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Qualitative study of Mollusca communities in the Serbian Danube stretch (river km 1260–863.4)

Vesna M. Martinovic-Vitanovic, Maja J. Rakovic, Natasa Z. Popovic & Vladimir I. Kalafatic

Department of Freshwater Ecology and Water Protection, Institute for Biological Research "Sinisa Stankovic", University of Belgrade, Despota Stefana Blvd. 142, 11060 Belgrade, Serbia; e-mail: vmartino@ibiss.bg.ac.rs

Abstract: First detailed limnological study was performed from April 2003 to June 2008 in a 396.6 km long section of the Serbian Danube (divided in three parts; from 1260 r-km to 863.4 r-km) to examine community composition and spatial distribution of Mollusca with special attention to the expansion of Ponto-Caspian species, propagation of invasive and introduced species and occurrence of endemic species. Mollusca samples were collected at 15 sites in April, June, September and November. We investigated the spatial distributions and calculated the faunistic similarity of localities with respect to the community composition using the Sørensen Quotient of Similarity. Site variation in analyzed qualitative traits was examined using correspondence analysis. Additionally, the obtained Complete Linkage City-block (Manhattan) distances among sites/parts were subjected to UPGMA (unweighted pair-group method using arithmetic averages) cluster analysis. The class Gastropoda was represented by 18 species from two subclasses (Prosobranchia – six families and Pulmonata – three families).The class Bivalvia was represented by 15 species from four families of order Eulamellibranchiata. Mollusca were represented by 33 species belonging to 17 genera and 13 families. Out of five recorded Ponto-Caspian species in the studied Danube stretch, *Lithoglyphus naticoides* (Pfeiffer, 1828) and *Dreissena polymorpha* (Pallas, 1771) are assumed to be invasive species with the highest occurrence frequency ($F = 1$, each). Four new species in invertebrate fauna for the Danube, denoted as the introduced species – Neozoa, were identified: *Theodoxus fluviatilis* (L., 1758), *Corbicula fluminalis* (Müller, 1774), *C. fluminea* (Müller, 1774), and *Sinanodonta woodiana* (Lea, 1834). The only endemic species of Gastropoda found in the Danube was *Viviparus acerosus* Bourguignat, 1862.

Key words: Gastropoda; Bivalvia; communities; qualitative composition; spatial distribution; Sørensen Quotient of Similarity (QS); Correspondence analysis (CA); cluster analysis; Ponto-Caspian, invasive and introduced species; Danube; Serbia

Introduction

The Danube is the second longest river in Europe, with a length of 2,857 km and a drainage area of about 817,000 km^2 flowing from west to east. On its way from the Black Forest to the Black Sea, it connects central and eastern Europe linking 10 countries, and connects eight additional countries via its tributaries. Flowing through many industrial and urban centres as well as rural communities with significant sources of pollution, the Danube endures high anthropogenic pressure through the impact of approximately 165 million people.

A direct effect of this pressure are changes in the flow of the river. In the 20th century, many large and small reservoirs were constructed on the Danube River and its tributaries. The flow of the Danube was regulated until the 1980s and during this time approximately 70 reservoirs were constructed, each with more than 1 million m^3 in storage capacity (Levashova et al. 2004).

The Serbian Danube stretch (587.4 km) is a significant natural resource. Before damming, in 1970 Djerdap I and in 1984 Djerdap II, the Danube in Serbia belonged to a type of "large Lowland River" ecosystem with the continuous macrobiotope of characteristic potamobenthic communities. Following the "River Continuum Concept" (according to Vannote et al. 1980 "that there is a continuous change in community structure from source to mouth of a river"), the Danube in Serbia belonged to the Middle part and partly to the Lower section of the river. The characteristics of a "large Lowland River" after damming change into a three types of ecosystems: Riverine zone, Transitional zone – flow through reservoir and Lacustrine zone – Djerdap I and II Reservoirs with the characteristic benthic communities belonging to the each of them. Construction of dams directly and indirectly influences a myriad of dynamic factors that affect habitat heterogeneity and succession trajectories and ultimately the ecological integrity of the river and newly formed ecosystems (Ward & Stanford 1995; Martinovic-Vitanovic & Kalafatic 2002a; Martinovic-Vitanovic et al. 2006).

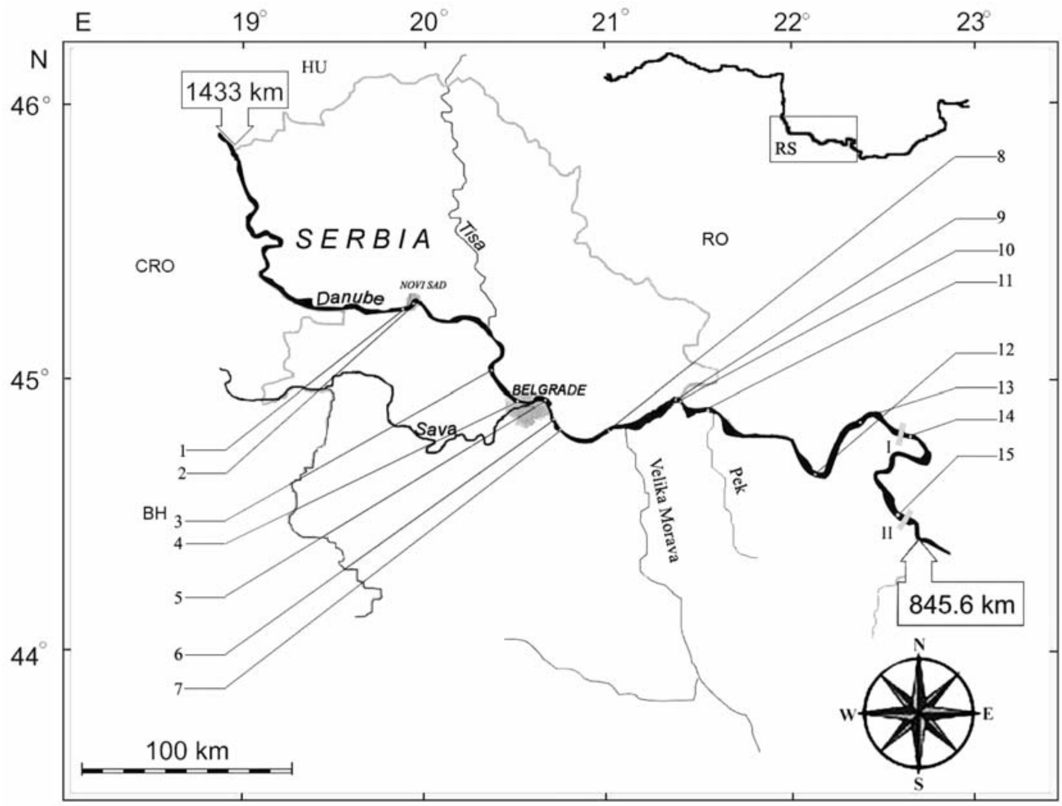

Fig. 1. Map of the Serbian Danube stretch with sampling sites (from 1260 to 863.4 r-km).
Legend: 1 – Ledinci – 1260 r-km; 2 – Novi Sad – 1252 r-km; 3 – Stari Banovci – 1192 r-km; 4 – Zemun – 1173 r-km; 5 – Visnjica –1160 r-km; 6 – Vinca – 1145 r-km; 7 – Oresac – 1124 r-km; 8 – Smederevo – 1112 r-km; 9 – Stara Palanka – 1077 r-km; 10 – Ram – 1076.2 r-km; 11 – Veliko Gradiste – 1059 r-km; 12 – Donji Milanovac – 991 r-km; 13 – Tekija – 956 r-km; 14 – Kladovo – 934 r-km; 15 – Kusjak – 864 r-km.

Investigations of freshwater ecosystems in Europe have been concerned with the study of benthic invertebrates, including mollusc fauna with special emphasis on taxonomic status of species and communities. These investigations also dealt with ecology of the species (autecology) and the study of their populations (synecology), study of biodiversity of benthic molluscs and their spatial distribution, life cycles, non-indigenous invasive species, bioindication, and water quality (Moog 1995, 2002; Moog et al. 2000; Sárkány-Kiss 1997, 2000; Mouthon 2007; Schmidlin & Baur 2007; Ayres 2008; Pérez-Quintero 2008; Sousa et al. 2008).

Generally speaking, there are few data about records of European freshwater Gastropoda and Bivalvia living in the Danube and its tributaries (Willmann & Pieper in: Illies 1978; Frank 1987; Sárkány-Kiss 1997, 2000; Sinicyna et al. 2004; Héra 2005; Bódis et al. 2006; Brezeanu & Cioboiu 2006; Cioboiu 2006; Zieritz & Waringer 2006; Beran 2008).

Although, an extensive limnological study of the Serbian Danube stretch and its tributaries (Sava, Tisa, Velika Morava) started in the middle of the 20th century and was conducted before and after construction of dams and formation of two Reservoirs, which affected the biota and the type of aquatic ecosystem (Nedeljkovic 1967, 1979; Jankovic 1975, 1978; Martinovic-Vitanovic & Kalafatic 1990, 1995, 2002a, b, 2009; Martinovic-Vitanovic et al. 1999a, b, 2004, 2006, 2007, 2008, 2009, 2010), there are scarce data about molluscs in the Serbian Danube stretch since preliminary investigations were limited both spatially and temporally (Pujin & Richnovszky 1987; Arambasic 1987, 1994).

Our continuous and detailed limnological monitoring of the Serbian Danube sector has been conducted since 2003. The purpose of the present long-term study was to provide for the first time a thorough insight into the state of the communities qualitative composition and spatial distribution of the representatives of Mollusca in the Serbian Danube sector, with special attention to the expansion of Ponto-Caspian species, and propagation of invasive species as well as introduced species – Neozoa. The occurrence of endemic species in this part of the Danube is also presented.

Study area, materials and methods

The length of the Danube stretch in Serbia is 587.4 km, of which 134 km of the Danube forms the border between Serbia and Croatia and 220 km between Serbia and Romania. Its respective drainage area is about 178,000 km^2 or approximately 20% of the river's total drainage area (Jankovic & Jovicic 1994). The floodplain covers approximately another 100,000 ha. The current study was performed at 15 sampling sites distributed along most of the Serbian Danube stretch from r-km 1260 to 863.4 (Fig. 1).

The construction of dams on the Danube at r-km 942.9 in 1972 and at r-km 863.4 in 1984, and the formation of two reservoirs, Iron Gate I (Djerdap I) and Iron Gate II (Djerdap II), resulted in changes in the hydrologic and hydrographical parameters.

