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Ecological status of fish fauna from Razim Lake and the adjacent area, the Danube Delta Biosphere Reserve, Romania

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Abstract

The aim of this study was to determine the ecological status of fish fauna of Razim Lake under the conditions of the water salinity changing from brackish, almost 70 years ago, into freshwater nowadays. The natural processes of siltation and organic deposits, characteristic of Danube Delta lake complexes, intensified in the last decades and included also Razim Lake. The presently reported study of Razim Lake and the adjacent area was undertaken in 2020 with intention to cover fish fauna collected with three different sampling methods (electrofishing, gillnetting, and seining). For each sampling method, Catch per Unit Effort (CPUE), relative abundance, and biomass were determined, as well as selected ecological parameters to determine ecological status of richness species in the area. Published data included 55 fish species, mainly marine and euryhaline, but in 2020 only 43 species were reported. Also, the species composition shifted from marine ones to freshwater or euryhaline ones. Of those 43 species captured in 2020 from Razim Lake and neighboring areas, 39 were native and four were non-native, including a newcomer, the Chinese sleeper, *Perccottus glenii* Dybowski, 1877. Few species were migratory, reophilous, or reophilous-stagnophilous which rarely enter Razim Lake, but the majority were limnophilous or stagnophilous-reophilous species. Four species were dominant in terms of the abundance; *Blicca bjoerkna* (Linnaeus, 1758); *Rutilus rutilus* (Linnaeus, 1758); *Alburnus alburnus* (Linnaeus, 1758); and *Carassius gibelio* (Bloch, 1782). In terms of the biomass the dominants were: *Cyprinus carpio* Linnaeus, 1758; *Carassius gibelio*; *Sander lucioperca* (Linnaeus, 1758); *Pelecus cultratus* (Linnaeus, 1758); and *Blicca bjoerkna*. Some differences between sampling methods used were observed. Eudominant, euconstant, and main species were *Blicca bjoerkna* and the majority of fish species were accessories, with differences amongst sampling methods used. Fish diversity parameters indicate a stable ichthyocoenosis, more stable along the lake shoreline. Ecological indicators of fish fauna from Razim Lake in 2020 grade the water lake quality as a moderate ecological class according to the Water Framework Directive of the European Union.

Keywords

fish species richness, abundance, biomass, fish ecology indicators, water ecological status

Introduction

The Razim–Sinoie lake complex is situated in the southern part of the Danube Delta Biosphere Reserve (DDBR) and formed in an old gulf of the Black Sea—Halmirys—with water surface of 86 770 ha. The largest lake in the complex is Razim Lake with 41 400 ha (Gâştescu 1971; Gâştescu and Ştiucă 2008;

Staras, unpublished*). The lake complex has two connections with the Black Sea from Sinoie Lake through the Periboina and Edighiol canals. These two openings to the sea maintain fish diversity and productivity of the entire lake complex (Staras, unpublished). Razim Lake is connected with Sinoie Lake through two canals (named Canal II and Canal V) that provide slightly brackish water for Razim Lake. The hydrotechnical works of the early 1970s transformed Razim Lake into a reservoir with 1 billion m^3 of freshwater (Staras, unpublished). Moreover, the salinity of Razim Lake changed over a short time, as proven by Leonte et al. (1956, 1960), from 2.5‰ in 1951 to 0.5‰in 1956 due to the freshwater influx from the Danube River. The Danube River, via the Sfântu Gheorghe arm as a major path, transports water and solids into Razim Lake via the Dunăvăţ, Dranov, Mustaca, and Lipoveni canals. The mean monthly flows on Sf. Gheorghe arm indicate 9.66% of total flow (135 $m^3 \cdot s^{-1}$ liquid flows) and almost 2 million t $\cdot$ $year^{-1}$ (solid flows) from the total flows of the arm by continuous lateral discharge to the Razim system (Driga 2004). The general water balance shows that the share of inputs is 90% from supply canals (Dranov, Dunăvăţ, and Lipoveni canals), 9% from precipitation, and 1% from small rivers (Slava, Taiţa, Teliţa, Agighiol) and the exits from the system are represented by evapotranspiration (15%) and 85% irrigation and evacuation (Bondar cited by Staras, unpublished). The Danube River is the water supplier for all Danube Delta lakes including Razim Lake with which it has also an active exchange of fish fauna, especially at high river water levels because of the high degree of siltation of connecting canals in 2020. The diversity and structure of the fish community varies amongst lakes and can be regarded as a good indicator of the ecological state of the lakes. The aim of this study was to describe the ecological status of fish fauna from Razim Lake and the adjacent area, based on a fish survey conducted in 2020 and to discuss changes, based on earlier scientific publications.

