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CURRENT ECOLOGICAL STATUS OF THE FISH FAUNA FROM THE FLUVIO-MARITIME AREA OF THE DANUBE DELTA (ROȘU-PUIU LAKE-COMPLEX, MUSURA AND SACALIN BAYS)

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KEYWORDS

Deltaic environment
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ABSTRACT

This paper is an outline of the current state (2020-2023) of the fish fauna of the fluvio-maritime environment still in formation of the Danube Delta, the youngest territory of Romania. The lakes of the Rosu-Puiu complex have become more fluvial in the course of time, due to the deltaic area and the breaking of the connection with the sea, while the sea areas of the Musura and Sacalin Bays have become fluvio-maritime freshwater areas, very slightly saline in the dynamics of sediment deposition. The collection of fish fauna was carried out with two complementary sampling methods: Nordic/commercial gillnets for open water and electrofishing for vegetated shorelines. The results are expressed in relative abundance and biomass as Catch Per Unit of Fishing Effort (CPUE standardisation is done by a calculation system so that catches can be compared over time or between lakes or complexes), but also ecological indicators such as ecological significance, biodiversity index Shannon-Wiener, evenness and ecological status using ECOFRAME methods and Biological Integrity Indicator (IBI) are used for comparative/complementary characterization of ecological status. The IBI index was adapted for metapotamal and hypopotamal region (bream and ruffe/carp fish region) where missing or weak-represented are Salmonidae family, replaced by *Percidae* family motivated. With few exceptions the ecological status of fluvio-maritime area was between moderate and good status (native fish gene pool affected to the limit by numerical and areal reduction, recovery capacity is not affected).

INTRODUCTION

The Danube Delta Biosphere Reserve (DDBR) is the largest Natura 2000 SCI site in Romania, covering about 2.5% of the country's surface area, and the newest territories in formation are those in the fluvio-marine delta, which includes the aquatic environment beyond the Letea-Caraorman ridge towards the sea: the Roșu-Puiu lake complex which is slowly becoming an area close to the fluvial delta and is almost completing its formation, and in full formation are the Sacalin bays south of the mouth of the Sfântu Gheorghe arm with a mini-delta formed by this arm, respectively the Musura bay south of the mouth of the Chilia arm which is already almost completely enclosed by the K island. There are two areas where the delta advances into the sea. One starts from Sfântu Gheorghe towards Sacalin Island and will probably close very soon (in a few years), forming a new lake, and the other is north of Sulina. A newly formed island in the Black Sea is Sacalin Island, a short distance off the Romanian coast, in the Sfântu Gheorghe branch of the Danube Delta. Two smaller islands: Sacalinu Mare and Sacalinu Mic are consisted originally Sacalin Island, but over time they were joined by innisipation to form a single island.
To observe the fauna status in changing aquatic ecosystem is important to start to know in new territories with freshwater the changes that have suffered the communities of aquatic organisms, especially fish fauna as the last link in the food web. Thus, the study of fish fauna through the application of synthetic ecological indices (dominance, constancy, ecological significance, IBI, ECOFRAME), we have accurate information on the extent of ecological status to the aquatic ecosystem.

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MATERIALS AND METHODS

Sampling was done in 2020-2023 in Danube Delta Biosphere Reserve (DDBR) in the fluvio-maritime delta (see Figure 1), 138 sampling sites accumulating a fishing effort of 2400 m gillnets/night Nordic gillnets, 1560 m gillnets/night Commercial gillnets and 1 hour of electrofishing collecting 12027 specimen weighting more than 595 kg (see Table 1), in the Rosu-Puiu lake-complex, Musura and Sacalin bays. At each site, GPS coordinates and physical-chemical water data were recorded. Collection of fish samples was performed by gillnets fishing ((Nordic gillnets according to European Standard *** CEN/TC 230 and commercial gillnets (mesh size more than 45 mm) and electrofishing, the standardised methods for rivers and reservoirs in Europe in Catch Per Unit Effort (CPUE: NPUE for abundance of individuals and BPUE for relative biomass). For this purpose, a special electric fishing device SAMUS 725M (600 W) was used, which generates a DC pulse of maximum 1000 V with a battery intensity of 5 to 60 A, which does not affect the collected specimens of the species.

