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Rapid expansion of the Asian clam *Corbicula fluminea* (O. F. Müller, 1774): a new alien species in the mollusk community of the Vistula

by

Maciej Bonk, Katarzyna Zając*,
Anna M. Lipińska

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Institute of Nature Conservation,
Polish Academy of Sciences, ul. Mickiewicza 33,
31-120 Kraków, Poland

Abstract

A new large population of the Asian clam *Corbicula fluminea* (O. F. Müller, 1774) was found within a reach (ca 210 km long) of one of the largest European rivers, the Vistula. The largest population and the largest individuals were found at the outlet of a channel collecting heated water from the cooling process at the Połaniec power station and adjacent parts of the river. In the northern part of the study area, bivalves occurred at the channel margins, in groyne fields, and in the shallows of sand banks or sandbars. The clams were less numerous in places where the river was regulated with straightened banks and stone ripraps. Twenty-five other taxa of mollusks were found altogether at the sampling stations where *Corbicula* was observed, including other non-indigenous mollusk species.

Key words: invasive alien species; non-indigenous bivalves; Vistula River; thermal pollution; geographic distribution

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* Corresponding author: *kzajac@iop.krakow.pl*

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Introduction

Mussels and clams (Bivalvia) are among the most invasive animals in freshwater ecosystems (Francis & Chadwick 2012). They include *Corbicula fluminea* (O. F. Müller, 1774), regarded as one of the 100 most invasive species in Europe (Minchin 2009).

The species originates in Southeast Asia. Genetic studies imply that expansive strains are of hermaphroditic, androgenetic lineages with extremely low levels of genetic diversity (like clones) and originate in Japan (Pigneur et al. 2014). Currently, *C. fluminea* is widely distributed, including also other parts of Asia, North and South America, Europe, Africa (Counts 1981; Ituarte 1981; Morton 1986; Araujo et al. 1993; Glaubrecht et al. 2007; Pigneur et al. 2011; 2014; Crespo et al. 2015), and Australia, where it is known only from few records based on dead shells (Ponder et al. 2016). The place of origin of European populations is not clear, but it could be located in either North or South America (Pigneur et al. 2014).

In the 1980s, *C. fluminea* was detected for the first time in Europe, in Portugal and France (Mouthon 1981; Araujo et al. 1993; Sousa et al. 2007). In 1985, it was found in the Rhine in the Netherlands (Bij de Vaate & Greijdanus-Klaas 1990), and since then it has spread mainly to the north and east, occupying river basins in France, Spain, Germany, the Netherlands, Luxembourg, Switzerland, and Austria (Minchin 2009), as well as in Great Britain and Ireland (Howlett & Baker 1999; Aldridge & Müller 2001; Minchin 2014). Recently, *Corbicula* has spread from western to central Europe and has been reported from Italy, Bulgaria, Serbia, Romania, Moldova, Hungary, Poland, the Czech Republic, and Slovakia (Tittizer & Taxacher 1997; Csányi 1998–1999; Bij de Vaate & Hulea 2000; Beran 2000; 2006; Vrabec et al. 2003; Domagała et al. 2004; Paunović et al. 2007; Munjiu & Shubernetski 2010; Bódis et al. 2011; Ciutti & Cappelletti 2009; Maćkiewicz 2013; Hubenov et al. 2013), and even from the European Arctic region in Russia (Bespalaya et al. 2016).

The first record from Poland comes from the heated water of the Lower Oder channel (Domagała et al. 2004), where *C. fluminea* occurs together with very similar also expansive *C. fluminalis* (Łabęcka et al. 2005). Next, the spread of *C. fluminea* was noted upstream of the Oder River (Wawrzyniak-Wydrowska 2007; Piechocki & Szlauer-Łukaszewska 2013). In the Vistula, one empty *Corbicula* shell was found in the debris on a boulevard near Wawel Hill in Kraków after an extreme spate in July 2010 (R. Żurek, personal communication). In 2011, live specimens of *C. fluminea* were reported from the Vistula in Kraków by Maćkiewicz (2013), who suspected that the clams had been in the river at least since 2008. Recently, *C. fluminea* was also collected in the Vistula and two oxbows in Warsaw in 2016 (Romanowski et al. 2016). Until the end of the twentieth century, there were no records of *C. fluminea* from the Vistula River (Kownacki 1999).

It is suspected that the introduction and spread of *C. fluminea* are probably the result of human activities (edible for humans, souvenirs, fish bait, released from aquariums or ballast waters, or transported passively by means of byssal attachment to boat hulls; McMahon 1999; 2002; Lee et al. 2005). Additionally, *C. fluminea* can disperse using natural factors as larvae (pediveligers) and juveniles can be transported passively by water currents or aquatic birds (Prezant & Chalermwat 1984; McMahon 1999; 2002).