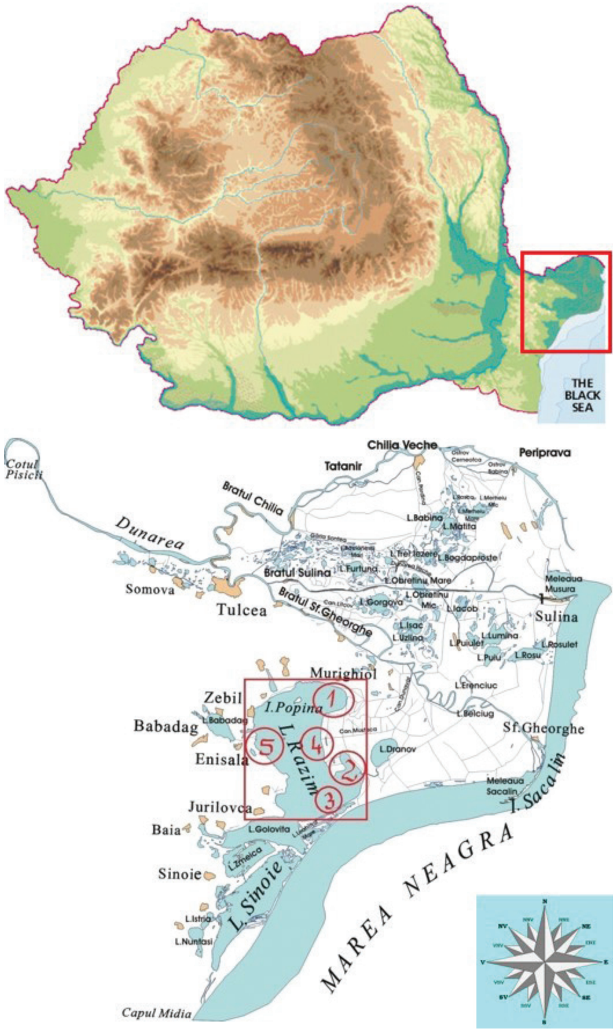

Figure 1. Investigation area from sectors of Razim Lake in the year 2020 (1 = Fundea Gulf, 2 = Holbina Gulf, 3 = South Lake, 4 = Mustaca sector north and south and Oaia Lake, 5 = west Lake Enisala).

Materials and methods

Study area, sampling period, fish, and water measurements. The study area was represented by five sectors of Razim Lake, a large-surface lake: Fundea Gulf (1), Holbina Gulf (2), southern lake (3), Mustaca sector north and south and Oaia Lake (4), west Lake Enisala (5), and canals (Dunăvăţ, Mustaca, Dranov) (Fig. 1), with each sector being sampled at multiple sites. The ichthyofauna was sampled in Razim Lake and the adjacent area in July, August, and September of 2020. For biometric measurements, an ichthyometer with an accuracy of 1 mm per 50 cm for fish length and for weight, an electronic scale with an accuracy of 1 g per 5 kg were used. Geographical coordinates and physical-chemical parameters observed in the area were recorded with a Garmin device and Hach multiparameter, as well as a Secchi disc for water depth and transparency.

Fish sampling. The fish sampling and Catch per Unit Effort calculation (CPUE) was done in accordance with EU recommendations by use of common methods:

- Electriofishing with SAMUS 1000 W electrofisher device, transect with multiple electric points during 10 min per site, the catch being standardized at individuals or g $\cdot$ h^{-1} of fishing effort (for shoreline or small canals from compact reed developed nearby lake).
- Passive gillnet fishing (stationary 12 h by night, the catch being standardized at 100 m^2 gillnets per night):

* Staras M (1995) Studiul populaţiilor piscicole din complexul de lacuri Razim–Sinoie şi elaborarea strategiei de pescuit.[Study of the fish populations in the Razim-Sinoie lake complex and elaboration of the fishing strategy.] PhD thesis, University Dunărea de Jos, Galaţi, Romania. [In Romanian]

commercial gillnets or Nordic gillnets multi-meshes fishing tools (30 m length × 1.8 m high each). The Nordic gillnets have 12 randomly joined panels, each panel being 2.5 m in length, with multiples meshes: 6, 6, 8, 10, 12, 16, 20, 24, 30, 35, 45, and 55 mm (Nyberg and Degerman 1988; Năvodaru 2008) (main tools used in Razim Lake and adjacent area).

- Seine fishing with 2 wings of 100 m length each and a codend of 7 mm knot-to-knot mesh size. Standardization to one haul of active fishing (1 h).
- Directly observed species from angling and some traditional fishing tools (fyke net, hand cast net, fish landing) just for fish species identification, without other standardization.

Taxonomy and ecology. The fish species scientific names used are consistent with the Eschmeyer's Catalog of Fishes (Fricke et al. 2021). The specimens collected were identified after Antipa (1909), Cărăusu (1952), Bănărescu (1964), and taxonomic name and support knowledge after revision by some authors (Otel et al. 1992, 1993; Kottelat 1997; Otel 2001, 2007; Sindrilariu et al. 2002; Nelson 2006; Kottelat and Freyhof 2007; Năvodaru and Năstase 2011; Năstase et al. 2017, 2019a; Froese and Pauly 2021; Năstase, unpublished[*]). Relative abundance and biomass for each species and sampling methods were calculated as standard CPUE (Catch Per Unit Effort). The relative abundance or dominance (D) for each species and sampling methods was calculated as the proportion of species to total catch (Mühlenberg 1993; Sindrilariu et al. 2002). The relative abundance or dominance (D) for each species and sampling methods was calculated as the proportion of species to total catch ($D_i = n_i \cdot 100N^{-1}$ (%), where, D_i = dominance of species i, ni = individuals of the species i, and N = total number of individuals) (Mühlenberg 1993; Sindrilariu et al. 2002). The frequency of occurrence (F) or constancy (C) for each species and sampling method was calculated as the proportion of samples containing a species from the total number of samples ($C_i = b_i \cdot 100a^{-1}$ (%), where, C_i = frequency of occurrence of species i, b_i = the number of samples in which species i was observed and a = total number of samples) (Schwerdtfeger 1975; Sindrilariu et al. 2002). Ecological significance (W) is a relation between frequency (C) and dominance (D) ($W = D \cdot 100C^{-1}$). For frequency, five classes were used; six classes were used for abundance/dominance data analysis, and seven classes were used for ecological significance (Table 1).

To determine ecological status of the lake, some quantitative ecological parameters were chosen as most expressive for fish communities: Relative Abundance in Number per Unit Effort (NPUE), Relative Biomass in Biomass Per Unit Effort (BPUE), the biodiversity index according Shannon–Wiener Index H_s, and Equitability Index = Evenness index (E) as in Năstase et al. (2019a, 2021) (Table 2).

An ecological status classification matrix in accordance with the Water Framework Directive (WFD) is presented in Table 2 regarding the fish community. The Biodiversity Index (H_s), according to the Shannon–Wiener formulae, as well as maximal fish Diversity (H_{max}) and Equitability (Evenness) Index (E) were calculated. The Equitability Index describes the quantum of unequal distribution of different effective species proportion as an ideal community, ranges between 0 and 1. The Shannon–Wiener Index varies from values of 0 for communities with one species, to various other values for more mixed species (Odum 1975; Botnariuc and Vădineanu 1982; Gomoiu and Skolka 2001; Sârbu and Benedek 2004). Formulas used:

$$H_s = -\Sigma\, p_i \cdot \ln(p_i)$$

according Shannon–Wiener formulae

$$p_i = N_r \cdot N^{-1}$$

Table 1. Frequency (constancy), dominance, and ecological significance classification according to: Botnariuc and Vădineanu 1982; Gomoiu and Skolka 2001; Șindrilariu et al. 2002 Sârbu and Benedek 2004.

