

Plant Diversity in the Area of Water Bodies near Kraków

Focus on Invasive Plants

Aleksandra Wagner

Dept. Geoinf., Photogrammetry & Remote Sensing of Env.
AGH University of Science and Technology
Kraków, Poland
e-mail: awagner@agh.edu.pl

Dario Hruševar

Department of Botany and the Botanical Garden
University of Zagreb
Zagreb, Croatia
e-mail: dario.hrusevar@biol.pmf.hr

Abstract— Thirteen locations were examined referring to the vegetation and alien species in particular. The locations were the areas surrounding anthropogenic water bodies in Kraków and vicinity. Most of them were borrow pits left to the process of natural succession. In all the locations alien species, including neophytes were found. There were 22 neophyte species found in total, six of them invasive transformers. The most common was the Canada golden-rod (*Solidago canadensis*) found in eight locations. *Erigeron annuus* was found in 7 locations. *Bidens frondosa* and *Conyza canadensis* were found in 6 locations. Most neophytes were of North American origin. 16 archaeophytes were found. Four species had uncertain status. In urban areas, the presence of alien species does not make much problem, however in rural areas the monitoring is recommended.

Keywords - alien species; invasive species; suburban areas.

I. INTRODUCTION

Water bodies (natural or artificial) and their vicinity make good environment for different plant and animal species. They attract both native and non-native species. In this paper, water bodies situated in Kraków and vicinity were studied. The region is not very rich in natural lakes, but includes a lot of artificial water bodies of various origin [1]: borrow pits of different size, made after the exploitation of limestone, gravel, sand or clay, fishing ponds, former decantation ponds, etc. In the process of natural ecological succession and sometimes due to human-made reclamation measures, these ponds get covered with vegetation and become inhabited by animal species [2]. Finally, they form semi-natural environment and can contribute to biodiversity of the region. The objective of the study is to examine the vegetation of selected water bodies in terms of the presence of non-native species. Non-native species can be divided into two groups: archaeophytes and neophytes. Archaeophytes are plants which arrived in the area in pre-historic or early historic times and neophytes were introduced in modern times and the usual border date is accepted as ca. 1500 – the discovery of the Americas [3]. Most archaeophytes in Europe arrived with the agriculture, as weeds growing in the fields and nowadays they make an integral part of the flora, although can also be invasive. Neophytes, however, are usually regarded more dangerous to biodiversity.

Crossbreeds between native and non-native plants are regarded non-native and if one of the parental species is neophyte, they are regarded neophytes [3]. Apart from the origin, the degree of naturalization in the environment is important; Pyšek et al. [3] distinguish casual species - alien species that do not form self-sustaining populations and naturalized species (synonym: established species) that form self-sustaining populations for several life cycles, as well as invasive species - a subset of naturalized species forming self-replacing populations, having the potential to spread over long distances. Tokarska-Guzik et al., after Richardson et al. [5] also differentiated the category of transformers (a subset of invasive plants) for the species which change the character of the ecosystems.

Section II gives the list of locations with a short description of every place and studying methods. The localities are also shown in the map – Figure 1. In section III the results are given, putting particular stress on alien species, presented in Table 1. The vegetation of each site was described in a separate sub-chapter. Chapter IV provides the conclusions and recommendations for further studies.

II. STUDY AREA AND METHODS

The study includes the vegetation in the areas of the water bodies in Kraków and vicinity in summer 2009 (in the case of Bagry and Zakrzówek also 2008). The studied areas are named below. More detail characteristics of the water bodies and their surrounding can be found in [2] [6] [7] [8]. The geographic distribution of the sites is presented in Figure 1. The area included:

1. Two borrow pits bodies situated south-east from the centre of Kraków in the area called Płaszów. The area of the bigger pond, called Bagry is 30.1 ha and the smaller one – called Staw Płaszowski (the Płaszów Pond) - is 9.0 ha. The ponds were formed after the exploitation of sand and gravel in 1930s. In Table 1., they are marked as BG and SP, respectively. The surrounding of SP is shown in figure 2.
2. Staw Dąbski (the Dąbie Pond, marked as D), 2.1 ha, situated in Kraków, east from the centre, was formed in 1930s after the exploitation of clay.

