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2-YEAR GRAIN SIZE MONITORING OF THE RIVERBED SEDIMENTS FROM DANUBE DELTA

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Abstract The Danube Delta was studied following the Geo-Eco-Mar expeditions in the summer and autumn of 2019 and 2020, respectively, from a sedimentological, faunal and environmental quality point of view. The grain size analyses of the sediments from the bed of the Chilia, Tulcea, Sulina, St. George Branches, as well as the meanders of the Dunărea Veche and Tătaru identified two types of sediments: sediments in which the sand fraction predominates, consisting, in general, of fine sand, and the fractions silt and clay have, in most cases, very low cumulative percentages, often below 1%; clay-silty sediments (muds), consisting predominantly of silt and clay, present in areas where the water velocity has low values. The presence of gravel is also noted, but subordinate to the sandy fractions. Gravel elements are an indicator of human impact in the area. In general, sediments also contain organogenic material, consisting of shells, fragments and plant remains. The interpretation of the data resulting from the granulometric analyzes (the percentages of clay, silt, sand, gravel and textural parameters) highlighted the dynamic conditions in which these sediments specific to the deltaic environment were deposited. In general, the amount of sand varies from one season to another and from one year to another, especially near the banks, with an increase in the sand content in the autumn season. Sandy sediments illustrate a faster flow regime, are well sorted, and are generally present in the central part of the Danube Branches bed.

Keywords: riverbed sediments, laser diffractometry, grain size distribution, flow regime, anthropogenic impact, Danube Delta

1. INTRODUCTION

Fan deltas represent coastal alluvial fans prograding into a lake or sea (Einsele, 1992). The Danube River is the most international river, draining 19 countries (Sommerwerk, et al., 2022, Tockner et al., 2022), crossing 4 capitals and flowing into the Black Sea, through a delta located on the territory of Romania and Ukraine, the second largest in Europe (after the Volga Delta). It has an important role in the sedimentation of the northwestern and western Black Sea (Panin & Jipa, 2002).

The Danube Delta is a natural ecosystem rich in biodiversity, but, unfortunately, it is affected by anthropogenic impact (Stănică et al., 2007, Giosan et al., 2012, Giosan et al., 2014, Bănăduc et al., 2016, Santos & Dekker, 2020, Liashenko et al., 2022, Constantinescu et al., 2023), through anthropogenic channels (Rich, 1987), dams (Jugaru Tiron et al., 2009, Maselli & Trincardi, 2013), irrigation, fish branching, fishing, construction, waste etc. The river has also been polluted with micro- and macroplastics (Lebreton et al., 2017, Pojar et al., 2021).

Due to water pollution and eutrophication, the Danube contaminates the waters of the Black Sea (Amouroux et al., 2002, Lancelot et al., 2002, Reschke et al., 2002, Secrieru, D., & Secrieru, A., 2002, Mîndrescu et al., 2022, Constantinescu et al., 2023). The riverbed sediments are contaminated with metals, PAHs, pesticids (Vîjdea et al., 2022, Hikov et al., 2023) and the deltaic soils can contribute to the global warming in the future due to SOC sequestration (Mocanu et al., 2022).

The main processes and dynamic factors that control the morphology and evolution of the delta are river input, wind system, waves and sea level (Grumăzescu, 1963, Galloway, 1975, Panin, 1998, Porębski & Steel, 2006, Tessler et al., 2015, Vespremeanu-Stroe et al., 2016, Zăinescu et al., 2019, Edmonds et al., 2020, Nienhuis et al., 2020, Zăinescu et al., 2021, Broaddus et al., 2022, Nguyen et al., 2023). Sedimentation rate is influenced by grain size, delta structure and vegetation (Giosan et al., 2014).

The river carries a significant volume of coarse sediment upstream, which is gradually dispersed downstream over time. The amount of deposited sediments depends on the energy of the river, the morphology of the river bed, external factors, as well as the physico-chemical characteristics of the clasts.

In order to have a better perspective on the composition and sources of sediments accumulated in the river basin, the parameters of the granulometric composition and their characteristics on the processes of erosion, transport and deposition of sediments in the Danube Branches were investigated in this study. These processes are important to river deltas because they build the land where they occur (Edmonds, 2012).

The Danube Delta was studied following the Geo-Eco-Mar expeditions (DD-19 and DD-20) in the summer and autumn of 2019 and 2020, respectively, from a sedimentological, faunal and environmental quality point of view. The objective of this study was to highlight the sedimentological aspects of the Danube Branches following grain size analyses. Sedimentological samples were taken from different locations of the Danube Branches and their meanders, generally three for each transverse profile. The location of the profiles is shown in Figure 1 and in Table 1.

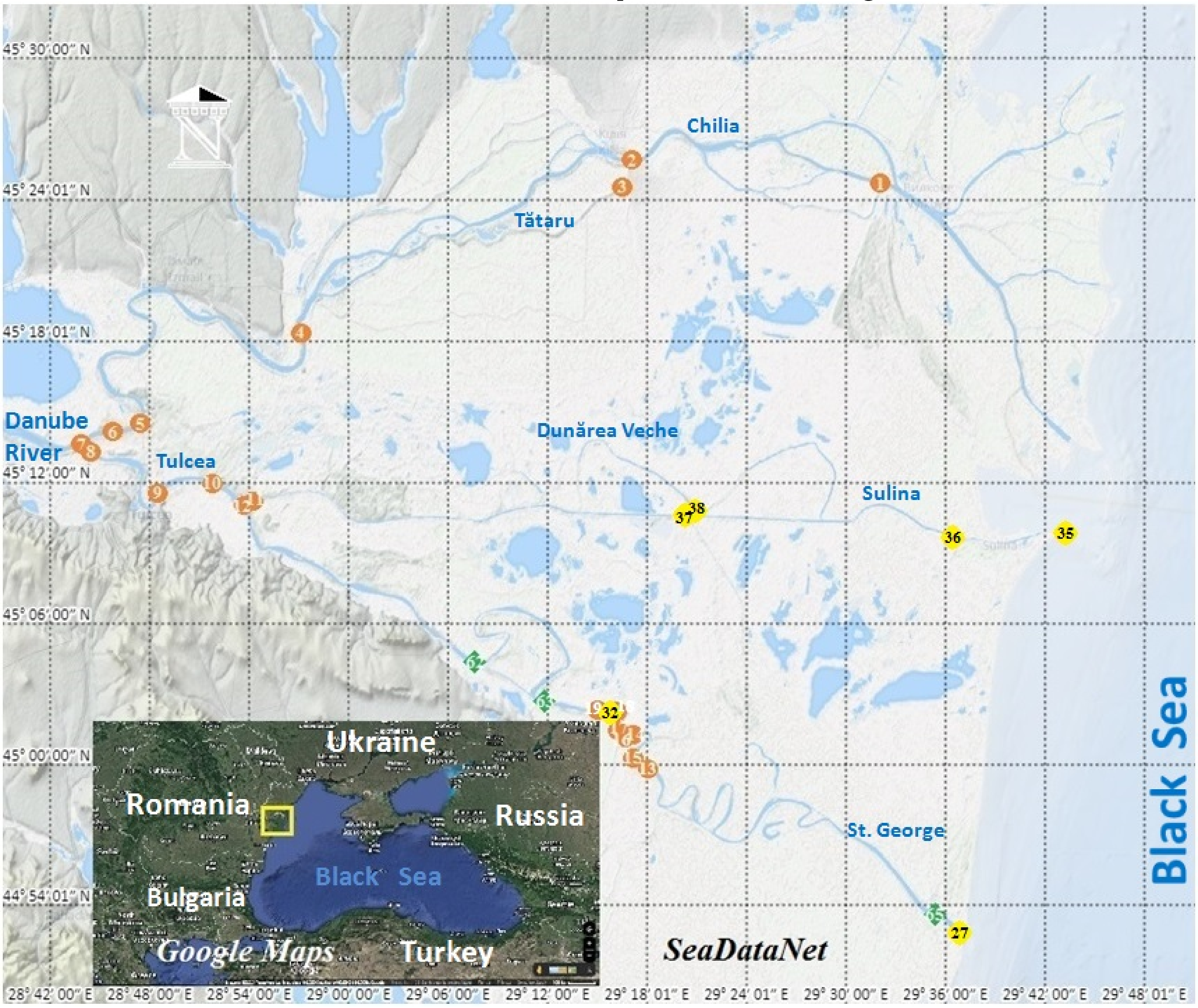

Figure 1. Location of the study area (bottom) and the sampling profiles (top). Legend: red circle – profile belonging to the first expedition (summer 2019); yellow square – profile belonging to the second expedition (autumn 2019); green square – profile belonging to the fourth expedition (autumn 2020). Because many profiles belonged to the same locations, were mentioned only the first realized (to check the numbers from Table 1)

