BioInvasions Records (2021) Volume 10, Issue 3: 623–628

Data Paper

Peracarid crustaceans in the River Danube and its tributaries: results of the 4th Joint Danube Survey

Péter Borza[1,*], Béla Csányi[2], Vjeran Đanić[3], Lyubomir Kenderov[4], Lidija Kladarić[3], Margita Lešťáková[5], Tjaša Muc[6], Denisa Němejcová[7], Miroslav Očadlík[8], Momir Paunović[9], Bernarda Rotar[6], József Szekeres[1], Marina Veseli[3,10] and Katarina Zorić[9]

[1]*Institute of Aquatic Ecology, Centre for Ecological Research, Karolina út 29, 1113 Budapest, Hungary*
[2]*Budai Nagy Antal utca. 10, 2131 Göd, Hungary*
[3]*Central Water Management Laboratory, Hrvatske vode, Ulica grada Vukovara 220, 10000 Zagreb, Croatia*
[4]*Faculty of Biology, University of Sofia "St. Kliment Ohridski", 8 Dragan Tsankov blvd, 1164 Sofia, Bulgaria*
[5]*Water Research Institute, Náb. arm. gen. L. Svobodu 7, 812 49 Bratislava, Slovakia*
[6]*Slovenian Environment Agency, Vojkova 1b, 1000 Ljubljana, Slovenia*
[7]*T.G. Masaryk Water Research Institute, p. r. i., Brno Branch Department, Mojmírovo náměstí 16, 612 00 Brno, Czechia*
[8]*WWF Slovakia, Medená 5, 811 02 Bratislava, Slovakia*
[9]*Institute for Biologica Research "Siniša Stanković", National Institute of Republic of Serbia, University of Belgrade, Bulevar despota Stefana 142, 11000 Belgrade, Serbia*
[10]*Department of Biology, Faculty of Science, University of Zagreb, Rooseveltov trg 6, 10000 Zagreb, Croatia*

Author e-mails: *borza.peter@ecolres.hu (PB), bela.csanyi@gmail.com (BC), Vjeran.Danic@voda.hr (VD), lubomir.kenderov@gmail.com (LKe), Lidija.Vukovic@voda.hr (LKl), margita.lestakova@vuvh.sk (ML), Tjasa.Muc@gov.si (TM), denisa.nemejcova@vuv.cz (DN), mocadlik@wwfsk.org (MO), mpaunovi@ibiss.bg.ac.rs (MP), Bernarda.Rotar@gov.si (BR), szekeres.jozsef@ecolres.hu (JS), marina.veseli@biol.pmf.hr (MV), katarinas@ibiss.bg.ac.rs (KZ)*

**Corresponding author*

Citation: Borza P, Csányi B, Đanić V, Kenderov L, Kladarić L, Lešťáková M, Muc T, Němejcová D, Očadlík M, Paunović M, Rotar B, Szekeres J, Veseli M, Zorić K (2021) Peracarid crustaceans in the River Danube and its tributaries: results of the 4th Joint Danube Survey. *BioInvasions Records* 10(3): 623–628, https://doi.org/10.3391/bir.2021.10.3.12

Received: 12 October 2020
Accepted: 20 March 2021
Published: 27 May 2021

Handling editor: Tatenda Dalu
Thematic editor: Kenneth Hayes

Abstract

The River Danube has played a pivotal role in the range expansion of Ponto-Caspian faunal elements in recent decades; therefore, the monitoring of its biota is of high scientific and conservation importance. In this publication, the records on peracarid crustaceans yielded by the macrozoobenthos samples for the 4th Joint Danube Survey (2019) are presented. Altogether 21 species (16 Amphipoda, 2 Isopoda, 3 Mysida) were recorded at 44 sites in the Danube (between river km 2581 and 18) and its major tributaries. Invasive Ponto-Caspian species showed the most common occurrence, some of which (*Chelicorophium robustum*, *Chelicorophium sowinskyi,* and *Paramysis lacustris*) have been observed beyond their previously known distribution. Nevertheless, the records of *Gammarus* spp. in the German Danube section might potentially indicate an improvement in the status of these native species in the region. The survey also confirmed the intensifying colonization of the River Tisza by Ponto-Caspian species, showing the first record of *C. robustum* in the river as well as additional occurrences of the previous invader, *Pontogammarus robustoides*. Besides these notable records, the dataset will also serve as a useful reference for potential further range expansions.

