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AN INVASION IN PROGRESS – *SINANODONTA WOODIANA* (LEA, 1834) (BIVALVIA: UNIONIDAE) IN POLAND

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Abstract: We summarise the current knowledge about the Polish population of the Chinese pond mussel. At least 53 locations of the Chinese pond mussel have been confirmed in Poland taking into consideration a literature survey and our own research data comprising new unreported sites. *S. woodiana* is mostly present in fish ponds (69.8%) but for the last few years it has been discovered in lowland rivers, canals and wetlands, too. Considering these population figures the current data about the distribution of *S. woodiana* seem to be underestimated. The spreading rate described in the literature and already available knowledge about *S. woodiana*'s biology and its resistance to the environmental conditions indicate that the species should be consider as a really risky invasive species. We suggest that monitoring of *S. woodiana* presence and abundance should be conducted.

Key words: alien species, Chinese pond mussel, distribution, freshwater mussel

INTRODUCTION

Invasive alien species have been recognised by "The EU Biodiversity Strategy to 2020" (European Commission 2011) as one of the greatest direct threats to European nature. Alien species predate, hybridise with, parasitise, and out-compete a wide range of native European taxa and, as a result, reduce biodiversity, threaten native species, increase the number of endangered species, and alter ecosystems across the majority of continents (Hulme 2007). Human activities in aquaculture and trade promote both the intentional and accidental spread of species across their natural dispersal barriers that has been happening for decades (Anderson et al. 2014).

The Chinese pond mussel *Sinanodonta woodiana* (Lea, 1934) provides a good example of the invasion process. This species has spread on a large scale all over the world. Its natural range lies in Asia and the species appeared in Europe and in America mostly due to the transport of farmed fishes (Watters 1997a, b). In Europe it was first discovered in fish farms in Romania in 1979 (Sárkány-Kiss 1986). Chinese pond mussels in Poland probably first appeared in the 1980's in thermal polluted waterbodies and it has already expanded significantly and quickly in recent years. On 9th September 2011 an ordinance was issued by the Ministry of Environment in Poland that concerns the list of plants and animals of alien species which can threaten native species or natural habitats if released to the environment. Among 52 species, the Chinese pond mussel is also named. The *S. woodiana* population has expanded in Poland due to many favourable factors of anthropogenic and environmental origin that have resulted in the growth of local *S. woodiana* populations and the number of locations where this species has been recorded. Every year new reports of the occurrence of the Chinese pond mussel in Poland are published. The first colonisation traces (empty shells) of *S. woodiana* in Poland were reported by Böhme (1998). The first stable population in Poland was recorded by

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Zdanowski (1996) who discovered it in reservoirs with elevated water temperature coming from the Konin power plant in western Poland. In 1992 it was discovered that this mussel could get settled even in water basins of natural thermal regime (Mizera & Urbańska 2003) and had appeared in fish ponds much earlier (Urbańska et al. 2012).

