Original Research

Invasion of *Fallopia* Genus Plants in Urban Environment

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Abstract

Biological invasions are one of the main problems of contemporary ecology. When considering invasive species a special attention should be paid to Asian weeds of *Fallopia* genus (knotweeds): *Fallopia japonica*, *Fallopia sachalinensis,* and their hybrid – *Fallopia* × *bohemica*, which is the most troublesome species among the *Fallopia* complex. The aim of this research was to determine distribution of three *Fallopia* taxa in urban environments using the example of the one of the largest Polish cities, Wrocław, and preferences of the examined species regarding their inhabiting different habitats in urban ecosystems. The presence of knotweeds was confirmed in over 23.0% of urban areas. The most commonly recorded species was *Fallopia japonica*, while *Fallopia sachalinensis* (a donor of pollen for female clones of *Fallopia japonica*) was rare. Despite this fact, their highly invasive hybrid occurs in approximately 6.8% of urban areas and accounts for 21.6% of the total number of all knotweed clones. It suggests that expansion of *Fallopia* × *bohemica* in the city advances, in most cases, in a vegetative way (as a result of rhizome regeneration).The highest number of knotweed sites was recorded in ruderal and greenfield sites, including, among others, illegal waste dumps, heaps, rubble, and debris fields. The investigation has shown that in urban conditions knotweeds are able to spread on soil with various pH ranges and nutrient content. Also, the higher content of heavy metals does not limit the expansion of *Fallopia* weeds – on the contrary, it can even enhance their competitiveness in relation to other plant species, which avoid toxic concentrations of heavy metals.

Keywords: biological invasion, *Fallopia japonica*, *Fallopia sachalinensis*, *Fallopia* × *bohemica*, urban ecosystem

Introduction

Biological invasions are one of the main problems of contemporary ecology and they are recognized as a significant component of global changes connected with human activity [1]. Susceptibility of ecosystems to the expansion of invasive species is connected with their ecological properties. The percentage of alien species found in a given habitat also depends on the number of species introduced (propagule pressure) [2]. Urban ecosystems are especially prone to biological invasions. The development of infestation with invasive species is an uncontrolled process, as far as human pressure on the natural environment is concerned. Extending the range of plant migration routes (roads, highways, tramways, railways) or urban parks and gardens, as well as garden allotments, are just a few examples of human activity that fosters plant invasions [1, 3].

Considering invasive species, special attention should be paid to Asian weeds of *Fallopia* genus. Its representatives belong to the most expansive plants that can currently be found in the whole area of Europe, North America, and Australia, as well as in New Zealand [4]. It is supposed that

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specific ecological characteristics of cities can facilitate spreading of species of *Fallopia* genus [5]. This phenomenon gives rise to a number of questions connected with knotweed ecology, which allows them to thrive in urban ecosystems.

The aim of our research was to determine of the distribution and current pace of invasion of three taxa of *Fallopia* genus in the area of Wrocław, and preferences of the examined species regarding their different habitats in urban conditions.

Materials and Methods

Study Area

Fieldwork was conducted in southwestern Poland, in the area of Wrocław, which is the fifth largest city in Poland at 293 km^2. The research of knotweeds was carried out using the method of landscape mapping. The basic research area involved regularly distributed plots 1,000 m × 1,000 m, which were plotted on map backgrounds. The representatives of *Fallopia* genus were inventoried using a GPS receiver. In every examination square we calculated the number of clusters and clone areas of *Fallopia japonica*, *Fallopia sachalinensis*, and *Fallopia × bohemica*. Then, taking into account land use regime, the habitats of species of *Fallopia* genus were classified according to the following types: residential area (with one- or multi-level buildings), urban green habitats (lawns, parks, green spaces, squares, and public parks), ruderal and greenfield sites (illegal waste dumps, heaps, rubble, and debris areas), service and industrial areas (including public houses), roadsides and stretches of railway, and urban riparian habitats. To determine preferences of particular species for specified types of habitats a percentage share of knotweed clones and the areas occupied by them were estimated. The final stage of work consisted in collecting soil samples from 10 randomly chosen locations of *Fallopia japonica* and *Fallopia × bohemica*, from a depth of 0-15 cm, for chemical analyses. In the case of *Fallopia sachalinensis,* soil samples were collected from 3 objects considering seldom occurrence of this species in the urban area.

