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CURRENT STATE OF THE MOLLUSC POPULATIONS IN THE RAZIM-SINOE LAGOON SYSTEM

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Abstract

Following the changes in physical factors, the benthic fauna was affected by the decrease in water salinity. The aim of this paper is to identify the trend of changes in the mollusc populations of the most important lagoon system on the Romanian Black Sea coast. After a period of reduced concern for the knowledge of Razim-Sinoe Lagoon System ecological evolution, the studies and researches carried out by GeoEcoMar in 2002-2017 aimed at updating the qualitative and quantitative assessment of the structure of the mollusc populations in the four main lakes, as well as improving the knowledge of the structural and functional changes in these lakes. Currently, the population structure is composed of 14 living species among of the 52 found in the composition of the substrate as recent or subfossil shell debris. By comparing the biological data recorded between 2002 and 2017 with data from the 1970s, it became obvious that a series of euryhaline species and the most sensitive freshwater forms had disappeared. These species were gradually replaced by new freshwater stenobiotic forms, which are more resistant.

Key words*: Danube Delta, mollusk populations, NW Black Sea.*

INTRODUCTION

Coastal lagoons are particular ecosystems in the boundary between continents and the sea (Tagliapietra et al., 2009). The particular features of the coastal lagoons make them one of the most productive ecosystems in the world and especially interesting for humans, whom they provide with a wide variety of societal benefits (Knoppers, 1994; Kennish and Paerl, 2010). Human activity has profoundly altered the state of the ecosystems, contributing to the massive depletion of natural resources and affecting a major part of the services provided by the lagoons ecosystems such as Venice Lagoon in Italy (Solidoro et al., 2010); Man Menor in Spain (Velasco et al., 2018); Razim-Sinoe Lagoon in Romania (Gomoiu, 2009).

Razim-Sinoe Lagoon System, situated in the NW part of the Black Sea, is part of Danube Delta Biosphere Reserve ROSCI0065 (North Lat 44º 54' 6''; East Long 28º 55' 19''). Human interventions of the past century have brought a morphological and hydrographic changes affecting the hydrologic regime, hypsometric changes modifying bottom habitat parameters (depths and sediment structure), water chemistry structure and regime changes modifying mineralization, nutrient and pollutant loadings, and biological changes marked by eutrophication, loss of biodiversity, decreased bioproductivity, and impoverished fishery (Vadineanu et al., 1997; Gomoiu et al., 2007; Gomoiu et al., 2008; Gomoiu, 2009; Gómez-Baggethun et al., 2019). These changes have resulted into a complete change of the Lagoon specific ecosystems compared to its pristine state. Antipa (1894) mentions the Razim Lake as one of the places with the greatest fisheries on the Black Sea coasts and maybe, without exaggeration, the greatest ones in Europe. This Lagoon System has come into light more than 100 years ago as a result of the practical interest in fisheries.

In order to improve the biological productivity and fish production, large scale technical works have been done (cutting canals, recalibration of some canals through widening and deepening their cross-sections for increasing the water discharge from Sf. Gheorghe distributor, building dams and closing the links with the Black Sea).

Recent variations in salinity regime and the obvious tendency toward water freshening have been caused on the one hand by the gradual reduction of marine influence (partial closing

the natural links with the sea) and, on the other hand, by the increasing amount of freshwater from the Danube. These changes have left their mark on the population's structure of mollusc. Molluscs are common, highly visible, ecologically and commercially important at global scale as valuable resources.
Species assemblages of the Lagoon System have been studied for more than 90 years by Borcea (1926), Antipa (1941), Grossu (1962), Teodorescu-Leonte et al. (1956), Teodorescu-Leonte and Leonte (1969), Teodorescu-Leonte (1966; 1977). Despite the fact that from the point of view of distribution of the Pontocaspian mollusc species of the complex is well documented (Popa et al., 2009; Popa et al., 2010; Popa et al., 2012; Wesselingh et al., 2019; van de Velde et al., 2019); the information regarding structure and ecological assessment is scarce (Gomoiu et al., 2007; Gomoiu et al., 2008; Paraschiv et al., 2010a; Paraschiv et al., 2010b). In this paper, we improve the knowledge regarding to mollusc fauna and analyse how the changes in lake dynamics have affected its populations. This is an attempt to provide a baseline for future data collection, in support of conservation and restoration of lagoon ecosystem.