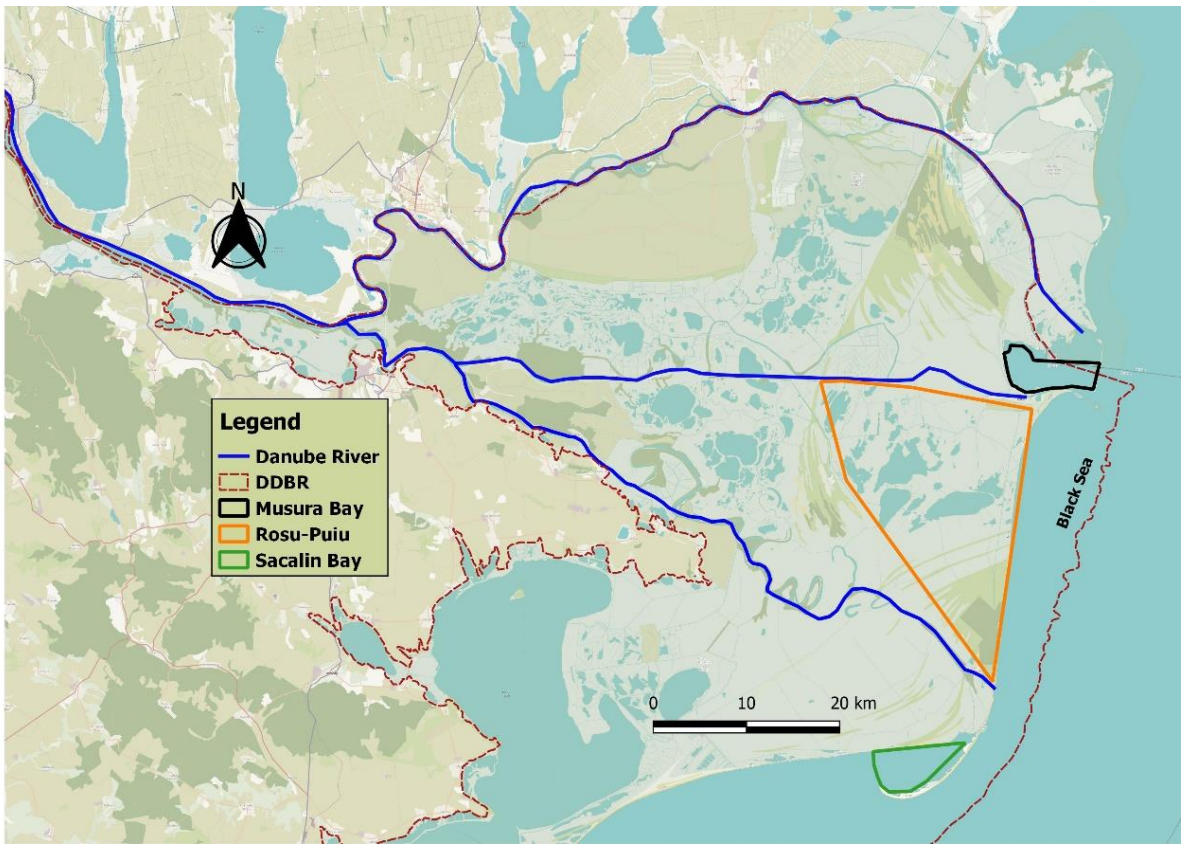

Figure 1. Studied fluvio-maritime area from DDBR

Table 1. Effort of fishing and total catch (individuals and grams) in the studied period in the fluvio-maritime delta