Identification of the Species

The objects of research were three invasive species of *Fallopia* genus (Polygonaceae): *Fallopia japonica* var. *japonica* (Houtt.) Ronse Decraense, *Fallopia × bohemica* (Chrtek et Chrtková) J.P. Bailey, and *Fallopia sachalinensis* (F.W.Schmidt ex Maxim.) Nakai. Despite extensive research on invasive *Fallopia* species (knotweeds), there still exist a number of vague ideas regarding the nomenclature and taxonomic classification of these plants. In this research, classification and nomenclature according to Bailey and Stace [6] was taken on, as the genus name *Fallopia*, according to recent molecular research, seems to be more appropriate than the one used by Czech [7, 8] or Polish [9-11] (*Reynoutria*) scientists.

Identification of species was based on morphological features of leaves (shape, size, hairiness of leaf blade) [12], which were collected from the medium part of a shoot. In the case of the hybrid – *Fallopia × bohemica* we conducted additional cytological examination in order to determine the number of chromosomes. To this end the method by Bailey and Stace [6] was followed. Because of considerable morphological similarity of some *Fallopia × bohemica* clones to parental species (especially to *Fallopia japonica*), the number of chromosomes is regarded as a crucial, decisive feature enabling distinguishing of these species [12]. In Europe a single genotype of *Fallopia japonica*, with only female flowers, has been found [13-16], and it is exclusively octoploid, characterizing 88 chromosomes [8, 13]. *Fallopia × bohemica* clones are genetically diverse, but most of them are hexaploid, of 66 chromosomes [17]. All specimens of *Fallopia × bohemica* originating from Wrocław possessed 66 chromosomes.

Soil Analyses

Soil samples collected from 23 sites were dried at room temperature in conditions providing protection against contamination. The soil material was crushed in a mortar, sieved (sieve of 2 mm mesh), and ground in an agate mill. Then, determination of exchange acidity of soil, active acidity of soil, the content of C and N, the content of available forms of potassium, and phosphorus and magnesium took place. We also determined the contents of selected heavy metals (Cd, Cr, Cu, Pb, Zn), after previous mineralization of soil samples in a pluggable terminal block, with the use of concentrated acids mixture of HCl and HNO_3 in 3:1 voluminous ratio.

Results

Distribution of *Fallopia* Genus in Wrocław

The research area was divided into 340 experimental plots. The presence of three *Fallopia* species was confirmed in 79 plots, i.e. in over 23.0% of urban area. The most commonly recorded taxon in Wrocław was *Fallopia japonica*, which provided for 73.2% of all knotweeds. That species was found in 53 squares, i.e. 15.6% of the research area. Locations of *Fallopia japonica* were spread throughout Wrocław, except for its northern and most western parts. On 1 km^2 of the examined area we found from 2 to 4 clones of this species (Fig. 1). Nearly half of *Fallopia japonica* clusters constituted clumps of the area from 10 to 40 m^2. The most widespread and dense aggregations of this species (exceeding 200 m^2) were found in 7 out of 53 research plots. The mentioned species agglomerations were, first of all, in the central and western, i.e. the most industrialized, parts of Wrocław (Fig. 2).

The second of the examined species – *Fallopia sachalinensis* occurs sporadicaly and accounts for merely 5.2% clones of all knotweed plants. It was recorded only in three out of 340 research plots (less than 1% area of the city), in southern, western, and eastern parts of Wrocław. Clusters of *Fallopia sachalinensis* featured density from 2 to 4, as well as from 5 to 10/ km^2 (Fig. 3). Rarely occurring in Wrocław specimen of *Fallopia sachalinensis* form large agglomerations as far as their area is concerned. In the western and southern parts of the city we recorded clones whose area did not exceed the range of 40-200 m^2. In the eastern part of Wrocław we found high and dense agglomerations occupying more than 200 m^2 (Fig. 4).

Despite the small number of *Fallopia sachalinensis* sites, regarding its role as a donor of pollen for exclusively female clones of *Fallopia japonica*, specimens of interspecific hybrid – *Fallopia* × *bohemica* could be relatively often found in the research area. Aggregations of this species provided for 21.6% of knotweed clones and they were recorded in 23 research plots, i.e. on approximately 6.8% of urban area. A hybrid was most frequently met in the central and western parts of Wrocław, usually accompanying *Fallopia japonica* clones, shaping common, dense phytocenoses. The density of *Fallopia* × *bohemia* clusters (number of clusters per 1 m^2 in research plots) was the same as the density of *Fallopia japonica*. Typically, on 1 km^2 from 2 to 4 clusters of *Fallopia* × *bohemica* occurred (Fig. 5). Agglomerations of *Fallopia* × *bohemica* showed slight diversity concerning their share of particular research areas. The highest number – 7 plots – were occupied by the smallest patches, whose area did not exceed 10 m^2. Clones measuring 10-40 m^2 and those of 40-200 m^2 area were recorded in 5 research plots. The largest agglomerations, measuring more than 200 m^2, occurred in 6 out of 23 squares. They were localized in the western, central, and southern parts of Wrocław (Fig. 6).