MATERIALS AND METHODS

Description of the area

The Razim-Sinoe lagoon system (RSLS) is situated on the north-western coast of the Black Sea, Romania. The surface area is 863.5 km^2 with a maximum depth of 3.5 m. It is the largest lagoon system of the whole Black Sea coast, located south of the Danube Delta. The main lakes are Razim with an area of 415 km^2, Golovița (118.7 km^2), Zmeica (54.6 km^2) and Sinoe (171.5 km^2) (Gâştescu, 1998). During the period that preceded the construction of the canals ensuring the connection with Dunavăţ and Dranov rivulets, the water of Razim lake used to have a salinity that was close to that of the Black Sea and even higher during certain periods (Antipa, 1916). During the 1924-1925 period it was variable, and in 1937 it reached the level of 0.5 g/l in Razim and 1.5 g/l in Goloviţa (Teodorescu-Leonte et al., 1956).
Currently, in the RSLS, the total salts content is ranged between 0.1-1.0 g/l, but it is not stabilized yet, being dependent on the regime of the Danube waters (Figure 1).

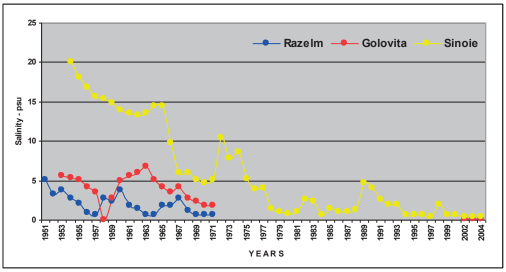

Figure 1. Evolution of salinity (psu) in the lakes from RSLS (period 1951-1956 after Teodorescu-Leonte et al., 1956; 1956-1968 - Teodorescu-Leonte, 1977; 1968-1971 - Breer, 1976; 1971-1998 - Lazar et al., 1995; Alexandrov et al., 1998; 2002-2004 - Dimitriu et al., 2008; Dinu et al., 2015)

According to Dimitriu et al. (2008), the superficial sediments of the Razim and Golovita lakes are dominated by silt and silty clays. The sandy sediments represent about 24% of the substrate of the Razim Lake, being present mainly in the southern sector. The substrate of Zmeica Lake is covered, to a large extent, by sandy sediments, with the exception of western extremity of it, where silty sediments appear. More than 60% of the substrate of Lake Sinoe is covered by silty sediments (silty clays ÷ silty sands).

Data collection and analysis

During several cruises of GeoEcoMar's R/V Istros performed in 2002-2017, 250 benthic samples (2002-2004: 239 samples, 2017: 11 samples) were collected by means of a van Veen-type grab (0.02 m^2) and Bacescu-type dredge (40 cm x 30 cm frame, with net's mesh size of 5 mm) (Figure 2). The samples were partly processed on-board (washing through 0.5 mm mesh size sieve), preserved with 4% formalin and stored for subsequent laboratory analyses.
The density and wet biomass data were represented at square meter (indv.m^{-2}, g.m^{-2}). Molluscs were weighed with shells.
The identification of molluscs was performed following the main key guide provided by Grossu (1956; 1962) and Jadin (1952). The species nomenclature was checked following the World Register of Marine Species portal (www.marinespecies.org).
Taxonomical references are based on the check-list of land and freshwater Gastropoda of

Europe (Bank, 2020) and Bivalvia (Araujo, 2020).

