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REVISION OF INVASION HISTORY, DISTRIBUTIONAL PATTERNS, AND NEW RECORDS OF COROPHIIDAE (CRUSTACEA: AMPHIPODA) IN HUNGARY

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The re-identification of archive samples revealed that the first records of Corophiidae in Hungary (1917) were erroneously attributed to *Chelicorophium curvispinum*; the first species expanding its range in the River Danube was in fact *C. sowinskyi*, while the actual colonization of the Danube and its tributaries by *C. curvispinum* took place somewhat later. In a sample of 1943 in the River Tisza *C. maeoticum* was found, representing its first and so far only record for Hungary. At present *C. curvispinum* is the most widespread corophiid in the country, while the once probably continuous range of *C. sowinskyi* in the Carpathian Basin has become fragmented; three isolated populations exist in the rivers Danube, Dráva, and Tisza. In 2007 *C. robustum* was found for the first time in Hungary, spreading downstream in the Danube. Our records denote that it has the potential to become an important member of the benthic macroinvertebrate assemblage, and may have negative effects on the corophiid species already present.

Key words: *Chelicorophium*, Corophiidae, distribution, Hungary, invasion history

INTRODUCTION

The rich Ponto-Caspian amphipod fauna consisting of many euryhaline species is one of the most important sources of aquatic invaders (JAŻDŻEWSKI 1980, RICCIARDI & MACISAAC 2000, TITTIZER *et al.* 2000, BIJ DE VAATE *et al.* 2002). Besides apparently spontaneous range expansions, passive transportation and intentional introductions have also played a role in their spread, in the course of which they colonized most of continental Europe, and some of the species have also invaded Great Britain and even North America (CRAWFORD 1935, JAŻDŻEWSKI 1980, RICCIARDI & MACISAAC 2000, BIJ DE VAATE *et al.* 2002). Among them corophiids represent a special group; they live in their self-made tubes and are filter-feeders, thus have an important role in the bentho-pelagic matter cycling. Owing to this functional role they have caused significant impacts in the ecosystems invaded in some documented cases, mainly by facilitating sedimentation, which led to the formation of a muddy layer negatively affecting bivalves (VAN DER VELDE *et al.* 1994). Displacement of native corophiid species has also been reported (NOORDHUIS *et al.* 2009).

Corophiids are represented by ten endemic species of the genus *Chelicorophium* BOUSFIELD and HOOVER, 1997 and the North-Atlantic element *Corophium volutator* (PALLAS, 1766) in the Ponto-Caspian region. Due to their special lifestyle they can take advantage of the ship traffic by attaching to their hulls or the walls of ballast tanks, for which they are considered to be among the most probable future invaders of the Laurentian Great Lakes (RICCIARDI & RASMUSSEN 1998). Despite their high potential to spread, for a long time *Chelicorophium curvispinum* (G. O. SARS, 1895) was the only – albeit very successful – species detected to have expanded its ranges in Central and Western Europe (erroneously, as discussed here). Its spread along the "central invasion corridor" (*sensu* BIJ DE Vaate *et al.* 2002) is relatively well documented (WUNDSCH 1912, WOLSKI 1930, CRAWFORD 1935, THIENEMANN 1950). A further species, *Chelicorophium sowinskyi* (MARTYNOV, 1924) was first reported to be present in Central-Europe by ŠTRASKRABA (1962). *C. sowinskyi* was first described as a subspecies of *C. curvispinum* (*Corophium curvispinum sowinskyi* MARTYNOV, 1924). Later, MORDUKHAI-BOLTOVSKOI (1947) elevated it to species level, which is now supported by molecular evidence, too (JAŻDŻEWSKI & KONOPACKA 1996, URYUPOVA & MUGUE 2007). These publications have not become widely known, which resulted in ignorance of the species by many authors (JAŻDŻEWSKI & KONOPACKA 1996), leading to confusions especially along the River Danube, where both species occur (ŠTRASKRABA 1962, BRTEK 2001, BORZA *et al.* 2010). Around the millennium a third species began to spread; *Chelicorophium robustum* (G. O. SARS, 1895) was surprisingly found in the River Main, Germany (BERNERTH & STEIN 2003, BERNERTH *et al.* 2005). Within a few years it colonised the River Rhine (BERNAUER & JANSEN 2006) and in 2007 it was found in the Upper Danube, too (BORZA *et al.* 2010).

