

FIRST RECORDS OF *SINANODONTA WOODIANA* (LEA, 1834) AND *CORBICULA FLUMINEA* (O. F. MÜLLER, 1774) (MOLLUSCA, BIVALVIA) FROM THE ADRIATIC PART OF CROATIA

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ABSTRACT: *Sinanodonta woodiana* (Lea) and *Corbicula fluminea* (O. F. Müller) are among the most invasive aquatic molluscs found in Europe. Both species were recorded in the Adriatic part of Croatia for the first time in 2019 although in the Danubian Croatia they were more common. An abundant population of *S. woodiana* was found in an oxbow of the Cetina River; mussels with shell length of ca. 12–17 cm dominated. A population of *C. fluminea* was recorded in the freshwater section of the Zrmanja River above the Jankovića Buk waterfall which forms the border between the brackish and the freshwater sections of the river. Possible pathways of their introduction and reasons for their rare occurrence in contrast to the Danubian Croatia are discussed.

KEY WORDS: non-native species; Chinese mussel; Asian clam; introduction; range expansion

INTRODUCTION

For the last few decades spread of non-native species has been one of the major threats to aquatic ecosystems (ABRAMOVITZ 1996). Most of the natural barriers for species dispersal have been weakened by human activities (LEPPÄKOSKI et al. 1991, 2002), thus allowing a long distance range expansion of many non-native species. In many areas dispersal of non-native species is one of the main reasons for biodiversity loss. Being easily transported by humans and often having a significant impact on native faunas and ecosystems, freshwater molluscs form an important group of non-native species (MEIER-BROOK 2002). A notable increase in the occurrence of non-native freshwater molluscs has been observed in the last decades (e.g. CIANFANELLI et al. 2007, LORENCOVÁ et al. 2015). Recently, *Sinanodonta woodiana* (Lea, 1834) and *Corbicula fluminea* (O. F. Müller, 1774) have been spreading rapidly. *S. woodiana* is known to occur in many localities in the Danube River basin in Croatia (LAJTNER & CRNČAN 2011, BERAN 2013, PETRAVIĆ et al. 2019, author's unpub-

lished data). According to KONEČNÝ et al. (2018) western Romania, southern Hungary and northern Croatia are one of the two probable source areas for European populations of *S. woodiana*. The species is common in Serbia (PAUNOVIĆ et al. 2006, 2008) and occurs in eastern Slovenia (GOVEDIĆ 2017). In the Adriatic Sea basin it is known from many sites in Italy (CIANFANELLI et al. 2007, CILENTI et al. 2019) and was also found in Montenegro (TOMOVIĆ et al. 2013). On the other hand, there were no previous records of the Chinese pond mussel from the Adriatic part of Croatia. Finding its empty shells on the shores of Lake Vrana was an exception, and later detailed research failed to confirm its occurrence in the lake (LAJTNER & CRNČAN 2011, BERAN et al. 2013). According to LAJTNER & CRNČAN (2011), the records of empty shells of *S. woodiana* were the consequence of transport of live individuals from continental parts of Croatia as fishing bait, since Lake Vrana is known for its rich fish fauna and is an important destination for anglers from continental Croatia, particularly during

the summer vacation period. It can be assumed that any live bivalves that may have been released into the lake probably did not survive, due to stress caused by increased salinity, as the lake is connected to the sea by a manmade channel (LAJTNER & CRNČAN 2011).

C. fluminea is native in southeastern Asia which includes southeast China, Korea and southeast Russia (ZHADIN 1952, MORTON 1986). Currently, the species is widely distributed, and its range includes also other parts of Asia, North and South America, Europe, Africa and Australia (MORTON 1986, ARAUJO et al. 1993, CRESPO et al. 2015, PONDER et al. 2016). *C. fluminea* can colonise fresh waters, as well as brackish estuaries with salinities of up to 17 PSU (LUCY et al. 2012). It was very often introduced into estuaries of large rivers with ballast water, due to increased international trade (KARATAYEV et al. 2007); it was probably brought to North America in the 1930s by Asian immigrants as a food source (BRITTON & MORTON 1979). Once introduced to a new catchment area, its

spread is limited by environmental factors and facilitated by transport for food and aquaculture, shipping, fish stocking, angling and deliberate introduction (for review see MCMAHON 1982, 1999, KARATAYEV et al. 2007).