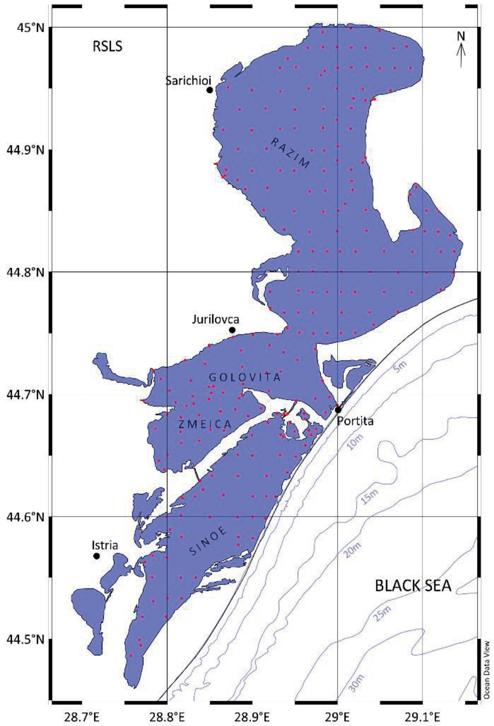

Figure 2. The Razim-Sinoe Lagoon System - map of stations performed in 2002-2004 period and 2017

The structure of the macrobenthic community was analysed in terms of species composition (S), population density (A), dominance (D), frequency (F), diversity and biomass and ecological significance index.

The research carried out in 2002-2004 period, was funded by the Romanian Ministry of Education and Research through the National Research Development and Innovation Programme CERES (Research Project Contract 156/2001), in the 2017 - by the Ministry of Research and Innovation - ANCSI - Core Program: PN16450104.

RESULTS AND DISCUSSIONS

Analyses of the 250 samples helped identify 52 species of molluscs (Appendices), out of which 14 species were found alive and form the present structure of the populations (*Acroloxus lacustris, Bithynia tentaculata, Ampullaceana balthica, Viviparus viviparus, Adacna fragilis* (possible *A. laeviuscula* Eichwald, 1829), *Hypanis (Adacna) plicata relicta, Anodonta cygnea, Corbicula fluminea, Dreissena polymorpha, Monodacna colorata, Monodacna pontica, Sphaerium corneum, Unio pictorum,* and *Unio tumidus*). The rest of the molluscs were found only as broken shells which made up the shell debris as sediment fraction in the substrate composition (Appendices). Most species are typical for freshwater environments and only five species have a Pontocaspian character (*D. polymorpha*, *A. fragilis, H. plicata relicta, M. colorata* and *M. pontica*).

The number of species in the sampling sites varies between zero and six, with a mean abundance of 246.1 indv.m^{-2} in density terms and 92.3 g.m^{-2} of biomass (Table 1).

Table 1. Ecological parameters for mollusc populations in the RSLS in 2002-2004 period

Lake	S	Density indv.m^{-2}	Biomass g.m^{-2}
Razim	9	856.2	216.3
Goloviţa	9	47.3	42.4
Zmeica	5	28	101.6
Sinoe	6	52.9	8.7
RSLS	14	246.1	92.3

As the ecological significance index reveals, the most important mollusc populations that inhabited the lagoon system benthic habitat were: *D. polymorpha* (A-398.4 indv.m^{-2} and 46.6 g.m^{-2}; F-20%), *A. cygnea* (A-6.3 indv.m^{-2} and 18.8 g.m^{-2}; F-11%), and *U. pictorum* (A-3.1 indv.m^{-2} and 20.9 g.m^{-2}; F-6%). *Dreissena polymorpha* was found in all lakes, either fixed on to *A. cygnaea*, *U. pictorum*, and *V. viviparus* shells or grapelike clustered with greatest abundance in front of Dunavăţ and Dranov channel (Figures 3 and 4). The freshwater species, *Anodonta cygnea* and *Unio pictorum*, incoming into the Razim-Sinoe lagoon, presented a "patchy" distribution. *Anodonta* prevail in the Razim Lake (11.51 indv.m^{-2}) and the *Unio* has been very abundant in Zmeica (14 indv.m^{-2}), in muddy and silty sediments rich in organic matter.

Overall high biomass values were recorded in Lake Razim in the mouth areas of the Dranov and Mustaca channel and around Popina Island, where a proper substrate type consist of mixed sediments (sand and mud) with large amount of shell debris used as secondary hard substrate or settlement of juveniles of epibenthic species (Figure 4).