Table 1. Transverse profiles corresponding to the four expeditions and their locations. Profiles were numbered in chronological order of sampling

Location	Summer 2019	Autumn 2019	Summer 2020	Autumn 2020
Chilia Branch – Km 23 (Periprava)	P1		P39	
Chilia Branch – Km 45 (Chilia Veche)	P2		P40	
Tătaru Branch	P3		P41	
Chilia Branch – Km 80 (Pardina)	P4		P42	
Chilia Branch – Km 112	P5		P43	
Chilia Branch – Km 114	P6	P21	P44	P56
Ceatal Izmail – Mm 43.5	P7	P20	P45	P55
Tulcea Branch – Mm 42.5	P8	P22	P46	P57
Tulcea Branch – Mm 37.5	P9	P23	P47	P58
Tulcea Branch – Mm 35	P10	P24	P48	P59
Sulina Branch – Mm 33	P11	P25	P50	P60
Ceatal St. George – Km 108	P12	P26	P49	P61
St. George Branch – Km 48	P13	P28		
St. George Branch – Km 53 (2 Est Meander)	P14			
St. George Branch – Km 49.5	P15	P29		
St. George Branch – Km 54	P16	P30		P64
St. George Branch – Km 54.5	P17	P31		
St. George Branch – Km 57.5	P18	P33		
St. George Branch – Km 59	P19	P34		
St. George Branch – Km 1		P27		
St. George Branch – Km 58.1		P32		
Sulina Branch – Mm 0		P35	P51	
Sulina Branch – Mm 2		P36	P52	
Sulina Branch – Mm 14		P37	P53	
Dunărea Veche Meander – Mm 14		P38	P54	
St. George Branch – Km 85				P62
St. George Branch – Km 63				P63
St. George Branch – Km 4.5				P65

2. MATERIALS AND METHODS

Sediment samples were taken using a van Veen bodengreifer, located on the river vessel Istros, at the water-sediment interface (0 – 20 cm), then kept under standard conditions and processed in the laboratory.

The grain size analysis of the sediment samples was performed by laser diffractometry, using the “Mastersizer 2000E Ver.5.20”, Malvern granulometric analyzer. The samples containing exclusively elements of gravel and sand were analyzed by the dry sieving method. In the case of heterogeneous sediments, which contain coarse elements and mud particles, the samples were analyzed by the combined diffractometry – sieving method.

The separation of the granulometric classes (gravel, sand, silt, clay) and the fractions within each class are in accordance with the Udden-Wentworth logarithmic scale (Udden, 1914, Wentworth, 1922), completed with three fractions, at 1φ intervals, in the clay field. The sediments were classified according to the Folk (1954) diagram (Table 2). Shell content present in sediments, bigger than 2 mm, was estimated as a percentage by macroscopic observation and removed from the overall sample amount.

Based on the primary data, the following grain size parameters were calculated: Median (Md = D50, Inman, 1952), graphic mean (M_z), standard

Table 2. Grain size composition and textural parameters of the riverbed sediments from the fourth expeditions in Danube Delta. The third column is reffering to the position of the sample in relation with the river bank. “Sl.” abbreviation means “Slightly”

Profile	Sample	Sample position	Grain size composition				Sediment texture (Folk, 1954)	Median (Φ)	Mean (Φ)	Standard deviation	Skewness	Kurtosis
			Gravel %	Sand %	Silt %	Clay %						
P1	S1	Right	0.00	26.20	54.97	18.83	Sandy mud	5.79	5.69	2.40	-0.02	0.81
P1	S2	Center	0.02	98.31	1.24	0.43	Slightly gravelly sand	2.57	2.57	0.47	0.18	1.15
P1	S3	Left	0.00	26.23	56.14	17.63	Sandy mud	5.79	5.72	2.29	-0.01	0.81
P2	S4	Right	0.00	8.54	68.42	23.04	Mud	6.33	6.46	1.98	0.10	0.95
P2	S5	Center	0.00	96.82	2.38	0.80	Sand	2.60	2.65	0.53	0.26	1.18
P2	S6	Left	0.00	35.63	51.86	12.51	Sandy mud	4.70	5.14	2.16	0.30	0.92
P3	S7	Center	0.00	28.05	56.92	15.03	Sandy mud	5.36	5.50	2.26	0.10	0.88
P4	S8	Right	0.10	78.25	17.21	4.44	Sl. gravelly muddy sand	2.93	3.52	1.74	0.57	1.74
P4	S9	Center	0.00	99.50	0.40	0.10	Sand	2.52	2.52	0.32	0.00	0.74
P4	S10	Left	0.00	92.13	6.26	1.61	Sand	3.35	3.27	0.86	0.08	1.89
P5	S11	Right	0.00	6.69	74.17	19.14	Mud	6.22	6.39	1.84	0.15	1.05
P5	S12	Center	0.00	99.53	0.37	0.10	Sand	2.50	2.50	0.32	0.00	0.74
P5	S13	Left	0.00	99.30	0.56	0.14	Sand	2.54	2.54	0.39	0.14	1.03
P6	S14	Left	0.00	99.40	0.48	0.12	Sand	2.51	2.51	0.35	0.03	0.79
P6	S15	Center	0.10	98.97	0.74	0.19	Slightly gravelly sand	2.51	2.51	0.43	0.06	1.08
P6	S16	Right	0.00	98.83	0.93	0.24	Sand	2.57	2.57	0.44	0.18	1.15
P7	S17	Right	0.00	17.24	65.87	16.89	Sandy mud	5.67	5.87	2.05	0.16	0.93
P7	S18	Center	0.00	98.83	0.93	0.24	Sand	2.51	2.51	0.32	0.00	0.74
P7	S19	Left	0.13	98.07	1.43	0.37	Slightly gravelly sand	3.03	3.02	0.63	-0.03	0.74
P8	S20	Right	0.00	96.13	2.88	0.99	Sand	2.77	2.87	0.63	0.23	0.81
P8	S21	Center	0.00	4.08	71.36	24.56	Mud	6.68	6.82	1.80	0.13	1.02
P8	S22	Left	0.00	11.89	72.36	15.75	Sandy mud	5.79	5.98	1.91	0.17	1.04
P9	S23	Right	0.87	97.26	1.46	0.41	Slightly gravelly sand	2.50	2.50	0.47	-0.01	1.27
P9	S24	Center	0.15	99.45	0.31	0.09	Slightly gravelly sand	2.35	2.27	0.55	-0.26	1.09
P9	S25	Left	0.41	82.85	13.15	3.59	Sl. gravelly muddy sand	2.85	3.13	1.33	0.56	1.77
P10	S26	Right	34.52	50.88	11.39	3.21	Muddy sandy gravel	2.20	1.53	2.74	-0.13	0.78
P10	S27	Center	0.00	99.40	0.47	0.13	Sand	2.46	2.46	0.42	-0.15	1.06
P10	S28	Left	0.00	6.24	73.63	20.13	Mud	6.26	6.44	1.85	0.16	1.02
P11	S29	Center	0.00	3.84	74.15	22.01	Mud	6.50	6.69	1.75	0.17	1.01
P12	S30	Left	0.00	99.77	0.18	0.05	Sand	2.18	2.11	0.61	-0.16	0.77
P12	S31	Center	1.36	96.35	1.79	0.50	Slightly gravelly sand	2.49	2.49	0.62	-0.04	1.62
P12	S32	Right	0.00	24.23	59.09	16.68	Sandy mud	5.42	5.65	2.18	0.17	0.87
P13	S33	Right	0.00	99.25	0.56	0.19	Sand	2.32	2.17	0.76	-0.42	1.37
P13	S34	Center	0.00	99.57	0.32	0.11	Sand	2.52	2.52	0.33	0.00	0.74