Key words: Amphipoda, Isopoda, Mysida, Ponto-Caspian, River Tisza, southern invasion corridor

Introduction

The River Danube, part of the so-called "southern invasion corridor", has played a pivotal role in the range expansion of Ponto-Caspian faunal elements in recent decades (Bij de Vaate et al. 2002; Borza et al. 2015); therefore, the monitoring of its biota is of high scientific and conservation importance not only for the riparian countries, but also for the entire North-Atlantic region. Although the strong political fragmentation of the catchment makes the implementation of such programmes challenging; cross-border initiatives also represent opportunities for cooperation (Hein et al. 2019).

In 2019, the so-called Joint Danube Survey was carried out for the fourth time (after 2001, 2007, and 2013), with the aim of scientific data collection and raising public awareness in relation to the conservation issues of the river. Besides the measurement of relevant physical and chemical parameters, various groups of the aquatic biota were sampled with special emphasis on invasive species.

Peracarid crustaceans represent the most diverse group of Ponto-Caspian invaders with considerable ecological impacts in the North-Atlantic region (Gallardo and Aldridge 2015; Pagnucco et al. 2015; Borza et al. 2017a). The previous surveys have already made a significant contribution to our knowledge about their distributional patterns (Borza et al. 2010, 2015, 2017a) as well as their ecological interactions (Borza et al. 2017b, 2018a, b). In this paper, we present the faunistic results of the fourth survey pertaining to this group.

Materials and methods

The macrozoobenthos sampling of the 4th Joint Danube Survey was carried out between 1 July and 30 September 2019 at 27 sites of the river between river km (henceforth rkm) 2581–18 and 19 sites in the major tributaries using three different methods (Table S1, Figure 1). Multi-habitat samples (AQEM Consortium 2002) were collected at all sites with a primary goal of ecological status assessment. These samples consisted of 20 replicates (each covering 25 × 25 cm sediment area) taken from different microhabitats in proportion to their coverage at the sampling site by a hand net (25 × 25 cm frame, 500 μm mesh size). Kick-and-sweep sampling (EN 27828:1994) was carried out in the nearshore region at all sites except for the German Danube section and the delta in order to support a more thorough exploration of macroinvertebrate biodiversity and to allow comparisons with the data from previous surveys. The samples (taken by a hand net with 25 × 25 cm frame and 500 μm mesh size) represented all available microhabitats irrespective of their coverage. In addition, dredge samples were collected in the Hungarian and Serbian Danube sections from a boat (using a triangular net of 30 × 30 × 30 cm aperture and 500 μm mesh size, pulled downstream for ~ 2 m, repeated 3 times per site) to provide insight into the fauna of the offshore zone (Szekeres et al. 2019). The samples were preserved in 4% formaldehyde solution or 70% ethanol, and stored in 70% ethanol after sorting and identification (based mainly on Băcescu 1954; Cărăuşu et al. 1955; Eggers and Martens 2001, 2004). The georeferenced