	Nordic gillnets		Electrofishing	Commercial gillnets		Total catch	
Lake/Tools	No.	L (m)	minutes	No.	L (m)	ex.	g
Iacub lake	12	360	30	22	660	4898	227173
Lumina lake	12	360	30	3	90	1404	54114
Puiu lake	12	360	0	3	90	2499	86594
Japsa Lunga	4	120	0	3	90	134	3557
Canal Crișan Caraorman	0	0	0	2	60	42	13807
Rosu lake	12	360	0	3	90	1350	54213
Rosulet lake	8	240	0	3	90	351	22550
Musura bay	9	270	0	3	90	151	8904
Sacalin bay	11	330		8	240	1078	106896
Bazin Mare Sulina	0	0	0	4	120	46	14913
TOTAL	**80**	**2400**	**60**	**52**	**1560**	**12027**	**595121**

No. = number of gears used, L = length, m = metres, ex. = exemplars, g = grams

Sampling was carried out mainly in the spring and autumn seasons. The fish species were identified according to Antipa (1909); Bănărescu (1964) and the taxonomic names were revised according to Nelson (2006), Kottelat & Freyhof (2007), Oțel (2007), Froese & Pauly (2024) www.fishbase and Fricke et al. (2024), which complete the

species lists with the fish species found in the DDBR area according to Năvodaru et al. (2011); Năstase et al. (2008, 2009, 2017, 2019a, 2022, 2023).
Sampling in the cold season (winter) proved to be ineffective as most species are unresponsive or very unresponsive to electric current at water temperatures below 5°C, or are immobile and cannot be captured.
The data were processed in the laboratory and by applying synthetic ecological indices (sinecological indices, ECOFRAME according to Moss et al. 2003, IBI estimates which was adapted for large rivers and reservoirs as in Năstase et al. (2021) the overall ecological status of the fluvio-maritime part of the Danube Delta was determined. Five classes of frequency (constancy), a number of six classes of abundance (dominance) and five classes of ecological significance (percentage of the product of dominance and constancy) were used to interpret the data (Table 2) (Gomoiu et al., 2001; Sârbu et al., 2004).

Table 2. Classification of constancy (frequency), dominance and ecological significance

Dominance (D)			Constancy (C)		Ecological significance	
Class		%	Class	%	Class	%
					Accidental-adventitious*	W1A< 0.001
sporadic	D1	<1 (2^0)	very rare	C1=0-10	Accidental-occasionally	W1< 0.1
subrecedent	D2	1 (2^0) - <2	rare	C2=10.1-25	accessory	W2=0.1-1
recedent	D3	2 (2^1) - <4	widespread	C3=25.1-45	associate	W3=1-5
subdominant	D4	4 (2^2) - <8	frequent	C4=45.1-70	complementary	W4=5-10
dominant	D5	8 (2^3) – 16	very frequent	C5=70.1-100	characteristic	W5=10-20
eudominant	D6	>16 (2^4)			main, leading	W6>20

* Accidental-adventitious (accented) (with W1A less values than 0.001) was a proposal for Danube Delta for accented degree of accidental fish species (used in Năstase PhD thesis in Năstase 2009); Accidental-occasional class from literature (with W1 higher value than 0.001, between 0.001-0.1) is more in the direction of accessory transitional values, which often appear as accidental bycatch (occasionally).

The evenness (E) and biodiversity (Hs) indices were calculated using the evenness and Shannon-Wiener formula (Gomoiu et al, 2001; Sârbu et al., 2004).