C. fluminea is regarded as one of the most important non-native invasive species in aquatic ecosystems, mainly due to its wide distribution and ecological and economic impacts (CRESPO et al. 2015).

The first record of *C. fluminea* in Croatia dates from 2001 when the species was recorded in the Danube River (PAUNOVIĆ et al. 2007, LAJTNER et al. 2016) and later also in the rivers Sava, Drava, Una and Kupa in the Danube River catchment area (PAUNOVIĆ et al. 2007, LAJTNER et al. 2016, ČUK et al. 2019, author's unpublished data). No record of the Asian clam existed from the Adriatic part of Croatia, though in the Adriatic Sea basin it was known from many localities in northern Italy (CIANFANELLI et al. 2007).

MATERIAL AND METHODS

The data were obtained during routine field surveys conducted in 2019 and confirmed in 2020. The main method was washing vegetation or sediments on a metal sieve (20 cm diameter, 0.8 mm mesh) combined with hand-collecting from the surface of stones, wood and artificial materials (e.g. plastic bags and bottles), and snorkelling in shallow parts (up to ca. 3 m deep). In the site where *C. fluminea* was discovered in 2019, the sediment from an area of 1 m²

was removed and sieved in 2020. The collected individuals were measured (length) and stored in 80% ethanol. A shallow place with abundant occurrence of *S. woodiana* was chosen in 2020. Individuals from this plot (10 m²) were collected by hand (without removing and sieving the sediment) and measured (length, height, width). Selected shells of *S. woodiana* and alcohol-preserved specimens of *C. fluminea* are deposited in the author's collection.

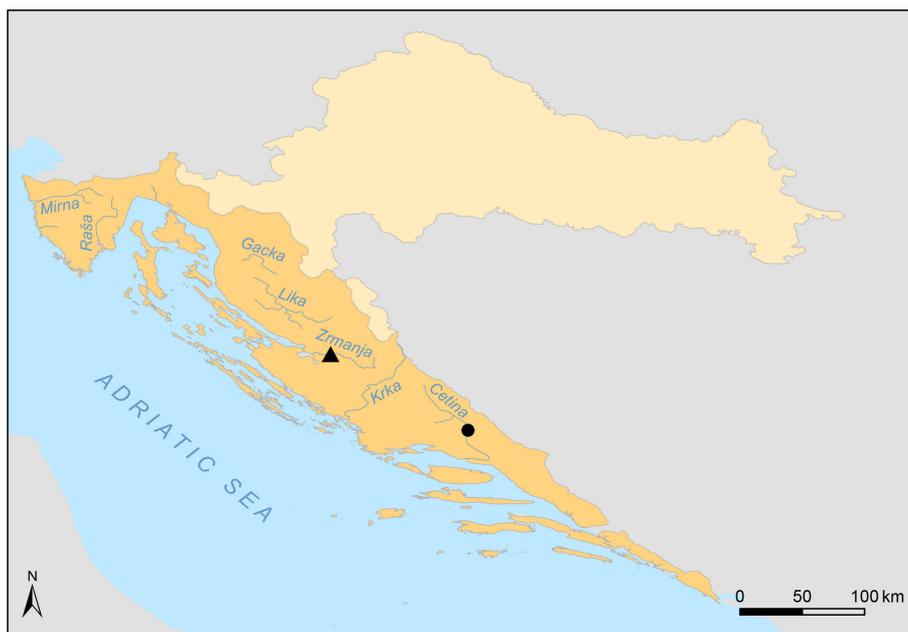


Fig. 1. Records of *Sinanodonta woodiana* and *Corbicula fluminea* in the Adriatic part (dark yellow) of Croatia. Circle – *Sinanodonta woodiana*, triangle – *Corbicula fluminea*. Drawing H. MEDKOVÁ