In Hungary UNGER (1918) reported on the first occurrence of a corophiid, identified as *C. curvispinum*. The next important event happened in the early 1930s, when *C. curvispinum* invaded the Lake Balaton, where it became very abundant in a few years (SEBESTYÉN 1934). In this well-studied lake several investigations have been conducted on the biology of this species (e.g. ENTZ 1943, 1949, MUSKÓ 1992, MUSKÓ *et al.* 2007); in the rivers, however, the research interest on Corophiidae had been much lower, being restricted to sporadic faunistic records (WOYNÁROVICH 1943, DUDICH 1947). Although the records of *C. sowinskyi* in the Middle Danube and in the Lake Balaton by ŠTRASKRABA (1962) were known (MUSKÓ 1994), they were audited only in the Lake Balaton, where the species has never been found again (MUSKÓ *et al.* 2007). This led to the point of view that the presence of *C. sowinskyi* in Hungary is "uncertain" (KONTSCHÁN *et al.* 2002, MUSKÓ *et al.* 2007), and the only species acknowledged was *C. curvispinum*.

As it can be seen, the discovery of the distribution of Corophiidae has been impeded by many unfortunate circumstances especially along the southern invasion corridor (taxonomical uncertainties, overlooked publications, low research interest, etc.), which made a thorough revision of the records necessary. In this paper we present a revision of the archive materials available in Hungary, and outline a comprehensive picture about the current distribution of the species based on a high number of samples covering all the main waters of the country.

MATERIALS AND METHODS

Altogether 357 samples of Corophiidae were identified from all of the main water bodies of Hungary. The material examined originated from the following sources: (1) Collection of Crustacea and Other Aquatic Invertebrates of the Hungarian Natural History Museum (Amphipoda 1430–1505, 1962, 1965, 1978, 1984–85, 2344–45, 3299–3300); (2) macroinvertebrate collection of the Hungarian Danube Research Station; (3) "kick and sweep" samples of the Joint Danube Survey 2 organized by the International Commission for the Protection of the Danube River (ICPDR); (4) collections of certain Regional Inspectorates for Environment, Nature, and Water; (5) samples collected by the author.

The animals were identified by the author using a Zeiss Stemi 2000-C stereomicroscope based on the works of CĂRĂUŞU *et al.* (1955) and JAŻDŻEWSKI and KONOPACKA (1996). The full georeferenced dataset is available online via the REABIC GIS database (http://www.reabic.net/).

RESULTS

Chelicorophium sowinskyi (MARTYNOV, 1924)

C. sowinskyi was the only species found in the archive samples of 1917–1934 (Fig. 1a) in the River Danube including the first record of Corophiidae for Hungary (UNGER 1918). It was also present in the River Tisza (at Szeged, 1943), but not in the Lake Balaton.

In the recent years (1991–2009, Fig. 1b) the species was recorded in the River Danube, in the River Tisza and its major tributaries (Bodrog, Körös), and in the River Dráva. In the Danube it occurred almost exclusively upstream of Göd (river km 1669) except for a single specimen recorded at Dombori (rkm 1507). In the River Tisza it was present in the lower reaches (Szeged, rkm 173), too, as well as in some connected irrigation canals. In the River Dráva the most upstream positive sample with regard to this species was taken at Barcs (rkm 153).

Chelicorophium curvispinum (G. O. SARS, 1895)

In the archive samples available for revision *C. curvispinum* was found only in the Lake Balaton (1933-, Fig. 1c). In recent years, however, it has proven to be the most widespread corophiid (Fig. 1d): while still being the only species present