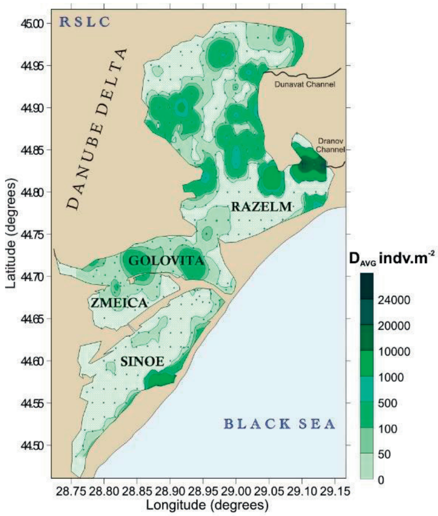

Figure 3. Average density distribution of mollusc populations in the RSLS in 2002-2004 period

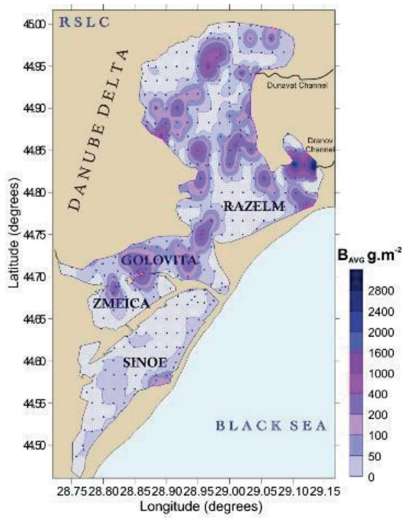

Figure 4. Average biomass distribution of mollusc populations in the RSLS in 2002-2004 period

Less abundant were *Adacna fragilis* and *H. plicata relicta* due to their ecological preferences for better-oxygenated sandy-mud sediments, which could explain their small number in the complex dominated by muddy substrata. In Sinoe Lake, these were found in the sandy area bordering the coastline in the eastern littoral zone, where they recorded the greatest densities (21.7 indv.m^{-2}) of the whole lagoon system. In general, *Adacna* species occur on sandy-mud substrate. In the Caspian Sea, they can tolerate salinities between 4-14 psu (Bogutskaya et al., 2013). *Monodacna colorata* inhabits muddy and sandy-mud substrate and has its optimum habitat between 0.03-4 psu, but can also tolerate higher salinities (Bogutskaya et al., 2013). Our results show that the freshwater species are found in more muddy-clay sediments, and Ponto-Caspian ones in the transition area between clay and sand.

We note the presence of invasive species of freshwater mollusc in the Razim Lake - the bivalve *Corbicula fluminea*, which came from the Danube, being limited to the mouth of the Dunavăţ Channel, where reached, in 2003, an average abundance of 1.57 indv.m^{-2}. The number of species considered under *Corbicula* genus is not yet known. We recognize two hyper variable species, *Corbicula fluminea* (Müller, 1774) and *Corbicula fluminalis* (Müller, 1774), although their taxonomical status is not clear yet. In the 20th century, *Corbicula* clams were introduced in North and South America, Europe and North Africa (Mouthon, 1981; Bij de Vaate, 1991; Arujo et al., 1993; Swinnen et al., 1998; Paunovic, 2007). In Romania it was first encountered at Berzasca, in the Porţile de Fier area in 1997 (Skolka and Gomoiu, 2001); two years later it was found downstream, at Vadu Oii (Bij De Vaate and Hulea, 2000). Currently, it inhabits the whole length of the Danube. Although negative effects of the introduction of Asian clams on industrial facilities have been documented for other recipient areas, such problems with *Corbicula* have not been reported for Romania and adjacent areas.

Other non-indigenous species, which invaded during the last decades the waters from Razim-Sinoe lagoon, are *Sinanodonta woodiana* (its dispersal history was established in several papers, Sárkány-Kiss (1986); Sárkány-Kiss et al., 2000; Sîrbu et al., 2006; Popa and Popa, 2006). In 2003, it found fresh valves of this species nearby of Popina Island.

The issue of ecological evolution has been a challenging subject for discussions and interpretations. Today, under the impact of global changes, the situation has become more and more complicated, uncertainties have grown, and predictions are more difficult to make.

