (Gâștescu & Breier, 1982). Also, Corbu Lake has an elongated circular shape and on its cliffs outcrop loess deposits (on the southeastern shore), alluvial-diluvial deposits (on the western shore) and Jurassic limestone, with a slope to the lake of about 45° (on the northeastern shore) (Caraivan, 2010).

Genetically, Corbu Lake, like all coastal lakes of the Black Sea, was formed due to abrasion and marine accumulation, this processes being caused by the sea level changes and local epeirogenic movements. In this evolution, three stages may be distinguished: the valley stage (when the sea level was 80 m lower than the current one, during

Neoeuxin), the gulf stage (when the sea level exceeded 3-5 meters the current level) and the lake stage (when the conditions for the formation of sandy belts appeared, most likely, in the Middle of the First Millennium AD) (Romanescu, 2008).

Although located in an arid region, Corbu I Lake is supplied with water by the Corbul and Valea Vetrei creeks, groundwater with a rich flow, favored by the lithological and tectonic conditions (breakable rocks, with numerous fractures and fissures), precipitation and the inflow of marine waters that penetrate the coastal belt, in certain conditions (Romanescu, 2008). Also, Corbu Lake communicates through a channel with Tașaul Lake (Alexandrov et al., 2007; Alexandrov et al., 2008).

The anthropogenic intervention has largely influenced, especially in recent decades, the lacustrine environment, in particular, the evolution of water chemistry. Currently, the lake is used for irrigation and pisciculture and is divided by a dam into two sectors: the northern one, called Corbu I (Little Corbu) Lake and the southern sector, much larger, called Corbu I (Big Corbu) Lake (Fig. 1).

During the summer's expedition of 2019, Corbu I Lake was analyzed, in terms of water quality and sedimentology. With the help of a boat, GeoEcoMar researchers moved and took water and bottom-sediment samples from 14 stations (Fig. 1), performing *in situ* measurements and laboratory analyses.