P13	S35	Left	0.00	83.26	12.61	4.13	Muddy sand	3.43	3.44	1.24	0.28	2.71
P14	S36	Center	0.00	99.17	0.67	0.16	Sand	2.55	2.55	0.42	0.16	1.09
P15	S37	Right	0.00	96.43	2.69	0.88	Sand	2.55	2.55	0.45	0.21	1.25
P15	S38	Center	0.00	98.55	1.09	0.36	Sand	2.39	2.30	0.68	-0.39	1.63
P15	S39	Left	0.00	12.00	66.29	21.71	Sandy mud	6.20	6.31	2.08	0.08	0.97
P16	S40	Right	0.00	25.49	60.39	14.12	Sandy mud	5.08	5.44	2.12	0.26	0.98
P16	S41	Center	0.00	98.87	0.92	0.21	Sand	2.48	2.48	0.38	-0.10	0.93
P16	S42	Left	0.00	98.40	1.30	0.30	Sand	2.72	2.82	0.59	0.25	0.88
P17	S43	Right	0.00	99.50	0.39	0.11	Sand	2.48	2.48	0.38	-0.11	0.94
P17	S44	Center	0.00	15.40	65.44	19.16	Sandy mud	5.80	6.04	2.08	0.18	0.91
P17	S45	Left	0.00	13.38	66.14	20.48	Sandy mud	5.92	6.15	2.07	0.17	0.91
P18	S46	Right	2.00	97.33	0.53	0.14	Slightly gravelly sand	2.47	2.47	0.42	-0.16	1.09
P18	S47	Center	0.00	99.60	0.32	0.08	Sand	2.51	2.51	0.32	0.00	0.74
P18	S48	Left	0.00	30.97	54.47	14.56	Sandy mud	5.10	5.37	2.24	0.19	0.88
P19	S49	Right	18.70	75.72	4.71	0.87	Gravelly sand	2.64	1.72	2.13	-0.50	1.18
P19	S50	Center	1.03	98.57	0.34	0.06	Slightly gravelly sand	2.49	2.49	0.34	0.00	0.74
P19	S51	Left	0.00	99.47	0.45	0.08	Sand	2.54	2.54	0.40	0.14	1.04
P20	S52	Right	0.52	98.72	0.61	0.15	Slightly gravelly sand	2.53	2.53	0.42	0.15	1.06
P20	S53	Center	0.00	100.00	0.00	0.00	Sand	2.50	2.50	0.32	0.00	0.74
P20	S54	Left	0.00	99.72	0.23	0.05	Sand	2.59	2.59	0.45	0.17	1.12
P21	S55	Right	0.48	99.34	0.14	0.04	Slightly gravelly sand	2.52	2.52	0.33	0.01	0.76
P21	S56	Center	0.00	99.82	0.15	0.03	Sand	2.50	2.50	0.38	-0.05	0.88
P21	S57	Left	0.00	99.80	0.16	0.04	Sand	2.57	2.57	0.44	0.17	1.11
P22	S58	Right	0.00	34.47	52.19	13.34	Sandy mud	4.83	5.20	2.25	0.24	0.91
P22	S59	Center	0.00	100.00	0.00	0.00	Sand	2.46	2.46	0.45	-0.17	1.11
P22	S60	Left	0.00	13.60	70.01	16.39	Sandy mud	5.69	5.94	1.97	0.21	1.00
P23	S61	Right	0.00	99.94	0.05	0.01	Sand	2.43	2.43	0.45	-0.17	1.11
P23	S62	Center	0.00	99.96	0.03	0.01	Sand	2.33	2.24	0.56	-0.26	1.02
P23	S63	Left	0.00	8.48	72.65	18.87	Mud	5.92	6.20	1.93	0.23	1.01
P24	S64	Right	0.00	99.84	0.13	0.03	Sand	2.44	2.42	0.55	-0.08	1.28
P24	S65	Center	0.00	99.94	0.05	0.01	Sand	2.43	2.43	0.44	-0.17	1.11
P24	S66	Left	28.30	71.42	0.22	0.06	Gravelly sand	-0.05	0.37	1.81	0.32	0.67
P25	S67	Center	0.00	99.96	0.03	0.01	Sand	2.22	2.14	0.60	-0.19	0.79
P26	S68	Right	4.46	94.64	0.72	0.18	Slightly gravelly sand	2.49	2.49	0.93	-0.24	2.66
P26	S69	Center	0.48	99.22	0.24	0.06	Slightly gravelly sand	2.47	2.47	0.41	-0.15	1.04
P26	S70	Left	12.55	87.05	0.32	0.08	Gravelly sand	2.44	2.19	1.19	-0.51	2.99
P27	S71	Right	0.00	15.90	64.93	19.17	Sandy mud	6.08	6.12	2.18	0.01	1.05

P27	S72	Center	0.00	17.08	65.84	17.08	Sandy mud	5.65	5.88	2.06	0.18	0.93
P27	S73	Left	0.00	38.10	49.85	12.05	Sandy mud	4.65	5.01	2.23	0.26	0.94
P28	S74	Left	0.00	49.23	42.25	8.52	Sandy mud	4.03	4.48	2.01	0.38	1.17
P28	S75	Center	0.00	100.00	0.00	0.00	Sand	2.40	2.36	0.50	-0.22	1.10
P28	S76	Right	0.00	7.05	69.01	23.94	Mud	6.42	6.58	1.97	0.12	0.99
P29	S77	Right	0.00	99.88	0.09	0.03	Sand	2.41	2.35	0.59	-0.13	1.23
P29	S78	Center	0.19	99.77	0.03	0.01	Slightly gravelly sand	2.46	2.46	0.40	-0.15	1.04
P29	S79	Left	0.00	22.31	59.51	18.18	Sandy mud	5.66	5.79	2.27	0.09	0.90
P30	S80	Right	0.00	20.95	62.70	16.35	Sandy mud	5.12	5.60	2.19	0.31	1.06
P30	S81	Center	0.00	99.94	0.05	0.01	Sand	2.39	2.32	0.56	-0.27	1.15
P30	S82	Left	0.00	29.22	56.63	14.15	Sandy mud	5.42	5.39	2.31	0.02	0.84
P31	S83	Right	0.40	98.89	0.55	0.16	Slightly gravelly sand	2.62	2.70	0.70	0.06	1.38
P31	S84	Center	0.00	99.75	0.19	0.06	Sand	1.65	1.70	0.92	-0.05	1.17
P31	S85	Left	0.00	99.92	0.06	0.02	Sand	2.28	2.17	0.69	-0.24	0.93
P32	S86	Center	0.00	99.96	0.03	0.01	Sand	2.49	2.49	0.38	-0.10	0.93
P33	S87	Right	0.00	99.94	0.05	0.01	Sand	2.49	2.49	0.33	0.00	0.74
P33	S88	Center	0.00	99.38	0.48	0.14	Sand	2.53	2.53	0.36	0.09	0.91
P33	S89	Left	0.00	99.88	0.09	0.03	Sand	2.19	2.09	0.74	-0.25	0.88
P34	S90	Right	0.00	99.76	0.19	0.05	Sand	2.37	2.29	0.73	-0.08	1.11
P34	S91	Center	0.00	99.91	0.07	0.02	Sand	2.45	2.45	0.45	-0.19	1.20
P34	S92	Left	0.00	99.84	0.12	0.04	Sand	2.38	2.30	0.58	-0.29	1.19
P35	S93	Right	0.00	16.19	69.09	14.72	Sandy mud	5.70	5.85	1.97	0.11	0.98
P35	S94	Right	0.34	99.26	0.33	0.07	Slightly gravelly sand	2.11	2.02	0.75	-0.23	0.89
P35	S95	Center	0.00	10.95	68.67	20.38	Sandy mud	6.12	6.27	2.01	0.11	0.98
P35	S96	Left	0.00	11.31	68.52	20.17	Sandy mud	6.21	6.30	2.02	0.07	1.02
P36	S97	Right	0.00	26.38	58.77	14.85	Sandy mud	5.24	5.46	2.29	0.14	0.99
P36	S98	Center	0.48	99.25	0.21	0.06	Slightly gravelly sand	2.36	2.27	0.74	-0.12	1.14
P36	S99	Left	18.15	81.43	0.38	0.04	Gravelly sand	1.38	0.75	1.46	-0.49	1.54
P36	S100	Left	0.00	27.12	66.46	6.42	Sandy mud	5.10	5.04	1.96	-0.04	1.14
P37	S101	Left	0.00	17.38	63.36	19.26	Sandy mud	5.76	5.97	2.26	0.12	1.00
P37	S102	Center	0.00	100.00	0.00	0.00	Sand	1.82	1.88	0.63	0.13	0.76
P37	S103	Right	0.00	31.14	52.53	16.33	Sandy mud	5.03	5.27	2.54	0.15	0.95
P38	S104	Center	0.00	21.96	57.79	20.25	Sandy mud	5.81	5.84	2.44	0.02	0.94
P39	S105	Right	0.00	99.74	0.21	0.05	Sand	2.53	2.53	0.37	0.10	0.91
P39	S106	Center	0.00	97.25	2.26	0.49	Sand	2.58	2.62	0.62	0.09	1.46
P39	S107	Left	0.00	99.84	0.13	0.03	Sand	2.58	2.58	0.44	0.17	1.12
P40	S108	Right	0.00	99.56	0.36	0.08	Sand	2.53	2.53	0.37	0.10	0.91