During the second half of the XXth century Razim-Sinoe lagoon has been seriously affected by human careless and destructive intervention, whether it had to do with the cutting of new water channels, blocking of inlets by engineering works, developing fishing ponds and agriculture polders or with the pollution of the Danube river due to sewage, industrial waste, pesticides and nutrients, reduction of flooding zones. Anthropogenic activities (closure of marine outlets, opening of channels connecting to the Danube) caused a salinity decrease of the lagoon system (Alexandrov et al., 1998; Bretcan et al., 2009; Romanescu and Cojocaru, 2010). At the beginning of the ’50 of the last century the salinity of the lagoon represented the object of some systematic researches, in order to increase the fish productivity. Therefore, the molluscs’ populations, from those periods, represented 44% of marine species, 25% of Ponto-Caspian relicts, 25% brackish water and 6% freshwater species (Teodorescu-Leonte et al., 1956). According to Teodorescu-Leonte (1966), the Ponto-Caspian relicts (especially *Adacna* and *Monodacna* genus) represent 28% the diet of the carp (*Cyprinus carpio*), 23% for the roach (*Rutilus rutilus*) and vimba bream (*Vimba vimba*), 13% for the gobies and 12% for the common bream (*Abramis brama*). As a result of this study, it appears that the *Adacna* and *Monodacna* genus, which recorded up to 300 kg/ha is an important source of fish feed.

After 1970, through the closure of the mouth Gura Portiţa, the freshwater input coming from the Danube increased. The period 1965-1977 is characterized by variations in salinity (Lazar et al., 1996) and the populations of molluscs were represented in Sinoe Lake by 12 species (33% - marine, 33% - brackishwater, 25% - Ponto-Caspian relicts and 9% freshwater).

In the period 1978-1982 there is a tendency of stability of mollusc populations. Related to this period, Lazar et al. (1996) found in Sinoe Lake 20 species: 50% - marine, 20% - brackish water, 20% - Ponto-Caspian relicts and 10% freshwater (Figure 5).

From 1982 to 1995, the few studies (Lazar et al., 1996; Mustata et al., 1996; Nicoara et al., 1995-1997) report a presence of small number of species of molluscs during the period of the accentuated process of water freshening in the lagoon (Figure 5). Most are Ponto-Caspian relicts (*A. fragilis, H. plicata relicta, D. polymorpha, M. colorata* and *M. pontica)* that have recorded in 1994 a biomass of 600 g.m^{-2} (Lazar et al., 1996). After 1995 these species appear sporadically and in an extremely small number.

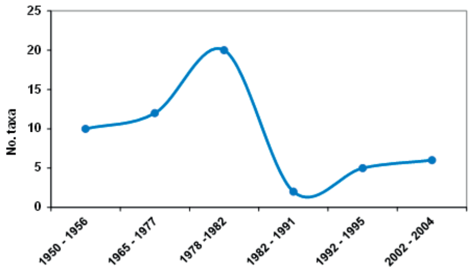

Figure 5. Diversity changes of the mollusc populations in Sinoe Lake

Today, Ponto-Caspian relicts in the Black Sea Basin are restricted to relatively small areas in lagoons, estuaries and deltas with salinity gradients along the coasts of Romania, Ukraine and Russia (Mordukhai-Boltovskoi, 1979; Anistratenko et al., 2011). The RSLS is a classic example of habitat for Ponto-Caspian species. Currently, these species are in decline, yet the causes of the decline are not fully known. Habitat destruction, pollution, poaching and invasive species (Popa et al., 2009; Paraschiv et al., 2010b; Zarbaliyeva et al., 2016). However, the molluscs’ fauna is mostly dominated by freshwater species while Ponto-Caspian species reduced their distribution area. In these studies only *Hypanis plicata relicta* (A-3.1 indv.m^{-2}) was found in Sinoe Lake in the sandy area. In 2002-2004, *Adacna fragilis* and *Monodacna colorata* had isolated populations, reaching an average density of 1.6 indv.m^{-2} and 2.1 indv.m^{-2} in Razim, 5.2 indv. m^{-2} and 1.7 indv.m^{-2} in Goloviţa and 4.7 indv.m^{-2} and 6.2 indv.m^{-2} in Sinoe Lake, respectively. *Monodacna pontica* in the Sinoe Lake in 2004, was identified in the vicinity of the littoral sand bank with the highest densities of 21.7 indv.m^{-2}. Average density of it in the 2002-2004 period was 3.6 indv.m^{-2} in Razim and 12.4 indv.m^{-2} in Sinoe. However, in 2017 only *M. colorata* (A-2.5 indv.m^{-2}) was recorded in Razim. Among all of the Limnocardiid species, the *Monodacna* genus species are the most common in the RSLS. Perhaps the small number of stations performed did not allow to surprise the real picture of the Ponto-Caspian species presence.