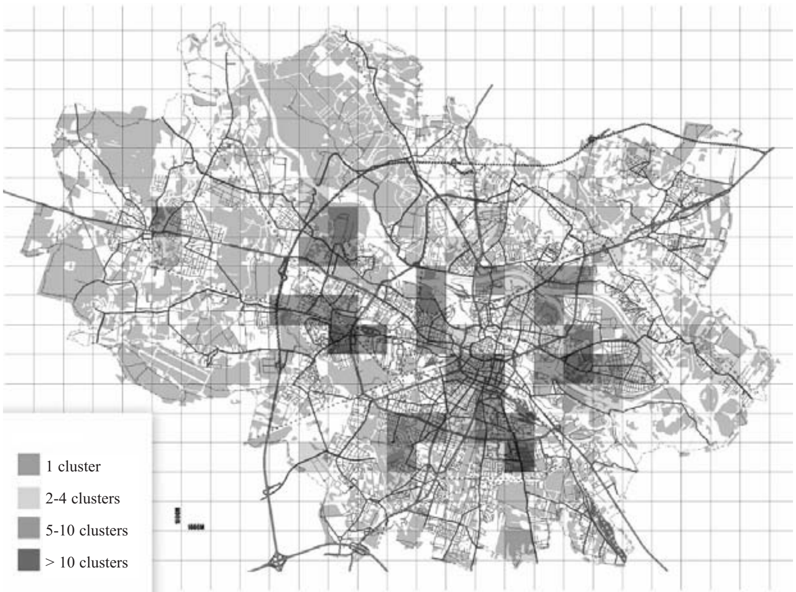

Fig. 1. Density of *Fallopia japonica* clusters in urban conditions of Wrocław city (number of clusters/1 km^2).

Fig. 2. Area of *Fallopia japonica* clusters in urban conditions of Wrocław with a division of class size (m^2/1 km^2).

Types of Habitats Invaded by Knotweeds in Urban Conditions

Considering the land use regime in Wrocław, we distinguished four types of *Fallopia* species habitats. The percentage share of knotweeds in particular types of habitats was shown in Figs. 7 and 8, taking into account the number of clones and their area.

The highest number of *Fallopia japonica* clusters was recorded for residential areas (26.0% of total urban area) and in ruderal and greenfield sites (20.7% of total urban area). The first of the mentioned areas included relatively small, highly dispersed clones. It seems that expansion of *Fallopia japonica* is in its early stage in those areas. In ruderal and greenfield sites, *Fallopia japonica* formed compact and large-surface clusters, accounting for 22.6% of the area occupied by that species. Similarly compact and widespread aggregations of *Fallopia japonica* were located on the waterfront, mainly along the Odra River. Their area provided for 51.4% of total urban area. The smallest number of *Fallopia japonica* sites was found in urban green habitats.

Among habitats most often occupied by *Fallopia × bohemica*, ruderal and greenfield sites were dominant (41.8% of total urban area). In riparian habitats *Fallopia × bohemica* was rarely found, while clones of interspecific hybrid formed large patches there and their share amounted to 45.4% of total urban area. As in the case of *Fallopia japonica*, the smallest number of *Fallopia × bohemica* sites was recorded in urban green habitats.

The presence of *Fallopia sachalinensis* was confirmed in three out of six distinguished types of habitats: in ruder-