Category	Symbol	[%]
Dominance		
Sporadic	D1	<1
Subrecedent	D2	1–2
Recedent	D3	2–4
Subdominant	D4	4–8
Dominant	D5	8–16
Eudominant	D6	>16
Constancy		
Very rare	C1	0.0–10.0
Rare	C2	10.1–25
Widespread	C3	25.1–45.0
Frequent	C4	45.1–70.0
Very frequent	C5	70.1–100
Ecological significance		
Accidental-adventitious	W1A	<0.001
Accidental	W1	<0.1
Accessory	W2	0.1–1.0
Associate	W3	1.0–5.0
Complementary	W4	5.0–10.0
Characteristic	W5	10.0–20.0
Main, leading	W6	>20

Table 2. Ecological matrix class for fish parameters assessment in accordance with the WFD (expert judgement based) according to the "one out, all out" principle.

Status	Color	Class	NPUE (n)	BPUE [g]	H_s	E
Very bad	Red	I	< 25	< 500	< 1	< 0.2
Bad	Orange	II	25–100	500–2000	1.0–1.4	0.2–0.4
Moderate	Yellow	III	100–250	2000–5000	1.4–1.8	0.4–0.6
Good	Green	IV	250–500	5000–10000	1.8–2.2	0.6–0.8
Very good	Blue	V	>500	>10000	>2.2	>0.8

NPUE = Number Per Unit Effort, BPUE = Biomass Per Unit Effort, H_s = Shannon–Wiener Biodiversity Index, E = Evenness Index (Equitability Index).

* Năstase A (2009) Cercetări asupra diversității ihtiofaunei din Delta Dunării pentru exploatarea durabilă a resurselor piscicole. [Researches of ichthyofauna diversity in the Danube Delta for sustainable management of fish resources.] PhD thesis, University Dunărea de Jos, Galați, Romania. [In Romanian]

where p_i is the dominance; N_r is the number of individuals belonging to a certain species; and N = total number of individuals in a sample.

$$E = H_s \cdot H_{max}^{-1}$$

According to the Water Framework Directive, it is desirable to test and apply known ecological parameters that could improve the methods of assessing the ecological status, using, when no other methods are available, even expert judgement analysis (this analysis from papers was thought of and used in a European project in 2014: Black Sea e-Eye - Innovative Instruments for Environmental Analysis in NW Black Sea Basin, to improve methodology after Moss et. al. (2003) and Ibram et al. (2015). The ecological lake classification matrix is in accordance with the Water Framework Directive. EU Water Framework) has five (I–V) limits classes marked with different colors. Actually, there are yet no developed statistical threshold limits classes (I–V) for those chosen ecological parameters (NPUE, BPUE, H_s, E) according to the WFD water quality regarding fish, but expert judgement was used as a future proposal. Class limits was proposed by the present authors, based on field experience and expert judgement in the Danube Delta (Năstase et al. 2019a, 2021). In the summer of 2020, sampling was conducted using 77 Nordic gillnets, totaling 2310 m of passive nets per night, 190 minutes of electric fishing, five seine active hauls and 48 commercial gillnets 1440 m in total of passive nets-nights–1 in total (Table 3).

Table 3. Fishing tools used in Razim Lake in 2020 and their yield and effort.

Sampling site		N gillnets		Electr.	C gillnets		Seine	Total catch	
Name	No.	No.	L [m]	[min]	No.	L [m]	H No.	*N*	[g]
Enisala	5	14	420	30	4	120	5	1537	68653.9
Fundea	1	12	360	30	3	90	0	2029	83557.5
Mustaca N	4	12	360	30	7	210	0	789	87343
Mustaca S	4	12	360	30	6	180	0	843	86432
Center	4	3	90	0	15	450	0	385	46174
Holbina	2	12	360	30	6	180	0	1029	70585
Periteasca S	3	12	360	30	3	90	0	1245	76443
Canal Mustaca	4	0	0	10	0	0	0	114	33403
Oaia mare	4	0	0	0	4	120	0	71	20826
TOTAL Fish		**77**	**2310**	**190**	**48**	**1440**	**5**	**8042**	**573417.4**
Crayfish								36	1446

N gillnets = Nordic gillnets, Electr. = electrofishing device, C gillnets = commercial gillnets, H No. = number of hauls, N = number of fish/crayfish.

Results

In the summer of 2020, we captured 8042 fish individuals with more than 573 kg of fish and 36 individuals weighting in a total of almost 1.5 kg of crayfish (Table 3).