It can reach very high densities and biomass, causing a significant impact not only on the environment but also on the local economy (Sousa et al. 2009; Ilarri & Sousa 2012), for example large aggregations of clams can clog waterways and pipes or clams burrowing in gravel or sand, used in the production of cement, can compromise its quality (McMahon 1983). Some life history characteristics of *C. fluminea*, such as quick ontogenetic development and high fecundity, result in the rapid population growth and prolific dispersion to new sites, where it becomes a new food resource for other species (e.g. Sickel 1986; Ferreira-Rodríguez et al. 2017a). As a filter-feeder with a high filtration rate (Beaver et al. 1991), it affects freshwater ecosystems in both positive (e.g. water purification) and negative ways, e.g. by outcompeting native species (Strayer 1999; Sousa et al. 2008a; Ferreira-Rodríguez et al. 2017b) or being a vector for diseases and parasites (Graczyk et al. 2003).

This paper presents data on the recent extension of the *C. fluminea* range to the Vistula River. It offers a unique opportunity to document the course of the potential range extension and to compare the status of the mollusks before and after the extension, with a discussion on the related predictable threats and a review of the current knowledge.

Materials and methods

Observations and sampling were carried out from 2011 to 2016, between May and September. Identification of *C. fluminea* was based on *Corbicula* studies in Poland (Domagała et al. 2004; Łabęcka et al. 2005; Stańczykowska & Kołodziejczyk 2011) and other Mollusca species were identified based on the publication by Horsák et al. (2013).

At first, we explored the whole reach of the river from a motorboat (section between Tarnobrzeg and

Annopol; Fig. 1) and checked each large sand bar and sand island for the presence of *Corbicula*. Other sampling stations presented in Fig. 1 were accessed from the bank (sections between Opatowiec and Tarnobrzeg as well as between Annopol and Puławy; Fig. 1); we searched for empty shells and sampled the bottom sediment until we found live specimens, where we performed detailed sampling (sampling stations no. 1–27 in Fig. 1). For the bottom sampling, a dredge rake (0.385 m wide) with nylon netting (mesh size 3 mm) was used. Based on the local survey at each sampling station, we selected 6–7 sites with clams and then at each site, we took 3 adjacent and slightly overlapping bottom samples with the rake, each 1 m long. The whole sediment from an area of 1 m^2 (3 × 0.385 m × 1 m of the marked bottom area of 1 m^2) was sampled in this way to a maximum sediment depth of 0.2 m and a water depth of up to 0.5 m. In places where the use of a rake was impossible (large stones on the banks, stones, woody debris, vegetation, or numerous sticks within the sediment impeding sampling), we carefully searched sediment in analogous 1 m^2 areas with small rakes or fingers. In order to calculate *Corbicula* distribution within the river channel and to estimate its abundance in natural channel sections, individual bottom samples (0.385 m^2, n = 42) were collected at regular intervals (every 2 m) along three transects (Fig. 2) perpendicular to the banks of the Vistula channel, near the mouth of the tributary Sanna in September 2015 (sampling station no. 22 in Fig. 1; Table 1). At this location, the Vistula channel is characterized by anastomosis between many sand islands and forms extensive shallows and sand bars. Within these transects, the depth of water and the flow rate were measured with a Geopacks flow meter. We were unable to sample locations deeper than 2 m, due to the limitations of the method employed.

Each Corbicula individual in samples collected in 2016 (eight sampling stations shown in Fig. 3) was measured using a Vernier caliper to the nearest 0.1 mm. Individual body size was determined through the length of the shell (maximum antero-posterior axis).

Results

In the autumn of 2011, *Corbicula* sp. shells were found for the first time within the heated water drain of the Połaniec power station (sampling station no. 2; Table 1; Fig. 1) and adjacent banks of the Vistula River in Tursko Małe (sampling station no. 3; Table 1; Fig. 1). Subsequently, empty shells were found near the bank of the main channel, ca 100 m below the mouth of the heated water channel (50°26′27.58′′N; 21°22′40.71′′E; Fig. 1) and further downstream (50°26′34.63′′N; 21°22′3.82′′E; Fig. 1). The empty shells were usually well preserved and shell valves were connected with a ligamentum. *C. fluminea* shells predominated. On 23 and 24 January 2016, the occurrence of the living individuals and the identification of *C. fluminea* within this locality were confirmed.