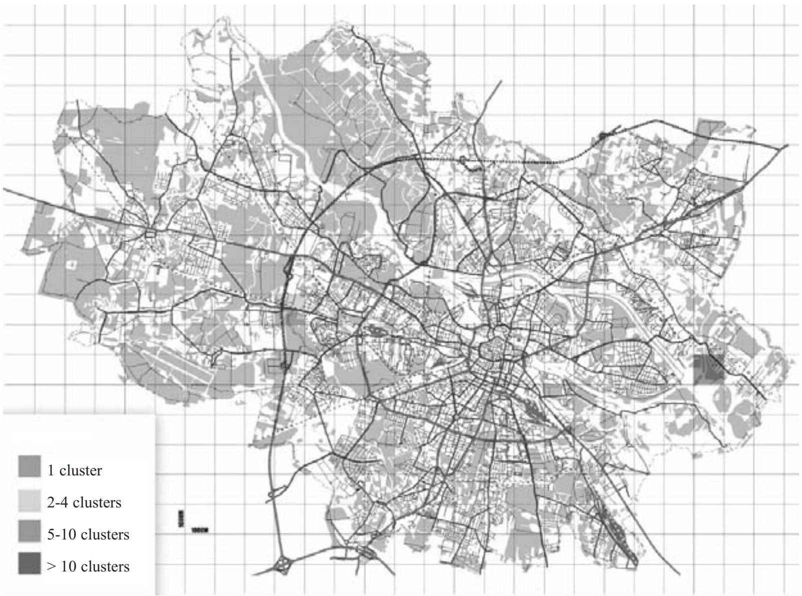

Fig. 3. Density of *Fallopia sachalinensis* clusters in urban conditions of Wrocław city (number of clusters/1 km^2).

Fig. 4. Area of *Fallopia sachalinensis* clusters in urban conditions of Wrocław with a division of class size (m^2/1 km^2).

al and greenfield sites (75%), in berms and stretches of railway (18.8%), and on the waterfront (6.2%). The largest surface, measuring 43.6% of total area of *Fallopia sachalinensis* clones, was occupied by clusters growing along roadsides and stretches of railway. The smallest site surface (covering 17.5% of total area occupied by knotweeds) was recorded for residential areas.

Characteristics of Urban Soils Overgrown by Knotweeds

Select chemical properties of collected soils samples from 23 knotweed sites were shown in Tables 1 and 2. Soil analyses proved that the species of *Fallopia* genus occur on soils featuring a wide range of reaction – from acid, through slightly acid, to basic. Moreover, these soils characterize very high content of available forms of P, K, and Mg (up to 129.5 mg P_2O_5·100 g^{-1}, 127.0 mg K_2O·100 g^{-1}, and 35.0 mg MgO·100 g^{-1}), as well as considerable total C and N content. In the soils subjected to analysis, the widest range of total C and N belong to samples originating from *Fallopia* × *bohemica* sites. The content of C ranged from 1.10% up to 14.48%, while N content amounted from 0.03% to 0.42%.

A characteristic feature of urban environment is soil contamination with heavy metals. Trace elements, whose level in urban conditions often exceeds threshold standard values, are Cd, Cr, Cu, Zn, and Pb. In soil material, higher than natural content values were determined for cadmium, chromium, copper, lead, and zinc. The highest amount featured zinc and lead, whose mean values ranged from 448.8 mg Zn·kg^{-1} and 216.3 mg Pb·kg^{-1} (*Fallopia* × *bohemica* sites) to 413.7 mg Zn·kg^{-1} and 105.9 mg Pb·kg^{-1} (*Fallopia japonica* sites), as well as 237.7 mg Zn·kg^{-1} and 45.1 mg Pb·kg^{-1} (*Fallopia sachalinensis* sites).

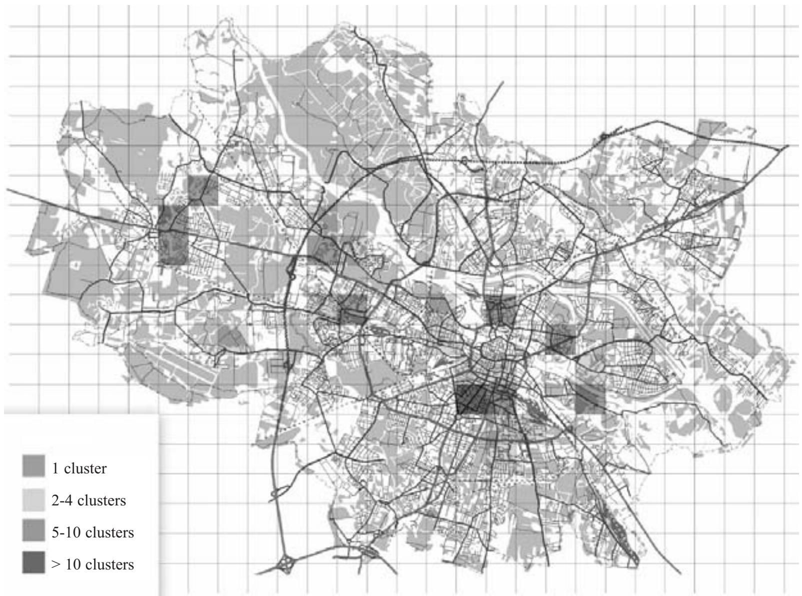

Fig. 5. Density of *Fallopia* × *bohemica* clusters in urban conditions of Wrocław city (number of clusters/1 km^2).