3. Zakrzówek (marked ZK) - a borrow pit south-west from the centre of Kraków of 17.0 ha surface, was made in 1990s, after quarrying limestone.
4. The Pond of the Kaczeńcowa Street (KA) was, by the Resolution no. XXXI/405/07 of the City Council of Kraków, established Ecologically Useful Area – the area is 0.82 ha [9]. The pond is situated in the quarter of Nowa Huta in Kraków. The pond was formed as a result of clay exploitation.
5. Former decantation pond of the Steelworks in Nowa Huta in the region called Kujawy (marked KU) has the area of 2.9 ha.
6. Przylasek Rusiecki (PR) – a group of 11 gravel borrow pits of the total area of 82.19 ha, situated in the Eastern part of Kraków, quarter Nowa Huta.
7. Borrow pits in Wola Batorska (WB) – the gravel quarrying is still going on, so the area is changing.
8. Two borrow pits (exploitation of gravel) of Zabierzów Bocheński (ZB), commune of Niepołomice area of 13.03 ha and 3.43 ha, respectively.
9. The fish pond in Zakrzowiec (ZC) - area c.a. 2.5 ha, used for commercial angling.
10. Two ponds in the town of Niepołomice - Mokra street (0.7 ha) and Akacjowa street (0.3 ha), marked as MK and A, respectively.
11. Two borrow pits in the Commune of Liszki called Zalew na Piaskach and Budzyń, formerly known as 'Kryspinów' - area 24.5 ha and 20.3 ha, respectively, marked as ZP.

In each location, plots of the area of 16 m² were randomly chosen and the plants were identified to the species or – if not possible – to the genus. The plants were listed and identified as native, archaeophytes or neophytes, invasive or not invasive, harmful or not harmful. To identify the species and define their status literature data from Poland [4] [10] [11] and other countries of Central Europe [3] [12] [13] [14] were used.

III. RESULTS AND DISCUSSION

The original data listing each species are available from the authors. In this paper, the results focus on alien species. Native species were mentioned, if predominant. Table 1. presents only non-native species or species of uncertain status. The list includes 22 neophyte species; six of them regarded invasive transformers. The most common of them were: *Solidago canadensis* L., found in 8 locations, and another invasive (although not harmful) plant – *Erigeron annuus* (L.) Pers. - found in 7 locations. *Bidens frondosa* L. and *Conyza canadensis* (L.) Cronquist were found on 6 locations. Most neophyte species, however, were represented only in one location. This particularly refers to

casual species. These were mainly tree species, mostly located in the area of the Mokra Street. This was a residential area and some 'exotic' trees were planted there. Nevertheless, casual species were also found in less human-influenced place, such as Zakrzówek. Archaeophytes were represented by 17 species. Four species have uncertain status: one can be archaeophyte or neophyte depending on subspecies, which was not determined and the origin of three species is still debatable. The most widespread archaeophyte species occurred in 3 locations, which suggests that their ecological niches were narrower than in case of neophytes. On the other hand (data available from the authors), non-native species rarely covered more than 25% of the surface, while native species (like *Phragmites australis* (Cav.) Trin. ex Steud. or *Typha* spp.) could cover up to 95%.

The number of alien species in each location ranged from 1 or 2 in Zalew na Piaskach to 11 in the Mokra street in Niepołomice. Nevertheless in the Mokra Street planted trees distort the real picture. Considering this, the highest number of non-native species would be in Zakrzowiec (10). The detail characteristic of the studied sites looks as follows:

A. Bagry

The studies in Bagry were carried out on 2/07/2008 by Samalzhhan Tleubayeva and Aleksandra Wagner in two locations: (1) – north-western shore of the water body and (2) – northern shore of the water body. Every location included coastal plant like *Juncus effuses* L., *Phragmites australis* (Cav.) Trin. ex Steud and *Schoenoplectus lacustris* (L.) Palla. In place (1) there was one alien species noticed - *Phalaris canariensis* L., a neophyte coming from southern Europe. This was the only alien species among 7 species scored in that place. The 2008 survey in place (2) did not show any alien species, however more detail survey of 3/08/2009 by Dario Hruševar, Aleksandra Wagner, Uroš Ljubobratović, and Barbara Patuła showed 7 out of 31 alien species, among which 3 (9.7%) were archaeophytes: *Melilotus albus* Med., *Melilotus officinalis* (L.) Lam and *Pastinaca sativa* L. The latter was considered native for a long time, but recent studies shown it was alien. Neophytes were represented by two (6.5%) species: *Acer negundo* L. and *Robinia pseudoacacia* L., both of them classified as invasive transformers. The encountered individuals (one of each species) were young and belonged to the undergrowth. The dominant plant was native: *Calamagrostis epigeios* (L.) Roth.