RESULTS

Both species were found during faunistic research in 2019 in the Adriatic part of Croatia. *S. woodiana* was recorded in an old oxbow of the Cetina River near Trilj (43°38.95'N, 16°42.88'E, 21.08.2019, Figs 1–3). Its population was abundant, with the density estimated at 2–5 individuals/m². Most mussels occurred at the depth of 100–150 cm. The occurrence was confirmed one year later (16.08.2020). The water level was ca. 50 cm lower than in 2019. Altogether 33 mussels were found within 10 m² at the depth of ca. 60 cm; individuals of shell length of ca. 12–17 cm dominated (Fig. 4). The oxbow is not connected to the Cetina River and the water is significantly warmer than in the river. The oxbow is an important angling site and several information boards with instructions for anglers are situated along its banks. No other unionids were found in the oxbow or in the main channel of the Cetina River during a thorough search conducted between 2018 and 2020 at more than 10 sites (author's unpublished data).

The molluscan communities of the Zrmanja and Krupa rivers have been studied since 2009 (BERAN

2011, author's unpublished data). *C. fluminea* was found in 2019 (11.07.2019) at the Zrmanja River, ca. 70 m above the Jankovića Buk waterfall (44°12.18'N,



Fig. 2. *Sinanodonta woodiana* from the oxbow of the Cetina River. The biggest and smallest collected individuals. Photo: L. BERAN



Fig. 3. The oxbow of the Cetina River in 2019 (the water level was ca. 50 cm lower in 2020). Photo: L. BERAN

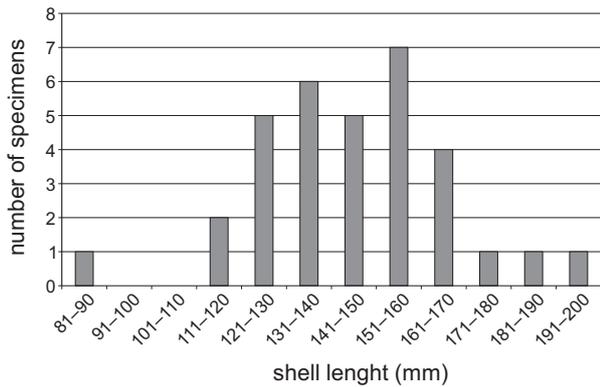


Fig. 4. Shell length of individuals of *S. woodiana* collected from 10 m²



Fig. 5. Individuals of *C. fluminea* collected from 1 m². Length of the biggest specimen 16.2 mm, length of the smallest specimen 3.9 mm. Photo: L. BERAN

15°43.32'E, Figs 1, 5, 6). The waterfall, ca. 4 m high, forms the border between the brackish and the freshwater sections of the river. Only two young individuals (less than 10 mm) were found during the routine faunistic survey. The occurrence was confirmed one year later (05.07.2020). *C. fluminea* was recorded in the sediment in a ca. 80 m long shallow section above the waterfall (see Fig. 6); the occurrence of live individuals was scattered except the place where *C. fluminea* was found in 2019. Altogether 42 specimens were collected from the sediment within an area of 1 m² at the depth of 50–70 cm, near the river bank. Smaller specimens dominated (Fig. 5). The largest shell was only 16.2 mm in length while the smallest specimen was 3.9 mm long. No empty shells were found in 2019 or 2020. Five other species (*Unio*

elongatulus, *Anodonta exulcerata*, *Pisidium amnicum*, *P. nitidum*, *P. subtruncatum*) co-occurred. The same site was visited in 2013 and 2015 and *C. fluminea* was not found. Above this short section the Zrmanja River is only slow-flowing and deeper, and *C. fluminea* had not been found there. It was not observed below the waterfall, in the brackish section where salinity varies from 2 PSU on the surface to 36 PSU at the bottom (FIKET et al. 2018). The species was not found in any other studied locality in the brackish or freshwater sections of the river (author's unpublished data, more than 20 localities between 2009 and 2020).