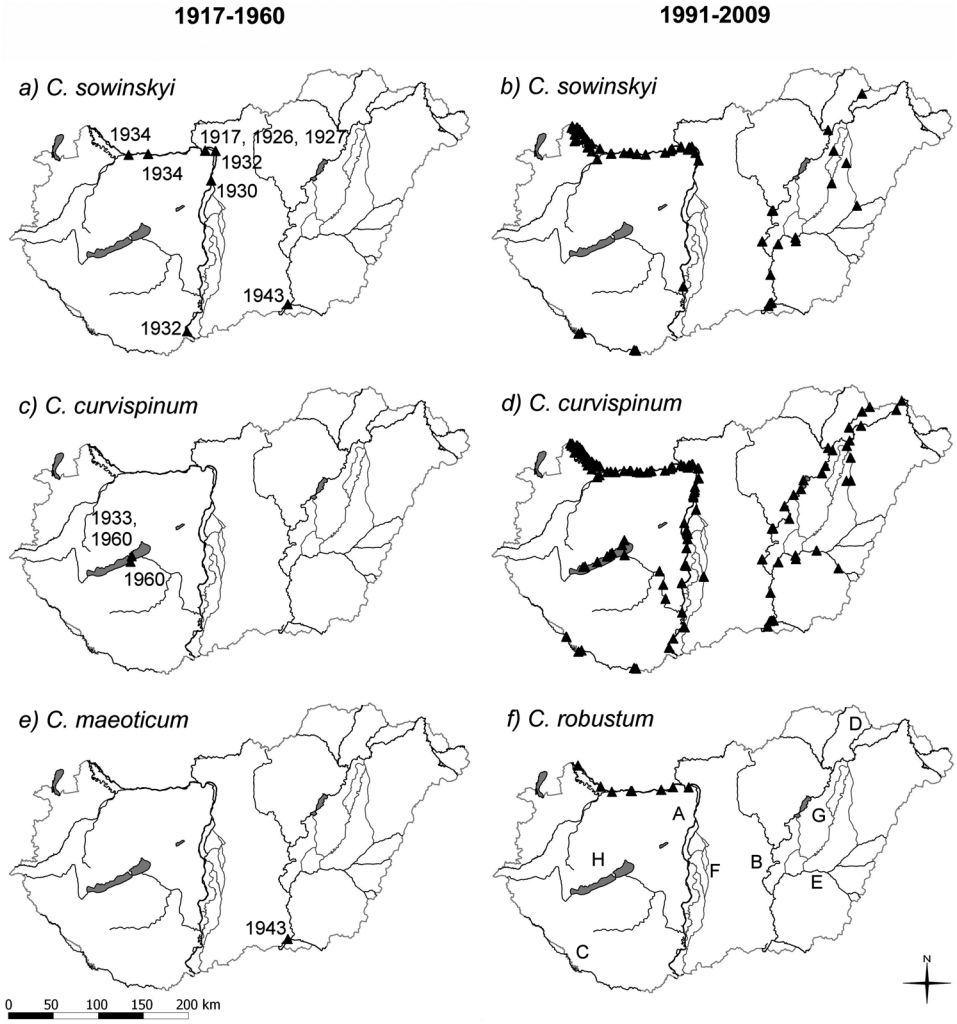

Fig. 1. Records of *Chelicorophium sowinskyi*: a = 1917–1960, b = 1991–2009; *C. curvispinum*: c = 1917–1960, d = 1991–2009; e = *C. maeoticum*, f = *C. robustum* in Hungary. Legends: A = River Danube, B = River Tisza, C = River Dráva, D = River Bodrog, E = River Körös, F = canal network of Kiskunság, G = canal network of Nagykunság, H = Lake Balaton

in the Lake Balaton, it was found in the whole course of the Hungarian Danube stretch, as well as in the connected Ráckeve-Soroksári Danube arm and the canal network of the Kiskunság area. It was also recorded in the River Tisza (up to rkm 628, at Záhony), and in some of its major tributaries (Bodrog, Körös) and connected canals.

In the River Dráva its most upstream occurrence was at Vízvár (rkm 192).

Chelicorophium maeoticum (SOWINSKY, 1898)

In the sample of 1943 at Szeged (River Tisza), among hundreds of *C. sowinskyi*, 11 specimens of *C. maeoticum* including gravid females were found, representing the first and so far only record of this species in Hungary (Fig. 1e). The species did not occur in recent samples, thus it can be regarded as extinct in the country.