Following the changes in physical factors, the benthic fauna was greatly affected by the decrease in water salinity. The variations of the salinity regime, the obvious tendency towards water freshening in the last years, caused on the one hand by the gradual reduction of marine influence (partial closing of the natural links with the sea) and, on the other hand, the increasing amount of freshwater from the Danube, left their mark on the structure of benthic populations. The most important changes in the species composition structure of the lagoon fauna occurred in the populations of molluscs. Before 1956 over 65% of the mollusc populations consisted of marine and brackish water forms, 25% - Ponto-Caspian relicts and only 6% of them were freshwater ones (Teodorescu-Leonte et al., 1966). This proportion was completely changed, at the time when our researches were performed; thus, during 2002-2017, freshwater species became dominant representing 64% of the total, followed by 35% Ponto-Caspian relicts, which yet found favourable conditions for development in the lagoon, brackish and marine elements were not found (Appendices and Figure 6).

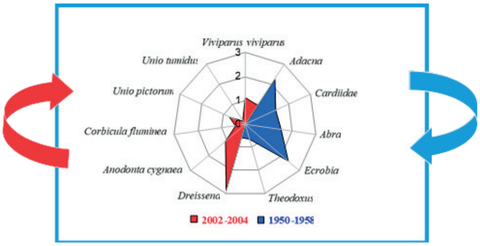

Figure 6. Shifting of the structure of the mollusc populations in Razim-Sinoe lagoon system from the `50s till present time

By comparing the present results concerning the moluscs fauna of Razim-Sinoe lagoon with the previously published data (Teodorescu-Leonte, 1977), we can affirm that some species have disappeared from the benthic community in the past years, especially the euryhaline species (Cardiidae, *Abra, Ecrobia*) and the more sensitive freshwater ones (*Theodoxus*). At the same time, there appeared new freshwater-stenobiotic, and more resistant forms (*Anodonta cygnea, Corbicula fluminea, Unio pictorum* etc.) (Figure 6).

CONCLUSIONS

In the 250 stations surveyed between 2002 and 2017 from RSLS, only 14 (4 - Gastropoda and 10 - Bivalvia) alive species forming the current structure of the populations out of 52 species identified in the substrate composition were found. Most species are typical for freshwater environments and only five species have a Ponto-Caspian character (*Dreissena polymorpha, Adacna fragilis, Hypanis plicata relicta, Monodacna colorata* and *Monodacna pontica*). After the ecological significance index, the most important mollusc populations were *Dreissena polymorpha, Anodonta cygnea* and *Unio pictorum.*

After analysing the molluscs data recorded between 2002 and 2017 with those from the 1970s, it became obvious that, euryhaline species and the most sensitive freshwater forms had disappeared. These species were gradually replaced by new freshwater stenobiotic forms, which are more resistant. Therefore, the gradual transition from a marine environment to a lacustrine one brought about the ecological succession of species in the lagoon system, which became an ecosystem consisting mainly of freshwater species.

Our results point to the necessity of a establishing a brackish water regime to support the conservation of mollusc populations (especially Ponto-Caspian species) and increasing the food variety of economically important fish species in the Razim-Sinoe Lagoon System.