According to Levashova et al. (2004), many dams were constructed in the Danube River channel (particularly, in the upper reaches) to improve the navigation conditions. In addition, in the second half of the 20th century there was a considerable reduction of sediment runoff accumulated in the reservoirs (reservoir as the so-called 'traps' for river sediments). The storage capacity of the Iron Gate I (full and usable storage capacities are 5 and 3 km^3, respectively) and Iron Gate II (full storage capacity is about 2 km^3) reservoirs considerably exceeds the total storage capacity of the remaining reservoirs in the Danube River channel and in the Danube River tributaries.

According to Martinovic-Vitanovic & Kalafatic (2002a) and Martinovic-Vitanovic et al. (2006), the study area of the Serbian Danube stretch was divided into three sectors:

I: Upper Part – Riverine zone (river part): from r-km 1260–1258 (Ledinci) to r-km 1250 (Novi Sad) (sites 1–2) – the least impact from impoundment of the Danube.

II: Middle Part – Transitional zone (flow through reservoir): from r-km 1192 (Stari Banovci) to r-km 1077–1076.2 (Stara Palanka-Ram) (sites 3–10) – impact from impoundment is evident; and

III: Lower Part – Lacustrine zone (lake part – reservoirs: Iron Gate I and II): from r-km 1059 (Veliko Gradiste) to r-km 956 (Tekija) and from r-km 934 (Kladovo) to 863.4 (Kusjak), (sites 11–13 and 14–15, respectively) – the hydrologic and hydrographical parameters of the course are extremely altered.

Generally, the construction of dams results in physical, chemical and biological changes to natural ecosystems. McCartney et al. (2000) claimed that most dams were constructed with the emphasis on maximising the short-term economic use of water, with little or no understanding of the long-term consequences of alterations to flow volumes, flow patterns and water quality. In addition, there are changes in flow regime, sediment transport, as well as in water temperature and quality.

Extensive limnological investigations were conducted in the period from April 2003 to November 2008 at 15 standard sites (in the long-term Project of the Institute for Development of Water Resources – IDWR "Jaroslav Cerni", 2002–2011, Programme for monitoring the Danube water quality changes at Djerdap sector – The impact of backwater of Danube on Riverine and Transitional zone–flow through reservoir, and Iron Gate I and II Reservoirs caused by the dams construction and exploitation of hydro power Djerdap I and Djerdap II systems), in a 396.6 km long investigated Danube streatch in Serbia (Fig. 1). Samples were collected seasonally in April, June, September and November.

Limnological studies were performed using standard methods and techniques (APHA-AWWA-WEF 1995).

Samples of sediment with benthic organisms were taken using a Van-Veen grab (270 cm^2 grab area) and benthological dredge, or hand collected.

Substrate classification was performed by visual evaluation *in situ,* and in the laboratory (using stereo zoom microscope with binocular magnifier – magnification 5–50×, Krüss, Germany), based on the diameter of sediment particles (Wentworth 1922) and according to national classification after Martinovic-Vitanovic and Kalafatic (1995) and Lakusic et al. (in: Lakusic 2005).

Aquatic invertebrates in each sample were separated from the sediment by washing and sieving (200 μm). All samples were fixed *in situ* with 4% formaldehyde and then transported to the laboratory for further processing. A stereo zoom microscope with binocular magnifier (magnification ×5–50), Krüss, Germany was used for sorting and identification of organisms. Appropriate keys were used for determining Mollusca representatives to the lowest possible taxonomic level: Pfleger (1990); Zhadin (1952) and Clench (1959).

Occurrence frequencies ($F = 0$–1) of species from Gastropoda and Bivalvia groups per site were calculated as $F = m \times M^{-1}$, where m stands for the number of samples in which the particular species was found, and M stands for the total number of samples.

Saprobial indication of Gastropoda and Bivalvia species was studied after Moog (1995, 2002) and Moog et al. (2000).

Similarities/dissimilarities in regard to qualitative composition of Gastropoda and Bivalvia groups were calculated according to the Sørensen Quotient of Similarity (QS) in order to compare all 15 sampling sites as well as communities from the three investigated parts of the Danube (Sørensen 1948). For the QS calculation the following formula was used: $\mathrm{QS} = (2c/a + b) \times 100$, where c stands for the number of species in common between two sites/parts, a stands for the total number of species at one site/part, and b stands for the total number of species at the other site/part.

Correspondence analysis (CA) was used to summarize the site variation in analyzed qualitative traits. The output of such an analysis was a coordinate for rows (species of Gastropoda – 18 /Bivalvia – 15; presence/absence of taxa at sampling sites) and that for columns (sites 1–15) on correspondence axes superimposed on the scatter diagram. Since distances between points have no straightforward interpretation in multiple correspondence analysis, the results obtained allowed only evaluation of relationships among the sites, according to features of the correspondence axes estimated by the positions of the column variables on the scatter diagram. Additionally, Complete Linkage City-block (Manhattan) distances among sites/parts were obtained and subjected to UPGMA (unweighted pair-group method using arithmetic averages) Cluster analyses (Pielou 1984). These analyses revealed the main faunistic features that characterized the sampling sites/parts. The Correspondence analyses and construction of UPGMA diagrams were carried out using the STATISTICA (StatSoft, Inc. 1997) software program, performed on a matrix of 18 Gastropoda and 18 Bivalvia species × 15 sites and × 3 Danube parts (presence/absence of taxa in samples from 15 sampling sites and 3 Danube sectors).

Results

Over the six-year study, 520 samples were taken from 15 sampling sites on the Serbian Danube stretch. The substrate of those 15 sampling sites (Table 1) was composed of: clay, silt (very fine, fine, and medium sized silt), and silt with detritus; sand (very fine, fine, medium sized and coarse sand) and gravel (pebble, cobble and boulder). Based on granulometric classification (Table 1), according to Wentworth (1922), clay as the smallest fraction (0.06–3.9 μm) was present at sites 4, 8, and 9 in the Danube part II; silt (3.9–31 μm) and

Table 1. Substrate classification at 15 sites along the Serbian Danube stretch divided in three parts (I–III) according to Wentworth (1922).

Site code	Sampling site	r-km	Substrate types
	Part I		
1	Ledinci	1260	b, co, msa, fsa, ms, cd, d, shz, Msh
2	Novi Sad	1252	b, p, msa, fsa, ms, vfs, d, shz, Msh
	Part II		
3	Stari Banovci	1192	p, msa, fsa, vfsa, ms, fs, vfs, cd, d, shz, Msh
4	Zemun	1173	b, msa, ms, fs, vfs, cl, cd, d, shz, Msh
5	Visnjica	1160	co, p, csa, msa, ms, fs, cd, d
6	Vinca	1145	co, p, msa, fsa, ms, fs, vfs, cd, Msh, V, L
7	Oresac	1124	co, p, csa, msa, ms, fs, vfs, cd, d, V, L, P, bo
8	Smederevo	1112	b, co, p, msa, fsa, ms, fs, vfs, cl, cd, d, Msh, V, S
9	Stara Palanka	1077	p, msa, ms, cl, cd, d, shz
10	Ram	1072	b, co, p, msa, ms, fs, vfs, d, shz, Msh, V, P
	Part III		
11	Veliko Gradiste	1059	b, p, csa, msa, ms, fs, d, shz, Msh, V, P, L
12	Donji Milanovac	991	p, csa, msa, fsa, ms, fs, vfs, cd, d, Msh, V, L, Sph
13	Tekija	956	b, co, msa, fsa, ms, vfs, d, shz, Msh, Sph
14	Kladovo	934	b, co, p, msa, fsa, ms, fs, shz, Msh, V, P, Sph, fa
15	Kusjak	864	p, msa, ms, fs, shz, Msh

Explanations: b – boulder (256–4096 mm); co – cobble (64–256 mm); p – pebble (4–64 mm); csa – coarse sand (0.5–1 mm); msa – medium sized sand (250–500 µm); fsa – fine sand 125–250 µm); vfsa – very fine sand (63–125 µm); ms – medium sized silt (15.6–31 µm); fs – fine silt (7.8–15.6 µm); vfs – very fine silt (3.9–7.8 µm); cl – clay (0.06–3.9 µm); cd – coarse detritus; d – detritus; shz – shelly zone; Msh – Mollusca shell; fa – filamentous algae; V – vegetation; L – *Lemna* spp.; M – *Myriophyllum* spp.; P – *Potamogeton* spp.; S – *Sagittaria sagittifolia*; Sph – *Sphaerotilus* sp.; bo – black oil.

sand (63 µm – 1 mm) were present at all the fifteen sites, while pebble (4–64 mm) was also found in the substrate of all the three parts, being at sites: 2 (Part I); 3, 5–10 (Part II); and 11, 12, 14, 15 (Part III). Cobble (64–256 mm) was present in all the three parts, at sites: 1 (Part I); 5–8, 10 (Part II); 13 and 14 (Part III), whereas boulder (256–4096 mm) characterized the habitats of all the three parts, at sites: 1, 2 (Part I); 4, 8, 10 (Part II); and 11, 13 and 14 (Part III). The substrate in all the three Danube parts in some minor number of 520 collected samples coming from eleven sites: 1, 2 (Part I); 3, 4, 6, 8, 9, 10 (Part II); 11, 13, and 14 (Part III) can be characterized as shelly zone. Also, in 2005, the presence of petroleum – black oil (bo) products was noticed on the water surface of site 7 but it was not found in the sediment (Table 1).

Submerged and floating vegetation was observed at seven sites: 6, 7, 8, 10 (Part II); 11, 12 and 14 (Part III), with species: *Lemna* spp., *Myriophyllum* spp., *Potamogeton* spp., and *Sagittaria* sp. Bacteria *Sphaerotilus* sp. was present at sites 12, 13 and 14 (Table 1). Only in 2008 at site 8, presence of the rare species *Sagittaria sagittifolia* L. was confirmed there, which was found several years ago near Stara Palanka and Ram (our unpublished results; Stevanovic et al. 2003; Sinzar-Sekulic 2006).

The qualitative composition of the Gastropoda and Bivalvia communities was deteremined for each site (Tables 2A, B), along with their species occurrence frequencies (F = 0–1). The occurrence frequency values were grouped into three categories: F = 0.07–0.30 – Low, 0.31–0.80 – Medium, and F = 0.81–1 – High.

Gastropoda was represented by 18 species from two subclasses (Prosobranchia and Pulmonata) (Table 2A). Subclass Prosobranchia was represented by two orders and six families. The most diverse and frequent order was Mesogastropoda with 5 families and 11 species, out of which the most frequent and abundant were *Lithoglyphus naticoides* (F = 1); *Bythinia tentaculata* (L., 1758) (F = 0.86); *Valvata piscinalis* (Müller, 1774) (F = 0.80); *Borysthenia naticina* (Menke, 1845) (F = 0.73) and *Viviparus acerosus* (F = 0.66). Order Archaeogastropoda was represented by two species only (family Neritidae), but their occurrence frequencies at the sites studied was high: *Theodoxus fluviatilis* (F = 0.86) and *Theodoxus danubialis* (Pfeiffer, 1828) (F = 0.66). Subclass Pulmonata was represented by one order and three families. The lowest occurrence frequencies had *Physa fontinalis* (L., 1758), found only at site 10, and *Radix auricularia* (L., 1758) found at site 9 (F of each = 0.07).