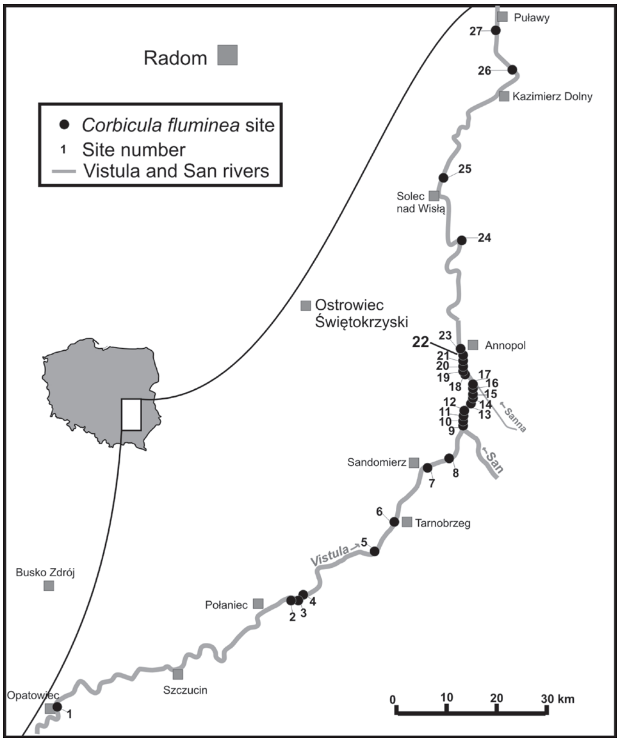

Figure 1

Distribution map of *Corbicula fluminea* sampling stations in the stretch of the Vistula River (ca 210 km long) between Opatowiec and Puławy. Sampling station no. 22 where samples were collected along the transects is indicated by a larger font size

Between 2012 and 2016, we confirmed the occurrence of the species at 27 sampling stations, distributed within a 210 km section of the Vistula River, where both empty shells and live individuals were found (Fig. 1; Table 1). Fewer clams were found within the regulated channel, where the Vistula was characterized by a stony and pebbly bottom: 2 individuals per m^2 at sampling station no. 1 and 6 individuals per m^2 at sampling station no. 6 (Fig. 1, Table 1).

Corbicula also occurred in large numbers in shallows on sand islands and sandbars spread over the riverbed of the Vistula channel, especially in the area near Kępa Chwałowska (samplings stations

Table 1

Occurrence of *Corbicula fluminea* in the stretch (ca 210 km long) of the Vistula River between Opatowiec and Puławy