Chelicorophium robustum (G. O. SARS, 1895)

A single specimen of *C. robustum* was found in a sample of July 2007 taken from the Danube at Nyergesújfalu (rkm 1734; Fig. 1f). In 2009 the species was recorded at several sites of the upper half of the Hungarian Danube section with the most downstream occurrence at Nagymaros (rkm 1694). The records are summarized in Table 1.

DISCUSSION

The past

The re-identification of the archive samples of the Hungarian Natural History Museum revealed a distribution very different from that observed in the recent years. It emerged that the first records of Corophiidae were erroneously attributed to *C. curvispinum*, the first species expanding its range in the River Danube was in fact *C. sowinskyi*. This mistake is forgivable if we take into account that *C. sowinskyi* was not yet described in 1917, and its status had remained unclear for a long time. The actual arrival date of the species is unclear, but from the remark of UNGER (1918) that, despite great efforts the species was found only at one site, it is possible that it was not long before it was discovered. Later, in the '20–30s the species was found at several sites including the lower parts of the Hungarian Danube section, where it does not occur at present. The colonization date of the River Tisza

Table 1. Records of *Chelicorophium robustum* in Hungary, and the relevant negative samples (2007: leg. J. Nosek, N. Oertel; 2009: leg. P. Borza). The specimens not identified ("ind.") involve mostly juveniles, which were abundant in some cases. Abbreviation: C.c. = *C. curvispinum*, C.s. = *C. sowinskyi*, C.r. = *C. robustum*.

Date	Location	Rkm	Latitude (N)	Longitude (E)	C.c.	C.s.	C.r.	ind.	Habitat
30.07.2007	Nyergesújfalu	1734	47.762694	18.539861	6	–	1	2	gravel, stones
15.09.2009	Dunakiliti	1843	47.994722	17.315305	–	1	4	–	rip-rap
16.09.2009	Győrzámoly	1805	47.788527	17.658166	–	–	2	–	rip-rap
16.09.2009	Gönyű	1792	47.738750	17.825222	–	–	6	–	gravel, stones
07.10.2009	Komárom	1769	47.791027	18.730583	3	6	618	206	gravel, stones
07.10.2009	Komárom	1768	47.749527	18.121333	9	1	133	45	rip-rap
07.10.2009	Nyergesújfalu	1733	47.763611	18.554194	–	–	19	–	gravel
07.10.2009	Esztergom	1720	47.750777	18.106972	2	6	35	2	gravel
07.10.2009	Nagymaros	1694	47.789305	18.961722	4	–	16	–	gravel, stones
12.10.2009	Göd	1668	47.680361	19.126000	65	–	–	–	rip-rap
19.10.2009	Budapest	1640	47.441972	19.055944	9	–	–	–	rip-rap

is even more obscure. It took place probably well before the detection in 1943, for in this year a corophiid was reported from one of its tributaries situated far upstream in the Hungarian section of the river (River Bodrog, WOYNÁROVICH (1943)). In the only sample available from the River Tisza (at Szeged, 1943) *C. sowinskyi* was found along with *C. maeoticum*; therefore, the record in the Bodrog can be attributed to a high certainty to one or both of these species.

The presence of *C. maeoticum* in the River Tisza is rather enigmatic. According to DUDICH (1967) the species occurred in the Danube as far as the Serbian (former Yugoslavian) section. BĂCESCU (1966) reported it to be the most abundant Ponto–Caspian species (65% of all individuals) in the Iron Gate narrows. It is quite evident that it colonized the River Tisza from here, but the date of its appearance as well as the causes of its disappearance will probably remain unknown. One possible explanation is that its extinction was connected with the subsequent appearance of *C. curvispinum*, but other causes (e.g. environmental changes) are also conceivable. The presence of gravid females among the 11 specimens found indicates that it had self-sustaining populations, but it is also possible that it failed to establish permanently in this region.