Fig. 6. Area of *Fallopia* × bohemica clusters in urban conditions of Wrocław with a division of class size (m^2/1 km^2).

Discussion

Urban flora in central Europe characterize a significant number of non-native species, especially kenophytes (neophytes) [3]. Among them a large group are invasive species [11], which are responsible for considerable losses in the natural environment due to biological invasion [18].

In urban conditions of Wrocław, three invasive species of *Fallopia* genus were subjected to investigation: *Fallopia japonica* var. *japonica* (Houtt.) Ronse Decraense, *Fallopia × bohemica* (Chrtek et Chrtková) J.P. Bailey, and *Fallopia sachalinensis* (F.W.Schmidt ex Maxim.) Nakai.

Species of *Fallopia* genus were introduced from East Asia into Europe in the 19th century and they have become destructive and aggressive weeds in a short amount of time [8]. Currently, *Fallopia* taxa is spreading around all of Europe (for instance in: Great Britain, Czech Republic, Germany, France, Poland) [8, 13, 17].

Among all species the most numerous in the area of Wrocław proved to be *Fallopia japonica*, while the least numerous was *Fallopia sachalinensis*. Similar tendencies regarding distribution of *Fallopia japonica* and *Fallopia sachalinensis*, can be observed in other parts of Europe (Great Britain, the Czech Republic, Germany), where the dominant species is *Fallopia japonica* var. *japonica*, while *Fallopia sachalinensis* was definitely less often recorded [8, 12, 19]. In the Czech Republic, out of a total number of knotweed sites (which equals 1982), 68% belong to *Fallopia japonica* and 13% to *Fallopia sachalinensis* [8]. In Wrocław, however, the share of *Fallopia japonica* amounts to 73.2% of all clones of this species, while *Fallopia sachalinensis* provides for merely 5.2%.

In invasive range the *Fallopia* species is spread mainly by a vegetative way, but they also show sexual reproduction by hybridization, which is known as a rapid mechanism for increasing genetic variation and provides the natural selection [20, 21]. Newly created hybrids often tend to have greater fitness, size, stronger competition abilities, and increased aggression [21]. Also, hybridization between widespread *Fallopia japonica* and *Fallopia sachalinensis* creates a very troublesome hybrid – *Fallopia × bohemica*. The occurrence of the hybrid in a particular areas constitutes a serious threat to local flora. *Fallopia × bohemica* features the best regeneration abilities among all knotweed species [22, 23], characterized by higher expansiveness than parental species [8], and it is also the most difficult to control [24]. In Wrocław, despite a small number of *Fallopia sachalinensis* clones – serving as a donor of pollen for

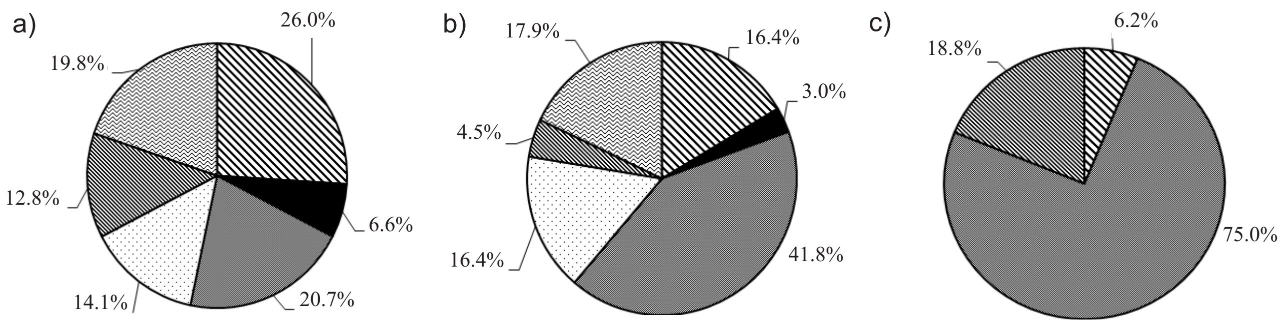

Fig. 7. Percentage share of knotweeds (a. *Fallopia japonica*, b. *Fallopia × bohemica*, c. *Fallopia sachalinensis*) in particular types of habitats taking into account the number of clones.