In addition to the reports about new locations, several types of research have been already conducted to investigate the populations of *S. woodiana* in Poland and their impact on the ecosystem. These include morphological characteristics (Afanasiev et al. 2001, Soroka & Zdanowski 2001, Kraszewski 2006a, b, Andrzejewski et al. 2012a, Eszer et al. 2016), reproduction potential (Soroka 2000, Labecka 2009, Labecka & Domagała 2018, 2019), habitat preferences (Kraszewski & Zdanowski 2001a, b, 2007, Spyra et al. 2012, 2016, Andrzejewski et al. 2013), density indices, population distribution (Domagała et al. 2003, 2007, Kraszewski 2007, Urbańska et al. 2012, 2013, Urbańska & Andrzejewski 2014, Szlauer-Łukaszewska et al. 2017), resistance in relation to different stress pollutants as well as variability at the genetic level (Soroka & Zdanowski 2001, Soroka 2005, 2010, Soroka et al. 2014). Natural enemies – oystercatcher (*Haematopus ostralegus*), white-tailed eagle (*Haliaeetus albicilla*), wild boar (*Sus scrofa*), red fox (*Vulpes vulpes*), musk rat (*Ondatra zibethicus*) and otter (*Lutra lutra*) (Andrzejewski et al. 2012b, Wojton et al. 2012, Urbańska et al. 2013, Romanowski & Winczek 2017), as well as fouling rates by *Dreissena polymorpha* on *S. woodiana* in relation to native species (Dzierżyńska-Białończyk et al. 2018, Urbańska et al. 2018) and parasites and symbionts of the Chinese pond mussel (Yuryshynets & Krasutska 2009, Cichy et al. 2016) have been also analysed because it allows determining interactions and conditions that affect the rapidity of its spread. Additionally, the research conducted in Poland in recent years also considered elements accumulation ability of *S. woodiana* (Królak & Zdanowski 2001, 2007, Królak et al. 2007), genotoxic potential (Woźnicki et al. 2004) and qualitative and quantitative characterisation of mussel protein preparation (MPP) obtained by electrophoretic separation and differential scanning calorimetry (DSC) (Konieczny et al. 2016, Stangierski et al. 2018). In this paper we summarise the data on the distribution of *S. woodiana* in Poland.

METHODS

We take into consideration many sources including the literature survey (scientific papers as well as popular press), internet resources browsing the scientific databases as Google Scholar, Research Gate and Mendeley using key words like "*woodiana*", "Chinese Pond Mussel", "freshwater mussels", "large mussels", "distribution" (also in Polish spelling) as well as regular, active, annual participation in the "National Carp (*Cyprinus carpio*) Breeders Conference" through a presentation of the results combined with an appeal for providing information about the observed mussels to the Institute of Zoology, Poznań University of Life Sciences. A short questionnaire was developed and 250 surveys were distributed personally among fishermen, farm pond owners, fish breeders and anglers and were sent to "Przegląd Rybacki" ("Fisherman Review") subscribers in 2014. 27 questionnaires have been returned. All information was confirmed at the source each time. The research has been performed in natural and artificial reservoirs of flowing or standing water. In some cases, we directly investigated the substrate when water levels were lowered in reservoirs for operational reasons.

RESULTS

We confirmed the presence of *S. woodiana* at 53 localities (Fig. 1). The list and basic information of known locations of *S. woodiana* in Poland is shown in Table 1. *S. woodiana* in Poland is mostly present in fish ponds (69.8%), it has also occurred in rivers (17%). The other populations were found in canals (3 sites), power plant cooling systems (2 sites), oxbow and artificial reservoir (one site each). However, it is expected that this number is underestimated because the research about freshwater bivalve molluscs is done by only a few scientific centres in Poland.

DISCUSSION

In Poland the early stages of *S. woodiana* expansion were found in ponds (Urbańska et al. 2012). For last few years it has also occurred in rivers – including the biggest ones like the Odra and the