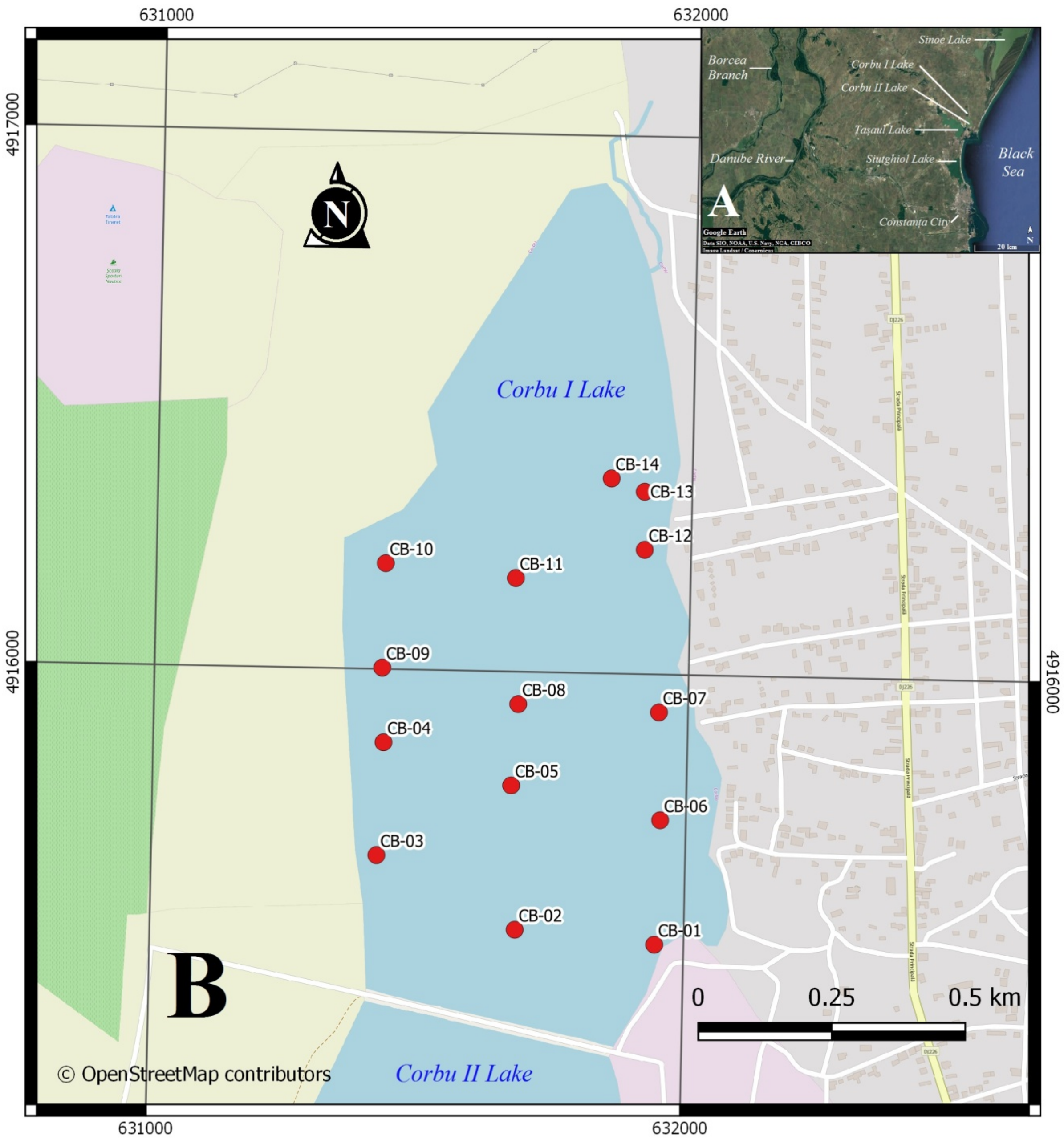

Figure 1. Location of the Corbu I Lake (A) and the sampling stations (B)

2. MATERIALS ȘI METHODS

2.1. Water quality analysis

The water samples were taken at a depth of 0.5 m using a non-metallic water sampler (Niskin bottle of 5 litres) and kept under standard conditions. Water quality parameters were determined by *in situ* measurements using the WTW Multiline P4F/SET3 multiparameter (for determinations of pH, salinity, TDS, TSS, redox potential, conductivity, dissolved oxygen, temperature), HACH 2100 P turbidimeter and HACH DR 5000 UV-VIS spectrophotometer (for nitrites, nitrates, phosphates, sulfur, sulfates, silica, detergents). Ammonium, total nitrogen, total phosphorus and TOC analyzes were performed by NIRD ECOIND from Bucharest.

2.2. Particle size analysis of bed surface sediments

The sediment samples were taken at the water-sediment interface (0-20 cm), using a van Veen bodengreifer and kept under standard conditions. Particle size analysis was performed in the NIRD GeoEcoMar laboratory, by laser diffractometry, using the granulometric analyzer "Mastersizer 2000E Ver. 5.20", Malvern. The separation of the granulometric classes (sand, silt, clay) and of the fractions within each class conforms to the Udden-Wentworth logarithmic scale (Udden, 1914, Wentworth, 1922), completed with the detailing of three fractions, at interval of 1 Φ, in the clay field.

Sediment classification was realized according to the Shepard diagram (1954). Based on the primary data, using the Gradistat program (Blott & Pye, 2001), the following statistical parameters were calculated: Median (Md = D50, Inman, 1952), graphic mean (M_z), standard deviation (σ_I, sorting), asymmetry coefficient (Sk_I, skewness) and graphic sharpness (K_G, kurtosis). The last four mentioned parameters were calculated according to the original formulas of Folk & Ward (1957).