RESULTS AND DISSCUSSION

In the study period 2020-2023, 36 fish species and 2 crustacean species (*Pontastacus leptodactylus* and *Erythrocheir sinensis*) were caught in the Roșu-Puiu lake complex, while 19 species were observed in Musura Bay and 21 fish species in Sacalin Bay (see Table 3). The entire ichthyofauna of the fluvio-maritime delta is dominated by limnophilic and stagnophilic-reophilic or reophilic-stagnophilic species, such as main species *Bilcca bjoerkna, Alburnus alburnus, Scardinius erythrophthalmus* and *Rutilus rutilus*, followed by characteristic associated species such as *Pelecus cultratus, Perca fluviatilis, Clupeonella cultriventris, Rhodeus amarus, Leuciscus aspius* and *Carassius gibelio*, majority of species have sporadic values in the area, with some occurring here occasionally - by chance, with differences between methods of sampling and between lake-complex and bay areas. Marine euryhaline species such as *Uranoscopus scaber, Liza aurata, Mugil cephalus, Pegusa lascaris and Platychthys flesus luscus* were present in the bays, but only a few individuals were found (Table 3). Sacalin Bay is a suitable breeding environment for euryhaline species such as sturgeon and carp, and Musura Bay is a suitable feeding ground for marine species such as mullet. The Rosu-Puiu lake complex is close to the fluvial delta in terms of the spectrum of fish species.
In the area, the non-native species *Perccottus glenii* became an accessory species over time mostly in shoreline of water (Table 3), increasing in number and area in Romania after the first record (Nalbant et al., 2003) and DDBR (Năstase 2007, 2009) with invasive behaviour (Năstase et al., 2019b).
In the lakes-complex area, in the main sampling tools using the Northern gillnets, the ichthyofauna was dominated by *A. alburnus, R. rutilus, S. erythrophthalmus, P. fluviatili*s and *B. bjoerkna* in term of abundance, but by *S. erythrophthalmus, A. alburnus, R. rutilus, P. fluviatilis* in term of biomass (Figure 2).
The physical parameters analysed were carried out in the autumn season (September-November). In 2020-2023, when the air temperature was 6-18°C, the water temperature averaged 18.7°C (between 9.7-24°C; depth averaged 157 cm and transparency between 25 and 100 cm, and their Ad./Tr. ratio generally showed a subunit average ratio of 0.5). The soil is loamy-sandy to sandy loamy and organic in the centre of the complex. Also, a loamy-sandy soil (sandy towards the sea and clay or organic towards the continent) for the bays. During the study period, the vegetation is dominated by a band of reeds along the banks; native vegetation is often absent and submerged plants have fallen to the bottom. Conductivity ranged from 309 to 467 μS/cm, oxygen averaged 11.8 mg/L (between 9.05- 16.47 mg/L) with an average saturation of 131.7% and an average pH more than 8. The salinity of the water is similar to that of fresh water even in the bays, except in the case of strong storms.

Table 3. Fish species richness and Ecological Parameters in the fluvio-maritime delta