Table 1. Known locations of *Sinanodonta woodiana* in Poland

No.	Site name	Ecosystem type	Geographic coordinates	References
1	Konin lakes and canals	cooling system of the Konin power plants	52°28'49"N, 16°10'27"E	Zdanowski 1996, Kraszewski 2007, Afanasiew et al. 2001
2	Narew	river	52°50'31"N, 21°26'42"E	Böhme 1998, Marzec 2016
3	Samita	pond	52°35'28"N, 15°56'39"E	Mizera & Urbańska 2003, Cichy et al. 2016
4	Canal Dolna Odra	cooling system of the power plants	53°12'24"N, 14°27'53"E	Domagała et al. 2004
5	Czesławicki	pond	51°29'00"N, 17°33'15"E	Gąbka et al. 2007, Cichy et al. 2016
6	Międzyodrze	canal	53°25'30"N, 14°35'29"E	Domagała et al. 2007
7	Czarny Młyn	pond	54°48'30"N, 18°17'57"E	Ożgo et al. 2010
8	Kasprzyca (Mnich)	canal	49°52'58"N, 18°50'08"E	Urbańska et al. 2011
9	Nowy Spytkowicki	pond	50°00'12"N, 19°47'53"E	Najberek et al. 2011
10	Wojnowice	pond	51°56'34"N, 16°42'52"E	Urbańska et al. 2012, Andrzejewski et al. 2013, Cichy et al. 2016
11	Parkowy and Rychlik (Góra)	pond	49°57'42"N, 19°06'52"E	Spyra et al. 2012
12	Maciek Kanałowy (Goczałkowice Zdrój)	pond	49°55'54"N, 18°58'10"E	Spyra et al. 2012
13	Budy Głogowskie	ponds	50°09'38"N, 21°51'36"E	Wojton et al. 2012
14	Trzebinia	pond	nd	Przełom.pl 2012
15	Stobrawski Park Krajobrazowy	pond	50°52'50"N, 17°51'48"E	Zespół Opolskich Parków Krajobrazowych 2012
16	Zgliniec	pond	53°07'14"N, 15°36'03"E	Urbańska et al. 2012, 2013
17	Dolna Postomia	river	52°34'33"N, 14°39'12"E	Domagała et al. 2013
18	Miejsce, Oko, Krajskie	oxbow	50°00'55"N, 19°30'48"E	Zając et al. 2013
19	Przeręb near Zator	pond	50°00'58"N, 19°24'12"E	Najberek et al. 2013
20	Duży (Białowąs)	pond	53°50'06"N, 16°15'11"E	Andrzejewski et al. 2013
21	Moryś	pond	53°01'35"N, 22°14'07"E	Andrzejewski et al. 2013
22	Żydowski	pond	52°51'35"N, 16°06'09"E	Andrzejewski et al. 2013
23	Wędkarski (Bogucin)	pond	52°26'06"N, 17°01'15"E	Andrzejewski et al. 2013
24	Trzęsina	pond	50°45'17"N, 18°03'23"E	Andrzejewski et al. 2013
25	San	river	nd	Garnek.pl 2013
26	Urocze Średnie/Żary	pond	51°19'17"N, 15°16'18"E	Andrzejewski et al. 2013, Cichy et al. 2016
27	Jedynka Nowy/Polna Rzeka	pond	51°17'16"N, 20°25'20"E	Andrzejewski et al. 2013, Cichy et al. 2016
28	Oko/Zaklików	pond	50°45'53"N, 22°08'16"E	Andrzejewski et al. 2013, Cichy et al. 2016
29	Wisła, Żerań	river	52°17'49"N, 20°59'02"E	Romanowski & Winczek 2016, Chmielewski et al. 2017
30	Smogulec (Noteć valley)	pond	53°04'08"N, 17°18'25"E	Waldon-Rudzionek & Rudzionek 2016
31	Ostrówek (Noteć valley)	ponds	53°06'11"N, 17°20'49"E	Waldon-Rudzionek & Rudzionek 2016
32	Piegza	pond	50°39'19"N, 18°38'40"E	Spyra et al. 2016
33	Łąki, Chłupska, Rajski (Dębowiec)	ponds	49°53'01"N, 18°59'49"E	Spyra et al. 2016
34	Zębowo (Obrowo)	pond	53°00'20"N, 18°56'22"E	Pozatorun.pl (2016)
35	Andrychów	pond	49°51'15"N, 19°20'38"E	Wadowiceonline.pl 2016
36	Nowy Lipsk	pond	53°45'06"N, 23°18'37"E	Urbańska et al. 2016
37	Odra near Kostrzyn	river	52°35'50"N, 14°36'46"E	Szlauer-Łukaszewska et al. 2017