Species richness. All captured individuals belong to 43 fish species and one crayfish species—*Pontastacus leptodactylus.* Overall, Razim's ichthyofauna is dominated by limnophilous or stagnophilic-rheophilic species, such as white bream, *Blicca bjoerkna* (Linnaeus, 1758) and roach, *Rutilus rutilus* (Linnaeus, 1758), followed by characteristic-complementary-associated species, such as ziege, *Pelecus cultratus* (Linnaeus, 1758); European perch, *Perca fluviatilis* Linnaeus, 1758; pike-perch, *Sander lucioperca* (Linnaeus, 1758); common bream, *Abramis brama* (Linnaeus, 1758); bleak, *Alburnus alburnus* (Linnaeus, 1758); and gibel carp, *Carassius gibelio* (Bloch, 1782), but the majority of species occur sporadically in the Lake, with a significant number of species being accidentally found here (Table 4). The numbers for the goby species—monkey goby, *Neogobius fluviatilis* (Pallas, 1814); round goby, *Neogobius melanostomus* (Pallas, 1814); racer goby, *Babka gymnotrachelus* (Kessler, 1857); bighead goby, *Ponticola kessleri* (Günther, 1861); syrman goby, *Ponticola syrman* (von Nordmann, 1840); mushroom goby, *Ponticola eurycephalus* (Kessler, 1874)—are worrying, as they are in a continuous decrease, being limited only to certain favorite places of the Lake, especially in the areas with submerged stones (used to avoid clogging of the mouths of the canals) and gravel areas, compared to the previous years when they dominated even sandy areas. It can be said that this phenomenon of numerical reduction of the gobies populations in Razim Lake is due to the obvious habitat changes which include increase of siltation, the mud of the Razim Lake transforming the lake into a pond, typical for lake complexes from the Danube Delta. Another question mark is the existence of percarina, *Percarina demidoffi* von Nordmann, 1840 (Percidae), a non-native not invasive, but sensitive species, first recorded 1986 (Otel and Bănărescu 1986). In recent years, it has not been found in Razim Lake, in the place where this species had formed vigorous populations in the past, even stronger populations than in its native range (Don River), the cause probably also being habitat change.

Out of the 43 fish species captured or observed in Razim Lake, nearly 1/3 are without commercial value (small fish) and 2/3 (30 fish species) have commercial value. From these 30 commercial fish species, more than 1/4 have high commercial value—pontic shad, *Alosa immaculata* Bennett, 1835; pike-perch, *Sander lucioperca*; Wels catfish, *Silurus glanis* Linnaeus, 1758; common carp, *Cyprinus carpio* Linnaeus, 1758; European eel, *Anguilla anguilla* (Linnaeus, 1758); and northern pike, *Esox lucius* Linnaeus, 1758). Almost half of the species have medium market value (like gibel carp, rudd, roach, tench, perch, bream, etc.) and almost 1/4 have low economic value (goby species). Of the 43 fish species, the majority are native and four are non-native species: Chinese sleeper, *Perccottus glenii* Dybowski, 1877; silver carp, *Hypophthalmichthys molitrix* (Valenciennes, 1844); grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844); pumpkinseed sunfish, *Lepomis gibbosus* (Linnaeus, 1758). While some of the species are migratory, reophilous or reofilous-stagnofilous, such as *Alosa immaculata*, *Anguilla anguilla*, and white-eye bream, *Ballerus sapa* (Pallas, 1814), occur rarely in the Lake, others are stagnofilous-reophilous or limnophilous species which are the majority. The stagnoph-

Table 4. Ecological significance of fish species from Razim Lake and the adjacent area (also included classes "Present = P" for species which could not be standardized, just observed).

Species	Nordic gillnets			Commercial gillnets			Electrofishing device			Seine			Other fishing gear
	D	C	W	D	C	W	D	C	W	D	C	W	
Abramis brama	D1	C2	W1	D4	C2	W3				D2	C3	W3	P
Alburnus alburnus	D4	C5	W4				D5	C5	W5	D4	C5	W4	P
Alosa immaculata	D1	C1	W1A										
Alosa tanaica	D2	C3	W2							D1	C2	W1	P
Pontastacus leptodactylus	D1	C3	W2	D1	C1	W1				D1	C3	W2	P
Atherina boyeri							D5	C2	W3				
Babka gymnotrachelus										D1	C3	W2	P
Ballerus sapa	D1	C1	W1A										
Blicca bjoerkna	D6	C5	W6	D2	C1	W1	D4	C4	W3	D6	C5	W5	P
Carassius carassius				D2	C1	W2							
Carassius gibelio	D1	C3	W2	D6	C5	W6	D4	C3	W3	D3	C5	W3	P
Clupeonella cultriventris	D6	C4	W4							D1	C2	W2	P
Cobitis tanaitica				D1	C1	W1							
Ctenopharyngodon idella										D1	C2	W1	P
Cyprinus carpio	D1	C1	W1A	D5	C3	W3	D4	C4	W3	D1	C2	W2	P
Esox lucius	D1	C1	W1	D1	C1	W1							P
Gymnocephalus cernuus	D1	C2	W2										
Hypophthalmichthys molitrix	D1	C1	W1A										
Knipowitschia caucasica							D2	C2	W2				
Lepomis gibbosus	D1	C1	W1A	D1	C1	W1	D1	C2	W1				
Leuciscus aspius	D1	C2	W1	D2	C2	W2				D1	C3	W2	P
Mugil cephalus	D1	C1	W1A										
Misgurnus fossilis	D1	C1	W1A										
Ponticola eurycephalus	D1	C1	W1A				D5	C2	W3				
Neogobius fluviatilis	D1	C1	W1				D1	C1	W1	D4	C4	W3	P
Ponticola kessleri							D2	C2	W2				
Neogobius melanostomus										D1	C2	W1	P
Pelecus cultratus	D5	C5	W5							D2	C5	W3	P
Perca fluviatilis	D4	C5	W4	D2	C1	W2	D4	C3	W3	D4	C5	W4	P
Perccottus glenii	D1	C1	W1A				D1	C1	W1				
Petroleuciscus borysthenicus	D1	C1	W1A										
Ponticola syrman	D1	C1	W1A							D1	C2	W1	P
Proterorhinus marmoratus							D1	C1	W1				
Pungitius platygaster							D1	C1	W1				
Rhodeus amarus	D1	C1	W1				D2	C2	W2				
Rutilus rutilus	D5	C5	W5				D6	C5	W6	D6	C5	W6	P
Sander lucioperca	D2	C4	W3	D4	C3	W3	D3	C3	W2	D5	C5	W5	P
Scardinius erythrophthalmus	D4	C4	W3	D1	C1	W1	D4	C3	W3	D5	C5	W4	P
Silurus glanis	D1	C1	W1A	D1	C1	W1	D1	C1	W1				
Syngnathus abaster	D1	C1	W1A							D1	C3	W2	P
Tinca tinca	D1	C1	W1	D4	C1	W2							
Umbra krameri							D1	C1	W1				
Vimba vimba	D1	C2	W1	D1	C1	W1							
Anguilla anguilla													P

ilous (limnophilous) species, like Caucasian dwarf goby, *Knipowitschia caucasica* (Berg, 1916) and mudminnow, *Umbra krameri* Walbaum, 1792, are very well represented in Razim Lake or the adjacent area.