Sampling station no.	Nearest locality name	Coordinates	Date of the first record/ density measurement	Number of samples	Mean density at occupied sites [ind. per m^2]	± SD	Description of sampling station
1	Opatowiec – ferry	50º14’23.93”N 20º43’41.25”E	9 February 2016 9 February 2016	7	2.0**	± 1.63	the left bank of the Vistula above the ferry route in Opatowiec, muddy-gravel bottom, regulated river channel
2	Połaniec – heated water drain	50º26’34.63”N 21º22’3.82”E	1 September 2011 3 September 2016		74.4	± 16.46	the left bank of the channel with stone lining, discharging heated water from the power plant
3	Tursko Małe – the Vistula below the mouth of the power station channel	50º26’27.58”N 21º22’40.71”E		6	142.0**	± 46.89	the left bank of the Vistula with stone lining, ca 100 m below the mouth of the channel discharging heated water from the power plant, bottom covered with stones
4	Niekurza	50º26’22.57”N 21º23’41.92”E	3 September 2016 3 September 2016		6694.5**	± 1458.21	the firth between the groyne field on the left bank of the Vistula opposite of the Wisłoka mouth, muddy-sandy bottom
5	Tarnobrzeg (Siarkopol) – bridge	50º31’15.65”N 21º36’11.98”E	9 February 2016 9 February 2016		37.0	± 10.32	sandy shoal in the river channel under the bridge (national road number 9)
6	Ciszyca – ferry	50º34’22.33”N 21º39’27.11”E			6.0	± 3.58	the left bank of the Vistula at the groyne field, muddy-gravel bottom
7	Sandomierz – bridge	50º40’29.93”N 21º45’26.34”E	7 June 2014 2 September 2016	7	1.9	± 1.77	
8	Kamień Łukawski	50º41’2.85”N 21º48’8.85”E	6 June 2014 2 September 2016		6.0	± 2.0	sand banks or sandbars and shoal water in the river channel
9	Kępa Chwałowska – sandbar 1	50º45’36.2”N 21º50’30.1”E	25 May 2012 2 September 2016	6	107.2	± 8.52	
10	Kępa Chwałowska – sandbar 2	50º45’48.2”N 21º50’41.9”E			84.2	± 14.03	
11	Kępa Chwałowska – sandbar 3	50º45’57.99”N 21º50’47.85”E	11 June 2014 2 September 2016		108.3	± 93.39	
12	Kępa Chwałowska – sandbar 4	50º46’6.43”N 21º50’55.06”E			84.8	± 37.93	
13	Winiary	50º46’48.1”N 21º51’24.1”E	25 May 2012 1 September 2016		23.3	± 8.09	
14	Popowice – sandbar 1	50º47’13.9”N 21º51’44.13”E	17 June 2014 1 September 2016		19.0	± 2.61	
15	Popowice – sandbar 2	50º47’30.5”N 21º51’36.6”E	25 May 2012 1 September 2016	7	16.0	± 7.53	
16	Popowice – sandbar 3	50º47’53.07”N 21º51’42.34”E	17 June 2014 1 September 2016	6	16.3	± 12.75	
17	Zawichost – ferry	50º48’20.77”N 21º51’48.66”E			11.5	± 1.97	the firth between groyne fields on the left bank of the Vistula, muddy-sandy bottom
18	Piotrowice – landing	50º50’18.73”N 21º50’22.62”E	6 June 2014 1 September 2016	7	11.9	± 3.39	the left bank of the Vistula at the groyne field, muddy-gravel bottom
19	Piotrowice – passage on road 759	50º50’37.94”N 21º50’26.05”E		6	10.8	± 5.12	
20	Opoka Duża – sandbar 1	50º51’8.62”N 21º50’41.53”E	8 May 2014 1 September 2016		12.5	± 3.94	sand banks or sandbars and shoal water in the river channel
21	Opoka Duża – sandbar 2	50º51’31.46”N 21º50’58.17”E	11 June 2014 1 September 2016		20.3	± 8.24	
22	Opoka Duża – sandbar 3	50º52’3.77”N 21º50’54.96”E	11 June 2014 11 June 2014	42*	17.8**	± 16.74	
23	Annopol – bridge	50º52’55.95”N 21º50’9.04”E	11 July 2014 1 September 2016	6	11.5	± 5.13	the firth between groyne fields on the right bank of the Vistula, muddy-sandy bottom
24	Józefów	51º 2’32.29”N 21º49’37.14”E	2 September 2016 2 September 2016	7	4.0**	± 2.16	the side channel on the right bank of the Vistula
25	Kłudzie – ferry	51º 9’17.90”N 21º46’46.02”E		6	88.0**	± 11.93	the left bank, gravel bottom, *Corbicula* in sand under a layer of gravel and small stones
26	Nasiłów – ferry	51º21’11.56”N 21º58’55.90”E	3 September 2016 3 September 2016		24.0**	± 4.15	sandbar on the left bank of the Vistula
27	Puławy	51º24’38.38”N 21º56’33.03”E			2.8**	± 1.72	the left bank of the Vistula at the groyne field, sandy bottom

* bottom samples (3 × 0.385 m × 1 m of the marked bottom area of 1 m^2) ; ** density and shell length measured in 2016 and shown in Fig. 4.

nos 9–23, 25, and 26; Figs 1 and 3; Table 1): from 10.8 individuals per 1 m^2 (SD = 5.12, n = 6) at site no. 19 to 108.3 individuals per 1 m^2 (SD = 93.39, n = 6) at site no. 11. The distribution of clams within the habitat of sand bars and islands near the Sanna river mouth (sampling station no. 22) shows that shallow riffle channels between the sandbars or islands occupy the whole cross section of the channel. At sampling station no. 22, clams were found in the channel with sandy bottom and the water flow rate ranging from 0.11 to 0.58 m s^{-1} (Fig. 4) at a depth from 5 cm to over 1 m. There was no significant relation between water depth (on average 0.25 m, SD = 0.190) and the number of clams in samples collected along the transect