3. RESULTS AND DISCUSSION

3.1. Spatial distribution of physico-chemical and water quality parameters

Corbu I Lake recorded an alkaline trend of pH values. The maximum values of the water pH were registered in the CB-14 station (Table 1). Salinity variations disturb the living conditions of bivalves (Velez et al., 2016, Pokhrel et al., 2019), but Corbu I Lake showed values of concentrations between 1.3 - 1.4‰. The fact is justified by the separation of Corbu II Lake, which in turn, is isolated by Tașaul and Siutghiol Lakes, relatively preserving its salinity (Romanescu, 2008). Given the arid climate of the region, the salinity of the lake should be high, following intense evaporation, but the low values were due to freshwater supply sources, as well as anthropogenic impact, which directly influences the water chemistry, especially through irrigation (Romanescu, 2008).

The values of TDS (Total Dissolved Solids) were in the range 1400 - 1480 mg/l and corresponded to oligomixohaline brackish waters (Order No. 161/2006). TSS (Total Suspended Solids) were situated between 29 - 112 mg/l, and the turbidity recorded values between 20 and 114 NTU (Fig. 2). The E_h (Redox Potential) values, predominantly negative, between -108 and 20 mV, showed a reducing environment, and the rH (Relative Humidity) values, between 15.39 and 19.18, indicated a slightly aerobic water.

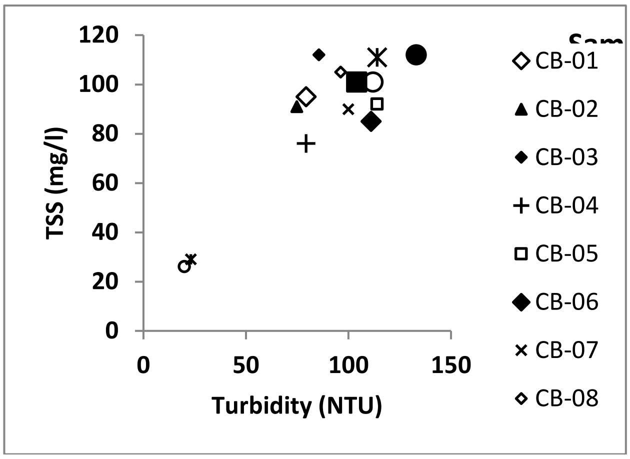

Figure 2. Turbidity and TSS distribution in the Corbu I Lake water

The electrical conductivity of water depends on the quantity of dissolved salts and had values between 2.8 and 2.96 mS/cm, the highest value being recorded in the CB-13 station.

Dissolved oxygen in water had values between 12.78 mg/l and 17.8 mg/l (Fig. 3). The concentrations suggested an oversaturation with oxygen, but corresponded, however, to a good water quality. The degree of water oxygenation (Fig. 3), at the temperature of measuring the oxygen concentration varied between 87.7% and 215% (coefficient of variation of 18.25%), corresponding to the first quality class (saturations between 90% and 110%). The highest saturation (215%) was recorded in CB-09 station. The water temperature was between 23.6 - 25.1°C. The highest temperature was recorded in the CB-07 station. Distribution of the physico-chemical parameters of Corbu I Lake water are shown in Table 1.

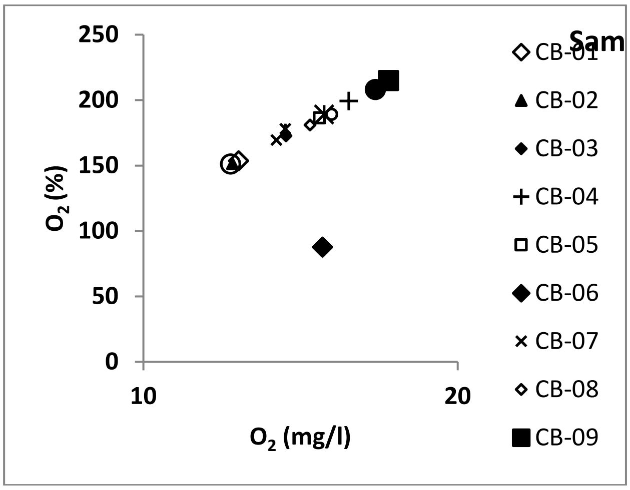

Figure 3. Dissolved oxygen concentrations and the degree of oxygenation of the Corbu I Lake water