residential area (with one – or multi – level buildings), urban green habitats (lawns, parks, green spaces, squares and public parks), ruderal and greenfield sites (illegal waste dumps, heaps, rubble and debris areas), service and industrial areas (including public houses), road sides and stretches of railway, urban riparian habitats

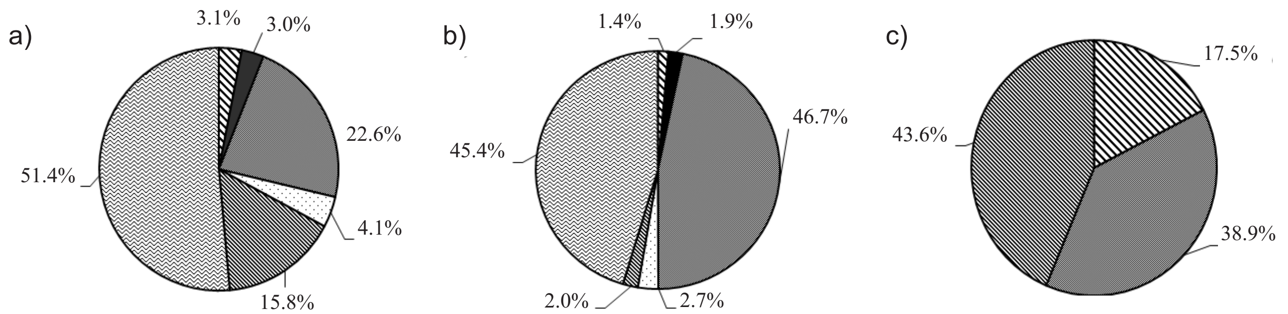

Fig. 8. Percentage share of knotweeds (a. *Fallopia japonica*, b. *Fallopia × bohemica*, c. *Fallopia sachalinensis*) in particular types of habitats taking into account their area.

residential area (with one – or multi – level buildings), urban green habitats (lawns, parks, green spaces, squares and public parks), ruderal and greenfield sites (illegal waste dumps, heaps, rubble and debris areas), service and industrial areas (including public houses), roadsides and stretches of railway, urban riparian habitats

Table 1. Chosen chemical properties of soil samples from the Wrocław area (sites of *Fallopia japonica*, *Fallopia × bohemica*, and *Fallopia sachalinensis*).

Chemical properties of soil samples	pH KCl	pH H_2O	N total %	C total %	C/N	K_2O	P_2O_5	Mg
Fallopia japonica								
Average	6.9	7.2	0.2	4.4	18.7	44.0	51.3	11.9
Minimum	6.1	6.9	0.1	2.1	6.8	11.5	22.1	6.2
Maximum	7.3	7.5	0.4	11.3	30.7	127.0	129.5	19.2
Standard deviation	0.4	0.4	0.1	2.6	7.9	32.7	33.3	5.0
Coefficient of variation [%]	5.6	4.0	33.9	60.0	42.4	74.4	65.0	41.8
Fallopia × bohemica								
Average	6.9	7.1	0.16	4.80	24.89	34.5	33.4	13.0
Minimum	5.4	6.0	0.03	1.10	10.64	21.4	12.4	3.6
Maximum	7.9	8.0	0.42	14.48	53.63	59.7	58.5	35.0
Standard deviation	0.8	0.6	0.1	4.3	14.1	12.0	16.5	9.7
Coefficient of variation [%]	11.0	8.3	68.0	89.5	56.7	34.7	49.6	74.4
Fallopia sachalinensis								
Average	7.2	7.5	0.14	2.5	17.7	41.8	26.0	10.6
Minimum	7.0	7.3	0.05	1.2	13.5	32.6	15.7	5.3
Maximum	7.7	7.8	0.24	3.2	25.0	57.7	39.5	14.1
Standard deviation	0.4	0.3	0.10	1.2	6.4	13.9	12.2	4.6
Coefficient of variation [%]	5.6	3.5	63.3	47.3	36.1	33.2	46.9	44.0

female clones of *Fallopia japonica*, specimens of *Fallopia × bohemica* occur quite numerously, accounting for 21.6% of the total number of knotweed clones. It proves that expansion of *Fallopia × bohemica* in the examined area advances, in most cases, vegetatively (as a result of rhizome regeneration). The presence of young shoots of *Fallopia × bohemica* in the vicinity of wild waste dumps, heaps and rubbles, indicates that human activity favors the spread of knotweed hybrid in the Wrocław area. It is probable that fragments of *Fallopia × bohemica* rhizomes are transferred with the soil from one part of the city to another.