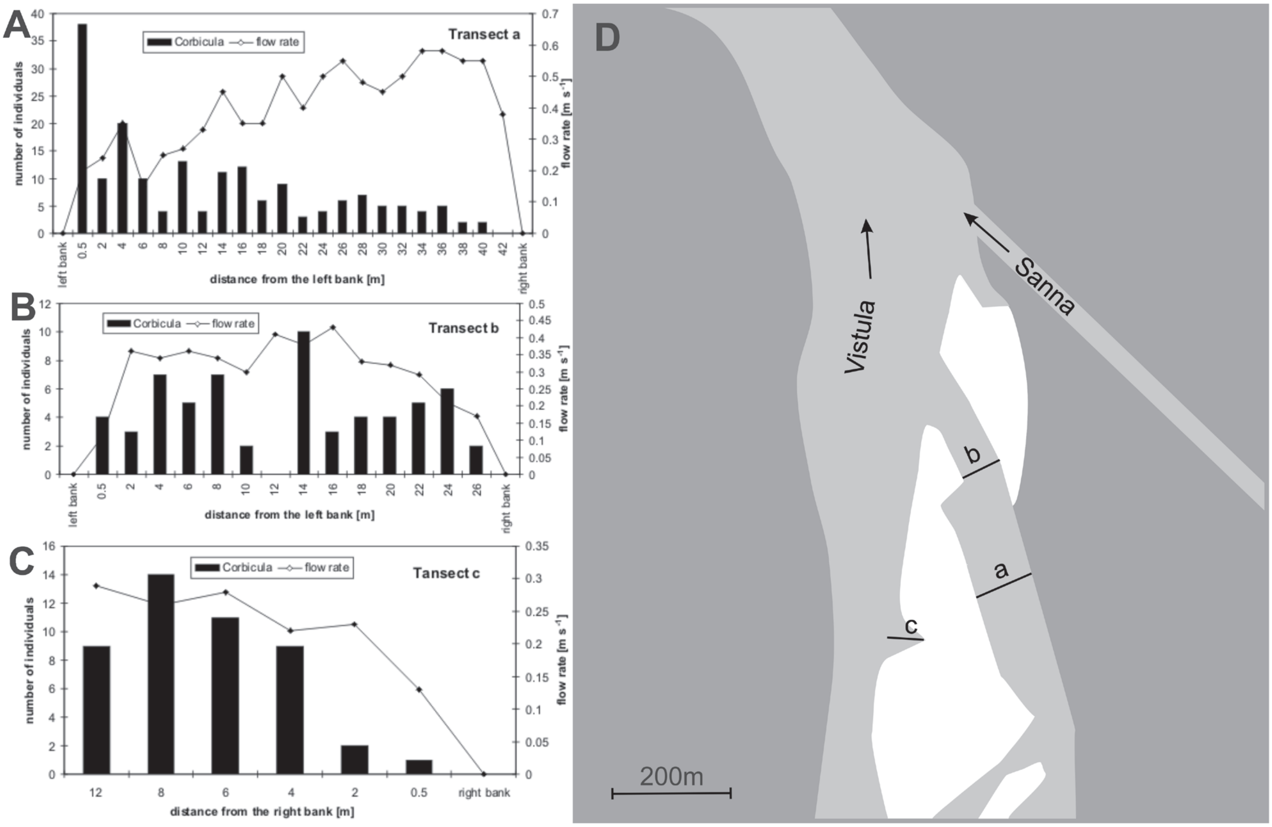

Figure 2

Distribution of *C. fluminea* along the transects in the Vistula channel at sampling station no. 22