Over the six-year study period, the presence of different species from the Gastropoda group was analyzed in the three parts of Serbian Danube stretch (Table 2A). The smallest number of taxa (5) was recorded in the upper part of the Danube (I – Riverine zone). At Ledinci (site 1) all the five species were found accounting for 28% of all recorded Gastropoda, while at Novi Sad (site 2) only two of those five, i.e., *Theodoxus fluviatilis* and *Lithoglyphus naticoides* were recorded, constituting 11% of the total number of in this study found Gastropoda. The Middle part of the Serbian Danube

Table 2A. Qualitative composition of Gastropoda communities (number and percent of taxa) and frequencies of taxa ($F = 0–1$) at sampling sites along the Serbian Danube stretch (r-km 1260–863.4) from 2003 to 2008.

Parts of Danube's course	Part I		Part II								Part III							
Species/Sampling sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	n	F	SI
Cl: GASTROPODA																		
Subcl: Prosobranchia																		
Ordo: Archaeogastropoda																		
Fam: Neritidae																		
Theodoxus danubialis (Pfeiffer, 1828)			+	+			+	+	+	+	+	+	+	+		10	0.66	1.80
Theodoxus fluviatilis (L., 1758)	+	+	+	+	+	+	+	+	+	+	+		+	+		13	0.86	1.70
Ordo: Mesogastropoda																		
Fam: Viviparidae																		
Viviparus acerosus Bourguignat, 1862	+		+	+	+		+	+		+	+	+	+			10	0.66	2.00
Viviparus contectus (Millet, 1813)					+		+	+				+	+			5	0.33	2.10
Viviparus viviparus (L., 1758)			+	+	+			+	+	+		+	+			8	0.53	2.00
Fam: Valvatidae																		
Valvata cristata Müller, 1774				+				+	+		+		+	+		6	0.40	2.20
Borysthenia naticina (Menke, 1845)			+	+	+		+	+	+	+	+	+	+	+		11	0.73	
Valvata piscinalis (Müller, 1774)			+	+	+	+	+	+	+	+	+	+	+	+		12	0.80	2.20
Valvata pulchella Studer, 1820								+		+	+	+	+			5	0.33	
Fam: Hydrobiidae																		
Lithoglyphus naticoides (Pfeiffer, 1828)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	15	1	2.20
Fam: Bithyniidae																		
Bythinia tentaculata (L., 1758)	+		+	+		+	+	+	+	+	+	+	+	+	+	13	0.86	2.20
Fam: Thiaridae																		
Microcolpia daudebartii (Prevost, 1821)				+				+					+	+		4	0.27	
Esperiana esperi (Férussac, 1823)			+					+				+		+		4	0.27	2.00
Subcl: Pulmonata																		
Ordo: Basommatophora																		
Fam: Physidae																		
Physa acuta Draparnaud, 1805							+	+	+							3	0.20	2.70
Physa fontinalis (L., 1758)										+						1	0.07	1.50
Fam: Lymnaeidae																		
Radix auricularia (L., 1758)									+							1	0.07	2.30
Radix labiata (Rossmässler, 1835)	+							+	+					+		4	0.27	2.00
Fam: Acroloxidae																		
Acroloxus lacustris (L.,1758)				+				+	+		+		+	+		6	0.40	2.20
Number of taxa per sites	5	2	9	11	7	4	9	16	12	10	10	10	13	11	2			
Number and percent of taxa per sectors $\Sigma = 18–100$	5–27.8		18–100								15–83.3							

Explanation: n – total number of sites where each taxon was found; SI – saprobic valence.

stretch (II – Transitional zone) was characterized by the largest number of species (18, which is equal to the total number of Gastropoda found in all three parts of the investigated Serbian Danube part). At Smederevo (site 8) the highest species diversity (16 species) was recorded – accounting for 89% of all recorded gastropods. At Stara Palanka (site 9), Zemun (site 4), and Ram (site 10) 12, 11 and 10 species were recorded, which makes 67%, 61% and 56% of all recorded Gastropoda, respectively. The Lower part of the Serbian Danube (III – Lacustrine zone) was characterized by 15 species. It should be noted that at site 13 – Tekija, the highest species diversity (13 species – 72%) was recorded, and at Kusjak (site 15) the lowest one (11%) where only *Lithoglyphus naticoides* and *Bythinia tentaculata* were recorded.

Bivalvia was represented by 15 species from one order (Eulamellibranchiata) and four families (Table 2B). Three representatives from two families in the juvenile stage were determined to the genus level: *Corbicula* sp. (juv.) – family Corbiculidae; and *Pisidium* sp. (juv.) and *Sphaerium* sp. (juv.) – Sphaeriidae family. The highest species occurrence frequencies were found for *Dreissena polymorpha* ($F = 1$), followed by *Unio tumidus* Philipsson, 1788, *Corbicula fluminea* and *Corbicula fluminalis* ($F = 0.73$, each). Species with the lowest occurrence frequency ($F = 0.13$) were *Anodonta anatina* (L., 1758), *Sinanodonta woodiana*, *Unio crassus* Philipsson, 1788 and *Pisidium obtusale* Lamarck, 1818).

Over the six-year of study period, the presence of different taxa from the Bivalvia group in the three parts of the Serbian Danube stretch was analyzed (Table 2B). The smallest number of species (8 taxa in total) was recorded in the upper part of the Danube (I – Riverine zone), i.e. five taxa at site 1 – Ledinci, and seven taxa at site 2 – Novi Sad, accounting for 33% and 47% of all recorded species, respectively. The Middle part of the Serbian Danube stretch (II – Transitional zone) was characterized by the largest number of taxa (15), which is equal to the total number of species found, while site 8 – Smederevo had the highest taxa diversity (12–80%). The Lower part of the Danube (III – Lacustrine zone)

Table 2B. Qualitative composition of Bivalvia communities (number and percent of taxa) and frequencies of taxa (F = 0–1) at sampling sites along the Serbian Danube stretch (r-km 1260–863.4) from 2003 to 2008.

Parts of Danube's course	Part I		Part II								Part III							
Species/Sampling sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	n	F	SI
Cl: BIVALVIA																		
Ordo: Eulamellibranchiata																		
Fam: Unionidae																		
Anodonta anatine (L., 1758)				+								+				2	0.13	2.20
Anodonta cygnea (L., 1758)				+		+		+		+		+	+			6	0.4	2.00
Pseudanodonta complanata (Rossmässler, 1835)				+		+	+	+			+		+	+		7	0.46	1.90
Sinanodonta woodiana (Lea, 1834)						+					+					2	0.13	2.30
Unio crassus Philipsson, 1788			+					+								2	0.13	1.80
Unio pictorum (L., 1758)				+			+	+	+	+	+	+	+			8	0.53	2.00
Unio tumidus Philipsson, 1788	+		+	+		+	+	+		+	+	+	+	+		11	0.73	2.00
Fam: Corbiculidae																		
Corbicula fluminalis (Müller, 1774)	+	+				+	+	+	+	+	+	+	+	+		11	0.73	
Corbicula fluminea (Müller, 1774)	+	+	+				+	+	+	+	+	+	+	+		11	0.73	
Corbicula sp. (juv.)	+	+	+	+		+	+	+	+	+	+	+	+	+		13	0.86	
Fam: Sphaeriidae																		
Pisidium obtusale (Lamarck, 1818)		+		+												2	0.13	1.70
Pisidium sp. (juv.)													+	+		2	0.13	
Sphaerium corneum (L., 1758)		+	+		+	+		+			+	+	+			8	0.53	2.30
Sphaerium lacustre (Müller, 1774)		+	+				+	+		+		+	+			7	0.46	2.80
Sphaerium rivicola (Lamarck, 1818)		+	+	+		+	+	+		+		+	+			9	0.6	2.20
Sphaerium solidum (Normand, 1844)					+		+	+								3	0.2	
Sphaerium sp. (juv.)	+	+	+	+	+			+	+	+	+	+	+	+		12	0.8	
Fam: Dreissenidae																		
Dreissena polymorpha (Pallas, 1771)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	15	1	1.90
Number of taxa per sites	5	7	7	9	3	8	9	12	5	8	8	10	11	7	1			
Number and percent of taxa per sectors Σ = 15–100	8–53.3		15–100								12–80.0							

Explanations: n – total number of sites where each taxon was found; SI – saprobic valence.

Table 3A. Values of Sørensen's Quotient of Similarity (QS) based on Gastropoda communities per sampling site (1–15) of the Serbian Danube stretch (r-km 1260–863.4) from 2003 to 2008.

Sampling site	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	57.14													
3	42.86	36.36												
4	50.00	30.77	80.00											
5	50.00	44.44	75.00	66.67										
6	66.67	66.67	46.15	53.34	54.54									
7	57.14	36.36	77.78	70.00	75.00	61.54								
8	47.62	22.22	72.00	81.48	60.87	40.00	40.00							
9	47.06	28.57	66.67	78.26	52.63	50.00	66.67	78.57						
10	53.33	33.33	88.89	76.19	70.59	57.14	73.68	69.23	63.64					
11	53.33	33.33	73.68	85.71	58.82	57.14	73.68	76.92	72.73	80.00				
12	40.00	16.67	88.89	66.67	70.59	42.86	73.68	76.92	54.54	80.00	70.00			
13	44.44	26.67	72.73	91.67	70.00	47.06	72.73	89.65	72.00	78.26	86.96	78.26		
14	50.00	30.77	70.00	81.82	44.44	53.33	60.00	81.48	78.26	57.14	76.19	57.14	75.00	
15	57.14	50.00	36.36	30.77	22.22	66.67	36.36	22.22	28.57	33.33	33.33	33.33	26.67	30.77

was characterized by 12 species in all. At Kusjak (site 15) only one Bivalvia species – *Dreissena polymorpha* was found, which accounts for 7% of the total number of species found in the present study. However, Tekija (site 13) had the higest number of species (11–73%) in this part of the Danube.

Saprobiological analysis showed that in the period between 2003 and 2008, 19 (70.4%) Mollusca species identified as bioindicator species (27 in all) had in-

Table 3B. Values of Sørensen's Quotient of Similarity (QS) based on Gastropoda communities in the investigated parts (I–III) of the Serbian Danube stretch (r-km 1260–863.4) from 2003 to 2008.

Parts of Danube's course	I	II	I	III	II	III
No. of species	5	18	5	15	18	15
No. of species in common	5		5		15	
QS (%)	43.48		50.00		90.91	

Table 4A. Values of Sørensen's Quotient of Similarity (QS) based on Bivalvia communities per sampling site (1–15) of the Serbian Danube stretch (r-km 1260–863.4) from 2003 to 2008.