Table 1. continued

No.	Site name	Ecosystem type	Geographic coordinates	References
38	Bajerki	pond	49°47'35"N, 18°51'04"E	Bonk & Bobrek 2017
39	Łazy	pond	49°48'51"N, 18°52'46"E	Bonk & Bobrek 2017
40	Wadowice (Tomice)	pond	49°53'41"N, 19°29'47"E	Bonk & Bobrek 2017
41	Zbiornik Włocławski	artificial water reservoir in the Vistula river	52°37'04"N, 19°24'28"E	Bonk & Bobrek 2017
42	Puszcza Knyszyńska	pond	nd	Wyborcza.pl (2017)
43	Wisła – Kozienice	river	51°40'06"N, 21°28'05"E	Chmielewski et al. 2017
44	Wisła – Wólka Dworska	river	52°01'11"N, 21°13'27"E	Chmielewski et al. 2017
45	Soła near Rajsko	river	50°00'44"N, 19°12'00"E	Cios S. pers. comm. 2017
46	Kwileń	pond	51°59'16"N, 17°50'49"E	Żurawlew 2018
47	Poryte (Zambrów)	pond	53°02'00"N, 22°12'35"E	unpublished data
48	Gorzyń	canal	52°33'42"N, 15°52'51"E	unpublished data
49	Pogórze	pond	49°48'00"N, 18°50'26"E	unpublished data
50	Stobno	pond	53°39'21"N, 17°50'04"E	unpublished data
51	Staw Bąków (Olesno)	pond	50°57'18"N, 18°18'43"E	unpublished data
52	Staw Czyściec (Ciasna)	pond	50°44'20"N, 18°36'48"E	unpublished data
53	Główna (Wierzenica)	river	52°27'27"N, 17°04'08"E	unpublished data