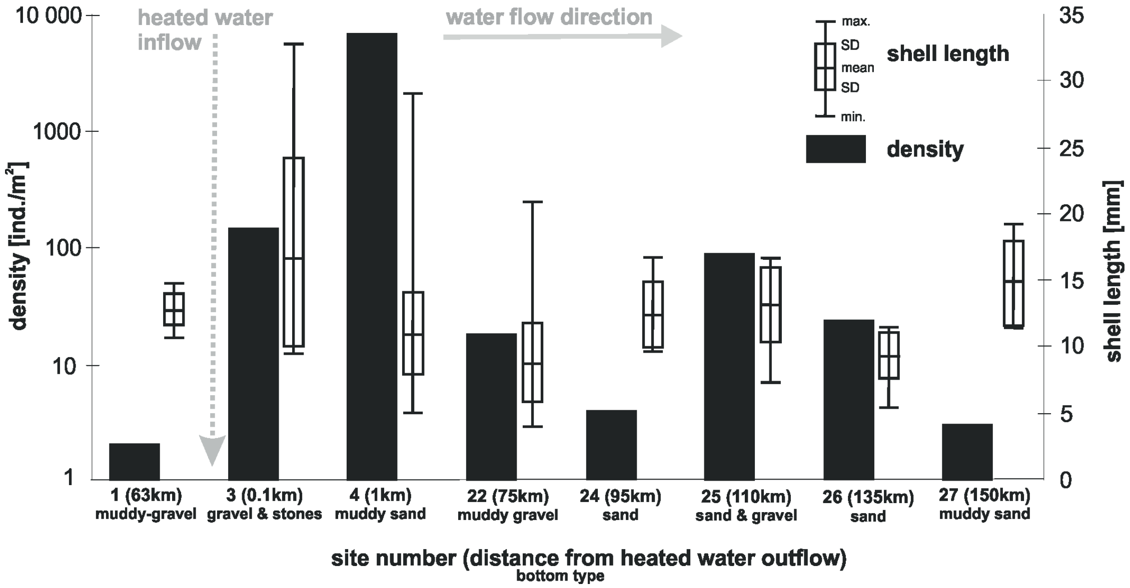

Figure 3

Density (ind. m^{-2}) and the maximum shell length (mm) of *C. fluminea* at eight sampling stations in the Vistula depending on the distance (km) from the mouth of the power plant channel with heated water lines (data pooled for all transects: $r_s = -0.16$, n = 42, *p* = 0.323). The main Vistula channel also features slopes of islands or sandbars. In this unregulated reach of channels characterized by anastomosis, sampled in a regular manner along transects perpendicular to the bank, we recorded a mean density of 17.8 individuals per 1 m^2 (SD = 16.74, n = 42). At sampling station no. 3 (0.1 km from the Połaniec power station's drain outflow, but with a stony bottom), the mean density at the occupied sites was much higher (142 individuals per 1 m^2, SD = 46.9, n = 6), whereas at sampling station no. 4 (1 km from the Połaniec power station's drain outflow with heated water, but with a sandy bottom), the mean density at the occupied sites was 6694.5 individuals per 1 m^2 (SD = 1458, n = 6) (Fig. 3, Table 1).

The largest individual body sizes were found in heated waters in an artificial channel near the power plant in Połaniec (maximum shell length 38 mm; sampling station no. 2). The maximum shell length of large individuals from the next two sampling stations, no. 3 and 4, was 32.9 mm (mean 17.0 mm, SD = 7.08, n = 34; Fig. 3) and 29.0 mm (mean 10.9 mm, SD = 3.11, n = 232; Fig. 3), respectively. At sandy-bottomed sampling station no. 22, with the natural thermal regime of water, the maximum shell length of individuals was much shorter (21 mm), and most of the individuals were shorter than 10 mm (mean 8.7 mm, SD = 2.91, n = 288; Fig. 4).

During the search for *Corbicula*, other mollusk species were found: 15 species of freshwater snails and 10 species of bivalves (Table 2). Within the surveyed reach, other non-indigenous species were also recorded, including some not listed yet from this stretch of the Vistula: *Dreissena polymorpha*, *Potamopyrgus antipodarum*, and *Sinanodonta woodiana*. The first two were previously recorded relatively far from the study area, in the lower Vistula (Kownacki 1999), with *P. antipodarum* found also

Table 2

Checklist of Mollusca species recorded in the studied reach of the Vistula River

No.	species	previous studies (Kownacki 1999: the reach of the river from Kraków to Warszawa)	the current study (2012–16): the reach of the river from Opatowiec to Puławy, and Maćkiewicz 2013: the Vistula in Kraków (in brackets)
GASTROPODA			
1	*Viviparus viviparus*	+	+
2	*Potamopyrgus antipodarum*	–	+ (+)
3	*Valvata piscinalis*	+	+
4	*Bithynia sp./Bithynia tentaculata*	+	+ (+)
5	*Physella acuta*	+	+
6	*Lymnaea stagnalis*	+	+
7	*Galba truncatula*	+	+
8	*Radix auricularia*	+	+
9	*Radix balthica*	+	+
10	*Planorbis planorbis*	+	+ (+)
11	*Bathyomphalus contortus*	+	+
12	*Anisus vortex*	+	+
13	*Gyraulus albus*	+	+
14	*Planorbarius corneus*	+	+
15	*Ancylus fluviatilis*	+	+
BIVALVIA			
16	*Anodonta anatina*	+	+ (+)
17	*Unio pictorum*	+	+
18	*Unio tumidus*	–	+
19	*Unio crassus*	+	+ (+)
20	*Corbicula fluminea*	–	+ (+)
21	*Dreissena polymorpha*	–	+
22	*Sinanodonta woodiana*	–	+
23	*Pseudanodonta complanata*	+	–
24	*Anodonta cygnea*	+	+
25	*Sphaerium corneum*	–	+ (+)
26	*Pisidium* sp.	–	+
Total number of taxa		19	25