The first authentic records of *C. curvispinum* in Hungary are its observations in the Lake Balaton (SEBESTYÉN 1934, ENTZ 1943, 1949). It was first identified in 1933, but, according to unpublished data referred to by ENTZ (1943, 1949), it was present already in 1929. The most probable way of its immigration is the passive transport on ships' hulls from the Danube through the Sió canal (SEBESTYÉN 1934, ENTZ 1943, 1949). Therefore, it is highly probable that it was present in the lower Danube section in the early '30s (as it can be concluded from the material examined by ENTZ (1943, 1949), too), but in the one sample available for revision from this area (at Mohács, 1930) only *C. sowinskyi* has been found. For *C. sowinskyi* (identified as *C. curvispinum*) was already present, the actual colonization of the Danube and its tributaries by *C. curvispinum* took place undetected. This process was probably not very fast; according to ŠTRASKRABA (1962) the species was not present in Czechoslovakia (i.e. the Hungarian–Slovak Danube stretch) even in the '50s.

At present *C. sowinskyi* and *C. curvispinum* both occur in the Upper Danube (BORZA *et al.* 2010); the reconstruction of their invasion history further upstream the southern corridor would, however, require further revisions of archive samples in the regions concerned.

The present

The intensive sampling in the recent years allows us to draw a consistent picture about the distribution of the species. At present *C. curvispinum* is the most widespread corophiid in Hungary, which indicates a broad tolerance for different environments; it is the only species to occur in still waters, while it is also the one to be found the farthest upstream in the rivers. *C. sowinskyi* is less euryoecous; at present it can be found only in the middle section of the rivers (Rivers Danube; Dráva; Tisza, and its tributaries Körös and Bodrog), and it is missing in the lower part of the Hungarian Danube reach and the Serbian section (BORZA *et al.* 2010), as well as in the Serbian part of the River Tisza (unpublished records of the Hungarian Natural History Museum). Accordingly, the once probably continuous range of the species in the River Danube basin has become fragmented; three isolated populations exist in the Middle and Upper Danube (between rkm 2354–1669, BORZA *et al.* (2010)), in the River Dráva (records at Drávaszabolcs and Barcs), and in the River Tisza system. In summary, the following patterns can be observed in the rivers with regard to these two species: in the upstream reaches *C. curvispinum* occurs alone (e.g. at Kelheim, rkm 2415 in the Danube (BORZA *et al.* 2010); at Vízvár in the Dráva; at Záhony in the Tisza; at Békés in the Körös; and probably the Slovakian part of the Bodrog (BRTEK 2001), followed by a section of coexis-

tence, and in the lowest reaches *C. curvispinum* can be found alone again (not considering the Lower Danube, where both species occur natively).

This pattern seems to be quite robust in our material; however, it should be kept in mind that the material is rather heterogeneous in terms of sampling routines; different habitats and water depths could have been sampled (escalated by the naturally fluctuating water levels), which adds some uncertainty to these results. Therefore, our results unfortunately do not allow conclusions to be made about the habitat preference of the species, testing the observations discussed by JAŻDŻEWSKI and KONOPACKA (1996). It is probable that river zonation is decisive, but to our current knowledge the effects of the mere physico-chemical variables (i.e. current velocity, temperature, and oxygen concentration) cannot be separated from the differences in habitat structure. To test this pattern further investigations are needed, with a sampling campaign where environmental variables are controlled for.

The future

In 2007 *C. robustum* was found for the first time in the Hungarian Danube section (Table 1). Our records support the assumption that the species is spreading downstream in the upper reaches of the river (BORZA *et al.* 2010). In some of our samples *C. robustum* showed a strong dominance over the species already present, and in some others it was the only corophiid found, denoting that the species has the potential to become an important member of the benthic macroinvertebrate assemblage. The mass occurrence of *C. robustum* could probably have negative effects on *C. curvispinum* and *C. sowinskyi*; however, their total disappearance is not very likely. According to BERNERTH *et al.* (2005) after the establishment of *C. robustum* in the River Main (2000–2002) the species coexisted with *C. curvispinum* at most of the sites examined with the one or the other species being dominant and in some cases even with high abundance of both. The impact of *C. robustum* will be obviously different among habitat types and will be judgeable only in years' time.

Owing to the recent colonization of the upper reaches of the river, *C. robustum* shows a disjunctive distribution in the Danube, being present in the lower parts natively (during the "Joint Danube Survey 2" in 2007 it was found downstream of Beograd, rkm 1151; BORZA *et al.* 2010). Our results show that this distributional gap is closing, and it is presumable that the species has not reached its limits and will continue to spread further downstream.

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