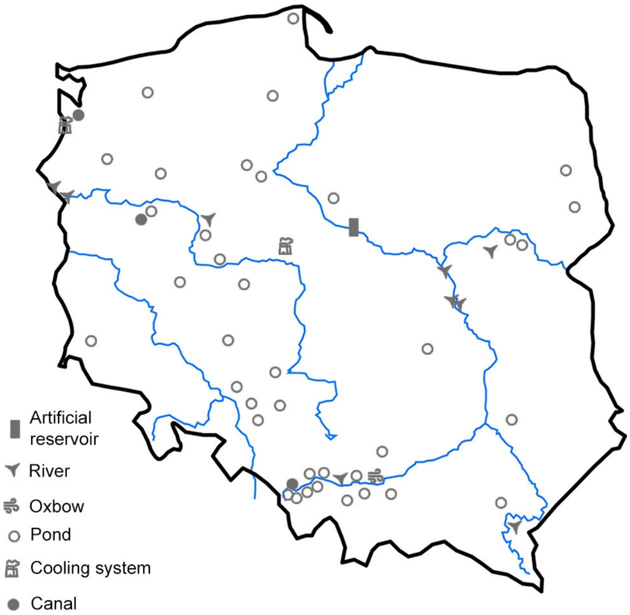

Fig. 1. Confirmed sites of *Sinanodonta woodiana* occurrence in Poland

Warta. In other countries including Croatia, Italy and the Czech Republic it occurs mainly in lowland rivers (Paunovic et al. 2006, Lajtner & Crnčan 2011, Andrzejewski et al. 2013). It means that both ponds and rivers are important water reservoirs for the spread of this species. In recent years more and more locations have been found on the protected areas (e.g. Mizera & Urbańska 2003, Ożgo et al. 2010, Domagała et al. 2013, Zając et al. 2013, Urbańska & Andrzejewski 2014) and also where *S. woodiana* coexists with native bivalve species (e.g. Najberek et al. 2011, Wojton et al. 2012, Zając et al. 2013, Urbańska et al. 2016, Szlauer-Łukaszewska et al. 2017). In the literature, there are reports of noticeable changes in the mussel communities after introduction of the species (Urbańska et al. 2019). Fabbri & Landi (1999) reported that *A. anatina* has been replaced almost completely by *S. woodiana* in some channels with soft substrate and high trophic level. Benko-Kiss et al. (2013), for Lake Balaton, compared data from 2011 to the distribution of unionids measured in 1992/1993. The impact of *S. woodiana* seemed high and concerned many species. For example *A. cygnea* has been replaced by *S. woodiana* and the species ratio of *A. anatina* was reduced from 17% to 8%. That is why further increase in population size (and dominance) can be expected in the future. In 2002, Niero (2003) noted the exclusive presence of *S. woodiana* in a channel with a high trophic level located in Venezia province where a high density of *A. anatina* (up to 10 adult specimens per square meter) was recorded in 1987. Native species reduction could result from competition for the host fish because of greater infestation capacity of *S. woodiana*'s glochidia (Watters 1997a, b, Fabbri & Landi 1999, DOUDA et al. 2012, 2017a). DOUDA et al. (2017b) demonstrated that the metamorphosis success rate of *A. anatina* glochidia was strongly reduced on fish hosts that had been previously exposed to *S. woodiana*. Such cross-resistance may decrease significantly the quality of the host resources available to native mussels and consequently may lead to reduction of species population. The spread of *S. woodiana* may also be the result of its high growth ratio and reproductive potential (POU-ROVIRA et al. 2009, LABECKA & DOMAGAŁA 2018) as well as overall stress-tolerance measured by biochemical markers such as cholinesterase enzyme activity (CORSI et al. 2007). The Chinese pond mussel has also a much higher tolerance of hypoxia than native species (SÎRBU et al. 2005). Cyanobacterial blooming has a small influence on this invasive species (DU et al. 2011). Moreover, it has been shown that low temperature of water does not always restrict reproduction (DOMAGAŁA et al. 2004), as originally believed. Larger shells are often found closer to water sources flowing into lakes because water in such places ensures better oxygenation and carries more biomass that constitutes the food consumed by bivalves (URBAŃSKA et al. 2012, ANDRZEJEWSKI et al. 2013). Finally, there are human actions that contribute to spreading of the mussels. It results from transport of farmed fishes (which can be infected by parasitic *S. woodiana* larvae) and even a commercial trade of specimens that are used in garden ponds to filter water. For example the idea to use mussels as the element of garden ponds cleaning systems were promoted in popular TV program in Poland (TVN 2018) (where *S. woodiana* was wrongly named *A. anatina*), and these mussels were often sold on the local markets and even abroad, e.g. 20,000 individuals from Konin Canals were ordered by garden shops in Germany few years ago (MOKRZYCKI H. pers. comm. 2016). *S. woodiana* as a large mussel with amber-brown colour of the shell seems more attractive than native species for many people. Moreover, it is often confused with native species so people do not consider it problematic.

As mentioned above the *S. woodiana* population has expanded in Poland recently because there are many anthropogenic factors supporting its current spread. Fish farming has become more extensive, rendering it more likely to introduce this species to other places. Analysis of the invasion history and genetic structure of *S. woodiana* in Europe (KONEČNÝ et al. 2018) suggests that the process of adaptation was initiated by repeated translocations across Europe. Cold-tolerant *S. woodiana* populations in Europe do not originate from a new invasion source but likely evolved in Europe and started occupying mussel-suitable habitats and threaten native species of mussels (KONEČNÝ et al. 2018).

Given the current status of *S. woodiana* in Poland it is recommended to collect data on new sites as well as to monitor already known mussel communities to estimate the spreading rate, the species' biology as well as habitat characteristics determining its occurrence and reproduction. Such detailed data may allow predicting the consequences of its presence and finding methods limit its further invasion (FERREIRA-RODRÍGUEZ et al. 2019). It is especially important to know how to protect native mussel species from *S. woodiana* negative impacts.

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