No.	SPECIES	Rosu-Puiu lake-complex						Sacalin bay			Musura bay		
		SN + C			Electric			SN + C			SN + C		
		D class	C class	W class	D class	C class	W class	D class	C class	W class	D class	C class	W class
1	*Abramis brama*	D2	C2	W2									
2	*Acipenser stellatus*							D2	C2	W2			
3	*Alburnus alburnus*	D6	C5	W6	D6	C4	W5	D4	C5	W4	D3	C3	W2
5	*Alosa immaculata*							D2	C2	W2			
6	*Alosa tanaica*	D2	C3	W2							D4	C3	W3
7	*Atherina boyeri*	D1	C1	W1							D1	C2	W1
8	*Babka gymnotrachelus*							D1	C2	W1			
9	*Ballerus sapa*	D1	C1	W1A									
10	*Bentophilus stellatus*	D1	C1	W1A							D1	C2	W1
11	*Blicca bjoerkna*	D5	C5	W5	D4	C5	W3	D6	C5	W6	D3	C2	W2
11	*Carassius carassius*	D1	C1	W1A	D1	C2	W1						
12	*Carassius gibelio*	D4	C4	W3	D5	C5	W4	D2	C5	W2	D4	C2	W2
13	*Clupeonella cultriventris*	D3	C3	W3							D6	C5	W6
14	*Cobitis elongatoides*	D1	C1	W1A									
15	*Cyprinus carpio*	D3	C3	W2	D2	C3	W2	D6	C5	W6			
16	*Esox lucius*	D3	C2	W2									
17	*Gasterosteus aculeatus*	D1	C1	W1A							D2	C2	W2
18	*Gymnocephalus cernua*	D1	C2	W1									
19	*Hypophthalmichthys molitrix*	D3	C1	W2				D1	C1	W1			
20	*Lepomis gibbosus*	D1	C1	W1	D5	C4	W4						
21	*Leucaspius delineatus*	D1	C1	W1	D1	C2	W1						
22	*Leuciscus aspius*	D2	C3	W2				D3	C5	W3	D4	C2	W3
23	*Liza aurata*										D3	C2	W2
24	*Mugil cephalus*							D1	C1	W1			
25	*Misgurnus fossilis*				D1	C2	W1						
26	*Neogobius fluviatilis*	D1	C2	W1							D5	C4	W4
27	*Ponticola kessleri*	D1	C1	W1	D1	C2	W1				D2	C2	W2
28	*Pelecus cultratus*	D1	C1	W1				D1	C2	W1			
29	*Pegusa lascaris*							D1	C1	W1			
30	*Platichthys flesus luscus*							D2	C2	W2	D1	C1	W1
31	*Perca fluviatilis*	D5	C5	W4	D3	C5	W3	D1	C3	W2			
32	*Perccottus glenii*	D1	C1	W1A	D2	C4	W2						
33	*Petroleuciscus borysthenicus*	D1	C2	W2	D3	C4	W3						
34	*Proterorhinus marmoratus*				D3	C4	W3						
35	*Pseudorasbora parva*	D1	C1	W1				D1	C1	W1	D1	C1	W1
36	*Rhodeus amarus*	D2	C3	W2	D3	C5	W3				D2	C3	W2
37	*Rutilus rutilus*	D5	C5	W5	D6	C4	W5	D6	C5	W5	D5	C4	W4
38	*Sander lucioperca*	D1	C2	W1				D3	C5	W3	D4	C4	W3
39	*Scardinius erythrophthalmus*	D5	C5	W5	D5	C5	W4	D5	C5	W5	D4	C4	W3
40	*Silurus glanis*	D1	C2	W1	D1	C2	W1	D1	C2	W1			
41	*Syngnathus abaster*				D1	C2	W1						
42	*Tinca tinca*	D1	C2	W1	D1	C2	W1						
43	*Uranoscopus scaber*							D1	C1	W1			
44	*Vimba vimba*	D1	C2	W1				D2	C4	W2	D6	C4	W5
TOTAL		33 species			19 species			21 species			19 species		

SN+C = Northern and Commercial gillnets, Electric = Electrofishing, D = Dominance, C = Constancy, W = Ecological Significance Index