Sampling site	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	50.00													
3	50.00	71.43												
4	28.57	37.50	37.50											
5	25.00	40.00	40.00	16.67										
6	46.15	53.33	53.33	23.53	36.36									
7	57.14	62.50	62.50	55.55	33.33	58.82								
8	47.06	63.16	73.68	57.14	40.00	70.00	85.71							
9	80.00	50.00	50.00	28.57	25.00	30.77	57.14	37.06						
10	61.54	66.67	66.67	58.82	18.18	62.50	82.35	80.00	61.54					
11	61.54	53.33	53.33	47.06	36.36	75.00	70.59	56.00	55.55	62.50				
12	53.33	70.59	70.59	63.16	30.77	66.67	73.68	81.82	53.33	88.89	66.67			
13	50.00	66.67	44.44	60.00	28.57	73.68	80.00	86.96	40.00	84.21	73.68	76.19		
14	83.33	42.86	42.86	37.50	20.00	53.33	62.50	52.63	50.00	53.33	66.67	47.06	66.67	
15	33.33	25.00	25.00	20.00	50.00	22.22	20.00	15.38	20.00	22.22	22.22	18.18	16.67	25.00

dividual saprobic valences ranging from 1.8 to 2.2 (beta-mesosaprobic indicators) in the studied Danube stretch (Tables 2A, B). Three (11.1%) and five (18.5%) bioindicators had saprobic valences varying from 1.5–1.7 (oligo- to beta-mesosaprobic indicators) and from 2.3 to 2.8 (beta-alpha- and alpha-mesosaprobic indicators). Among the Mollusca bioindicator species, the most frequent in the Serbian Danube stretch were representatives of Gastropoda – primarily *Lithoglyphus naticoides*, *Theodoxus* spp., *Valvata piscinalis*, and *Bythinia tentaculata* with saprobic valences in the oligo- to beta- and beta-mesosaprobic zones. Analysis of occurrence frequency showed that Bivalvia species with high frequencies were: *Dreissena polymorpha*, *Sphaerium corneum* (L., 1758) and *S. lacustre* (Müller, 1774), the former indicating beta-mesosaprobity, while the latter had saprobic valences in the beta- to alpha-mesosaprobic zone.

QS values, according to Sørensen (1948), were calculated for Gastropoda communities of the Danube (Tables 3A, B). According to Sørensen's QS for Gastropoda communities (Sørensen, 1948) medium to high degrees of similarity were found between benthocenoses of all 15 sampling sites. The majority of sites (51%) showed medium faunistic similarity being between 21–60%, 48% of sites had high QS values between 61–100%, while only 1% of sites had similarity values between 11–20%. Comparison between the three Serbian Danube parts showed medium to high degrees of similarity. A minimal QS value (43%) was recorded between parts I and II, whereas a maximum one (91%) was recorded between parts II and III.

QS values were also calculated for Bivalvia communities of the Danube (Tables 4A, B). According to Sørensen's QS for Bivalvia communities (Sørensen, 1948) medium to high degrees of similarity were found between benthocenoses of all 15 sampling sites. The majority of sites (54%) were shown to have faunistic similarity between 21–60%, another 37% of sites had similarity between 61–100%, while 9% of sites had similarity between 11–20%. The comparison between the three Danube parts revealed a high degree of similarity. A minimal QS value (70%) was recorded between parts I and II, and a maximal one (89%) was recorded between parts II and III.

Table 4B. Values of Sørensen's Quotient of Similarity (QS) based on Bivalvia communities in the investigated parts (I–III) of the Serbian Danube stretch (r-km 1260–863.4) from 2003 to 2008.

Parts of Danube's course	I	II	I	III	II	III
No. of species	8	15	8	12	15	12
No. of species in common	8		8		12	
QS (%)	69.56		80.00		88.89	

A comparison of the list of all species of Danube Mollusca found in the present study (33 species – 100%) with findings of species by other authors indicated medium and high degree of overlap (Table 5): 22 species – 67% (Arambasic 1994) and 32 species – 97% (Martinovic-Vitanovic et al. 2006), respectively.

The variation in the presence of Mollusca species of the Danube study sites as summarized by CA was examined through ordination diagrams (Figs 2, 3).

CA (codes given in Appendix to Figs 2–7) for Gastropoda (Fig. 2) revealed statistically significant separation of sites and species in the space of the first two correspondence axes, which accounted for 38.85% of the total variance (DIM 1 = 21.15%; DIM 2 = 17.70%).

The first correspondence axis (Fig. 2, negative scores on DIM 1) tended to separate site 10 from other sites based on the presence of *Physa fontinalis* species, found only at that site ($F = 0.07$). Site 9 (positive scores on DIM 1) is separated from all other sites. Species that contributed to the separation of site 9 are characterized by the low F values for *Radix auricularia* (0.07) and for *Radix labiata* (Rossmässler, 1835) (0.27). Along the second correspondence axis (DIM 2) sites 6, 1, 15 and 2 (scored negatively) were sharply separated from the other sites. Similarity among these sites is reflected in the presence of species characterized by high oc-

Table 5. List of Gastropoda and Bivalvia species of the Danube in papers of the following authors: 1. this paper; 2. Arambasic (1994); 3. Martinovic-Vitanovic et al. (2006).

Species/Sources	1	2	3
Cl: GASTROPODA			
Theodoxus danubialis (Pfeiffer, 1828)	+	+	+
Theodoxus fluviatilis (L., 1758)	+		+
Theodoxus transversalis (Pfeiffer, 1828)		+	
Viviparus acerosus Bourguignat, 1862	+	+	+
Viviparus contectus (Millet, 1813)	+		+
Viviparus viviparus (L., 1758)	+	+	+
Valvata cristata Müller, 1774	+		+
Valvata naticina Menke, 1845 syn. *Borysthenia naticina* (Menke, 1845)	+	+	+
Valvata piscinalis (Müller, 1774)	+		+
Valvata pulchella Studer, 1820	+		+
Lithoglyphus naticoides (Pfeiffer, 1828)	+	+	+
Bythinia tentaculata (L., 1758)	+		+
Fagotia acicularis (Férussac, 1823) syn. *Microcolpia daudebartii* (Prevost, 1821)	+	+	+
Fagotia esperi (Férussac, 1823) syn. *Esperiana esperi* (Férussac, 1823)	+	+	+
Amphimelania holandri (Férussac, 1828)		+	
Physa acuta Draparnaud, 1805	+	+	+
Physa fontinalis (L., 1758)	+	+	+
Planorbarius corneus (L., 1758)		+	+
Planorbis sp.		+	
Gyraulus laevis (Alder, 1838)		+	
Bulinus tentacularis (L.)		+	
Lymnaea auricularia (L., 1758) syn. *Radix auricularia* (L., 1758)	+	+	+
Lymnaea peregra (Müller, 1774) syn. *Radix labiata* (Rossmässler, 1835)	+	+	+
Acroloxus lacustris (L.,1758)	+		+
Cl: BIVALVIA			
Anodonta anatine (L., 1758)	+		+
Anodonta cygnea (L., 1758)	+		
Pseudanodonta complanata (Rossmässler, 1835)	+		+
Sinanodonta woodiana (Lea, 1834)	+		+
Unio crassus Philipsson, 1788	+		+
Unio pictorum (L., 1758)	+	+	+
Unio tumidus Philipsson, 1788	+	+	+
Corbicula fluminalis (Müller, 1774)	+		+
Corbicula fluminea (Müller, 1774)	+		+
Corbicula sp. (juv.)	+		
Pissidium obtusale (Lamarck, 1818)	+		+
Pissidium amnicum (Müller, 1774)			+
Pissidium sp. (juv.)	+		
Sphaerium corneum (L., 1758)	+	+	+
Sphaerium lacustre (Müller, 1774)	+		+
Sphaerium rivicola (Lamarck, 1818)	+	+	
Sphaerium solidum (Normand, 1844)	+		
Sphaerium sp. (juv.)	+		
Dreissena polymorpha (Pallas, 1771)	+	+	+
Total number of species	33	22	32
Total number of genera	17	15	18
Total number of families	13	11	13

currence frequencies: *Lithoglyphus naticoides* ($F = 1$), *Theodoxus fluviatilis* ($F = 0.86$), and *Bythinia tentaculata* ($F = 0.86$).

CA for Bivalvia (Fig. 3) showed that sites and species were statistically significantly separated in the space of the first two correspondence axes (DIM 1 and DIM 2). DIM 1 and DIM 2 combined to explain 39.78% of the total variance (DIM 1 = 21.85%; DIM 2 = 17.93%).

As depicted in Fig. 3, site 5 differed from other sites (scored negatively along DIM 2). *Sphaerium solidum* (Normand, 1844), which contributed to this separation, was characterized by a low occurrence frequency ($F = 0.20$). Additionally, sites 9, 1 and 14, with positive scores along DIM 1, were also isolated, mostly due to the presence of the species *Pisidium* sp. juv. ($F = 0.13$) and *Sphaerium* sp. juv. ($F = 0.20$) with low occurrence frequencies. Site 4 was distinguished from other sites along the first correspondence axis (scored negatively along DIM 1). Species that contributed to this

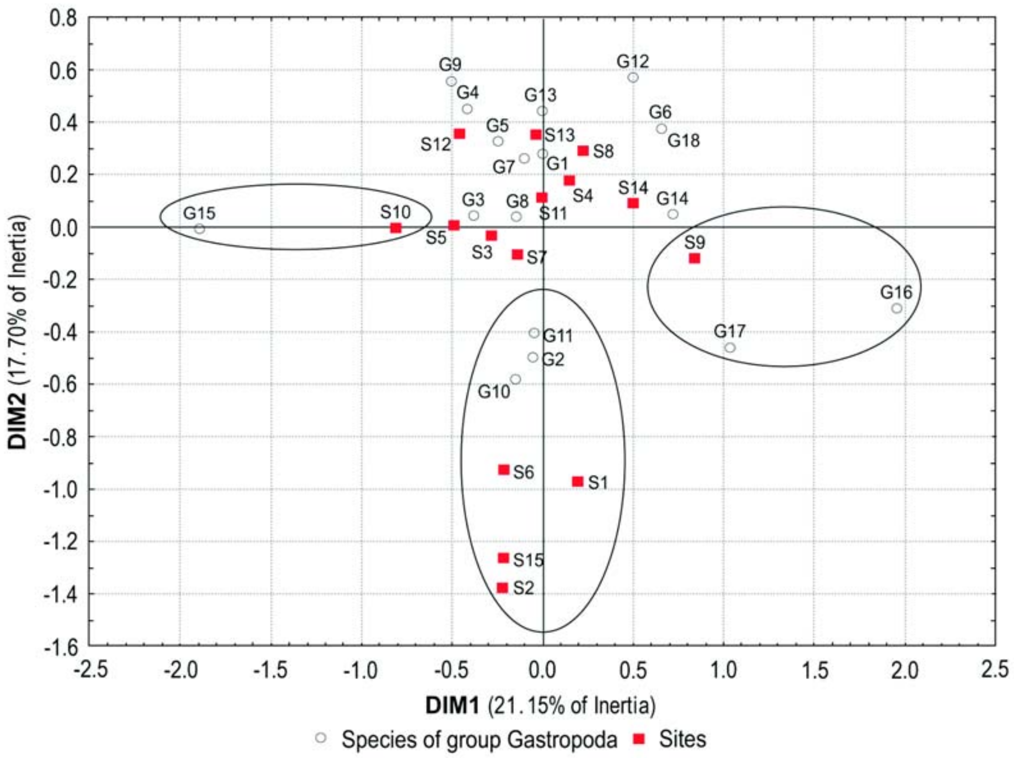

Fig. 2. Plot of sites (squares) and species (circles) in the space of the first two correspondence axes (DIM 1 and DIM 2) for Gastropoda of the Danube (km 1260–863.4) in the period from 2003–2008. Codes/abbreviations of sites and analyzed species are given in Appendix.