P40	S109	Center	0.00	99.84	0.13	0.03	Sand	2.54	2.54	0.39	0.13	0.99
P40	S110	Left	0.00	28.24	58.92	12.84	Sandy mud	5.12	5.34	2.17	0.16	0.95
P40	S111	Left	0.00	99.20	0.66	0.14	Sand	2.54	2.54	0.41	0.15	1.06
P41	S112	Center	0.00	12.94	67.50	19.56	Sandy mud	5.84	6.10	2.02	0.20	0.89
P42	S113	Right	0.00	99.94	0.04	0.02	Sand	2.46	2.46	0.40	-0.14	1.02
P42	S114	Center	0.00	99.88	0.09	0.03	Sand	2.54	2.54	0.38	0.13	0.98
P42	S115	Left	0.00	9.66	67.39	22.95	Mud	6.23	6.39	2.04	0.12	0.93
P43	S116	Right	0.00	0.66	74.90	24.44	Mud	6.70	6.85	1.70	0.16	0.98
P43	S117	Center	0.00	99.92	0.06	0.02	Sand	2.47	2.47	0.36	-0.09	0.90
P43	S118	Left	0.00	99.54	0.35	0.11	Sand	2.56	2.56	0.43	0.17	1.10
P44	S119	Left	0.00	99.86	0.11	0.03	Sand	2.48	2.48	0.34	-0.05	0.82
P44	S120	Center	0.00	99.88	0.09	0.03	Sand	2.49	2.49	0.34	-0.01	0.76
P44	S121	Right	0.00	99.94	0.05	0.01	Sand	2.49	2.49	0.33	0.00	0.74
P45	S122	Right	0.00	11.63	64.95	23.42	Sandy mud	6.40	6.45	2.12	0.03	1.02
P45	S123	Center	0.00	99.90	0.07	0.03	Sand	2.46	2.46	0.40	-0.14	1.03
P45	S124	Left	0.00	17.16	67.64	15.20	Sandy mud	5.67	5.82	2.04	0.11	1.01
P46	S125	Right	0.00	7.84	72.21	19.95	Mud	6.12	6.34	2.00	0.14	1.10
P46	S126	Center	0.00	99.96	0.03	0.01	Sand	1.56	1.56	0.44	0.17	1.13
P46	S127	Left	0.00	55.36	39.86	4.78	Muddy sand	3.80	4.01	1.70	0.29	1.21
P46	S128	Left	0.00	98.48	1.36	0.16	Sand	2.57	2.57	0.45	0.18	1.16
P47	S129	Right	0.00	99.28	0.56	0.16	Sand	2.45	2.45	0.47	-0.19	1.17
P47	S130	Center	0.00	99.96	0.03	0.01	Sand	2.14	2.08	0.63	-0.15	0.76
P47	S131	Left	0.00	99.96	0.04	0.00	Sand	2.34	2.25	0.56	-0.25	1.03
P48	S132	Right	0.00	98.71	1.01	0.28	Sand	2.52	2.52	0.42	0.15	1.06
P48	S133	Center	0.00	99.94	0.05	0.01	Sand	2.28	2.20	0.60	-0.22	0.86
P48	S134	Left	0.00	99.85	0.13	0.02	Sand	1.36	1.29	1.00	-0.11	1.08
P49	S135	Right	0.00	98.47	1.18	0.35	Sand	2.52	2.52	0.48	0.06	1.27
P49	S136	Center	0.00	99.96	0.03	0.01	Sand	2.20	2.13	0.61	-0.17	0.78
P49	S137	Left	0.00	19.61	62.10	18.29	Sandy mud	5.53	5.83	2.12	0.23	0.86
P50	S138	Center	0.00	23.89	68.37	7.74	Sandy mud	4.70	4.91	1.58	0.32	1.42
P51	S139	Right	0.00	13.90	68.58	17.52	Sandy mud	5.77	6.00	2.01	0.18	0.96
P51	S140	Center	0.00	5.70	71.90	22.40	Mud	6.36	6.50	1.87	0.14	0.92
P51	S141	Center	0.00	99.94	0.05	0.01	Sand	2.11	2.06	0.62	-0.11	0.75
P51	S142	Left	0.00	10.99	70.02	18.99	Sandy mud	5.81	6.11	2.01	0.22	0.96
P52	S143	Right	0.00	14.03	71.24	14.73	Sandy mud	5.52	5.82	1.91	0.25	1.00
P52	S144	Left	0.00	99.13	0.64	0.23	Sand	2.37	2.29	0.56	-0.26	1.08
P52	S145	Left	0.00	8.52	67.58	23.90	Mud	6.32	6.48	2.07	0.13	0.99

P52	S146	Center	0.00	99.73	0.21	0.06	Sand	1.95	1.96	0.64	0.03	0.74
P52	S147	Center	0.00	16.56	66.64	16.80	Sandy mud	5.62	5.87	2.07	0.18	0.97
P53	S148	Right	0.00	14.05	71.47	14.48	Sandy mud	5.41	5.76	1.88	0.30	1.01
P53	S149	Left	0.00	11.63	65.43	22.94	Sandy mud	6.04	6.30	2.22	0.15	1.01
P54	S150	Center	0.00	6.67	66.09	27.24	Mud	6.65	6.73	2.04	0.09	0.98
P55	S151	Right	0.00	5.04	71.55	23.41	Mud	6.40	6.59	1.90	0.18	0.95
P55	S152	Center	0.00	99.96	0.03	0.01	Sand	2.51	2.51	0.32	0.00	0.74
P55	S153	Left	0.00	98.22	1.34	0.44	Sand	2.57	2.57	0.48	0.18	1.15
P56	S154	Right	0.00	97.00	2.26	0.74	Sand	2.69	2.79	0.61	0.26	0.93
P56	S155	Center	0.00	99.68	0.24	0.08	Sand	2.44	2.44	0.49	-0.19	1.20
P56	S156	Left	0.00	99.90	0.08	0.02	Sand	2.47	2.47	0.40	-0.14	1.02
P57	S157	Right	0.00	93.98	5.00	1.02	Sand	2.97	2.99	0.79	0.16	1.00
P57	S158	Center	6.87	88.93	3.49	0.71	Gravelly sand	2.46	2.31	1.17	-0.37	2.73
P57	S159	Left	0.00	8.70	75.86	15.44	Mud	5.75	6.00	1.82	0.24	1.03
P58	S160	Right	0.23	99.71	0.05	0.01	Slightly gravelly sand	2.40	2.39	0.47	-0.20	1.13
P58	S161	Center	2.69	97.23	0.06	0.02	Slightly gravelly sand	2.07	1.99	0.80	-0.27	1.03
P58	S162	Left	19.16	79.69	0.92	0.23	Gravelly sand	2.29	1.32	1.72	-0.72	1.46
P58	S163	Left	0.00	5.62	75.36	19.02	Mud	6.07	6.32	1.83	0.23	1.00
P59	S164	Right	0.00	99.40	0.48	0.12	Sand	2.53	2.53	0.35	0.07	0.86
P59	S165	Center	0.00	99.94	0.05	0.01	Sand	2.43	2.43	0.44	-0.17	1.10
P59	S166	Left	0.00	99.92	0.06	0.02	Sand	1.68	1.75	0.75	0.04	1.06
P60	S167	Center	0.00	100.00	0.00	0.00	Sand	1.73	1.82	0.59	0.23	0.85
P61	S168	Right	0.00	13.90	71.99	14.11	Sandy mud	5.38	5.74	1.88	0.31	1.03
P61	S169	Center	0.00	99.90	0.08	0.02	Sand	2.43	2.43	0.44	-0.17	1.11
P61	S170	Left	0.30	83.64	13.43	2.63	Sl. gravelly muddy sand	3.26	3.15	1.34	0.01	1.88
P62	S171	Right	0.00	99.84	0.12	0.04	Sand	2.49	2.49	0.33	0.00	0.74
P62	S172	Center	0.00	99.92	0.06	0.02	Sand	2.43	2.43	0.47	-0.17	1.13
P62	S173	Left	0.00	99.46	0.40	0.14	Sand	2.48	2.48	0.37	-0.10	0.91
P63	S174	Right	0.00	1.96	73.46	24.58	Mud	6.61	6.78	1.79	0.17	0.98
P63	S175	Center	0.00	99.82	0.13	0.05	Sand	2.51	2.51	0.32	0.00	0.74
P63	S176	Left	0.00	98.84	0.86	0.30	Sand	2.58	2.58	0.46	0.18	1.14
P63	S177	Left	0.00	2.92	72.13	24.95	Mud	6.72	6.80	1.74	0.09	0.94
P64	S178	Right	4.32	92.09	2.69	0.90	Slightly gravelly sand	2.43	2.10	1.26	-0.43	2.35
P64	S179	Center	0.00	99.96	0.03	0.01	Sand	2.45	2.45	0.41	-0.15	1.06
P64	S180	Left	0.00	99.70	0.22	0.08	Sand	2.52	2.52	0.35	0.05	0.82
P65	S181	Right	0.00	3.44	80.13	16.43	Mud	5.90	6.20	1.68	0.31	1.06
P65	S182	Center	0.00	99.80	0.17	0.03	Sand	2.51	2.51	0.33	0.00	0.74
P65	S183	Left	0.00	99.60	0.33	0.07	Sand	2.53	2.53	0.40	0.14	1.01