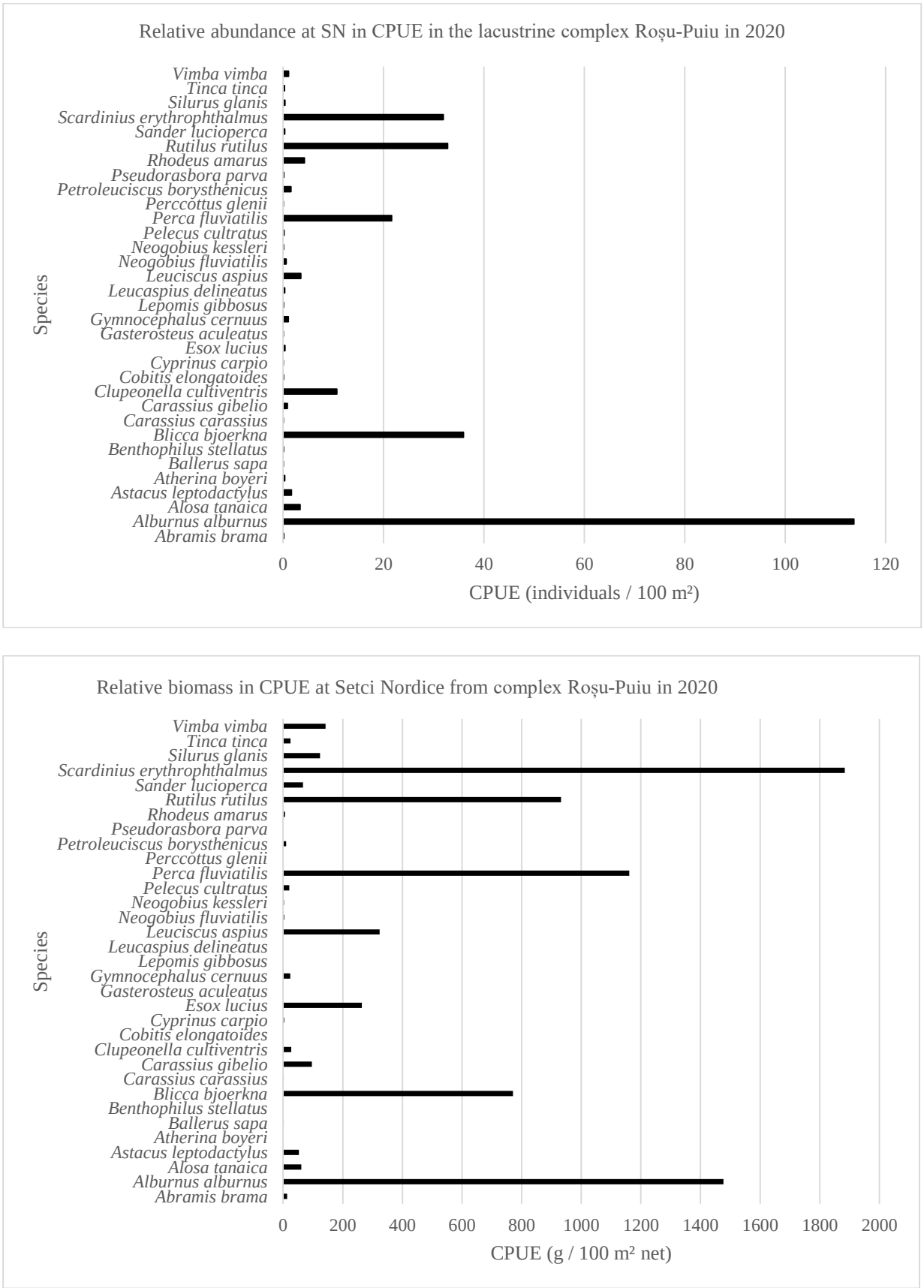

Figure 2. Relative abundance (top graph) and relative biomass (bottom graph) of the Nordic Gillnets main gear of sampling in the Roșu-Puiu lake complex in autumn 2020

For the Danube estuaries at Sacalin and Musura Bays, the ECOFRAME model shows a moderate (Sacalin Bay) or good (Musura Bay) status, but for the Rosu-Puiu lake complex the same model shows a moderate ecological status (see Table 4).

Table 4. Ecological status of the fluvio-maritime delta according to the parameter fish (all 3 variables for more than 80% of the cases), according to ECOFRAME version 8 (Moss et. al., 2003) for the main fishing gear (gill nets)

River / Lakes-Complex	Ecological status	Fish community	Fish biomass (g/m²) CPUE	Piscivorous/ zooplanktivorous (ratio after biomass)	Fish community	Fish biomass (g/m²) CPUE	Piscivorous/ zooplanktivorous (ratio after biomass)
Roșu-Puiu	Moderate	Pi or Abex	> 20	0.5-1	Pi or Abex Moderate	74.9 Moderate	0.98 Moderate
Sacalin bay	Moderate	Pi or Abex	> 20	>1	Pi or Abex Moderate	108.5 Moderate	15,8 Moderate
Musura bay	Good	Pi or Abex	> 20	>1	Pi or Abex Moderate	18.2 Good	9 Good