Both within the range of natural (primary) and secondary geographic distribution, knotweeds show preferences to grow in anthropogenic habitats [8, 12]. The most common sites of their occurrence are along roads, highways, railways, on waste dumps, in rubble and embankments, as well as along river banks. As it results from our research, a similar situation takes place in Wrocław, where all species of *Fallopia* genus prefer ruderal habitats, as well as those which are significantly disturbed sites due to human activity. The highest number of knotweed sites was recorded in greenfield ruderal sites, including, among others, wild (illegal) waste dumps, heaps, and rubble.

Knotweeds, especially *Fallopia japonica,* often occur in the areas of intensive residential development, although they form not large, highly dispersed clones. Rapid development of cities such as Wrocław, accompanied by spontaneous occurrence of rubble and waste heaps, fosters fast spreading of species from *Fallopia* genus. The area in the vicinity of a newly built sports stadium can serve as an example – in 2011, on newly-formed soil heap, there were recorded *Fallopia × bohemica* sites. Previous observation did not confirm the presence of this species.

Suburban wetlands and riparian habitats are eagerly covered by the species of *Fallopia* genus. In Wrocław, in those types of habitats, clusters of *Fallopia japonica* were most commonly recorded. The highest number of sites belonging to this species can be found along the banks of the Odra River. Aggregations of *Fallopia japonica* are also accompanied by clones of *Fallopia × bohemica*. Both species develop compact phytocenoses in waterfront of the Odra River.

Urban green areas, as well as parks and gardens with frequently introduced exotic plants as ornamentals, are regarded as significant centers of spreading invasive species. Yet in Wrocław, in urban green areas (lawns, parks, green squares, and green spaces) the smallest number of representatives of *Fallopia* genus were localized. Aggregations of knotweeds are often mowed and observation proved that regular treatments considerably reduced the growth and expansion of *Fallopia* species in those areas. Also, Wrocław parks do not play an important role in

Table 2. Heavy metal content in soil samples from Wrocław area (sites of *Fallopia japonica*, *Fallopia* × *bohemica*, and *Fallopia sachalinensis*).

Heavy metal content [mg·kg^{-1}]	Cd	Cr	Cu	Pb	Zn
Fallopia japonica					
Average	0.9	22.1	72.2	105.9	413.7
Minimum	0.2	13.1	15.0	20.6	139.7
Maximum	3.3	61.5	171.7	321.9	1007.0
Standard deviation	1.0	14.8	51.2	87.6	299.5
Coefficient of variation [%]	102.3	66.8	70.4	82.7	72.4
Fallopia × *bohemica*					
Average	0.9	20.0	51.6	216.3	448.8
Minimum	0.04	7.9	11.6	11.5	65.0
Maximum	3.0	47.3	116.0	1336.0	1721.0
Standard deviation	0.98	11.9	37.2	406.3	511.8
Coefficient of variation [%]	112.5	59.3	72.0	187.8	109.2
Fallopia sachalinensis					
Average	0.4	15.3	27.3	45.1	237.7
Minimum	0.01	10.1	7.2	10.6	55.6
Maximum	0.6	18.0	39.6	62.6	500.0
Standard deviation	0.3	4.5	17.5	29.9	232.8
Coefficient of variation [%]	86.5	29.3	64.3	66.3	98.0

invasive knotweeds spreading within the city area. The sites of the mentioned plant species were located only in the Urban Park in Leśnica (the western part of the city).

Invasive plants owe their success to their broad tolerance in relation to environmental conditions, as well as the possibility of quick adaptation to the changes taking place in the environment [25]. Most of them inhabit a wide range of habitats [2]. These features are possessed by the species of genus *Fallopia*. Especially, in secondary sites of their occurrence, ecological tolerance of knotweeds is high. Representatives of the *Fallopia* genus are able to grow in diverse soil types, with various pH ranges and nutrient content: from colliery soils through alluvial soils, clays and loams to mineral soils and peats [4]. Richards et al. [26] reported clones of knotweeds even on highly saline soils in the United States.