Fig. 6. The Zrmanja River at Jankovića Buk waterfall. Photo: L. BERAN



DISCUSSION

Sinanodonta woodiana was probably introduced to Europe with glochidia-infected Asian carps (KONEČNÝ et al. 2018). Its larvae successfully parasitise a wide spectrum of European fish species (DOUDA et al. 2012, HUBER & GEIST 2019) and develop more successfully than those of the native *Anodonta* species (HUBER & GEIST 2019). In the case of the oxbow of the Cetina River it is very likely that *S. woodiana* was introduced with infected fish. The population was abundant (at least hundreds of individuals), the largest mussel was 194 mm in length, so it is probable that *S. woodiana* was introduced more than 10 years ago. The oxbow is used by anglers, the species composition of its fish fauna differs from that in the river and it is likely that most of the fish have been introduced by anglers. It cannot be excluded that anglers from continental Croatia bring them as live bait and some of them survive. This possibility is invoked by LAJTNER & CRNČAN (2011) to explain finding of empty shells of *S. woodiana* on the shores of Lake Vrana (see Introduction). The diverse and abundant fish fauna combined with warmer stagnant water offers optimal conditions for development of the dense mussel population in contrast to the fast-flowing and colder main channel of the Cetina River with its smaller fish density. Although the population was abundant, no individuals smaller than 80 mm were recorded. The causes are not well known. In the case of the smallest individuals living in the sediment, the reason may be the fact that the sediment was not sieved. However, no individuals with shell length of less than 80 mm were documented. They may have occurred in other parts of the oxbow and were overlooked, or the reproduction was irregular. *C. fluminea* was found in the Zrmanja River above the Jankovića Buk waterfall. Because the species was not observed there during the previous visits in 2013 and 2015, no empty shells were found, and only small individuals were recorded, the invasion was probably detected in its early stage. The way of introduction remains unclear. The nearest known localities are situated in the Danube River basin, ca. 120–150 km away. The species was found only above the Jankovića Buk waterfall which forms the border between the brackish and the freshwater sections of the river and presents a barrier to dispersal. Except the Razovac reservoir, the river is not very popular for angling, the recreational cruises operate only in the brackish section, and *C. fluminea* was not found anywhere else, either in the freshwater or the brackish sections. An unintentional introduction, for example by tourists or divers, can be considered; the introduction may have been caused by birds, but the river is not an important route for bird migrations.

Abiotic factors in the freshwater section (ŠTAMBUK-GILJANOVIĆ 2003) correspond with the environmental limits mentioned in LUCY et al. (2012) and there are probably no barriers to further upstream expansion of this species. It can be assumed that *C. fluminea* can gradually overcome the barriers formed by the Razovac reservoir and waterfalls and its natural spread might be facilitated by local human activities (kayaking, rafting, angling, diving and other forms of recreation). The reason for its absence in the brackish section may be the high salinity at the bottom of the Zrmanja River (25–36 PSU) (FIKET et al. 2018) while the limit for the species is ca. 17 PSU (LUCY et al. 2012).

Croatian rivers and lakes in the Adriatic Sea basin are inhabited by diverse communities of aquatic molluscs with many endemic or endangered species (e.g. BERAN 2011, 2016, 2017, FROUFE et al. 2017). The invasion of *S. woodiana* and *C. fluminea* may cause negative changes in these communities.