The biodiversity indices of the fluvio-maritime delta showed that there is a stable ecosystem more than medium (equitability index is more than 0.5) with a good ichthyodiversity (Shannon-Wiener index values between 1.8-2.3), with the number (NPUE) of specimens in CPUE low value in Musura bay but very increased in Rosu-Puiu lake complex and a relative biomass (BPUE) between 1.8 -17.7 kg/100 m² used gear, that is 18-177 grams/m² used gear (see Table 5).

Table 5. Biodiversity indices of the fluvio-maritime Delta (Areas: R-P=Rosu-Puiu, Sacalin and Musura bays)

River-Lakes-complex (tools)	NPUE	BPUE	Hs	E
R-P (SN+C)	267	7497	1.863	0.532
R-P (Ele)	380	17765	2.139	0.740
Sacalin (SN+C)	179.8	10847	1.912	0.662
Musura (SN+C)	30.963	1827.4	2.307	0.814

NPUE = catch per unit effort of individuals in abundance, BPUE = catch per unit effort in grams of biomass, Hs = Shannon-Wiener ichthyodiversity, E = ichthyological evenness). for electric fishing (Ele), Nordic and commercial gillnet fishing (SN+C)

For the Danube estuaries at Sacalin Bay and Musura Bay, the IBI has a value of 57, which means moderate-good status, but for the Rosu-Puiu lake complex, the IBI slightly increased to a value of 61 (status III good: which means that the native fish genetic stock is affected by the reduction in numbers and area, but the recovery capacity is not affected) (see Table 6).

Table 6. Score of IBI model and ecological status of the mounths of the Danube for fish in period of studies

	Rosu-Puiu complex	Sacalin bay	Musura bay
1. Total fish species (from initial) in number	5	3	3
2. Total cyprinids in number	5	5	5
3. Total percids in number	5	5	5
4. Other fish species in number	5	5	5
5. Total native fish species in number	5	5	5
6. Total non-native species in number	1	1	3
7. Total disappearing fish species in number	5	1	1
8. Proportion of zoobentivorous species	3	3	3
9. Proportion of piscivorous species	5	5	5
10. Proportion of piscivorous and planktivorous	3	3	3
11. Proportion herbivores and detritivores	5	5	5
12. Numerical of Stock (ex./100 m²) (ex./100 m linear / collectors)	5	5	3
13. Gravimetrical of Stock (g/100 m²) (g/100 m linear / collectors)	5	5	5
14. Hybrid individuals' proportion	1	3	3
15. Proportion of sick individuals	3	3	3
VALUES	61	57	57
STATUS	III	IV	IV
	GOOD	MODERATE-GOOD	MODERATE-GOOD

CONCLUSION

A number of 44 fish species were caught in the fluvio-maritime delta of the DDBR during the study period 2020-2023: 36 fish species in the Rosu-Puiu lake-complex (plus 2 species of decapod crustaceans with a new record for *Erythrocheir sinensis*), 21 fish species for Sacalin Bay and the fewest species were caught in Musura Bay with 19 fish species. The ichthyofauna is dominated by limnophilic and stagnophilic-reophilic or reophilic-stagnophilic species such as *Bilcca bjoerkna, Alburnus alburnus, Scardinius erythrophthalmus* and *Rutilus rutilus,* but there are also numerous euryhaline marine species that enter in the studied bays mainly for breeding or feeding, as long as the bays are still connected to the sea, because very soon these bays will also become freshwater, as a normal natural phenomenon that leads to the delta retreating into the sea. With few exceptions the ecological status of fluvio-maritime area was between moderate and good status. For future new studies are necessary.

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