"+" - indicates species present; "–" - indicates species absent

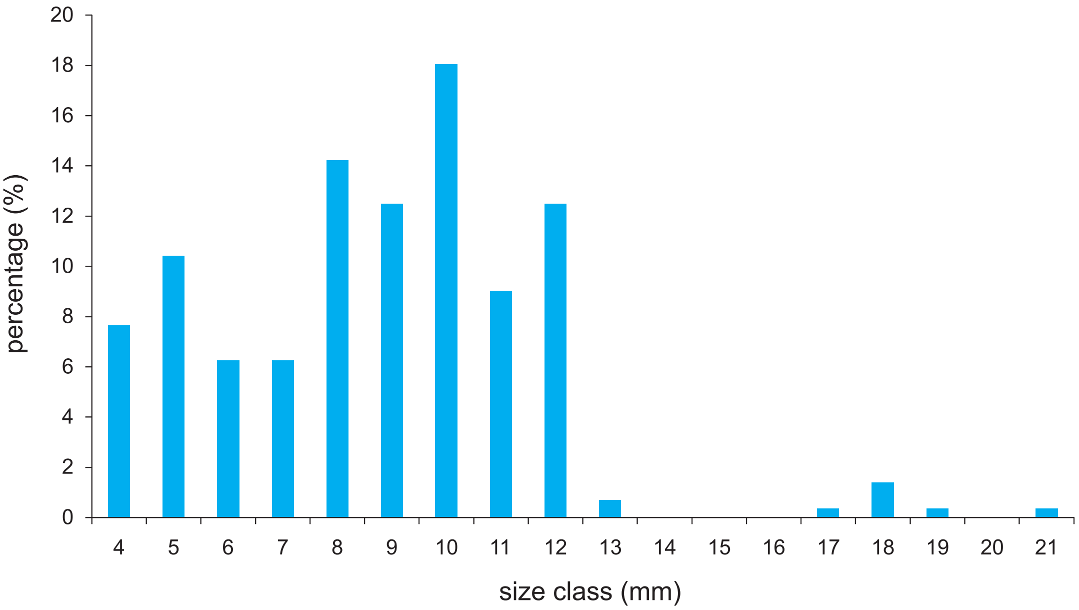

Figure 4

Percentages of *C. fluminea* in size classes in the Vistula channel near the Sanna river mouth (sampling station no. 22; clams were grouped into shell length classes differing by 1 mm); mean 8.7 mm, SD ± 2.91, n = 288

in the reach in Kraków (Maćkiewicz 2013), whereas *S. woodiana* has never been found in the river before. Only one snail species regarded as non-indigenous and known from the Vistula for decades, *Physella acuta*, still occurs in the river.

Discussion

This new population of *C. fluminea*, found in the ca 460 km Vistula reach (including 210 km from Opatowiec to Puławy), stretching from Kraków (Maćkiewicz 2013) to Warsaw (Romanowski et al. 2016), has existed since at least 2008. The earlier spread of this species in the Oder River was characterized by a similar progress: the first observations of the clams were carried out in 2003 in the Lower Oder channel, in the heated water drain from the power station (NW Poland; Domagała et al. 2004; Stańczykowska & Kołodziejczyk 2011). Similarly, during the first few years after the first recording of its presence, a large number of individuals was found in a long stretch of the Oder channel (Wawrzynak-Wydrowska 2007; Piechocki & Szlauer-Łukaszewska 2013; Cebulska & Krodkiewska 2017). In the lower and middle course of the Oder, *C. fluminea* occurs together with *C. fluminalis* (Łabęcka et al. 2005; Kołodziejczyk & Łabęcka 2011; Piechocki & Szlauer-Łukaszewska 2013). However, to date, the latter species has not been recorded within the studied reach of the Vistula.

The population of *Corbicula*, found during this study, is located over 80 km from the first known individual record of this species in the Vistula in Kraków. Due to its high dispersal ability that may exceed 100 km per year (Bij de Vaate 1991), the species can colonize most of the river's course in just a few years. The direction of expansion is not significant, because the rapid spread of this clam may be boosted by the transport of gravel and sand along the river by barges.

The question about the source of the expansion remains unanswered. It is rather unlikely that the Vistula was invaded from the Oder River. This and other species of *Corbicula* are bred as ornamental pets in aquariums, and we suspect that this is the most likely source of dispersion, assuming it starts in cities. It is suspected that the larvae of this species could be a component of plankton in the water used for transport of fish to breeding devices set up for commercial purposes in discharge canals (Domagała et al. 2004; Stańczykowska & Kołodziejczyk 2011). Fish, including alien species, are quite often released into heated waters to control the rapid growth of submerged vegetation. Therefore, this source of expansion cannot be excluded.

Although the source of the expansion has not been identified, it should be noted that the first individuals of *C. fluminea* in the Vistula were recorded in the warm waters of the Połaniec power station channel (2011) and in the regulated river channel in a big city

(Kraków, in 2008). Warm waters may facilitate initial stages of invasion for species less adapted to local climates. They may also be an effective refuge during harsh winters, enabling colonization when climate conditions become favorable (Panov et al. 2009; Müller & Baur 2011; Simard et al. 2012; Yanygina 2017). The Vistula River basin lies in the climate zone of Central Europe, under the significant influence of continental climate characterized by long winter periods of frost, which might be one of the factors limiting the spread of *Corbicula*. Winter die-offs have been reported – for most populations, 2°C is the lower temperature limit (McMahon 1983). According to Müller & Bauer (2011), some individuals, especially larger ones (> 15 mm in length), can survive 9 weeks at 0°C. While *C. fluminea* has also been found in water with a typical Polish temperature regime, heated water may accelerate the ontogenetic development of individuals, because they inhabit water no cooler than 2°C for extended periods of time (Mattice & Dye 1976) and produce much more larvae during warm winters (Weitere et al. 2009). It appears that low water temperatures and ice formation during winter have limited the northern distribution of this species (Crespo et al. 2015). Recently, however, *Corbicula* has spread north in heated water produced by power plants (Simard et al. 2012; Bespalaya et al. 2016). The short life cycle (up to two overlapping generations per year; Sousa et al. 2008a) of this species may result in its mass occurrence in some areas, however, this enormous fecundity may also affect the downstream reaches of the Vistula and thus may facilitate the dispersal.