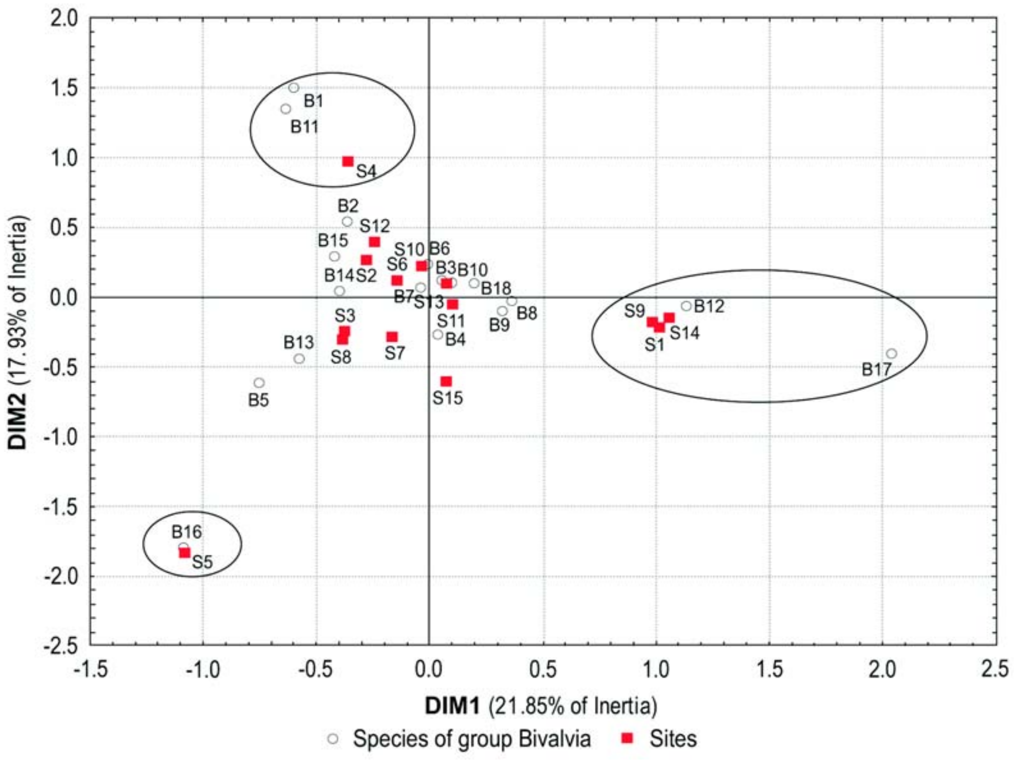

Fig. 3. Plot of sites (squares) and species (circles) in the space of the first two correspondence axes (DIM 1 and DIM 2) for Bivalvia of the Danube (km 1260–863.4) in the period from 2003–2008. Codes/abbreviations of sites and analyzed species are given in Appendix.

separation are characterized by low occurrence frequencies; *Pisidium obtusale* $F = 0.13$ and *Anodonta anatina* $F = 0.13$.

Relationships between the analyzed sites/parts, derived from the obtained distance matrix using the complete linkage clustering method (Pielou 1984) for

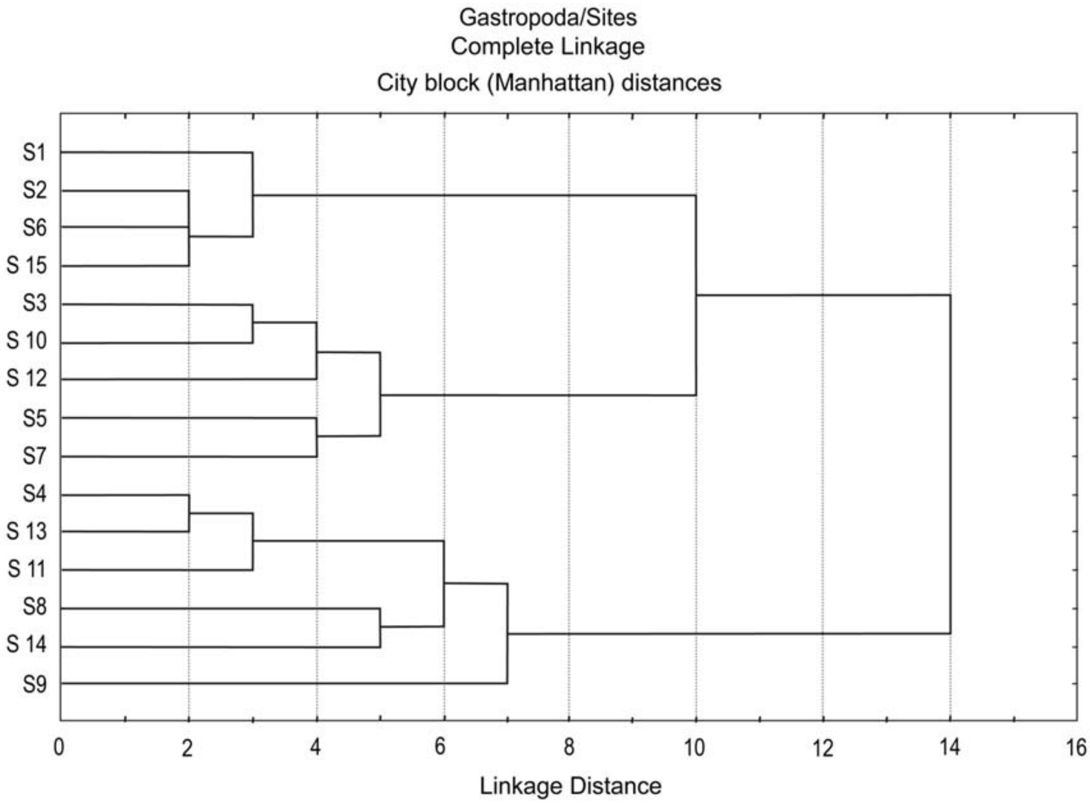

Fig. 4. UPGMA cluster diagram of 15 sites of the Danube (km 1260–863.4) in the period from 2003–2008 based on Complete Linkage City-block (Manhattan) distances for Gastropoda. Sites abbreviations are given in Appendix.

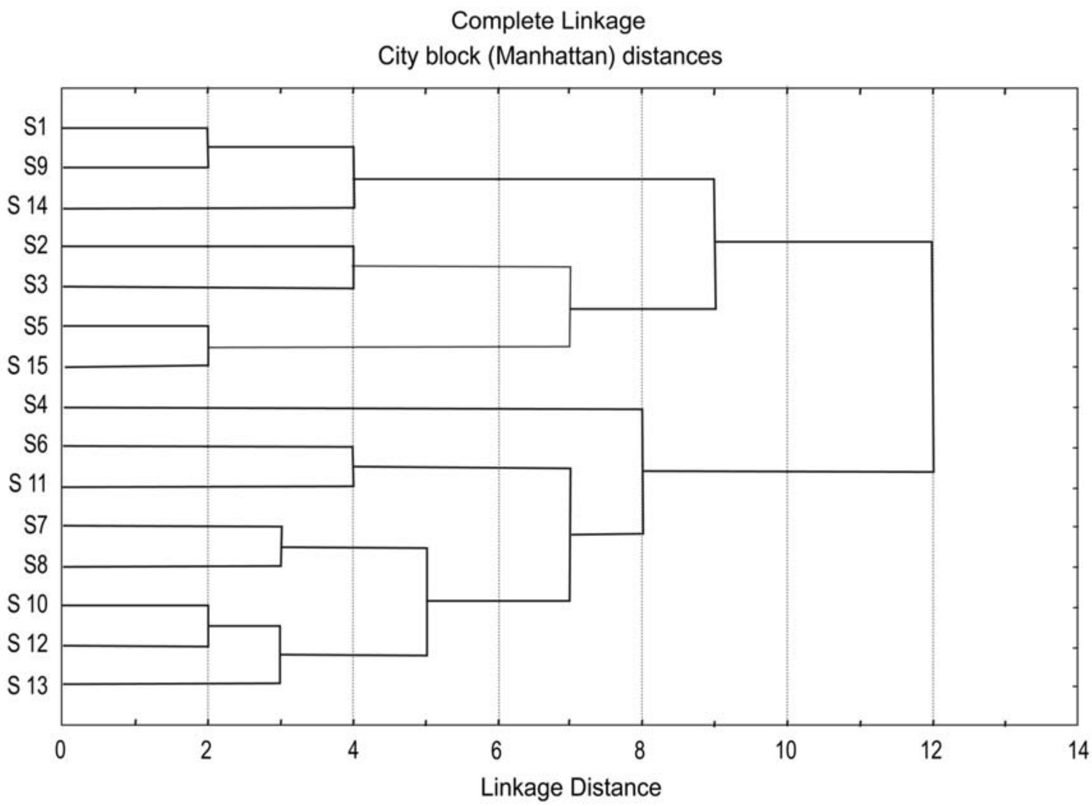

Fig. 5. UPGMA cluster diagram of 15 sites of the Danube (km 1260–863.4) in the period from 2003–2008 based on Complete Linkage City-block (Manhattan) distances for Bivalvia. Sites abbreviations are given in Appendix.