Chemical analyses of soil collected from 23 knotweed sites proved that in Wrocław these species occur on soils featuring a wide range of reaction: from acid – pH in KCl – 5.4 and in H_2O – 6.0, to basic – pH in KCl 7.9 in H_2O – 8.0). An even wider range regarding soil pH is reported [4] from the area of England. The soil samples collected in Wrocław characterized significantly high content of available forms of phosphorus, potassium, and magnesium. The research on chemical composition of Japanese soils proved that knotweeds also can cover soils poor in nutrients, as well as those of low water capacity [4]. High contents of organic carbon and organic nitrogen also were assayed in the analyzed soils. The content of organic carbon ranged from 1.10% up to 14.48%, while the content of organic nitrogen amounted from 0.03% to 0.42%. Evenly high content of organic matter was recorded for English soils, where organic carbon content in the soils overgrown with knotweeds equaled 18.6% [4].

The species of *Fallopia* genus abide relatively well in environmental pollution. The spread of the mountain ecotype of *Fallopia japonica* var. compacta in the neighborhood of volcanoes suggests tolerance of this species to increased sulphur dioxide content [19]. Moreover, within the natural range of their occurrence, knotweeds inhabit areas polluted by heavy metals [4]. The soil sample collected from the area of Wrocław included more elevated contents of Cd, Cu, Pb, and Zn than the natural ones. The highest quantities belonged to Pb and Zn, whose average values ranged from 448.8 mg Zn·kg^{-1} and 216.3 mg Pb·kg^{-1} – *Fallopia* × *bohemica* sites, 413.7 mg Zn·kg^{-1} and 105.9 mg Pb·kg^{-1} at sites of *Fallopia japonica*, to 237.7 mg Zn·kg^{-1} and 45.1 mg Pb·kg^{-1} – *Fallopia sachalinensis* sites. Natural content of Pb in soils amounts from 1 to 25 mg·kg^{-1} [27], while the most frequent Zn content ranges from 5 to 50 mg·kg^{-1} [15]. According to Burkhead et al. [28] average Zn abundance is 70 mg·kg^{-1}. Also the primary investigation of the urban conditions of Wrocław and Prague cities has shown that *Fallopia japonica* and *Fallopia* × *bohemica* spread on soils with higher than natural content of Cd, Fe, Pb, and Zn [29]. A higher tolerance of invasive species to stressful environments may result in exotic plants being more competitive than native, thus promoting plant invasion [30]. Among some invasive plants the mechanisms of metals tolerance have been found. Examples of this species are *Spartina densiflora* and *Solidago canadensis*. Both species developed physiological mechanisms to tolerate or avoid heavy metals, hence they are able to germinate [31] and spread in soils polluted by heavy metals [32]. It seems that, in the case of the *Fallopia* genus, increased content of heavy metals in urban soils does not reduce its expansion. On the contrary, it enhances their competitiveness in relation to other species, which avoid higher concentrations of heavy metals, especially toxic ones.

Conclusions

Based on the results of the presented study the following conclusions can be drawn:

1. Invasive plants of *Fallopia* genus are frequent components of urban ecosystems. On the example of Wrocław city (in the area of 293 km^2), the presence of three *Fallopia* species was confirmed in over 23.0% of the urban area. Among all species the most numerous in the urban area proved to be *Fallopia japonica*, while the least numerous was *Fallopia sachalinensis*.
2. Despite a small number of *Fallopia sachalinensis* clones – serving as a donor of pollen for female clones of *Fallopia japonica*, a strongly invasive specimen of *Fallopia* × *bohemica* occur in the city quite numerously, on approximately 6.8% of urban area and accounting for 21.6% of total number of all knotweed clones. It is suggested that expansion of *Fallopia* × *bohemica* in the examined area advances, in most cases, vegetatively (as a result of rhizome regeneration). This process could contribute to the future invasive success of hybrid in urban areas and it should not be underestimated.
3. The highest number of knotweed sites in an urban area was recorded in ruderal and greenfield sites including, among others, illegal waste dumps, heaps, and rubble and debris areas. Urban green areas, as well as parks and gardens (with frequently introduced exotic plants as ornamentals), do not play an important role in invasive knotweeds spreading within the city area.
4. In urban conditions knotweeds are able to spread on soil with various pH ranges and nutrient content. Also, the higher content of heavy metals does not limit the expansion of *Fallopia* weeds; on the contrary, it can even enhance their competitiveness in relation to other plants that avoid toxic concentrations of heavy metals.

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