Therefore, Corbu I Lake had brackish water, presenting oxygen oversaturation, a high degree of mineralization, pH more alkaline than CMA according to Order No. 161/2006, a subunitary water transparency index (0.2), due to strong winds in the zone (Godeanu & Galațchi, 2007) and corresponded to a moderate ecological status (III) at the time of surface sampling, because of punctiform and diffuse local anthropogenic influences, such as irrigation and fish farming. The predominance of stenohaline organisms, which support small variations in water salinity, such as European carp (*Cyprinus carpio*), Gibel carp (*Carrassius gibelio*), European perch (*Perca fluviatilis*), Pinchuck's goby (*Ponticola cephalargoides*), certified the brackish environment of the lake. The brackish water is considered sweeter than standard seawater and saltier than freshwater, but continental brackish environments are compositionally different from the marine brackish environments (Bright et al., 2018).

Table 1. Physico-chemical parameters of the Corbu I Lake water

Sample	**Date**	**Water depth (m)**	**pH**	**Salinity (‰)**	**TDS (mg/l)**	**TSS (mg/l)**	**Turbidity (NTU)**	**E_h (mV)**
CB-01	7/24/2019	0.8	9.27	1.3	1410	95	79.4	-6
CB-02		1.0	8.33	1.4	1415	91	74.9	15
CB-03		1.1	9.25	1.3	1410	112	85.6	20
CB-04		1.0	9.30	1.3	1400	76	79.4	-14
CB-05		1.0	9.25	1.3	1410	92	114.0	-23
CB-06		0.8	9.48	1.3	1410	85	111.0	-44
CB-07		0.8	9.26	1.3	1410	90	100.0	-60
CB-08		1.1	9.29	1.3	1420	105	96.2	-26
CB-09		1.0	9.25	1.3	1400	101	104.0	-26
CB-10		1.0	9.31	1.3	1410	112	133.0	-92
CB-11		1.0	9.25	1.3	1420	111	114.0	-90
CB-12		0.5	9.26	1.3	1410	101	112.0	-34
CB-13	7/29/2019	0.5	10.16	1.4	1480	26	20.0	-95
CB-14		0.5	10.33	1.4	1480	29	23.2	-108

Sample	**Date**	**Water depth (m)**	**rH**	**CND (mS/cm)**	**O_2 (mg/l)**	**O_2 (%)**	**T (^{0}C)**	**Water transparency (m)**
CB-01	7/24/2019	0.8	18.33	2.82	13.03	153.5	23.7	0.2
CB-02		1.0	17.17	2.83	12.84	151.4	23.6	0.2
CB-03		1.1	19.18	2.82	14.54	172.6	24.4	0.2
CB-04		1.0	18.11	2.80	16.54	199.2	24.6	0.2
CB-05		1.0	17.71	2.82	15.61	186.4	24.4	0.2
CB-06		0.8	17.44	2.82	15.70	87.7	24.4	0.2
CB-07		0.8	16.45	2.81	14.23	169.5	25.1	0.2
CB-08		1.1	17.68	2.83	15.30	181.0	24.3	0.2
CB-09		1.0	17.60	2.80	17.80	215.0	24.8	0.2
CB-10		1.0	15.44	2.82	17.38	208.0	25.0	0.2
CB-11		1.0	15.39	2.83	15.75	189.0	24.6	0.2
CB-12		0.5	17.34	2.82	12.78	151.1	24.4	0.2
CB-13	7/29/2019	0.5	17.04	2.96	16.00	189.0	24.4	0.2
CB-14		0.5	16.93	2.95	14.52	178.0	24.5	0.2

The values of the chemical parameters of the Corbu I Lake water on sampling stations are highlighted in Table 2.