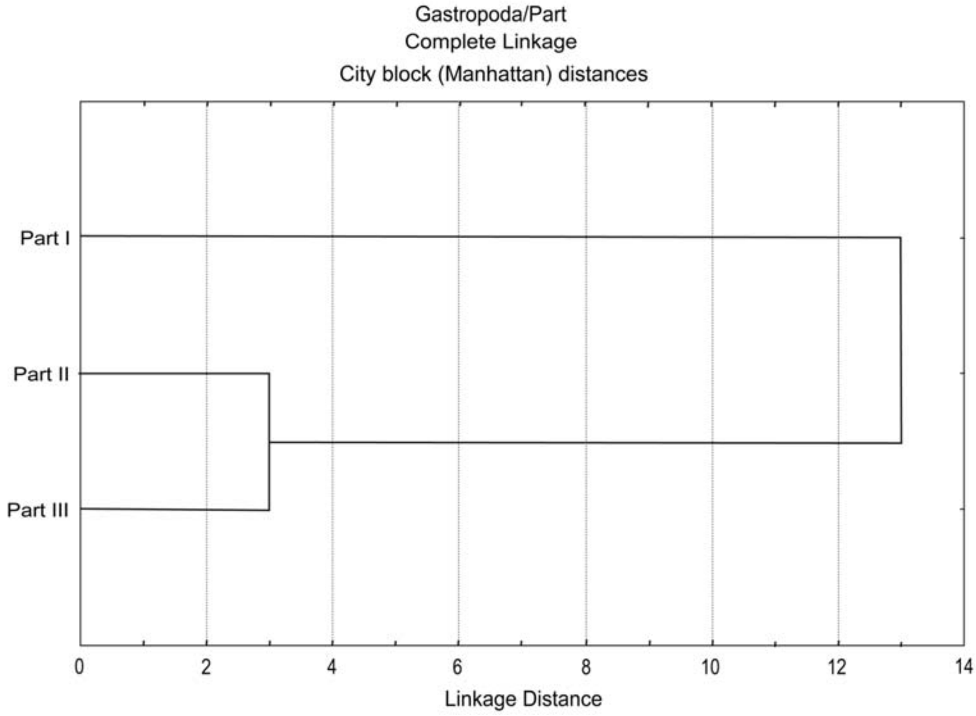

Fig. 6. UPGMA cluster diagram of three parts (I–III) of the Danube (km 1260–863.4) in the period from 2003–2008 based on Complete Linkage City-block (Manhattan) distances for Gastropoda.

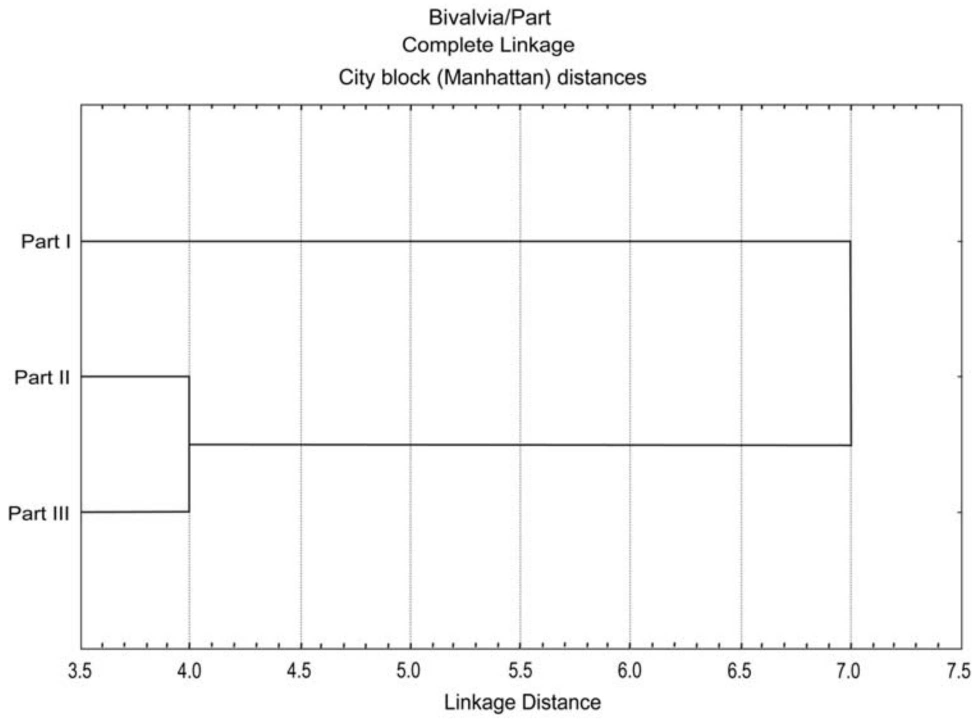

Fig. 7. UPGMA cluster diagram of three parts (I–III) of the Danube (km 1260–863.4) in the period from 2003–2008 based on Complete Linkage City-block (Manhattan) distances for Bivalvia.

Gastropoda and Bivalvia are shown in Figs 4 and 5 (sites 1–15), as well as on Figs 6 and 7 (parts I–III), respectively (codes given in Appendix to Figs 2–7).

The UPGMA cluster diagram for Gastropoda (Fig. 4), revealed the occurrence of two clusters. The first was formed by nine sites with 14 species belonging to Parts I and II except for sites 12 and 15. The second one included six sites with 17 species belonging to Parts II and III.

The UPGMA cluster diagram for Bivalvia (Fig. 5) also showed two clusters,. The first one was formed by seven sites with 15 species identified therein. These sites

Table 6. Ponto-Caspian species, endemic, invasive and introduced species in Mollusca fauna of the Danube and their occurrence frequencies per sampling sites ($F = 0$–1).

Ponto-Caspian species	Sampling sites / Frequency
Gastropoda	
Theodoxus danubialis (Pfeiffer, 1828)	3, 4, 7, 8, 9, 10, 11, 12, 13, 14 ($F = 0.66$)
**Lithoglyphus naticoides* (Pfeiffer, 1828)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 ($F = 1$)
Microcolpia daudebartii (Prevost, 1821)	4, 8, 13, 14 ($F = 0.27$)
Esperiana esperi (Férussac, 1823)	3, 8, 12, 14 ($F = 0.27$)
Bivalvia	
**Dreissena polymorpha* (Pallas, 1771)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 ($F = 1$)
Species endemic to Danube	
Gastropoda	
****Viviparus acerosus* Bourguignat, 1862	1, 3, 4, 5, 7, 8, 10, 11, 12, 13 ($F = 0.66$)
Introduced Species – Neozoa	
Gastropoda	
***Theodoxus fluviatilis* (L., 1758)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14 ($F = 0.86$)
Bivalvia	
***Corbicula fluminalis* (Müller, 1774)	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14 ($F = 0.73$)
***Corbicula fluminea* (Müller, 1774)	1, 2, 3, 7, 8, 9, 10, 11, 12, 13, 14 ($F = 0.73$)
***Sinanodonta woodiana* (Lea, 1834)	6, 11 ($F = 0.13$)

Explanations: ( ) – Ponto-Caspian species; (*) – invasive species; (**) – introduced species – NEOZOA; (***) – endemic species.

belong to Parts I and II except for sites 14 and 15. The second cluster contains eight sites with all 18 species belonging to Parts II and III.

UPGMA cluster diagrams of the three Danube parts for Gastropoda and Bivalvia (Figs 6, 7) show that Parts II and III were grouped together, while Part I was the most divergent. For both Gastropoda and Bivalvia, Part I is characterized by the presence of small number of species with higher values of occurrence frequency, in contrast to Parts II and III that have high numbers of species with medium to high values of occurrence frequency.

Over the six-year study period of Mollusca fauna in the Serbian Danube stretch, we found the presence of Ponto-Caspian, endemic, invasive and foreign so-called introduced species – Neozoa (Table 6). The Ponto-Caspian species which had the highest occurrence frequencies were *Lithoglyphus naticoides* ($F = 1$) and *Dreissena polymorpha* ($F = 1$), denoted as invasive species. Introduced species *Theodoxus fluviatilis* ($F = 0.86$), *Corbicula fluminalis* ($F = 0.73$) and *Corbicula fluminea* ($F = 0.73$) had moderate to high occurrence frequency ($F = 0.66$–1). *Sinanodonta woodiana* ($F = 0.13$), also an introduced species, had the lowest F value. The remaining Ponto – Caspian species found in our present study, including the endemic species *Viviparus acerosus* ($F = 0.66$), had moderate occurrence frequency ($F = 0.27$–0.66).

Discussion

By comparing our results with those of other authors who have investigated the benthic fauna generally or with special emphasis on molluscs of the Danube (Willmann & Pieper in: Illies 1978; Rusev et al. 1998; Arambasic 1994; Moog 1995, 2002; Moog et al. 2000; Bretschko & Schönbauer 1998; Sinicyna et al. 2004; Cioboiu 2006) we are able to discern certain features of compatibility and correspondence. In our six-year study of the Serbian Danube stretch, a rich invertebrate community with 33 species from Gastropoda and Bivalvia, was revealed. This is expected owing to the results of the surveys of other sectors of the Danube as the second-largest European river. Given that some molluscan taxa have not been identified to the species level, and that in the future our monitoring will be extended to the whole Serbian Danube sector including up to 40 more sites and different habitat types, the total number of species for this stretch is likely to be much higher.

Results of our present study are in agreement with those of other studies concerned with molluscan fauna inhabiting the Danube in Serbia: Arambasic (1994), Martinovic-Vitanovic & Kalafatic (1995), and Martinovic-Vitanovic et al. (2006). Willmann & Pieper (1978) reported that along the entire Danube course, 85 Mollusca species from 19 families were recorded (Gastropoda – 61 spp. from 16 families and Bivalvia –

24 spp. from 3 families). In the Serbian Danube stretch Arambasic (1994) found 22 species (11 families); and Martinovic-Vitanovic et al. (2006) found 32 species (13 families), whereas in our present study we recorded 33 species (13 families) thus giving percentage participation of the total number of Mollusca species presented in the checklist of the Limnofauna of Europe (Illies, ed., 1978). Thus, if Illies's percentage participation is taken as 100%, then that of Arambasic's (1994), Martinovic-Vitananovic et al. (2006) and that obtained in our present study is 26, 38 and 39%, respectively.

Out of 18 Gastropoda species, the percentage participation in each investigated part of the Danube was I – 28%, II – 100%, and III – 83%. Percentage participation of Gastropoda species per site ranged from 11–28% (Part I), 22–89% (Part II) and 11–72% (Part III). The smallest number of species (only two species per site) was recorded at site 2 (Part I) – *Theodoxus fluviatilis* and *Lithoglyphus naticoides*, and at site 15 (Part III) – *Lithoglyphus naticoides* and *Bythinia tentaculata*, otherwise all the three species were the most frequent in the investigated Serbian Danube stretch. Site 8, Smederevo (Part II), was the site with the highest taxa diversity (16 species – 89%).

Out of 15 Bivalvia species, the percentage participation in each investigated part of the Danube was I – 53%, II – 100%, and III – 80%. Percentage participation of Bivalvia species per site ranged from 33–47% (Part I), 20–80% (Part II) and 7–73% (Part III). The smallest number of species (*Dreissena polymorpha* only) was recorded at site 15 (Part III), while site 8, Smederevo (Part II), was the site with the highest taxa diversity (12 species – 80%).