Ecological status. The main species (eudominant, very frequent) in Razim Lake and adjacent waters are *Blicca bjoerkna*, *Rutilus rutilus* and *Alburnus alburnus*, but the majority of the species are accessory, as well as a significant percentage of species being accidental, with some differences between sampling methods (Table 4).

The parameters used in the ecological characterization of Razim Lake from the point of view of the ichthyofauna show that they fall into the moderate class, the majority of the indicators having moderate and good values, but according to the "one out, all out" principle there are some indicators in the moderate state class, which makes us assert that Razim Lake has a Moderate ecological status in 2020 (Table 5 and 6).

Some large fish individuals like *Sander lucioperca*, *Silurus glanis*, and *Abramis brama* were rarely found during our sampling campaign in Razim Lake, probably due to legal and illegal overfishing. Extensive poaching with nylon and small mesh-size gillnets fishing is one of the most dangerous practices in reducing the quality and size of fish populations in the area. There is no precise estimate of the extent of poaching in Razim Lake since 1990, but it is believed that poaching is threatening all animals, especially fishes. Razim Lake, the largest lake of Romania has always been fascinating for studies of fish fauna, especially due to the contact of freshwater with the brackish water, which make it a "natural biological laboratory" of living fish population species, with a lot of hybrid individuals or subspecies. The diversity indices of Razim Lake and adjacent water bodies indicate a stable ecosystem, so a stable fish coenosis, with values of equitability (E) more than medium 0.5 for each sampling method. Shannon–Wiener Index values are increased, the

Table 5. The ecological status of fish species from Razim Lake and the adjacent area according to Moss et al. (2003) (Pi = presence of locally native piscivores, Abex = absence of non-native species, Altd = either an absence of locally piscivores or presence of introduced species).

EcT	T [°C]	Ar [km²]	Geo	C	EcS	Fc	Fb	P:Z	FcR	FbR	P:Z/R
17	10–25	<100	Peat	101–800	High	Pi + Abex	5–20	>1			
					Good	Pi + Abex	5–20	>1			1.4
					Mod.	Pi or Abex	>20	0.5–1	Yes	68	
					Poor	Altd	>20	<0.5			
					Bad	Altd	<5	<0.5			

EcT = ecotype number, T = temperature of warmest month, Ar = area, Geo = catchment geology, C = conductivity [μS· cm^{-2}], EcS = ecological status, Fc = fish community, Fb = fish biomass [g · m^{-2}], P:Z = Piscivores:zooplanktivoures (ratio by biomass), FcR = fish community of Razim Lake, FbR = fish biomass of Razim Lake [g · m^{-2}], P:Z/R = Piscivores/zooplanktivoures (ratio by biomass) of Razim Lake; Mod. = moderate, Pi = presence of locally native piscivores, Abex = absence of non-native species, Altd = either an absence of locally piscivores or presence of introduced species.

boundaries are more than 1.955 with the maximum on the shorelines or canals from the reed band on the shoreline of the Lake (Fig. 2).

Relative abundance and biomass. Relative abundance (CPUE) is dominated by bream species (especially white bream), roach, giebel carp, perch, bleak, rudd, and ziege, but for the majority of fish species, it has low values, with some differences between sampling methods (Fig. 3). Relative biomass (CPUE) was dominated by common carp, gibel carp, roach, white bream, ziege, perch, pikeperch, and rudd with some differences between sampling methods (Fig. 4).

Table 6. Ecological status of Razim Lake and the adjacent area (according to WFD) using the "one out, all out" principle for fish biological parameters.

Parameter	NPUE (A)	BPUE (B)	H_s	E
Nordic gillnets (NG)	158.6	6843.6	1.955	0.564
Ecological status NG	Moderate	Good	Good	Moderate
Electrofishing (E) values	126	18853.5	2.320	0.774
Ecological status E	Moderate	Very Good	Very Good	Good
Seine (S) values	136.8	7249.5	2.082	0.695
Ecological status S	Moderate	Good	Good	Good
TOTAL	**Moderate**	**Good**	**Good**	**Moderate**

A = relative abundance, NPUE; B = relative biomass, BPUE; H_s = Shannon–Wiener Biodiversity Index; E = Evenness Index; by type of sampling methods; Nordic gillnets (NG) values [No. of individuals (or grams) per 100 m² of nets per night]; Electrofishing (E) values individuals or [g · h^{-1}]; Seine (S) values [individuals (or grams) per haul].

Physico-chemical parameters of water. Geographical coordinates in some sites and physico-chemical parameters of water are presented in Table 7. Sampled water body points had depth between 25 and 250 cm, transparency 20–35 cm, conductivity 369–1183 μS · cm^{-1}, salinity did not exceed 0.5‰, dissolved oxygen 4.45–16.06 mg · L^{-1}, and oxygen saturation 55.1%–174.6% (Table 7).