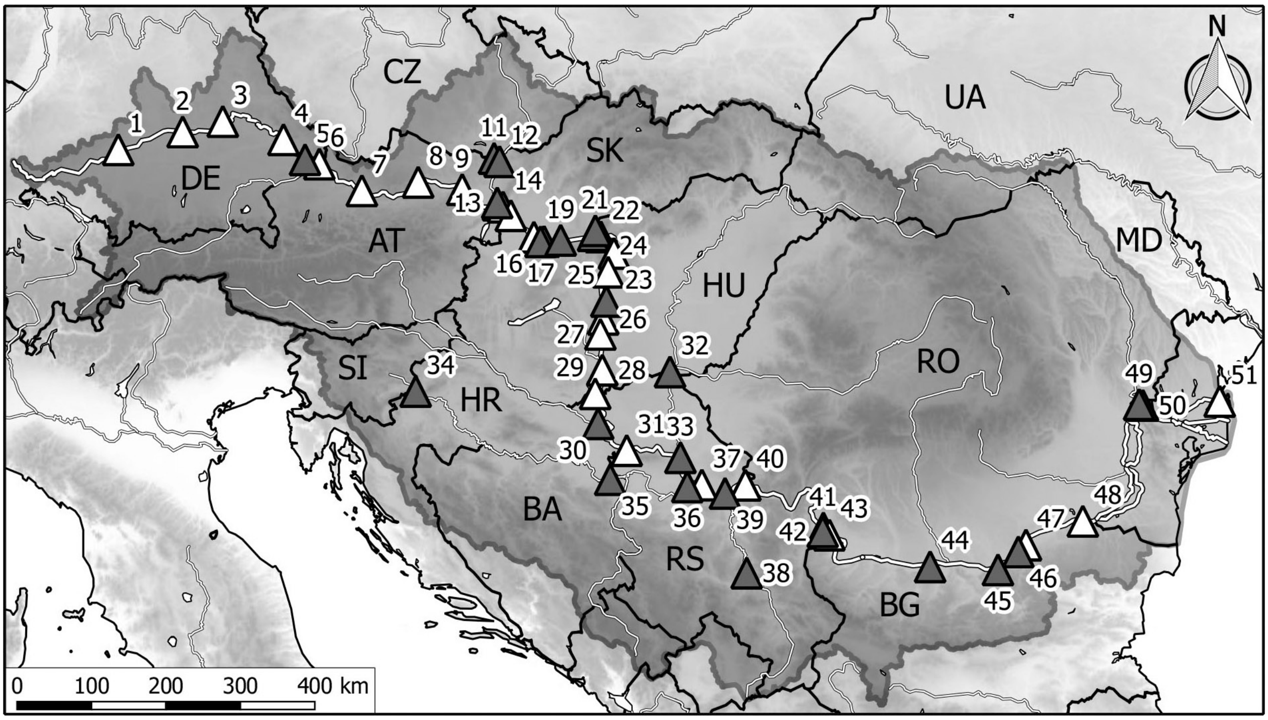

Figure 1. Map of the sampling sites during the 4th Joint Danube Survey. Numbers as in Table S1. White triangles: main channel, grey triangles: tributaries/sidearms. The dark shaded area represents the Danube catchment, Country codes: BA – Bosnia and Herzegovina, CZ – Czechia, DE – Germany, AT – Austria, SI – Slovenia, SK – Slovakia, HU – Hungary, HR – Croatia, RS – Serbia, RO – Romania, BG – Bulgaria, MD – Moldova, UA – Ukraine.

records (Supplementary material Table S2) and environmental background data (Table S3) are available in the REABIC data repository.

Results and discussion

Altogether 21 peracarid species were recorded during the survey (Tables 1, S2) which is considerably lower than in the previous survey (yielding 28 species; Borza et al. 2015). The missing species were mainly non-invasive Ponto-Caspian elements native to the lower section of the Danube, The main reason for this might be the overall lower sampling effort; i.e. the fewer sampling sites (46 vs. 55) and that dredge samples could only be collected in the Hungarian and Serbian sections. The latter is especially unfortunate in the light of the unfavourable hydrological conditions for inshore macroinvertebrate sampling. In the late spring-early summer of 2019, the water level of the Danube was high, followed by a gradual descent in the weeks preceding the survey which resulted in an increased sedimentation in the inshore zone of the river, presumably forcing macroinvertebrates to seek favourable substrates in the deeper zones.

Despite the high number of missing species as compared to the previous survey, some additional ones were recorded, as well. Three of them, the native *Gammarus balcanicus* Schäferna, 1923, *Gammarus kischineffensis* Schellenberg, 1937, and *Synurella ambulans* (F. Müller, 1846) were found at sites not sampled in the previous survey in the tributaries Velika Morava, Prut, and Sava, respectively. However, *Gammarus pulex* (Linnaeus, 1758)

Table 1. The list of peracarid species recorded during the 4th Joint Danube Survey. Site numbers as in Table S1.