The distribution and diversity (as judged by species richness) of potamobenthic communities is influenced by the substrate of different habitats, e.g., soft-bottom habitats where clay and silt are dominant, sand, hard-substrates such as gravel and substrates with macrophytes, filamentous algae, and detritus. Generally, differences in macrophyte communities structures (species composition and density) contribute to habitat complexity and, consequently, to the diversity of invertebrate community. In our limnological study of the Serbian Danube stretch performed in a six-year period, a rich invertebrate community with 142 potamobenthic taxa from 23 groups was established with the dominating group of Oligochaeta in muddy sediments at all investigated sites of the three Danube parts. In the river bank region (depending on the substrate heterogeneity and the presence of vegetation), species of the groups Mollusca and Amphipoda were most often dominant. In addition, the presence of luxuriant, spreading vegetation in parts II and III significantly affects the composition and distribution of the bottom fauna. The habitats of the river littoral zone, which are overgrown with vegetation, are occupied not only by the mentioned groups, but also by phytophilic potamobenthic insect larvae. Larvae of Chironomidae, Ephemeroptera and Trichoptera are most frequent. Alien invasive species from the groups Amphipoda, Mysidacea and Polychaeta (*Hypania invalida* and *Manayunkia caspica*, the later according to Martinovic-Vitanovic et al. 2009 and other unpublished author's results) have been repeatedly found.

A similar faunistic structure, with dominance of Oligochaeta and Mollusca, was recorded in the limnological study of the Serbian Danube stretch performed in the period from 1987–2003 (Martinovic-Vitanovic et al. 2006).

In our study, the 520 samples analysed were derived mostly from mixed type substrates with respect to the mechanical properties of the particles/fractions present therein (Martinovic-Vitanovic & Kalafatic 1995). The most common types of substrates were silt, sand and detritus at all 15 sites, gravel or pebble at 12 sites, and both cobble and boulder were at eight sites. Clay, the least common substrate, was present at only three sites. The mixed substrate types were present along all three Danube parts. At the majority of sites, the presence of Gastropoda and Bivalvia shells in the mixed type substrates was recorded, whereas at a small number of sites the substrate was formed by molluscs' shells exclusively ("shell zone"). Thus, in 2005 at site 4 the occurrence of a large number of shells of *Viviparus* spp. and *L. naticoides*, were noticed. In the same year at site 8 there was a great number of shells of *Viviparus* spp., *D. polymorpha*, *Corbicula* spp. and *Sphaerium* spp.

The construction of hydro-power plants (Djerdap I and II, i.e., Iron Gate I and II) have had numerous consequences on biota given that parts II and III of the Danube's course are within the zone of their operation. Namely, forced water level oscillations and sudden changes in the course velocity have caused physical disturbance to the bottom communities in the littoral zone. After the construction of dams, water velocity was decreased and the composition of organic-mineral sediment changed, accumulating in the regions of the reservoir. About 80% of the bottom surface, especially the bay and flat surfaces, is covered with a layer of mud, which contributes to spreading of pelophylic biocenoses. Gradually, owing to the reduction of rocks, sand and clay, as well as combined types of substrate, organisms that once inhabited these types of surfaces have disappeared (Nedeljkovic 1967, 1979; Jankovic 1975, 1978; Martinovic-Vitanovic et al. 2006; Brezeanu & Cioboiu 2006).

Brezeanu & Cioboiu (2006) reported that the benthic community in the Romanian Danube stretch has a completely new spatial and taxonomic structure. Out of 493 benthic invertebrate species identified before damming, 353 disappeared during the first year after the formation of reservoir(s), while after the year 2000 only about 90 species are identified. The loss in biodiversity did not involve a reduction in density and biomass. On the contrary, there was an increase in the abundance and biomass of the benthic invertebrates between 1971 and 1980 in a reverse trend with respect to the number of species (Nedeljkovic 1967, 1979; Jankovic 1975, 1978; Martinovic-Vitanovic et al. 2006; Brezeanu

& Cioboiu 2006). Brezeanu & Cioboiu (2006) also found a development burst of the mussel species *D. polymorpha* and *Sphaerium rivicola* (Lamarck, 1818), the density and biomass of which were ten times higher than these recorded before the damming.

The Lower Part or Lacustrine zone (i.e., lake part – reservoirs: Iron Gate I and II) can be said to represent lentic ecosystems. Our findings in the present study, together with records of other authors (Martinovic-Vitanovic et al. 2006; Obolewski et al. 2009; Sárkány-Kiss 2000), show that typical species inhabiting lentic ecosystems are pulmonates such as *Planorbarius* sp. or *Radix* sp., although the latter one colonized macrophytes only. Their pulmonary respiration allows survival under low oxygen conditions when the detritus at the bottom assures the food. The presence of species in the different subtypes of habitats found in that part of the Serbian Danube, with or without aquatic vegetation, indicates their preference towards the habitat. Accordingly, the species *Viviparus contectus*, *V. acerosus*, *B. tentaculata*, *Acroloxus lacustris* (L., 1758) and many others live only in habitats that have rich vegetation.

The greatest impact on the structure of Gastropoda and Bivalvia communities is exerted by water level oscillation induced by human activities. Consequently, when dam operations reduce the water level, Gastropoda and Bivalvia remain on dry surface, as was the case in the Djerdap I reservoir for the years 2004, 2005 and 2006, which endangered their populations. From an ecological point of view, riparian areas are often the breeding ground of macroinvertebrates, which can be very sensitive to pollution. Low flows, resulting downstream from the dams, can have a marked impact on water quality, its temperature, and consequently on biota (McCartney et al. 2000).

Freshwater gastropods are either herbivores or detritivores, although they occasionally ingest carrion (Bovbjerg 1975) or passively consume small invertebrates associated with periphyton (Cuker 1983). They evidently prefer periphyton to macrophyte tissue because it is easier to scrape and contains higher concentrations of nitrogen and other limiting nutrients. Algae (green and diatom) also remain predominately in the guts of snails. Analyses of gut contents indicate that Lymnaeids are "micro – herbivores" scraping algae, and among them diatoms, from rocks or macrophytes, *Radix labiata* thus grazing selectively on filamentous green algae (Brown 1991). However, some gastropods consume macrophytes and may indeed suppress macrophyte species richness if the snails reach high enough densities (Sheldon 1987).

Over the six-year study period, we noted the connection between the findings of Lymnaeidae species and the presence/absence of filamentous algae and diatoms on/from rocks or macrophytes in substrate. At site 14 (Kladovo), the habitat of which is characterized mainly by the presence of diatoms (species from the genera *Cymatopleura, Diatoma, Fragilaria, Gomphonema, Gyrosigma, Navicula, Nitzschia, Stauroneis, Surirella*), and filamentous green and blue-green algae (*Spirogyra, Ulotrix, Oscillatoria, Phormidium, Anabaena*, etc.) *Radix labiata* was found in Danube's (phyto)periphyton and phytobenthos.

The prosobranch *Bithynia tentaculata* can graze on both periphyton and use its ctenidium to filter phytoplankton. Filter feeding may be more efficient than scraping, which explains why this species has become so abundant in nutrient-rich, eutrophic lakes (Brown 1991). During our investigations, the wealth of background nutrients at the investigated sites (Damjanovic & Vulic 2004) explained the frequency of occurrence of *B. tentaculata* as one of the most frequent and abundant species in all the three Danube's zones.

The Middle Part or Transitional zone (i.e., flow through reservoir) is a semi-lotic ecosystem. This type of ecosystem is characterized by the presence of Viviparidae, and generally, Gastropods are more numerous in the Middle Part, as compared to the other two parts of the Serbian Danube stretch. Diversity of the malacocenoses resulted mainly from different abilities to adapt to temporary oxygen deficits (Obolewski et al. 2009). The species *Viviparus contectus* and *V. acerosus* live only in habitats that have rich vegetation (Sárkány-Kiss 2000). Available data also suggest that physids and planorbids are detritivores and/or bacterial feeders, but prefer detritus (Brown 1991). In the present study, detritus prevailed in the substrate, which helps physids and planorbids to expand their distribution ranges. According to McMahon (1991), physical factors and sediment type clearly affect bivalves' distributions. Unionacea are generally most successful in stable, coarse sand or sand-gravel mixtures and are generally absent from substrata with heavy silt loads (Cooper 1984; Salmon & Green 1983; Stern 1983). The expansion of Unionidae species is likely to happen in all rivers that display a low degree of pollution, as in Europe (Sárkány-Kiss 1997). In contrast to unionaceans, species diversity in the genus *Pisidium* increases with decreasing particle size becoming maximal at a mean particle diameter of 0.18 mm. *Pisidium* density and diversity were maximal in very fine sand-clay and silt-clay sediment, while peak *Sphaerium* diversity occurred at substrates of somewhat larger particle sizes (McMahon 1991). Corbiculidae have much broader sediment preferences, successfully colonizing habitats ranging from bare rock through gravel and sand to sediment with relatively high silt loads (McMahon 1991).

The distribution of *D. polymorpha* depends on the depth of the habitat, however, adults are rarely found in great numbers above 2 m and dense populations can extend to depths of 4–60 m, but always occur in well-oxygenated waters above the epilimnion. Younger, recently settled individuals tend to migrate toward deeper water after settlement (Mackie et al. 1989).

The Upper Part or Riverine zone (i.e., river part) represents a lotic ecosystem. According to our results, Sphaeridae (*Pisidium* sp.) prefer this type of ecosystem (Martinovic-Vitanovic et al. 2006; Obolewski et al. 2009).

In the present study, mollusc species with different ecological requirements were recorded in the samples collected along the entire investigated Danube course. Generally, streambed stability, as a function of hydrological conditions and sediment composition, as well as habitat homogeneity/heterogeneity, seem to be major structuring forces of the benthocenoses of the Danube in Serbia regarding species richness (Martinovic-Vitanovic et al. 2006). The presence of cosmopolitan species contributes to faunistic similarity thus affecting QS values of the studied sampling sites and observed Danube's parts.

The mixed type substrate/habitat exerted noticeable influence on the composition and distribution of Gastropoda and Bivalvia communities at the study sites, affecting species richness. A medium to high degree of similarity between Gastropoda (medium similarity with QS values – 43% between parts I and II; and – 50% between parts I and III) and Bivalvia communities (high similarity with QS values – 70% between parts I and II; and – 80% between parts I and III) in the three parts of the Danube was evident: reaching maximum QS of – 91% between parts II and III) and – 89% (between parts II and III), respectively.