Discussion

Since the 19th century, when Grigore Antipa drew attention to the decline in fish production in Razim Lake, reaching less than 1/3 of what it was 15 years before his studies

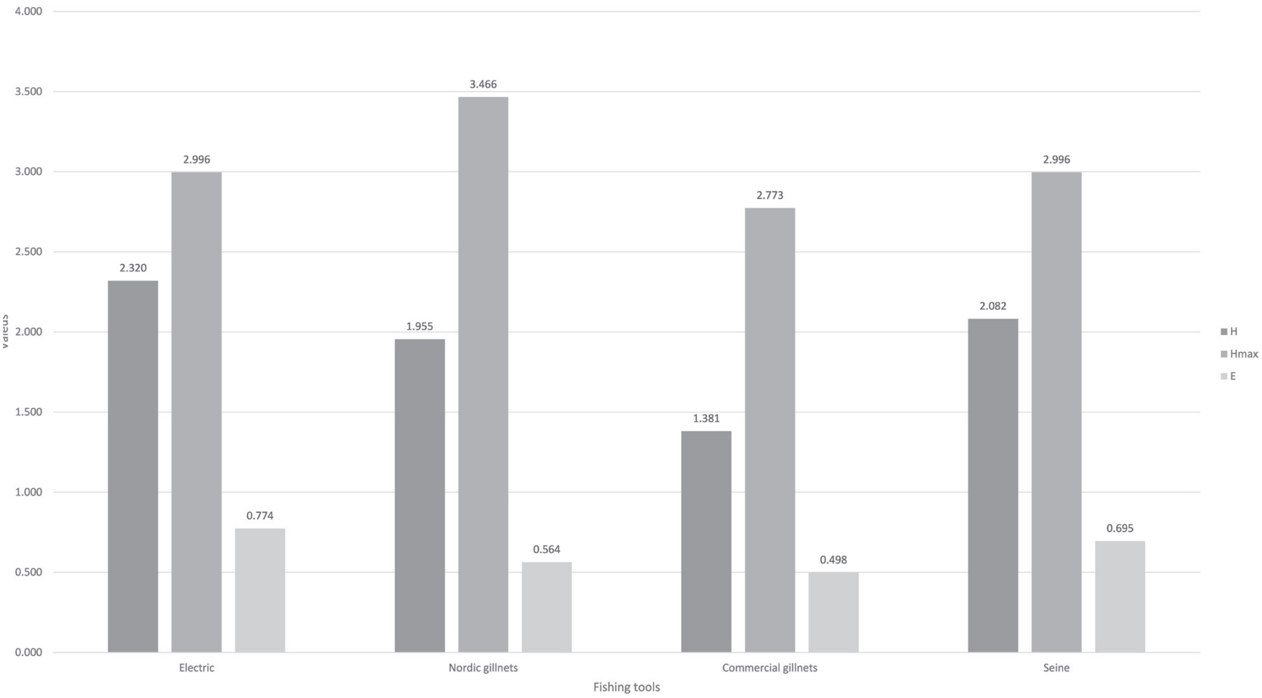

Figure 2. Comparative biodiversity indices between sampling methods in Razim Lake in 2020 (H_S = Shannon–Wiener Index, H_{max} = the maximal diversity, E = Evenness Indices.

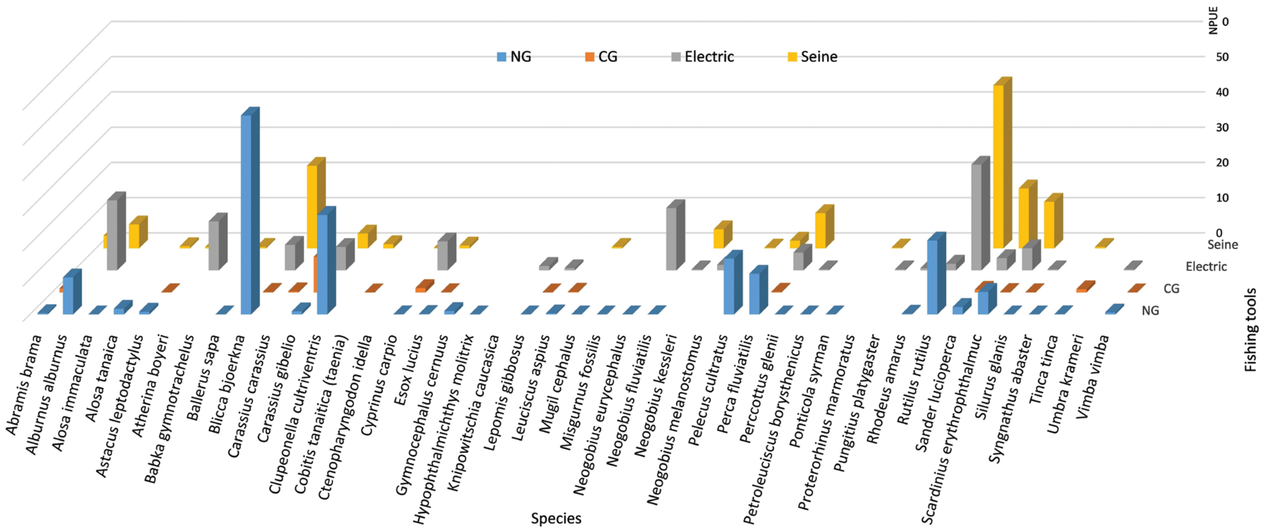

Figure 3. Relative abundance (CPUE = Catch per Unit Effort) in Razim Lake in 2020 (NG = Nordic gillnets, CG = commercial gillnets).