Species	Occurrences (Site no.)	Σ
Amphipoda		
Chelicorophium curvispinum (G. O. Sars, 1895)	2, 3, 13, 17–19, 23–24, 26–33, 36–37, 39–41, 43, 47–51	27
Chelicorophium robustum (G. O. Sars, 1895)	4, 13–14, 16, 18, 22–24, 27, 29, 31–32, 36–37, 40–41, 43, 47–48, 50	20
Chelicorophium sowinskyi (Martynov, 1924)	6, 14, 16, 22, 29, 32–33, 35–37, 40–41, 43, 47–48	15
Dikerogammarus bispinosus Martynov, 1925	6–8, 10, 13–14, 16, 18–19, 22–28, 40	17
Dikerogammarus haemobaphes (Eichwald, 1841)	6–8, 10, 16–19, 22–29, 32–33, 35–36, 40–41, 43, 47–49	26
Dikerogammarus villosus (Sowinsky, 1894)	1–8, 10, 13–14, 16–19, 21–33, 35–37, 39–41, 43, 47–48, 50–51	38
Echinogammarus ischnus (Stebbing, 1899) (= *Chaetogammarus ischnus*)	4, 7–8, 10, 14, 16, 18, 22–24, 26–27, 29–31, 35–37, 40–41, 43, 47–49	24
Echinogammarus trichiatus (Martynov, 1932) (= *Trichogammarus trichiatus*)	40	1
Gammarus balcanicus Schäferna, 1923	38	1
Gammarus fossarum Koch, 1836	10, 34	2
Gammarus kischineffensis Schellenberg, 1937	49	1
Gammarus pulex (Linnaeus, 1758)	1	1
Gammarus roeselii Gervais, 1835	1, 2, 12, 20	4
Obesogammarus obesus (G. O. Sars, 1894)	6–8, 16–19, 22–24, 26–27, 29, 31–32, 35–37, 40, 47–48	21
Pontogammarus robustoides (G. O. Sars, 1894)	32, 33, 40, 43	4
Synurella ambulans (F. Müller, 1846)	34	1
Isopoda		
Asellus aquaticus (Linnaeus, 1758)	21, 29–30, 34, 38, 40, 51	7
Jaera sarsi Valkanov, 1936 (= *Jaera istri* Veuille, 1979)	3–4, 6–8, 10, 14, 16, 18, 20, 23, 26–27, 29–31, 35–37, 40–41, 43, 47–48	24
Mysida		
Katamysis warpachowskyi G. O. Sars, 1893	19, 31, 40	3
Limnomysis benedeni Czerniavsky, 1882	13, 16–17, 19, 22, 24–27, 29–33, 35–37, 40–41, 43, 47–51	25
Paramysis lacustris (Czerniavsky, 1882)	16, 18–19, 22–24, 26–29, 31, 36–37, 39–41, 43	17

was found again at the most upstream site in the Upper Danube (rkm 2581) where it was missing during the third, but present during the second survey (Borza et al. 2015). *Gammarus roeselii* Gervais, 1835, was also recorded here (as well as at Site 2), and although *Gammarus fossarum* Koch, 1836 was not formerly identified, it is likely that it was represented among the numerous unidentified juveniles (Table S2). The continued occurrence of *Gammarus* spp. at this site despite the presence of the invasive *Dikerogammarus villosus* (Sowinsky, 1894) can be regarded as a good sign potentially indicating that the gradual disappearance of native species in the upstream part of the river has stopped (Borza et al. 2015).

The most common species were invasive Ponto-Caspian elements with a continuous distribution in the river, in agreement with previous findings (Borza et al. 2015). Nevertheless, the records indicate that some of the species with a formerly disjunct distribution in the river have been able to close the gap. The occurrence of *Chelicorophium robustum* (G. O. Sars, 1895) at rkm 1300 suggests that the species has been able to complete its downstream spread after its presumed jump dispersal (Borza et al. 2015). Similarly, the distribution of *Paramysis lacustris* (Czerniavsky, 1882)—the most recent invader of the Middle Danube (Borza et al. 2019)—can also be regarded as continuous based on its presence at rkm 1300. The record of *Chelicorophium sowinskyi* (Martynov, 1924) at rkm 1434 (formerly missing between rkm 1630–1199 due to ecological reasons; Borza et al. 2010, 2015) might indicate that the conditions have become more favourable for this species in this section of the river, potentially in connection to the trend of decreasing average cell sizes in the phytoplankton (Abonyi et al. 2020) which might be advantageous for this suspension feeding species with a relatively small filter mesh size (Borza et al. 2018c). Nevertheless, the distribution of this species might still not necessarily be continuous.