deviation (σ_I, sorting), asymmetry coefficient (Sk_I, skewness) and graphic sharpness (K_G, kurtosis). These parameters were calculated according to the original Folk & Ward (1957) formulas, using the Gradistat program (Blott & Pye, 2001) (Table 2).

The mean and median have the role of highlighting the speed of the transport and sedimentation agent, the inclusive graphical standard deviation, correlated by Folk (1968) with the degree of sorting shows the ability of the transport agent to separate and deposit the particles according to their specific weight (Anastasiu & Jipa, 2000). The bed layer thickness varies with particle size (Einstein, 1950). Asymmetry represents the textural parameter that expresses the difference of the distribution from the normal one (symmetrical to the median) and the graphic sharpness (Kurtosis) calculates the ratio between the sorting of the extremities of the grain size distribution and the sorting of its central part (Anastasiu & Jipa, 2000).

3. RESULTS AND DISCUSSION

3.1. Chilia Branch (with Tătaru Branch)

Following the expeditions in the summer of 2019 and 2020, the samples taken from the bed of Chilia Branch between Km 23 – Km 112 revealed, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material (Figure 2, Table 2). In a few samples, sandy, organogenic muds with the predominant silty fraction were also discovered. In general, there is an increase in the sand content in 2020 compared to the previous year. Within the sands, the fine subfraction predominated, and within the silty sediments, the medium and coarse silt subfractions. The mean and median values were positive and indicate fine sand overall. The standard deviation had values that indicate a shift from moderately sorting in 2019 to poorly sorting in 2020. In general, high standard deviation values were recorded near the banks and less in the central part. Asymmetry generally had positive values, indicating an excess of fine material. The graph sharpness (Kurtosis) was, on average, mesokurtic.

Sedimentological samples taken in the summer of 2019 and 2020 from the bed of the Tătaru Branch identified sediments made up of organogenic muds, with the predominant silt fraction (Figure 2, Table 2). Secondary, there was also a sand content, as well as organogenic material, made up of shells, fragments and plant remains. The most common subfraction was coarse silt. The mean and median had positive values, indicating average silt, and the standard deviation indicated very poorly particle sorting due to low water velocity. The asymmetry index indicated a surplus of fine material, and the graphic sharpness was platykurtic.

Following the four field campaigns, the samples taken from the bed of Chilia Branch at Km 114, as well as at Ceatal Izmail (Mm 43.5) discovered, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material (Figures 3, 4, Table 2). In most of the samples taken near the right bank, at Ceatal Izmail, sandy, organogenic muds were discovered, with the predominant silt fraction. Within the sands, the fine subfraction predominated, and within the muddy sediments, medium silt. The mean and median values were positive and indicated fine sand overall. The standard deviation had values that indicated well sorting at Km 114 and moderately sorting at Ceatal Izmail. High values of standard deviation were recorded in silty sediments. Asymmetry generally had positive values, but overall exhibits a symmetric particle distribution. The graph sharpness (Kurtosis) was, on average, mesokurtic.

3.2. Tulcea Branch

The samples taken from the bed of the Tulcea Branch between Mm 35 – Mm 43.5 in the four field campaigns, showed, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material (Figures 3, 4, Table 2). In some samples, sandy, organogenic muds with the predominant silt fraction were also discovered, and in other samples, subordinate lithic gravel elements. The presence of lithic gravel in the sediments was due to the anthropogenic impact justified by construction works, Tulcea city and other small localities being located in the proximity. The sand content varied from one season to another, with an increase in 2020 compared to the previous year. Within the sands, the fine subfraction predominated, and within the muddy sediments, medium silt. The mean and median values were generally positive and indicated fine sand, except for the summer 2019 expedition, where very fine sand was indicated. The standard deviation had values indicating poorly sorting, except for the summer 2020 campaign, in which moderately sediment sorting was indicated. Asymmetry showed, as a whole, a symmetrical particle distribution. The skewness (Kurtosis) was, on average, mesokurtic, except for the autumn 2020 expedition, where it was leptokurtic.

At Ceatal St. George (Km 108), the samples taken in the four field campaigns identified, in most

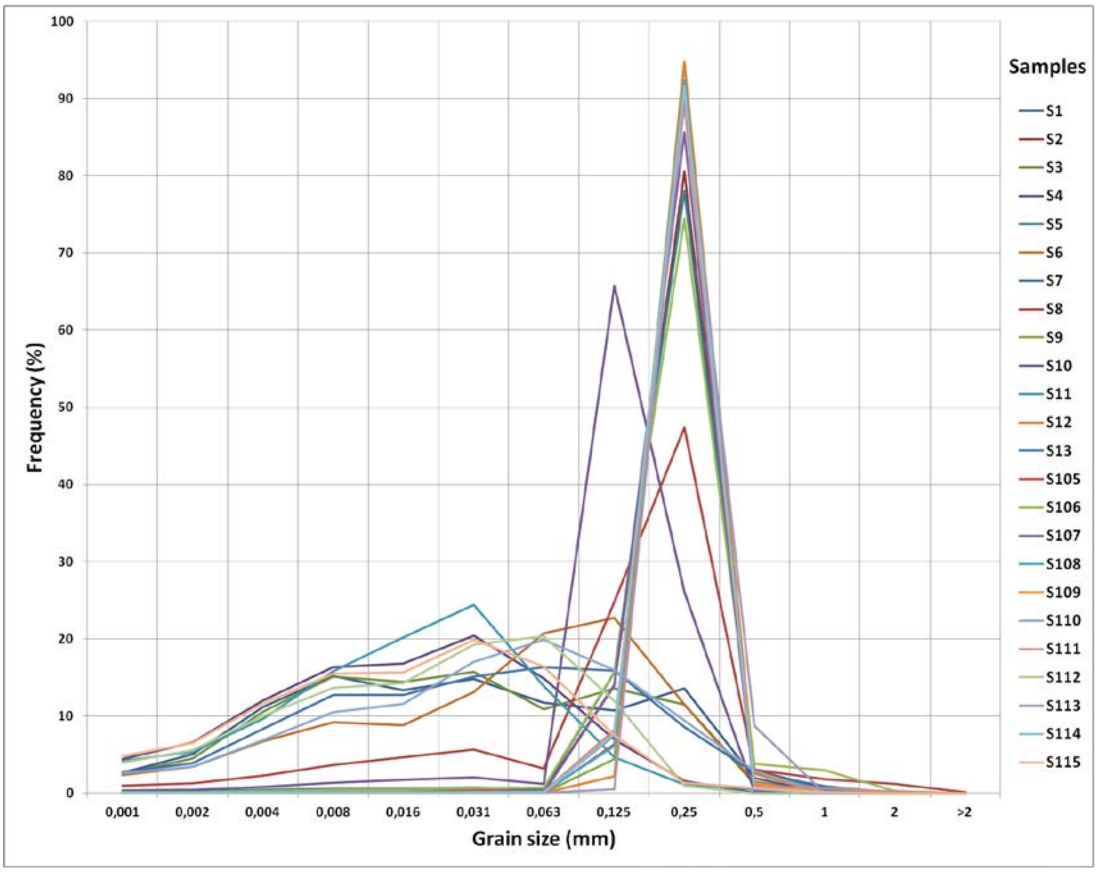

Figure 2. Comparative grain size distributions between some profiles (P1 – P5 and P39 – P43) from Chilia Branch (with Tătaru Branch) during the summer expeditions of 2019 – 2020 (S1 – S13 and S105 – S115 samples)