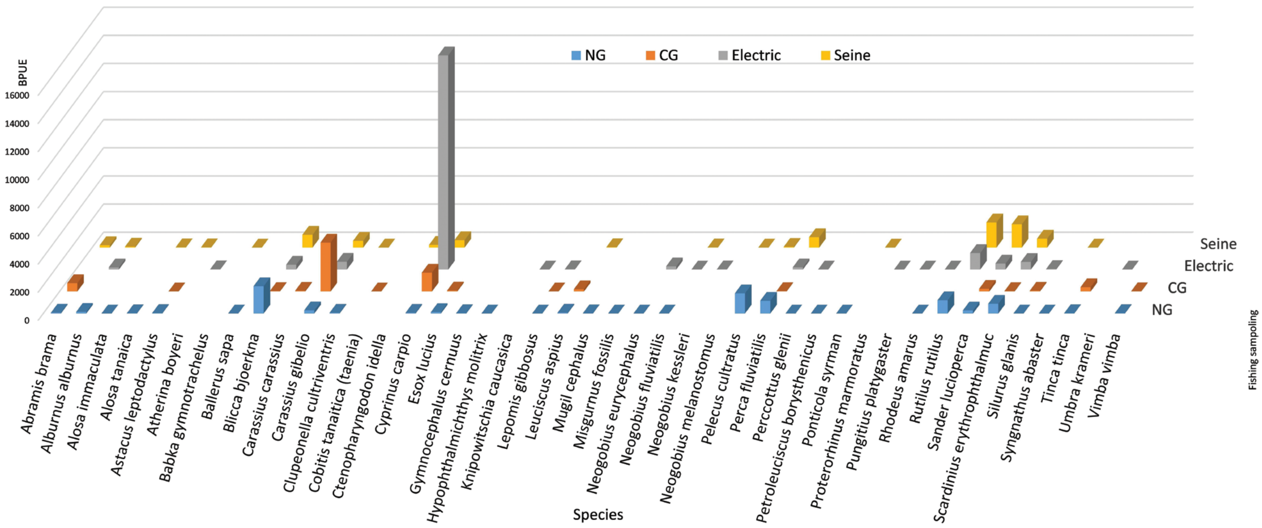

Figure 4. Relative biomass (BPUE = Biomass catch per Unit Effort) in Razim Lake in 2020 (NG = Nordic gillnets, CG = commercial gillnets).

(Antipa 1894), the trend in 2020 remains the same, mainly due to legal and illegal overexploitation, even with the appearance (1895 first fishing permit) and periodic updating of fishing laws. Even at the beginning of the 21st century, contravention of the fishing laws is usually not considered a serious offence in courts of law. In the past, the marine species entering Razim Lake in significant quantities were: blunt-snouted mullet, *Mullus ponticus* Essipov, 1927; Volga pikeperch, *Sander volgensis* (Gmelin, 1789); European flounder *Platichthys flesus* (Linnaeus, 1758); Black Sea turbot, *Scophthalmus maeoticus* (Pallas, 1814); beluga, *Huso huso* (Linnaeus, 1758); Danube sturgeon, *Acipenser gueldenstaedtii* Brandt et Ratzeburg, 1833; starry sturgeon, *Acipenser stellatus* Pallas, 1771; fringebarbel sturgeon, *Acipenser nudiventris* Lovetsky, 1828 (which is currently an extinct species in the Danube delta); garfish, *Belone belone* (Linnaeus, 1760); big-scale sand smelt, *Atherina boyeri* Risso, 1810; Mediterranean sand smelt, *Atherina hepsetus* Linnaeus, 1758; *Chelon auratus*; leaping mullet, *Chelon saliens* Risso, 1810; flathead grey mullet, *Mugil cephalus* Linnaeus, 1758; black goby, *Gobius niger* Linnaeus, 1758; knout goby, *Mesogobius batrachocephalus* (Pallas, 1814); *Alosa immaculata*; Black Sea shad, *Alosa tanaica* (Grimm, 1901); Atlantic mackerel, *Scomber scombrus* Linnaeus, 1758; bluefish, *Pomatomus saltatrix* (Linnaeus, 1766); *Anguilla anguilla*; and European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758) (Antipa 1894; Leonte et al. 1960; Otel et al. 1992, 1993; Staras, unpublished), but succession of species happens due to changes in water salinity. Namely, in 2020, only rare, accidental entry of *Alosa immaculata*, *Anguilla anguilla* and some mullets species was observed, with higher presence of *Alosa tanaica*, *Atherina boyeri* and freshwater species. Historic data (Leonte 1969 cited by Staras, unpublished) cite around 55 fish species, a considerable number being marine and euryhaline. In 2020, 43 fish species were described in Razim Lake, with 39 native and four non-native (*Perccottus glenii*;

Table 7. Geographical coordinates and physical-chemical parameters observed in some fishing points from Razim Lake and the adjacent area in summer 2020.

Site code	Geographical coordinates	*T* [°C]	WD [cm]	TR [cm]	Sal [‰]	*C* [µS · cm⁻¹]	Ox [mg · L⁻¹]	OxS [%]
Raz_iul_20_N1	44.90654°N, 028.86275°E	28.7	160	35	<0.5	495	8.58	112.4
Raz_iul_20_N2	44.90374°N, 028.86633°E	30.2	180	35	<0.5	492	9.01	121
Raz_iul_20_N3	44.89632°N, 028.86646°E	28.7	140	35	<0.5	495	8.58	112.4
Raz_iul_20_N4	44.86862°N, 028.88374°E	23.0	130	30	<0.5	505	8.01	92.7
Raz_iul_20_N5	44.85979°N, 028.89621°E	22.8	180	30	<0.5	508	8.18	94.5
Raz_iul_20_SN1-12	44.893994°N, 028.865412°E	23.0	150	30	<0.5			
Raz_iul_20_Ave	44.898313°N, 028.871662°E	23.0	150	30	<0.5			
Raz_iul_20_E1	44.88736°N, 028.83898°E	26.6	80	20	<0.5	1142	14.06	174.6
Raz_iul_20_E2	44.88985°N, 028.84497°E	25.4	110	20	<0.5	531	9.72	118.8
Raz_iul_20_E3	44.89308°N, 028.82632°E	28.3	110	20	<0.5	1183	13.85	173
Raz_aug_20_SN1-12		25.0	150	30	<0.5			
Raz_aug_20_Ave		25.0	200	30	<0.5			
Raz_aug_20_E1	44.89899°N, 029.09472°E	25.3	250	20	<0.5	398	6.58	80.1
Raz_aug_20_E1	44.89899°N, 029.09472°E	25.9	250	20	<0.5	369	6.08	75.3
Raz_aug_20_E2	44.86952°N, 029.09857°E	25.6	50	25	<0.5	388	8.07	99.5
Raz_aug_20_E3	44.85786°N, 029.11197°E	26.0	80	35	<0.5	426	8.93	110.8
Raz_aug_20_E4	44.84264°N, 029.09601°E	25.8	120	35	<0.5	388	8.65	107.8
Raz_aug_20_E5	44.82828°N, 029.07246°E	25.7	130	30	<0.5	466	10.8	124.4
Raz_aug_20_E6	44.85986°N, 029.04191°E	25.5	140	30	<0.5	435	8.96	110.1
Raz_aug_20_E7	44.88725°N, 029.03616°E	25.7	90	35	<0.5	440	11.6	143.3
Raz_DrMus_aug_20_E1	44.90084°N, 029.03267°E	26.7	110	25	<0.5	438	11.8	147.7
Raz_Est_aug_20_E2	44.91323°N, 029.03304°E	25.8	90	25	<0.5	443	10.15	124.1
Raz_Duna_aug_20_E3	44.94065°N, 029.03714°E	26.1	25	25	<0.5	383	6.53	81.5
Raz_GoFu_aug_20_E4	44.94658°N, 029.05917°E	26.3	45	25	<0.5	445	12.81	159.2
Raz_GoFu_aug_20_E5	44.96377°N, 029.09998°E	26.9	80	20	<0.5	426	10.74	134.4
Raz_GoFu_aug_20_E6	44.98711°N, 029.09542°E	26.6	50	35	<0.5	431	9.1	113.6
Raz_Peri_aug_20_E1	44.78973°N, 029.13181°E	27.0	40	25	<0.5	424	10	126
Raz_Peri_aug_20_E2	44.80348°N, 029.13816°E	26.5	40	25	<0.5	394	10.33	130
Raz_Peri_aug_20_E3	44.83177°N, 029.1365°E	26.1	80	25	<0.5	381	4.45	55.1