Thus, it is observed that biogenic elements containing nitrogen and phosphorus, sulfates and detergents, are not in compliance with the maximum limits allowed by Order No. 161/2006. Regarding the degree of eutrophication, the indicators of total mineral nitrogen and total phosphorus corresponded to the eutro-hypertrophic and respectively, hypertrophic stages. The $N_{T\ mineral}/P_T$ ratio was 5.72 - 68.53, pointing the higher incidence of eutrophication in this lake, which it also had a high content of organic matter (>20 mg/l), due to diffuse zonal sources of pollution: industrial and agricultural waste, groundwater. This process can be amplified during the rainy periods of the year, because of the flow of contaminated groundwater (Alexandrov et al., 2008), which feeds the lake. Nitrogen and phosphorus have an important role in the lake environment because they promote plant development, representing a limiting nutrient responsible for eutrophication (Conley et al., 2009, Barik et al., 2018). This process also benefits from the ability of lake sediments to store phosphorus through a high sedimentation rate and efficient burial, helping to regulation of phosphorus concentration in the water column (Leote & Epping, 2015, Kowalczewska-Madura et al., 2017, Barik et al., 2018, 2019). Eutrophication is common in lakes on the western coast of the Black Sea, especially in recent decades, due to anthropogenic impact. Coastal lakes such as Tașaul (Alexandrov & Bloesch, 2009), Tăbăcărie (Godeanu & Galațchi, 2007), Costinești I and II (Romanescu, 2008), fluvial limans from southwestern Dobrogea (Romanescu et al., 2010), Danube Delta lakes, including the Razim-Sinoe lagoon complex (Galațchi & Tudor, 2006, Dinu et al., 2015, Catianis et al., 2018), lakes from the lowland and mid-altitude regions of Romania (Kelly et al., 2019), glacial lakes from Rodnei Mountains

Table 2. Chemical parameters of the Corbu I Lake water

Sample	**Date**	**Water depth (m)**	**N-NO$_3^-$ (mg/l)**	**N-NO$_2^-$ (mg/l)**	**N-NH$_4^+$ (mg/l)**	**P-PO$_4^{3-}$ (mg/l)**	**N$_T$ (mg/l)**	**P$_T$ (mg/l)**	**N$_{T\ mineral}$ (mg/l)**
CB-01	7/24/2019	0.8	0.09	0.0225	2.1931	0.191	5.25	0.19	2.3056
CB-02		1.0	0.09	0.0950	2.0920	0.075	4.87	0.12	2.2750
CB-03		1.1	0.09	0.0325	1.7265	0.175	4.83	0.23	1.8492
CB-04		1.0	0.18	0.0275	2.0297	0.116	4.69	0.10	2.2372
CB-05		1.0	0.09	0.0300	1.7265	0.100	4.54	0.12	1.8465
CB-06		0.8	0.09	0.0378	1.1821	0.133	4.86	0.15	1.3099
CB-07		0.8	0.06	0.0425	1.9831	0.116	4.95	0.19	2.0856
CB-08		1.1	0.03	0.0200	1.7109	0.216	4.39	0.10	1.7609
CB-09		1.0	0.03	0.0275	2.4186	0.133	4.70	0.08	2.4761
CB-10		1.0	0.09	0.0400	1.5242	0.083	5.06	0.14	1.6542
CB-11		1.0	0.09	0.0475	1.7732	0.108	4.46	0.09	1.9107
CB-12		0.5	0.15	0.1175	1.8509	0.108	4.98	0.20	2.1184
CB-13	7/29/2019	0.5	0.03	0.0200	0.6222	0.708	1.25	0.26	0.6722
CB-14		0.5	0.03	0.0150	0.8788	0.516	2.78	0.33	0.9238