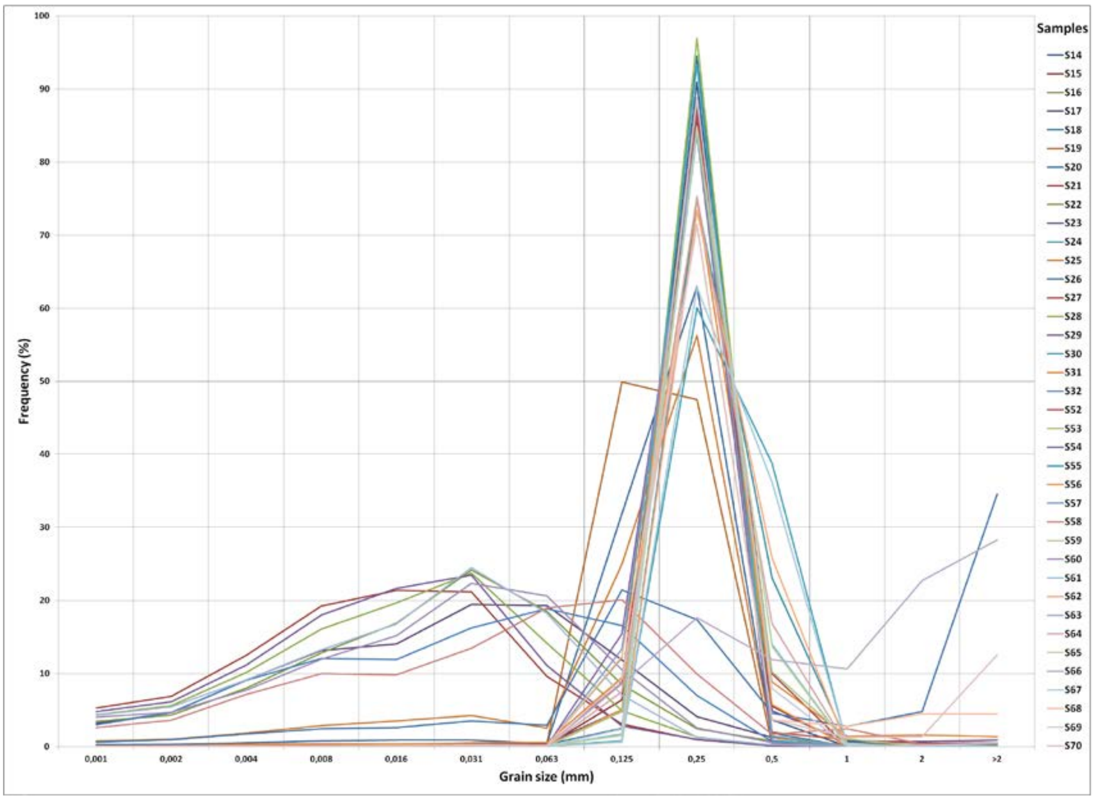

Figure 3. Comparative grain size distributions between some profiles (P6 – P12 and P20 – P26 profiles) from Chilia, Tulcea and Sulina Branches during the summer and the autumn expeditions of 2019 (S14 – S32 and S52 – S70 samples)

cases, sediments made up of sands, with subordinate fractions of mud and organogenic material (Figures 3, 4, Table 2). In some samples, sandy, organogenic muds with the predominant silt fraction were also discovered, and in other samples, subordinate lithic gravel elements. The content of lithic gravel within the sediments is explained by various existing construction works in the area, Tulcea city and other small localities being situated nearby. The amount of sand varied from one season to another, and from one year to another near the banks. Within the sands, the fine subfraction predominated, and within the muddy sediments, the coarse silt. The mean and median values were positive and indicated fine sand, except for the autumn 2019 expedition, in which medium sand was indicated, as well as the autumn 2020 expedition, in which very fine sand was shown. The standard deviation had values indicating moderately well and well sorting in the central part of the bed and different sorting (from well to very poorly) near the banks. This fact is explained by a faster flow regime in the central part of the bed in 2019 (Duțu et al., 2022). Skewness generally had negative values, but overall showed a symmetrical particle distribution. The graphic sharpness (Kurtosis) varied from one season to another, and from one year to another being, on average, leptokurtic.

3.3. Sulina Branch (with Dunărea Veche Meander – Mm 14)

The samples taken from the bed of Sulina Branch between Mm 0 – Mm 14, following the autumn 2019 and summer 2020 expeditions, discovered, in most cases, sediments made up of sandy, organogenic muds, with the predominant silt fraction (Figures 5, Table 2). In a few samples, sands were also discovered, with subordinate fractions of mud and organogenic material. A more significant percentage of lithic gravel was also identified in S99 sample, taken in 2019, signaling an anthropogenic impact, Sulina town being located in the proximity. There was a decrease in the sand content in 2020, compared to the previous year.

Also, in some cases, textural variations were observed within the same sample (overlapping layers). Within the silts, the medium silt subfraction predominated, and within the sandy sediments, the fine sand. The mean and median values were positive and indicated overall very fine sand for 2019 and coarse silt for 2020. The standard deviation had values that indicated poorly sorting in the two seasons. High values of standard deviation were recorded in silty sediments. Skewness generally had positive values, indicating a symmetrical distribution of particles in the year 2019 and a surplus of fine material in the year 2020. The graphic sharpness (Kurtosis) was, on average, mesokurtic.

Following the four field campaigns, the samples taken from the central part of the Sulina Branch bed, at Mm 33, revealed sandy, organogenic muds, with the predominant silt fraction, in the summer campaigns, as well as sediments made up of sands, with organogenic material, in the autumn campaigns (Figure 3, 4, Table 2). This fact is explained by more intense entrainment processes during autumn 2019, even if the flow rate was lower (Duțu et al., 2022). Within the silts, the subfractions of medium silt (2019 year) and coarse silt (2020 year) predominated, and within the sandy sediments, the subfractions of fine sand (2019 year) and medium sand (2020 year). Mean and median values were positive and indicated average silt in summer expeditions and average sand in autumn expeditions. The standard deviation had values indicating poorly sorting within silty sediments (summer expeditions) and relatively well sorting within sandy sediments (autumn expeditions). Asymmetry generally had positive values, indicating an excess of fine material. The graphic sharpness (Kurtosis) was meso-leptokurtic within the silty sediments (summer expeditions) and platykurtic within the sandy sediments (autumn expeditions).

The two samples taken from the central part of the bed of the Dunărea Veche Meander, at Mm 14, following the expeditions in the autumn of 2019 and the summer of 2020, identified sediments made up of sandy, organogenic muds, with the predominant silt fraction (Figure 5, Table 2). The most frequent subfraction was represented by the medium silt. The mean and median were positive and indicated medium silt for 2019 as well as fine silt for 2020. The standard deviation values indicated very poorly sorting in the two seasons. Asymmetry had positive values, indicating a symmetrical distribution of particles. Kurtosis was mesokurtic.