B. Staw Płaszowski (the Płaszów Pond)

In the western part the studies were carried out on 2/07/2008 by S. Tleubayeva and A. Wagner. Eleven species were found, among them two neophytes, none of them invasive: *Oenothera biennis* L. and one of North American ash trees, probably *Fraxinus pennsylvanica* Marshall, rarely encountered in natural environment in Poland. The study of

20/08/2009 by D. Hruševar and A. Wagner in the eastern side of the pond showed 22 species, among which the dominant was *Phragmites australis* (Cav.) Trin. ex Steud. There were four (18.2%) neophytes: *Solidago gigantea* Aiton, *Solidago canadensis* L., *Bidens frondosa* L., *Acer negundo* L. – all of them invasive transformers. There was also a feral cultivar - *Humulus lupulus* L. Apart from the plot, yet another neophyte was found: *Conyza canadensis* (L.) Cronquist, according to [11] the most common alien species in Poland. The site is shown in figure 2.

C. Staw Dąbski (the Dąbie Pond)

The survey of 07/08/2009 by D. Hruševar, U. Ljubobratović and A. Wagner showed 12 species in the plot in the eastern part of the pond. Significantly dominant was *Typha angustifolia* L. There was only one alien species: *Bidens frondosa* L. In other parts around the pond 32 more species were observed, including *Nuphar lutea* L. – a native species protected by the Polish law – the only place in the city of Kraków where it occurs naturally. There were also three invasive neophyte plants: *Acer negundo* L., *Solidago canadensis* L. and *Erigeron annuus* (L.) Pers. The first two are regarded transformer species and the latter is regarded harmless.

D. Zakrzówek

Two surveys were carried out in Zakrzówek – on 18/06/2008 by Samalzhana Tleubayeva, Aleksandra Wagner and Robert Mazur – on the hill in the eastern part of the area and on 13/08/2009, by D. Hruševar, U. Ljubobratović and A. Wagner – in the place slightly further from the previous one. In the first place 17 species were observed, including one archaeophyte *Echium vulgare* L. and one neophyte *Fraxinus pennsylvanica* Marshall, usually occurring only as a cultivated plant. In the second place 23 species were present. Among them three alien species: *Lathyrus tuberosus* L. – an invasive, but not harmful archaeotype and *Juglans regia* L. – a cultivated tree (originating from Caucasus and Central Asia) and now expanding into natural and semi-natural habitats. Another invasive neophyte found there was *Solidago canadensis* L., classified as a transformer, although it was not numerous in that place.

E. The Pond of the Kaczeńcowa Street

Around the water body, 24 species were found, three of them neophyte invasive transformers - North American: *Bidens frondosa* L. and *Solidago canadensis* L. and Asian - *Impatiens parviflora* DC. The study was carried out on 19/08/2009 by D. Hruševar and A. Wagner

F. Former decantation pond of Kujawy

The survey, carried out on 19/08/2009 by D. Hruševar and A. Wagner, showed 15 species, where *Calamagrostis epigejos* (L.) Roth. was dominating. One of them was archaeophyte: *Melilotus albus* Medik and two invasive neophytes: *Conyza*

canadensis (L.) Cronquist and *Solidago canadensis* L. Outside the plot, one more neophyte species - *Erigeron annuus* (L.) Pers. was observed as well as 8 native species, including *Centaureum erythraea* Rafn, protected by the Polish law.