Sample	**Date**	**Water depth (m)**	**TOC (mg/l)**	**SO$_4^{2-}$ (mg/l)**	**Detergents (mg/l)**	**H$_2$S (mg/l)**	**S^{2-} (mg/l)**	**SiO$_2$ (mg/l)**
CB-01	7/24/2019	0.8	22.11	197.5	1.73	0	0	1.0550
CB-02		1.0	22.70	197.5	1.64	0.0138	0.0130	0.9470
CB-03		1.1	21.65	182.5	1.62	0.0162	0.0100	1.4775
CB-04		1.0	21.07	135.0	1.96	0.0162	0.0100	1.8075
CB-05		1.0	21.94	172.5	2.29	0.0026	0.0025	1.9725
CB-06		0.8	22.06	172.5	2.07	0.0026	0.0025	2.0425
CB-07		0.8	22.08	190.0	3.02	0.0026	0.0025	2.2175
CB-08		1.1	21.77	165.0	2.00	0	0	1.7800
CB-09		1.0	20.21	227.5	2.40	0.0079	0.0075	1.9700
CB-10		1.0	23.18	175.0	0.57	0	0	1.8525
CB-11		1.0	22.63	182.5	0.54	0.0053	0.0050	1.5175
CB-12		0.5	21.72	195.0	0.81	0.0026	0.0025	1.3600
CB-13	7/29/2019	0.5	14.28	192.5	0.84	0	0	0.3900
CB-14		0.5	14.27	202.5	0.92	0	0	0.3900

(Mare Roșca et al., 2020), lakes from the Bulgarian Black Sea coast (Kalchevl & Botev, 1999), as well as regions from the Black Sea basin (Borysova et al., 2005, Bănăduc et al., 2016, Poikane et al., 2019) are affected by eutrophication. Globally, the increase of eutro-phication in the aquatic environment, especially in recent years, is a threat (Borek, 2018).

The ecological status of the studied aquatic environment was good to poor for nitrites, ammonium and phosphates, moderate for sulfates and poor for detergents. It had a low silica content, as well as undetectable and quantitatively insignificant anaerobic fermentation products (H_2S and S^{2-}).

Fortunately for the water of Corbu I Lake, in the area it was observed a low concentration of radioactive elements, such as ^{137}Cs, ^{40}K, ^{226}Ra, ^{228}Ac isotopes in the sands of Corbu beach (Mursa et al., 2017), but high concentrations of ^{129}I in coastal water of the Black Sea represent a threat (Enăchescu et al., 2018).

For good ecological status and to have control over eutrophication and water pollution factors, it is necessary to develop a management strategy, involving the evaluation of the relative contributions of natural variability and anthropogenic impact on lake flows (Wurtsbaugh et al., 2017), selection of suitable nutrient criteria (Poikane et al., 2019), as well as conducting seasonal limnological studies of water quality (Guo et al., 2020).

3.2. Textural characteristics of bottom-sediments

The grain size analyses of the samples taken from the bottom-sediments of this maritime liman revealed the occurence of muds, with a predominant silt fraction and a subordinated sand content. The most common textural category was the clayey silt, followed by sandy silt, according to the Shepard classification (1954). CB-02 sample contained a percentage of silt higher than 75%. Of the silty subfractions, the most abundant was the medium subfraction. The percentage particle size distribution is shown in figure 4.

Along with the inorganic matter, it was also an organogenic fraction, consisting of shells, fragments and plant debris. Due to the accumulated and decomposed biogenic material, black and unctuous muds with a specific odor of the reducing environment were also formed. This phenomenon is frequently encountered in eutrophic lakes, such as those from the Danube Delta (Rădan et al., 2016).