3.4. St. George Branch (with 2 Est Meander – Km 53)

Following the expeditions in the summer and autumn of 2019, respectively, the samples taken from the bed of St. George between Km 48 – Km 59 discovered, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material (Figure 6, Table 2). In a few samples, sandy, organogenic muds with the predominant silty fraction

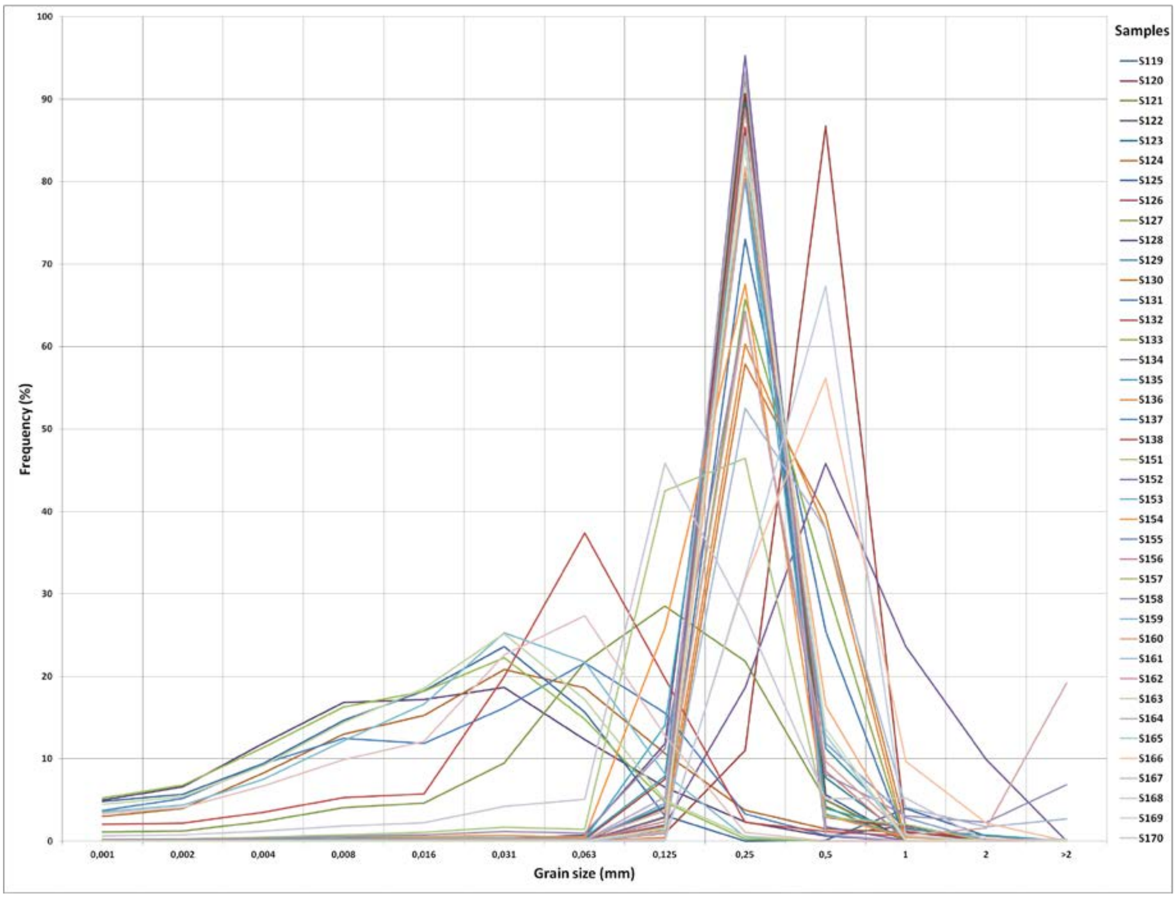

Figure 4. Comparative grain size distributions between some profiles (P44 – P50 and P55 – P61) from Chilia, Tulcea and Sulina Branches during the summer and the autumn expeditions of 2020 (S119 – S138 and S151 – S170 samples)

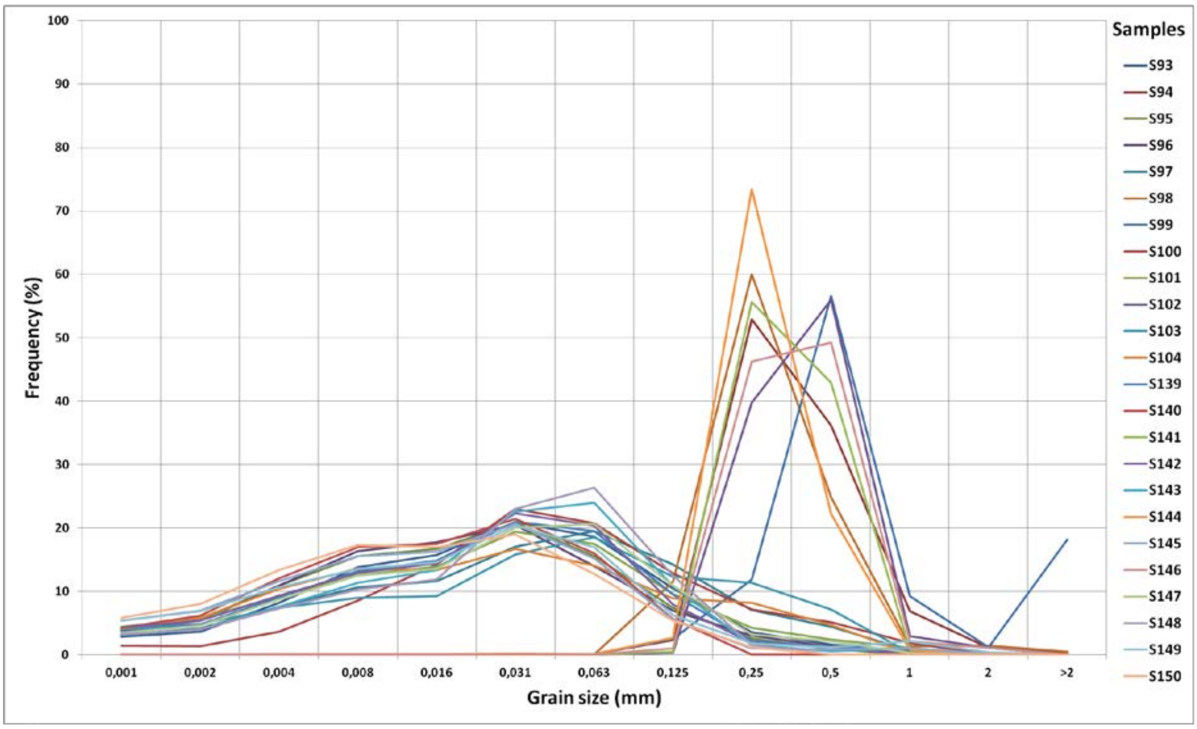

Figure 5. Comparative grain size distributions between some profiles (P35 – P38 and P51 – P54) from Sulina Branch (with Dunărea Veche Meander) during the expeditions from the autumn of 2019 and the summer of 2020 (S93 – S104 and S139 – S150 samples)

were also discovered. A more significant percentage of lithic gravel was also identified in S49 sample, taken in the summer campaign, signaling anthropogenic impact, Dunavățu de Sus village being located in the proximity. The amount of sand varied from one season to another, and from one year to another, especially near the banks. There was generally a slight increase in the sand content in the autumn season, compared to the summer season. Within the sands, the fine subfraction predominated, and within the muddy sediments, medium silt. The mean and median values were positive and indicated fine sand. The standard deviation had values that indicated poorly sorting in the two seasons. High values of standard deviation were recorded in silty sediments. The asymmetry had predominantly positive values in the summer campaign and negative values in the autumn campaign, indicating, overall, a symmetrical particle distribution. The graph sharpness (Kurtosis) is, on average, mesokurtic.

The samples taken from the bed of the St. George Branch at Km 1 and, respectively, Km 58.1, following the expedition in the autumn of 2019, revealed sediments made up of sandy, organic silts, with the predominant silty fraction, at Km 1, as well as organic sands, at Km 58.1 (Figure 7, Table 2). Within the silts, the medium silt subfraction predominates, and within the sandy sediments, fine sand predominates. The mean and median are positive and indicate overall medium silt at Km 1 as well as medium sand at Km 58.1. The standard deviation has values indicating poor sorting in the samples taken at Km 1 and good sorting in the sample taken at Km 58.1. High values of standard deviation were recorded in silty sediments. Asymmetry has positive values at Km 1, indicating an excess of fine material, as well as negative value at Km 58.1, indicating a symmetric particle distribution. The graphic sharpness (Kurtosis) is mesokurtic.

Following the expedition in the autumn of 2019, the samples taken from the bed of the St. George Branch between Km 4.5 – Km 85 discovered, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material (Figure 7, Table 2). In a few samples, sandy, organogenic muds with the predominant silty fraction were also discovered. The amount of sand varied from one location to another, especially near the right bank. Within the sands, the fine subfraction predominated, and within the muddy sediments, medium silt. The mean and median values were positive and indicated fine sand. The standard deviation had values that indicated overall moderately sorting. High values of the standard deviation were recorded especially in muddy sediments. Asymmetry had predominantly positive values indicating, overall, a symmetrical particle distribution. The graph sharpness (Kurtosis) was, on average, mesokurtic.