S. woodiana can compete with the native unionids for food, increase resistance to glochidia in their potential fish hosts and serve as vector for introduction of new parasites and diseases (DONROVICH et al. 2017, LOPES-LIMA et al. 2017, DOUDA & ČADKOVÁ 2018). Compared to the native *Anodonta* species glochidia develop more successfully, metamorphose faster and these traits, together with faster growth and greater fecundity of *S. woodiana*, are likely to contribute to a competitive advantage over the native anodontines (HUBER & GEIST 2019). The spread of this species to rivers inhabited by autochthonous species would have a negative impact on their populations. *S. woodiana* has so far been found in only one oxbow of the Cetina River. No other unionids were detected in this oxbow and in the main channel of the Cetina River while other rivers (e.g. Zrmanja, Krka, Neretva) hold abundant unionid populations (BERAN 2011, 2016, FROUFE et al. 2017, author's unpublished data, LOPES-LIMA pers. comm.). For this reason it is important to avoid further spread of the Chinese mussel outside the existing locality. It is necessary to inform anglers about the occurrence of this species, for example in the form of information boards. Transfer of fish from the locality should be excluded, as well as transfer of *S. woodiana* (e.g. as live bait). The population of *S. woodiana* is now confined to the isolated oxbow but the possibilities of reducing it are limited. Methods of controlling the mussel are mentioned by DOUDA et al. (2016). Only regular collection of the mussels could be used in this case. However, it would only lead to a reduction of the species' abundance and not to its complete eradication.



C. fluminea is regarded as a non-native species which may endanger the native fauna or natural habitats (CEBULSKA & KRODKIEWSKA 2019, HAAG 2019). Due to its rapid growth, competition for food, earlier sexual maturity, short life span and high fecundity it may present a threat to other bivalves (SOUSA et al. 2008). On the other hand, the genus *Corbicula* is known from interglacial deposits of Europe (LOŽEK 1964, MEIJER & PREECE 2000) and is among the best-known interglacial molluscs in the Pannonian Plain (PAUNOVIĆ et al. 2007). These facts raise a question whether to consider the recent invasion of *Corbicula* in Europe as an introduction or as a natural reintroduction, albeit accelerated by human activities (PAUNOVIĆ et al. 2007). The molluscs of rivers and other freshwater (or brackish in the case of *C. fluminea*) habitats suitable for both species in the Adriatic part of Croatia have been intensively studied for more than a decade. Since 2009 I have visited more than 50 localities in the rivers Cetina, Krka, Krupa, Mirna, Neretva, Ričica and Zrmanja, lakes near Bačina and Lake Vrana (e.g. BERAN 2011, 2016, unpublished data, BERAN et al. 2013). Other scientists have also paid attention to freshwater molluscs of the area (LAJTNER & CRNČAN 2011, VUČKOVIĆ 2013). Nevertheless, these species have so far been found in only one locality each, while in the Danube River basin they are already common (PAUNOVIĆ et al. 2007, LAJTNER & CRNČAN 2011, BERAN 2013,

LAJTNER et al. 2016, ČUK et al. 2019, PETRAVIĆ et al. 2019, author's unpublished data). In the case of *C. fluminea* the probable reason is the fact that the species is very often introduced to new catchment areas with ballast water of big ships (e.g. KARATAYEV et al. 2007). However, the rivers in the Adriatic part of Croatia are short and with low flow, so the ships do not use their estuaries.

S. woodiana is mainly introduced with glochidia-infected fish (e.g. KONEČNÝ et al. 2018), and the introduction is facilitated by the wide spectrum of host species for glochidia in Europe (DOUDA et al. 2012, HUBER & GEIST 2019). In the Adriatic part there are much fewer waterbodies suitable for fish farming or intensive angling in comparison with the Danubian Croatia. These are the probable reasons why neither of the two species has become widespread yet in the Adriatic part of Croatia.

Due to the possible negative impact on the native mollusc communities it is advisable to monitor further spread of the two non-native species in the Adriatic part of Croatia.

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