CA for Gastropoda and Bivalvia revealed similar statistically significant separation of sites and species in the space of the first two correspondence axes. Although investigated Danube stretches in Serbia are considered to be of similar water types belonging to large lowland rivers, certain differences within the three parts (i.e., Riverine, Transitional and Lacustrine zones) have been identified. The positions of the studied sites explained by CA suggest that their grouping was associated with the composition of the Gastropoda and Bivalvia communities. The differences between the sites resulted from the presence/absence of rare species, while typical species of potamon-type river characterized by medium and high occurence frequency were common. Thus, as for Gastropoda, sites 9 and 10 are separated, located at opposite ends of the first correspondence axis. Sites 6, 1, 15 and 2 are grouped and separated from the sites by low values on the second axis. As for Bivalvia, sites 4 and 5 are separated, located at opposite ends of the second correspondence axis. Sites 9, 1 and 14 are grouped and separated by their values on the first axis. The difference in species richness, recorded in Mollusca communities in certain Serbian Danube parts, could be also attributed to the different lengths of the studied river sections (part I, II and III), i.e., to the different number of sampling sites.

Comparison of the UPGMA cluster diagrams of the three Danube parts for Gastropoda and Bivalvia showed the same diagram topologies. Transitional zone-flow through reservoir and Lacustrine zone-lake part were grouped together, while the Riverine zone-river part was the most divergent. Riverine zone is characterized by the presence of a small number of species with higher occurrence frequency, in contrast to Transitional zone and Lacustrine zone, which have high number of species with the medium and high occurrence frequencies.

The diversity and distribution of the potamobenthic Mollusca communities in the Serbian Danube stretch is mostly affected by different types of habitat/substrate but also by the permanent presence of biodegradable organic pollutants received from its tributaries (Sava, Tisa, Velika Morava) and/or from poorly treated industrial and communal waste waters. Thus, besides the changes in overall characteristics of the Danube in investigated Riverine, Transitional and Lacustrine zones as a result of damming the river (Chapman 1997), according to Martinovic-Vitanovic & Kalafatic (2002a, b), Martinovic-Vitanovic et al. (1999b, 2004, 2006, 2008), and the results of the present study, the saprobic status of the Danube in Serbia, as judged from the bottom fauna, corresponds to mesosaprobic conditions (beta-meso- to alpha-mesosaprobity). Damjanovic & Vulic (2004), who monitored organic pollution, on the bases of BOD, reported that BOD tended to increase from Bezdan (on the Danube entrance in Serbia) to Smederevo – in Riverine and partly in Transitional zone (flow through reservoir), whereas this tendency was less pronounced downstream from Smederevo to Radujevac (in Lacustrine zone and on the exit of the Danube from Serbia).

Moog et al. (2000) listed 34 species of Mollusca (23 species of Gastropoda and 11 species of Bivalvia) in the Austrian Danube stretch. The authors report that most invertebrate species (a total of 1,289) have individual saprobic values between 1.6 and 2.8 on average, characterizing a beta-mesosaprobic zone whereby molluscs, in particular, have lower values of saprobic valence in the range of oligo- and beta-mesosaprobity.

Expansion of invasive and introduced benthic invertebrate species, mainly from Asian to European continental waters, took place about 60 years ago (Nedeljkovic 1979; Lyashenko et al. 2004; Ojaveer et al. 2002; Sinicyna et al. 2004). The same tendency of some molluscan species was also noted in our present six-year study on Mollusca fauna inhabiting the Serbian Danube stretch. Thus, we recorded Ponto-Caspian, endemic, invasive and foreign so-called introduced species – Neozoa. Out of five Ponto-Caspian species, two species, *L. naticoides* and *D. polymorpha*, are assumed to be invasive species in the Serbian part of Danube and have the status of an invasive species in the entire Danube course (Martinovic-Vitanovic et al. 2006; Tittizer 1997; Russev et al. 1998; Ojaveer et al. 2002).

First records of *D. polymorpha* and *L. naticoides* in the Serbian Danube stretch dates from 1947 and 1985 and the species has been found repeatedly since then (and in the Tisa and Sava River) as very frequent and abundant (Martinovic-Vitanovic & Kalafatic unpublished results; Martinovic-Vitanovic & Kalafatic, 2002a, b; Martinovic-Vitanovic et al. 1999b, 2004, 2006, 2008). Our findings, together with records of other authors (Arambasic 1994; Russev et al. 1998; Cioboiu 2006; Tittizer 1997; Ketelaars 2004), supports the premise that the main path of the range extension of Ponto-

Caspian aquatic invertebrates in continental Europe was the Danube River as one of four main migration corridors, denoted as the "south-western corridor" connecting the Danube with the Rhine and neighboring basins. Mouthon (2007), in a nine-year study, presented the distribution of *L. naticoides* as an invasive species in France, as well as the species population dynamics and life cycle in a large lowland river such as the Saône River at Lyon. In addition, the author addressed the invasive potential of *L. naticoides* by comparing it with two molluscan species, *D. polymorpha* and *C. fluminea*. He concluded that it took *D. polymorpha* less than thirty years to colonize the completely metropolitan France, but it took *C. fluminea* only twenty years. On the contrary, it has taken *L. naticoides* almost the entire twentieth century to colonize only the eastern part of the country. Mouthon suggests that the main reason of the observed disappearance of *L. naticoides* in the Saône River at Lyon since November 2004 may be due to the increased water temperature occurring in the context of global warming and potential/possible interspecific competition (*L. naticoides vs. Valvata piscinalis*). In the Serbian Danube stretch, a high density of *L. naticoides* population was recorded, being maximal at Smederevo (site 8) – 10,608 ind. m^{-2} in June 2003. Water temperature was extremely high – 27.2℃. The following year a substantial decrease of its population was observed (at same site in June 2004 – 74 ind. m^{-2}).

Other Serbian Danube' Ponto-Caspian species are *Theodoxus danubialis*, *Microcolpia daudebartii* (Prevost, 1821) and *Esperiana esperi* (Férussac, 1823). Among Gastropoda, as Danube's endemic species, only *Viviparus acerosus* is quoted (Pfleger 1990; Martinovic-Vitanovic et al. 2006).

Ketelaars (2004) reported that range extensions of Ponto-Caspian species have probably been facilitated by the alteration of waters through pollution, eutrophication and other forms of human impacts that changed habitat characteristics. The Ponto-Caspian region is characterized by a very high level of endemism. The euryhalinity of the Ponto-Caspian biota makes them ideally pre-adapted to invade and survive in new environments. An important corridor for the Ponto-Caspian fauna to reach Western Europe is undoubtedly the Main-Danube Canal, which directly connects the Rhine basin with that of the Danube. During the past 200 years, the dispersal of Ponto-Caspian aquatic invertebrates outside their historic geographical range has been primarily caused by the construction of canals between once separated biogeography regions and by unintentional introduction *via* vessels ballast water.

According to Martinovic-Vitanovic et al. (2006), molluscan species in invertebrate fauna new to the Serbian Danube, designated as introduced species – Neozoa, are *C. fluminalis, C. fluminea* and *Sinanodonta woodiana*, whereas in our present study *Theodoxus fluviatilis, C. fluminalis and C. fluminea* were recorded far upstream at site 1 (1260–1258 r-km) and downstream at site 14 (934 r-km), while only *Sinanodonta woodiana* was found at site 6 (1144 r-km) and at site 11 (1059 r-km).

In the Hungarian part of the Danube, invasive species are *C. fluminea*, *C. fluminalis* and *D. polymorpha*, whereby *Pisidium amnicum* (Müller, 1774), *P. milium* Held, 1836, *Sphaerium rivicola* (Lamarck, 1818) and *S. solidum* were denoted as the rare ones (Csányi 1998–1999; Bódis et al. 2006).

It should be noted that data on the distribution and range expansion (a mean spread of 2.4 km per year), types of substrates (fine-grained, sand), types of water (slowly flowing, shallow water) preferred by the invasive clam *C. fluminea* in Switzerland, Germany and France are reported by Schmidlin & Baur (2007).

Mouthon after Pérez-Quintero (2008) recorded for the first time a representative from the genus *Corbicula* on the Iberian Peninsula (Tajo River basin) at the beginning of the 1980's. Since then, distribution data on the Asian clam have been exponentially increasing (Mouthon 2007, Pérez-Quintero 2008).

The snail *T. fluviatilis*, as a currently less numerous species, migrated from the Western European region such as the Rhine or the Atlantic coast. Among introduced species are also *C. fluminea* and *C. fluminalis,* which are recorded in the present study, and earlier in the Danube tributary Sava (Martinovic-Vitanovic et al. 2008). Martinovic-Vitanovic & Kalafatic (2002a) have recorded *C. fluminea* and *C. fluminalis* in the Serbian Danube stretch since 2001. These mussel species are the most common species in the middle and lower Danube stretch and in the Sava and Tisa tributaries (Martinovic-Vitanovic & Kalafatic 2002a, b; Martinovic-Vitanovic et al. 2004, 2006, 2008).

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Appendix to Figs 2–7. Codes (Abbreviations) of sampling sites (S) with Danube River parts (I–III) and kilometres (r-km) and of Gastropoda (G) and Bivalvia (B) analyzed species.

Number and name of the site (S)		River parts (I–III) and r-km	
S1	Ledinci	I	1260
S2	Novi Sad	I	1252
S3	Stari Banovci	II	1192
S4	Zemun	II	1173
S5	Visnjica	II	1160
S6	Vinca	II	1145
S7	Oresac	II	1124
S8	Smederevo	II	1112
S9	Stara Palanka	II	1077
S10	Ram	II	1072
S11	Veliko Gradiste	III	1059
S12	Donji Milanovac	III	991
S13	Tekija	III	956
S14	Kladovo	III	934
S15	Kusjak	III	864

Gastropoda (G)		Bivalvia (B)	
G1	*Theodoxus danubialis*	B1	*Anodonta anatina*
G2	*Theodoxus fluviatilis*	B2	*Anodonta cygnea*
G3	*Viviparus acerosus*	B3	*Pseudanodonta complanata*
G4	*Viviparus contectus*	B4	*Sinanodonta woodiana*
G5	*Viviparus viviparus*	B5	*Unio crassus*
G6	*Valvata cristata*	B6	*Unio pictorum*
G7	*Borysthenia naticina*	B7	*Unio tumidus*
G8	*Valvata piscinalis*	B8	*Corbicula fluminalis*
G9	*Valvata pulchella*	B9	*Corbicula fluminea*
G10	*Lithoglyphus naticoides*	B10	*Corbicula* sp. (juv.)
G11	*Bythinia tentaculata*	B11	*Pisidium obtusale*
G12	*Microcolpia daudebartii*	B12	*Pisidium* sp. (juv.)
G13	*Esperiana esperi*	B13	*Sphaerium corneum*
G14	*Physa acuta*	B14	*Sphaerium lacustre*
G15	*Physa fontinalis*	B15	*Sphaerium rivicola*
G16	*Radix auricularia*	B16	*Sphaerium solidum*
G17	*Radix labiata*	B17	*Sphaerium* sp. (juv.)
G18	*Acroloxus lacustris*	B18	*Dreissena polymorpha*