The survey also yielded a notable record for *Dikerogammarus bispinosus* Martynov, 1925; it was found at rkm 1073 although previously it was missing in the downstream section (< ~ 1200 rkm; Borza et al. 2015). This peculiar distributional pattern was attributed to the competitive exclusion of the species by *D. villosus* under low current velocity (Borza et al. 2017b). The record in the Iron Gates section might indicate that the flow conditions required by the species are still present in the narrower parts of the gorge despite the impoundment.

In recent years, the expansion of Ponto-Caspian peracarids has accelerated in the River Tisza (Borza and Boda 2013; Csabai et al. 2020) which has reached another milestone; *C. robustum* was found for the first time in this tributary during the survey. Further samples are needed to establish the upstream distributional limit; nevertheless, even the record of the survey at rkm 163 suggests that the species got there by jump dispersal. The previous invader, *Pontogammarus robustoides* (G. O. Sars, 1894) was also found during the survey in the downstream part of the River Tisza as well as in the Danube section downstream of the Tisza mouth; therefore, it seems that its distribution was already continuous by 2019 after its presumed jump dispersal (Csabai et al. 2020).

In summary, the 4th Joint Danube Survey has made a significant contribution to our knowledge about the distribution of peracarids in the river and its tributaries despite the somewhat lower sampling effort and less favourable hydrological conditions as compared to the previous survey. This dataset will also serve as a useful reference for potential further range expansions.

Acknowledgements

The 4th Joint Danube Survey was organized by the International Commission for the Protection of the Danube River (ICPDR). The authors would like to thank everyone involved in the organization and implementation of the survey for their work, especially Katalin Bodolai, Michael Effenberger, Thomas Huber, Victoria Luchianova, Monica Mainerici, Maja Raković, and Florentina Soare. The authors also thank three anonymous reviewers for their useful comments on an earlier version of the manuscript.

Funding Declaration

The survey was financed by the contracting parties of the ICPDR.

References

Abonyi A, Kiss KT, Hidas A, Borics G, Várbíró G, Ács É (2020) Cell Size Decrease and Altered Size Structure of Phytoplankton Constrain Ecosystem Functioning in the Middle Danube River Over Multiple Decades. *Ecosystems* 23: 1254–1264, https://doi.org/10.1007/s10021-019-00467-6

AQEM Consortium (2002) Manual for the application of the AQEM system, A comprehensive method to assess European streams using benthic macroinvertebrates, developed for the purpose of the Water Framework Directive. http://www.aqem.de/ftp/aqem_manual.zip

Băcescu M (1954) Crustacea: Mysidacea. Editura Academiei Republicii Populare Romîne, Bucureşti, 126 pp

Bij de Vaate A, Jażdżewski K, Ketelaars HAM, Gollasch S, Van der Velde G (2002) Geographical patterns in range extension of Ponto-Caspian macroinvertebrate species in Europe. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 1159–1174, https://doi.org/10.1139/f02-098

Borza P, Boda P (2013) Range expansion of Ponto-Caspian mysids (Mysida, Mysidae) in the River Tisza: first record of *Paramysis lacustris* (Czerniavsky, 1882) for Hungary. *Crustaceana* 86: 1316–1327, https://doi.org/10.1163/15685403-00003229

Borza P, Csányi B, Paunović M (2010) Corophiids (Amphipoda, Corophioidea) of the River Danube The Results of a Longitudinal Survey. *Crustaceana* 83: 839–849, https://doi.org/10.1163/001121610X504315

Borza P, Csányi B, Huber T, Leitner P, Paunović M, Remund N, Szekeres J, Graf W (2015) Longitudinal distributional patterns of Peracarida (Crustacea, Malacostraca) in the River Danube. *Fundamental and Applied Limnology* 187: 113–126, https://doi.org/10.1127/fal/2015/0769

Borza P, Huber T, Leitner P, Remund N, Graf W (2017a) Success factors and future prospects of Ponto-Caspian peracarid (Crustacea: Malacostraca) invasions: Is 'the worst over'? *Biological Invasions* 19: 1517–1532, https://doi.org/10.1007/s10530-017-1375-7