T = water temperature, WD = water depth, Tr = transparency, Sal = salinity, *C* = conductivity, Ox = oxygen content, OxS = oxygen saturation (%).

Hypophthalmichthys molitrix; *Ctenopharyngodon idella*; and *Lepomis gibbosus*), compared to 44 fish species with seven non-native species—*Percarina demidoffi*; *Hypophthalmichthys molitrix*; *Ctenopharyngodon idella*; *Lepomis gibbosus*; stone moroko, *Pseudorasbora parva* (Temminck et Schlegel, 1846); black carp, *Mylopharyngodon piceus* (Richardson, 1846); and bighead carp, *Hypophthalmichthys nobilis* (Richardson, 1845)—found by Otel et al. (1993) and Staras (unpublished) in the Razim–Sinoie Lake complex in the 1990s. *Carassius gibelio* and *Cyprinus carpio* are given as native species from Central Europe to Siberia (Kottelat and Freyhof 2007; Otel 2019). The current living conditions favor the development of freshwater eutrophic species with less than 0.5‰ salinity, large variations in dissolved oxygen and increased quantities of nutrients in water. A new non-native fish species was recently recorded in the natural environment of the Lower Danube River Basin, *Perccottus glenii*, first recorded in the Romanian River Suceava (Nalbant et al. 2004). It was first recorded in DDBR by Năstase (2007). Its range has expanded to Razim Lake, being first recorded in 2016 in Holbina Gulf of Razim Lake (Năstase et al. 2019a). Its population has increased in the Danube Delta (Năstase et al. 2019b) also in the Razim–Sinoie Lake complex, having a strong invasive behavior (Vilizzi et al. 2021), well adapted to new biotope conditions in Razim Lake. Qualitative and quantitative decreases in species numbers and abundance is undesirable throughout the DDBR, not only for Razim Lake. For that reason, the absence of *Percarina demidoffi* is worrying, as well as the reduction in the number of goby species (*Ponticola syrman*, *Neogobius melanostomus*). Future studies and new actions to avoid their population collapse are necessary, in conditions of habitat change. Species, such as *Anguilla anguilla*; *Acipenser stellatus*; three-spined stickleback, *Gasterosteus aculeatus* Linnaeus, 1758; golden grey mullet, *Chelon auratus* (Risso, 1810); *Platichthys flesus*; schraetzer, *Gymnocephalus schraetser* (Linnaeus, 1758); and white-finned gudgeon, *Romanogobio albipinnatus* (Lukasch, 1933) were present in the Razim–Sinoie Lake complex in the 1990s (Otel et al. 1992, 1993; Staras, unpublished), some of them in considerable quantities. However, in 2020, only a few species in Razim Lake are migratory, reophilous or reofilous–stagnofilous, such as *Alosa immaculata*, *Anguilla anguilla*, and *Ballerus sapa*, which occur rarely in the Lake and the majority are stagnofilous–reophilous or limnophilous species.

Conclusions

The main species (eudominant, very frequent) in Razim Lake and adjacent waters were white bream, *Blicca bjoerkna*; roach, *Rutilus rutilus*; and bleak, *Alburnus alburnus*, but mostly are accessory, also a significant percentage of species being accidental, with some differences between sampling methods. Relative abundance (CPUE) was dominated by bream species (especially white bream), roach, gibel carp, perch, bleak, rudd, and ziege with low values for the majority of fish species, but relative biomass (BPUE) is dominated by common carp, gibel carp, roach, white bream, ziege, perch, pike-perch, and rudd with some differences between sampling methods. The diversity indices of Razim Lake and the adjacent area point to a more than medium stable fish coenosis, with the most stable being the shoreline area. The parameters used (according to Moss et al. 2003) and four selected ecological parameters used according to the WFD) in the ecological status characterization of Razim Lake from the point of view of the fish fauna, categorise Razim Lake into the moderate class, using the "one out, all out" principle of the WFD. The ecological indicators have not completely captured a decreasing trend in commercial fishing. This aspect is studied for fisheries resources using stock estimations from fishery landings. However, the absence of large fish (pike-perch, wells catfish, common bream) is a sign of overfishing, especially when adult individuals are missing or an insignificant number is spawning, that could have negative repercussions on future generations, such as for pike-perch). The investigation of Razim Lake has always been a challenge for researchers and this paper aims to be a benchmark for future fish ecological studies. From another perspective, monitoring of fish fauna from Razim Lake is vital because it represents the main reservoir of some commercial fish species like pike-perch, common bream, common carp, but also for some important ecological species, such as *Percarina demidoffi*, *Ponticola syrman*, and *Umbra krameri*, as well as to adjust ecological parameters as support for the determination of conservation status.

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