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APPENDICES

The mollusc species composition in the Razim-Sinoe Lagoon System (R-Razim, G-Goloviţa, Z-Zmeica, S-Sinoe) in 2002-2004 period and 2017 year

Crt. no.	Species	Shell debris		Living fauna			
		R	S	R	G	Z	S
	GASTROPODA						
1	*Acroloxus lacustris* (Linnaeus, 1758)				+		
2	*Ampullaceana balthica* (Linnaeus, 1758)						+
3	*Bithynia tentaculata* (Linnaeus, 1758)				+		
4	*Bittium reticulatum* (da Costa, 1778)		+				
5	*Caucasotachea vindobonensis* (C. Pfeiffer, 1828)	+					
6	*Chrysallida sp.*		+				
7	*Clathrocaspia gmelinii* (Clessin & W. Dybowski in W. Dybowski, 1887)	+					
8	*Clessiniola variabilis* (Eichwald, 1838)	+					
9	*Ecrobia maritima* (Milaschewitsch, 1916)		+				
10	*Ecrobia ventrosa* (Montagu, 1803)	+	+				
11	*Esperiana esperi* (Férussac, 1823)	+					
12	*Hydrobia acuta* (Draparnaud, 1805)	+					
13	*Lithoglyphus naticoides* (C. Pfeiffer, 1828)	+	+				
14	*Planorbarius corneus* (Linnaeus, 1758)	+					
15	*Potamopyrgus antipodarum* (Gray, 1843)	+	+				
16	*Pseudamnicola razelmiana* Grossu, 1986	+					
17	*Rapana venosa* (Valenciennes, 1846)		+				
18	*Retusa truncatula* (Bruguière, 1792)	+	+				
19	*Retusa variabilis* (Milaschewitsch, 1912)		+				
20	*Rissoa membranacea* (J. Adams, 1800)		+				
21	*Rissoa splendida* Eichwald, 1830		+				
22	*Theodoxus danubialis* (C. Pfeiffer, 1828)	+	+				
23	*Theodoxus fluviatilis* (Linnaeus, 1758)	+					
24	*Tritia neritea* (Linnaeus, 1758)	+					
25	*Tritia reticulata* (Linnaeus, 1758)		+				
26	*Valvata piscinalis* (O. F. Müller, 1774)	+	+				
27	*Viviparus viviparus* (Linnaeus, 1758)	+	+	+	+	+	
	BIVALVIA						
28	*Abra alba* (W. Wood, 1802)		+				
29	*Abra segmentum* (Récluz, 1843)	+	+				
30	*Adacna fragilis* Milaschewitsch, 1908	+	+	+	+	+	
31	*Anodonta cygnea* (Linnaeus, 1758)	+	+	+	+	+	+
32	*Cerastoderma glaucum* (Bruguière, 1789)	+	+				
33	*Cerastoderma sp.*	+					
34	*Corbicula fluminea* (O. F. Müller, 1774)			+			
35	*Dreissena polymorpha* (Pallas, 1771)	+	+	+	+	+	+
36	*Euglesa subtruncata* (Malm, 1855)	+					
37	*Hypanis (Adacna) plicata relicta* Milaschevich, 1916	+	+				+
38	*Hypanis dolosmiana* (Borcea, 1926)	+					
39	*Lentidium mediterraneum* (O. G. Costa, 1830)		+				
40	*Monodacna colorata* (Eichwald, 1829)	+	+	+	+		+
41	*Monodacna pontica* Eichwald, 1838	+	+	+			+
42	*Mya arenaria* Linnaeus, 1758		+				
43	*Mytilaster lineatus* (Gmelin, 1791)		+				
44	*Mytilus galloprovincialis* Lamarck, 1819		+				
45	*Parvicardium exiguum* (Gmelin, 1791)		+				
46	*Pseudanodonta complanata* (Rossmässler, 1835)	+					
47	*Sinanodonta woodiana* (I. Lea, 1834)	+					
48	*Sphaerium corneum* (Linnaeus, 1758)				+		
49	*Sphaerium rivicola* (Lamarck, 1818)	+					
50	*Spisula subtruncata* (da Costa, 1778)		+				
51	*Unio pictorum* (Linnaeus, 1758)	+	+	+	+	+	
52	*Unio tumidus* Philipsson, 1788			+			
	Total	**31**	**31**	**9**	**9**	**5**	**6**