Borza P, Huber T, Leitner P, Remund N, Graf W (2017b) Current velocity shapes co-existence patterns among invasive *Dikerogammarus species*. *Freshwater Biology* 62: 317–328, https://doi.org/10.1111/fwb.12869

Borza P, Huber T, Leitner P, Remund N, Graf W (2018a) Niche differentiation among invasive Ponto-Caspian *Chelicorophium* species (Crustacea, Amphipoda, Corophiidae) by food particle size. *Aquatic Ecology* 52: 179–190, https://doi.org/10.1007/s10452-018-9653-8

Borza P, Huber T, Leitner P, Remund N, Graf W (2018b) How to coexist with the 'killer shrimp' *Dikerogammarus villosus*? Lessons from other invasive Ponto-Caspian peracarids. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1441–1450, https://doi.org/10.1002/aqc.2985

Borza P, Huber T, Leitner P, Remund N, Graf W (2018c) Correction to: Niche differentiation among invasive Ponto-Caspian *Chelicorophium* species (Crustacea, Amphipoda, Corophiidae) by food particle size. *Aquatic Ecology* 52: 191–192, https://doi.org/10.1007/s10452-018-9659-2

Borza P, Kovács K, György A, Török JK, Egri Á (2019) The Ponto-Caspian mysid *Paramysis lacustris* (Czerniavsky, 1882) has colonized the Middle Danube. *Knowledge & Management of Aquatic Ecosystems* 420: 1, https://doi.org/10.1051/kmae/2018039

Cărăuşu S, Dobreanu E, Manolache C (1955) Amphipoda forme salmastre şi de apă dulce [Freshwater and brackish water Amphipoda]. Editura Academiei Republicii Populare Romîne, Bucureşti, 407 pp

Csabai Z, Borza P, Rewicz T, Pernecker B, Berta BJ, Móra A (2020) Mass appearance of the Ponto-Caspian invader *Pontogammarus robustoides* in the River Tisza catchment: bypass in the southern invasion corridor? *Knowledge & Management of Aquatic Ecosystems* 421: 9, https://doi.org/10.1051/kmae/2020003

Eggers TO, Martens A (2001) Bestimmungsschlüssel der Süßwasser-Amphipoda (Crustacea) Deutschlands. *Lauterbornia* 42: 1–68

Eggers TO, Martens A (2004) Ergänzungen und Korrekturen zum "Bestimmungsschlüssel der Süßwasser-Amphipoda (Crustacea) Deutschlands". *Lauterbornia* 50: 1–13

Gallardo B, Aldridge DC (2015) Is Great Britain heading for a Ponto-Caspian invasional meltdown? *Journal of Applied Ecology* 52: 41–49, https://doi.org/10.1111/1365-2664.12348

Hein T, Funk A, Pletterbauer F, Graf W, Zsuffa I, Haidvogl G, Schinegger R, Weigelhofer G (2019) Management challenges related to long-term ecological impacts, complex stressor interactions, and different assessment approaches in the Danube River Basin. *River Research and Applications* 35: 500–509, https://doi.org/10.1002/rra.3243

Pagnucco KS, Maynard GA, Fera SA, Yan ND, Nalepa TF, Ricciardi A (2015) The future of species invasions in the Great Lakes - St. Lawrence River basin. *Journal of Great Lakes Research* 41: 96–107, https://doi.org/10.1016/j.jglr.2014.11.004

Szekeres J, Borza P, Csányi B, Graf W, Huber T, Leitner P, Milosević D, Paunović M, Pavelescu C, Erős T (2019) Comparison of littoral and deep water sampling methods for assessing macroinvertebrate assemblages along the longitudinal profile of a very large river (the Danube River, Europe). *River Research and Applications* 35: 989–998, https://doi.org/10.1002/rra.3486

Supplementary material

The following supplementary material is available for this article:

Table S1. Sampling sites during the 4th Joint Danube Survey.

Table S2. Peracarid crustacean records of the 4th Joint Danube Survey.

Table S3. Basic physical/chemical/hydrological background parameters of the sampling sites during the 4th Joint Danube Survey.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2021/Supplements/BIR_2021_Borza_etal_SupplementaryMaterial.xlsx