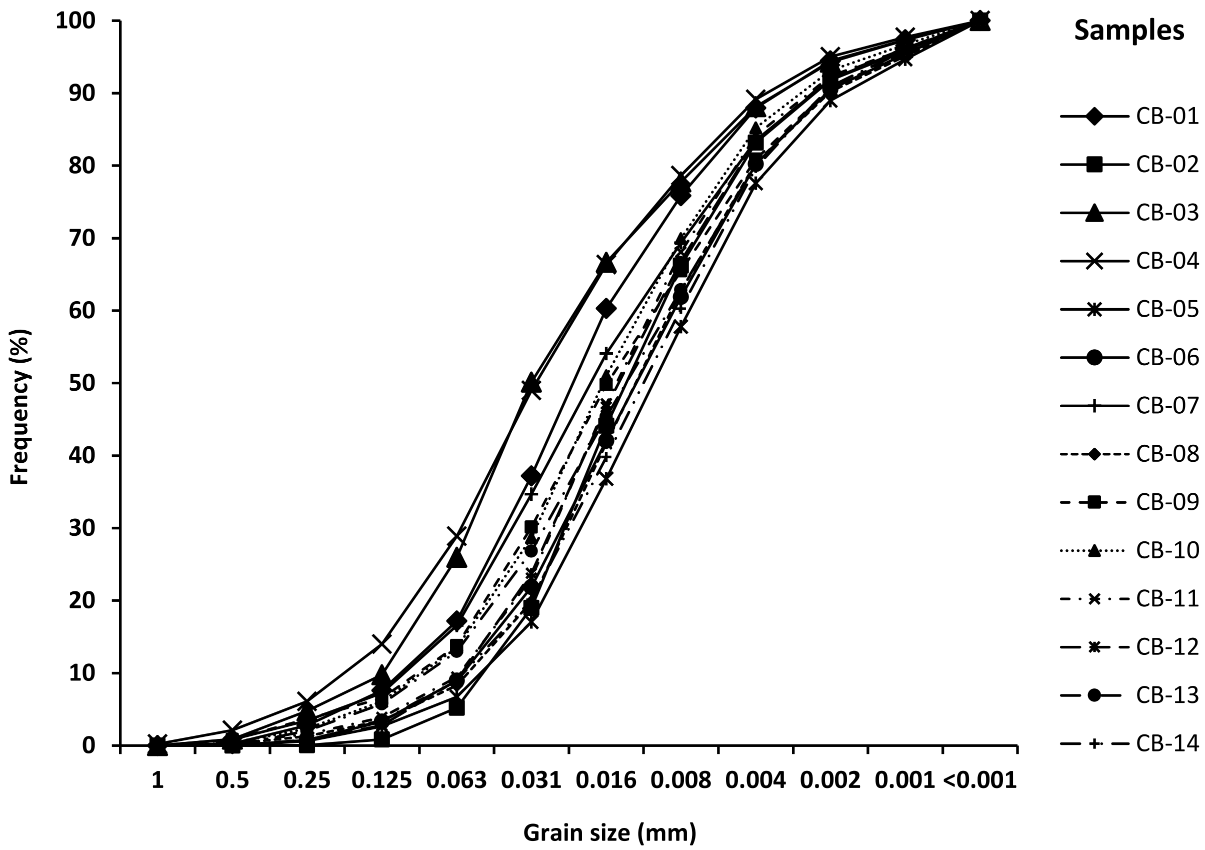

Figure 4. Cumulative frequency curves of the Corbu I Lake bottom-sediments

The presence of oxidation indicates that the bottom-sediments were recently exposed to the aerial environment (Lo et al., 2019), but in the case of Corbu I Lake, the sediments did not show oxidation.

The interpretation of the data resulting from the grain size analyses (percentages of clay, silt, sand and textural parameters, Table 3) highlighted the dynamic conditions in which these lacustrine sediments were deposited.

The median represents the average particle diameter and included values between 5.01 - 6.59 Φ. The graphic mean recorded close values, between 5.22 - 6.68 Φ, classifying the sediments in the medium and fine silt subclasses. These results indicated that the main process that led to the formation of sediments is the deposition by suspensions in calm water with poor circulation (Shang et al., 2019).

The standard deviation illustrates the sorting degree of particles and also provides information about sediment dynamics. In the case of these samples, the sorting degree of sediments varied in the range of 1.7 - 2.18 (poorly and very poorly sorting domains, according to the correlation between the inclusive graphic standard deviation and the sorting degree, proposed by Folk, 1968). Poorly sorting is a common feature of the deposited sediments by suspensions into quiet aquatic environments, being determined by the process of particle agglomeration, which prevents the selective deposition.

Asymmetry expresses the difference between the distribution compared to the normal distribution, which is symmetric with respect to its median value and, usually, is an indicator of the deposition (positive domain) or erosion (negative domain) processes (Anastasiu & Jipa, 2000). In this study, the asymmetry had positive values, generally close to 0, comprised the range of 0.02 - 0.2 and indicated an excess of fine clastic material.