The only sample taken from the central part of the 2 Est Meander bed, at Km 53, following the summer 2019 expedition, identified sediments made up of organogenic sands (Figure 7, Table 2). The most common subfraction was represented by fine sand. The mean and median were positive and indicated fine sand. The standard deviation indicated well particle sorting. Asymmetry was positive, indicating an excess of fine material. Kurtosis was mesokurtic.

4. CONCLUSIONS

The samples taken from the bed of Chilia Branch between Km 23 – Km 112 following the expeditions in the summer of 2019 and 2020, revealed, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material. There was a shift from moderately sorting in 2019 to poorly sorting in 2020. In general, poorly particle sorting was recorded near the banks and less in the central part.

In the four field campaigns, the samples taken from the bed of the Tulcea Branch between Mm 35 – 43.5 showed, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material. In some cases, sandy, organogenic muds with the predominant silt fraction were also discovered, and in other cases, subordinate lithic gravel elements. The presence of lithic gravel in the sediments was due to the anthropogenic impact justified by constructions. The sand content varied from one season to another, with an increase in 2020 compared to the 2019 year.

Following the expeditions in the autumn of 2019 and the summer of 2020, the samples taken from the bed of the Sulina Branch between Mm 0 – Mm 14, discovered, in most cases, sediments made up of sandy, organogenic muds, with the predominant silt fraction. There was a decrease in the sand content in 2020, compared to the 2019 year. Also, in some cases, textural variations were identified within the same sample (overlapping layers).

The samples taken from the bed of the St. George Branch between Km 48 – Km 59 following the expeditions in the summer and autumn of 2019, revealed, in most cases, sediments made up of sands, with subordinate fractions of mud and organogenic material. The sand content varied from one season to another, and from one year to another, especially near the banks. There was generally a slight increase of the sand percentage in the autumn season, compared to the summer season.

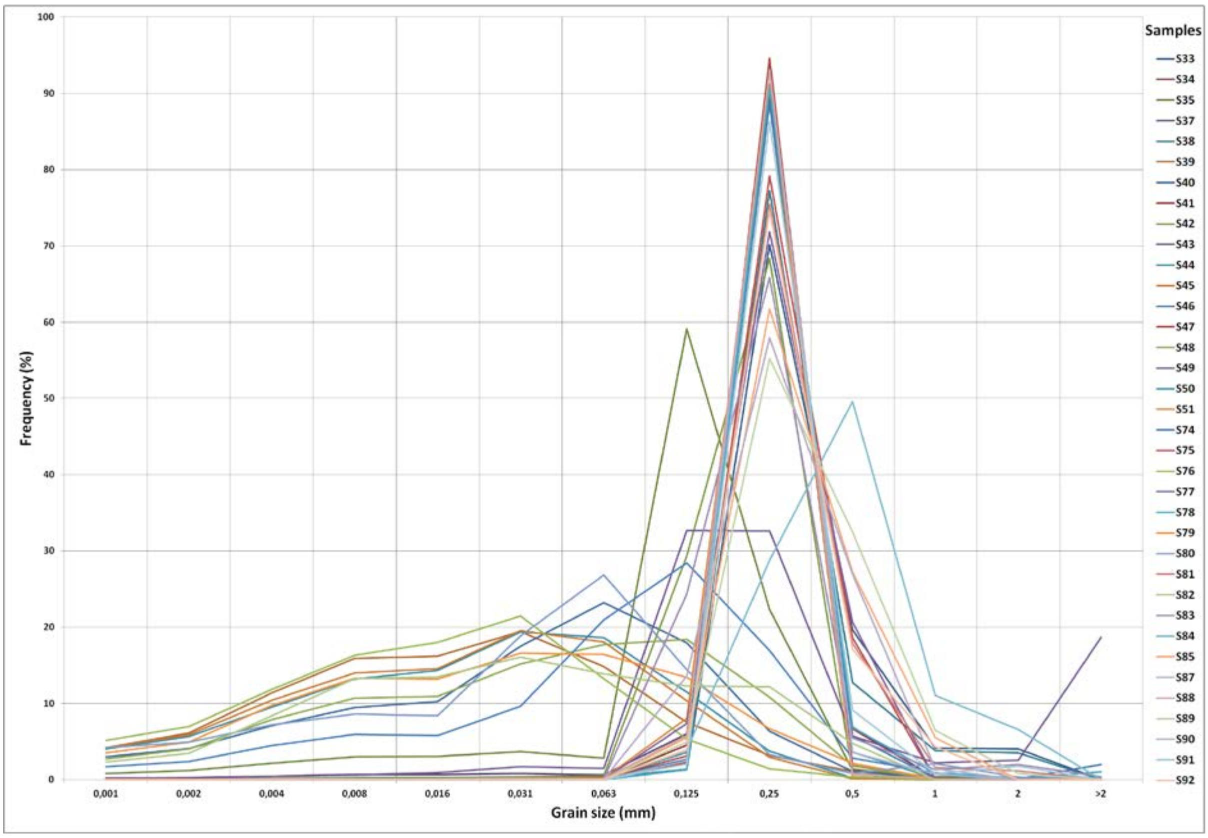

Figure 6. Comparative grain size distributions between some profiles (P13, P15 – P19 and P28 – P31, P33 – P34) from St. George Branch during the summer and the autumn expeditions of 2019 (S33 – S35, S37 – S51 and S74 – S85, S87 – S92 samples)

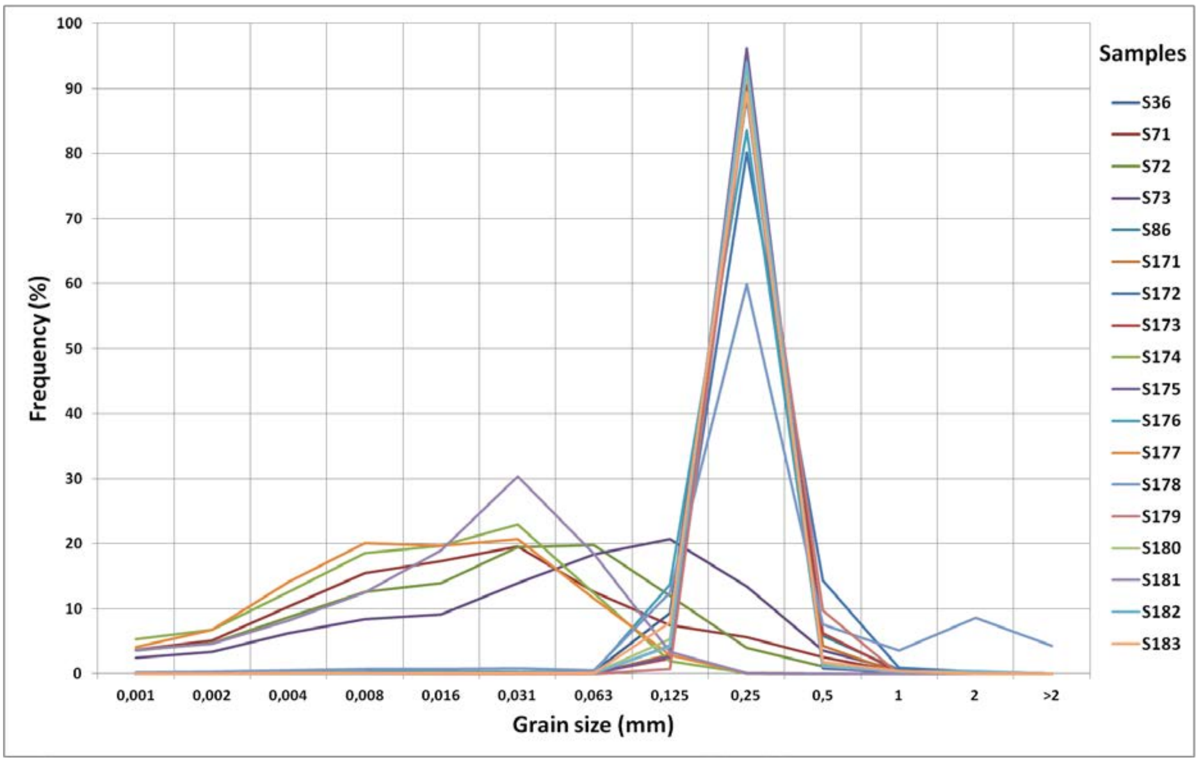

Figure 7. Grain size distributions of some profiles (P14, P27, P32 and P62 – P65) from St. George Branch (with 2 Est Meander) during the summer expedition of 2019, the summer and the autumn expeditions of 2020 (S36, S71 – S73, S86 and S171 – S183 samples)

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