In Central Europe, the maximum recorded body size of *Corbicula* (in unmodified thermal regimes) was smaller than in the south and west of the continent, e.g. ca 21 mm in Poland (this study) and 16 mm in Hungary (Bódis 2007), compared to ca 30 mm in the Minho (Portugal; Sousa et al. 2008b), 28 mm in the Thames (England; Elliott & zu Ermgassen 2008), and 25 mm in the upper Rhine (Schmidlin & Baur 2007). These differences may be related to size-dependent mortality (Zając 2014), however, the most likely explanation is the effect of temperature: both due to accelerated ontogenetic growth and/or earlier onset of reproduction resulting in a more advanced developmental stage and thus the body size of the young of the year. The individuals found in the heated water of the Połaniec power station were over 30 mm long, whereas in the semi-natural river channel with floating sands, the maximum shell length was 21 mm, and most clams were smaller than 13 mm (Fig. 4). Similar differences between artificially heated (35–40 mm) and unmodified waters (16 mm) were reported from the Danube by Bódis et al. (2007, 2011).

Not only is the shell size of *Corbicula* smaller in the Vistula in unmodified conditions than in heated water, but clam density is also much lower (Table 1, Fig. 3). The density of *C. fluminea* can be extremely variable between the study sites. For example, the mean abundance per site in the Minho River in Portugal ranged from 80 (2004) to 4185 (2005) individuals per 1 m^2 (Sousa et al. 2008b), in the Altrhein River (near Basel) – from 1–50 in the upper parts of the river to 200–600 individuals per 1 m^2 (Schmidlin et al. 2012) and in the Hungarian stretch of the Danube, the density varied from 736 (Bódis 2007) to 5000 individuals per 1 m^2 (Csányi 1998–99). The reason for such differences is not only the water temperature (Sousa et al. 2008b). It seems that the hydraulic conditions can be an important factor in the Vistula, because the distribution of the species varied in the channel cross sections (Fig. 2), despite the fact that its individuals occur in the whole channel.

According to the studies conducted to date, it should be expected that the expansion of *Corbicula* may cause a series of significant ecological and economic effects (Sousa et al. 2009; Ilarri & Sousa 2012). They probably cause some native populations to decline, while others seem to coexist with this species (e.g. Gardner et al. 1976, Kraemer 1979, Leff et al. 1990, Strayer 1999, Yeager et al. 1999). In the Rhine, the abundance of the native gastropod *Ancylus fluviatilis* (O. F. Müller, 1774) has decreased after *C. fluminea* expansion. This could partly be a result of competition between *A. fluviatilis* and *C. fluminea* for space and food (Schmidlin 2004). Ferreira-Rodríguez et al. (2017) discovered that the native bivalve *Unio delphinus* is characterized by reduced growth, reduced physiological condition, and increased locomotor activity (likely searching for a competitor-free habitat) at higher densities of *C. fluminea*.

The impact of *Corbicula* on native species could be confounded with other non-indigenous species (Leuven et al. 2009), including co-occurring alien snails and bivalves: *P. antipodarum*, *P. acuta*, *D. polymorpha* and *S. woodiana* (Table 2). The published results of the research show the negative impact of the two snail species on the native fauna (Spyra et al. 2015; Zukowski & Walker 2009). Numerous papers report the negative impact exerted by *D. polymorpha* on the native freshwater fauna including mollusks (e.g. Hebert et al. 1991; Sousa et al. 2011; 2014; Bódis et al. 2014; Krebs et al. 2015), whereas there is no direct evidence for the negative impact of *S. woodiana* on native mollusks (but see Cappelletti et al. 2009). Some negative effects can be expected in the lower course of the Vistula from the newcomer bivalve *Rangia cuneata* (G. B. SowerbyI, 1831) that prefers brackish waters near the Vistula mouth (Warzocha & Drgas 2013; Janas et al. 2014).

The occurrence of *C. fluminalis* and other alien species in the Vistula should be considered an important nature conservation challenge in Poland. The potential strong and negative synergies of these dispersions should be carefully monitored to identify measures capable of mitigating any expected negative effects in the Vistula, one of the largest unmodified rivers of Europe.

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