Graphic sharpness (kurtosis) was included in the range of 1.01 - 1.15 (mesokurtic - leptokurtic distributions, according to the variation scale of graphic sharpness, proposed by Folk, 1968), suggesting a different sorting.

The dynamic conditions of the lakes are determined by several factors, such as depth, water volume, bottom morphology, size of the reception basin, groundwater, climatic conditions, trophic status (Telteu & Zaharia, 2012). Given the small area and volume, the main factors that determine the entrainment of particles and the sedimentation rate of Corbu I Lake are waves caused by strong winds, the anthropogenic activities (irrigation), the flow of surface waters and groundwater. The sedimentation rate in lakes is usually higher than in marine environments (Einsele, 1992).

4. CONCLUSIONS

Corbu Lake is a maritime liman, located on the western Black Sea coast, connected by a channel with Tașaul Lake. Anthropic intervention has greatly influenced the lacustrine environment, currently, the lake is being used for irrigation and fish farming. It is divided by a dam into two sectors, Corbu I and Corbu II.

Table 3. Grain size composition and textural parameters of the Corbu I Lake bottom-sediments

Sample	Grain size composition			Shepard (1954) classification	Median (Φ)	Graphic mean (Φ)	Sorting	Skewness	Kurtosis
	Sand (%)	Silt (%)	Clay (%)						
CB-01	17.21	70.76	12.03	sandy silt	5.54	5.68	1.96	0.10	1.09
CB-02	5.22	77.95	16.83	silt	6.23	6.36	1.70	0.16	1.06
CB-03	25.99	62.13	11.88	sandy silt	5.01	5.32	2.13	0.20	1.05
CB-04	28.89	60.27	10.84	sandy silt	5.07	5.22	2.18	0.09	1.01
CB-05	6.70	70.86	22.44	clayey silt	6.59	6.68	1.91	0.08	1.11
CB-06	8.99	71.25	19.76	clayey silt	6.37	6.41	1.94	0.05	1.07
CB-07	16.55	66.96	16.49	sandy silt	5.77	5.91	2.13	0.09	1.03
CB-08	8.29	72.13	19.58	clayey silt	6.36	6.45	1.92	0.08	1.12
CB-09	13.80	67.10	19.10	clayey silt	5.98	6.13	2.16	0.08	1.05
CB-10	13.53	71.67	14.80	clayey silt	5.92	5.99	1.96	0.05	1.10
CB-11	9.46	74.70	15.84	clayey silt	6.10	6.18	1.85	0.08	1.15
CB-12	9.00	74.41	16.59	clayey silt	6.13	6.21	1.85	0.10	1.08
CB-13	13.00	67.20	19.80	clayey silt	6.23	6.25	2.09	0.02	1.03
CB-14	9.02	70.67	20.31	clayey silt	6.46	6.48	1.91	0.02	1.08

Limnological studies conducted by NIRD GeoEcoMar in the summer of 2019 on Corbu I Lake reported a brackish and supersaturated with oxygen water, a high degree of mineralization, a rather alkaline pH, and a subunitary water transparency index. Due to the pollution, especially the anthropic one, the water of Corbu I Lake corresponded to a moderate ecological status (III) at the time of taking the surface samples.

From a chemical point of view, the nitrogen and phosphorus content, sulphates and detergents, did not comply with the maximum limits allowed in the Order No. 161/2006. Total mineral nitrogen and total phosphorus indicators highlighted the more pronounced incidence of eutrophication in this lake, which also had a high content of organic matter.

The noted negative features represent a threat to the ecological balance. Consequently, it is necessary to develop a management that involves a control of eutrophication and water pollution factors, reducing of anthropogenic impact on the environment, as well as systematic monitoring of water quality.

The bed surface sediments of Corbu I Lake are made up of muds, with a sand content. The sedimentation rate is conditioned by the action of waves caused by strong winds, the anthropogenic activities (irrigation), the flow of surface waters and the inflow of groundwater.

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