G. Przyłasek Rusiecki

The survey carried out on 25/07/2009 by D. Hruševar, U. Ljubobratović and A. Wagner in two places near the only pond available for bathing: in the eastern part of the shore, near the beach and in the northern part – a popular place for angling. In the first place 39 species were found and the ones occurring in the biggest quantities were *Achillea millefolium* L. and *Melilotus albus* Medik. The latter is archaeophyte and both are characteristic for pastures. In fact, the habitats in Przyłasek Rusiecki are typically rural despite the fact of being situated in the administrative borders of the city of Kraków. Another archaeotype was *Humulus lupulus* L. Neophytes were represented by 3 species: *Erigeron annuus* (L.) Pers., *Bidens frondosa* L. and *Solidago canadensis* L. In the second place the most common species was *Euphorbia virgata* Waldst. et Kit. This plant has an uncertain status in the Polish flora. There were an archaeophyte species - *Melilotus albus* Medik. Apart from the neophyte plants known from the previous place: *Erigeron annuus* (L.) Pers. and *Solidago canadensis* L., four more species: *Medicago sativa* L., *Conyza canadensis* (L.) Cronquist, *Oenothera biennis* L. and a tree species: *Populus × euramericana* (Dode) Guinier ex Piccarolo were found.

H. Wola Batorska

The survey was carried out on 19/08/2009 by D. Hruševar and A. Wagner near the ponds in the eastern part of the complex of the water bodies. Place (1) was near the bigger pond and place (2) near the smaller pond. In place 1 36 species were found, among them 7 of alien origin: archaeophytes: *Matricaria perforata* Merat., *Capsella bursa-pastoris* (L.) Medik. and *Lactuca serriola* L., all of them invasive, but usually not harmful. *Panicum miliaceum* L. was also found. The subspecies was not defined, which in this case, does not allow stating in the plant was archaeophyte or neophyte, but it is invasive. Other alien species included *Phalaris canariensis* L., *Acer negundo* L. and *Bidens frondosa* L. In place (2) twelve species were found, including one archaeophyte: *Echinochloa crus-galli* (L.) P.Beauv. and one neophyte: *Conyza canadensis* (L.) Cronquist. In the area outside the plots one more neophyte was found: *Picea pungens* Engelm. The specimen found was in a very poor shape. Probably it was deliberately planted.

I. Zabierzów Bocheński

On 10/08/2009 D. Hruševar, U. Ljubobratović and A. Wagner surveyed two plots in the area: (1) in the central part of the complex – near the beach and (2) in the southern part of the area.

In place (1) 34 species were found, where *Bolboschoenus maritimus* (L.) in the part near water and *Trifolium repens* L. – further from the shore were predominant. There was only one neophyte: *Bidens frondosa* L. and one of uncertain status *Cirsium vulgare* (Savi) Ten. In site (2) there were 39 species recorded and only one - *Solidago canadensis* L. was neophyte. There were also *Rumex crispus* L. – a plant of an uncertain status and *Prunus cerasus* L. – a cultivated species, in that site occurring as feral. In the water a protected by the Polish law species was found - *Salvinia natans* (L.) All.

J. Zakrzowiec

The survey was carried out on 17.08.2009 by D. Hruševar and A. Wagner in two sites. Site (1) was close to the pond and site (2) was in the place of the pond that was dried out a few years before the survey. In the site (1) 37 plant species were found. The dominant species was *Phragmites australis* (Cav.) Trin. ex Steud., covering more than 75% of surface. There were only two neophytes: *Erigeron annuus* (L.) Pers. and *Conyza canadiensis* (L.) Cronquist and one archaeophyte: *Lactuca serriola* L. In place (2) 24 species were found. The dominant one was an archaeophyte *Echinochloa crus-galli* (L.) P.Beauv. Other archaeophytes included *Setaria pumila* (Poir.) Schult. and *Matricaria perforata* Merat. There was also *Cirsium vulgare* (Savi) Ten., an invasive plant of uncertain status. Neophytes included *Bidens frondosa* L., *Conyza canadiensis* (L.) Cronquist and *Erigeron annuus* (L.) Pers.

K. The Mokra Street – Niepołomice

The survey was carried out by D. Hruševar and A. Wagner on 17/08/2009. There were 31 plants found in the plot near the pond. Archaeophytes included: *Pastinaca sativa* L. and *Setaria pumila* (Poir.) Schult. Neophytes were: *Erigeron annuus* (L.) Pers., *Conyza canadiensis* (L.) Cronquist and *Veronica persica* Poir. The presence of privet *Ligustrum vulgare* L. could be of anthropogenic or natural origin, but anthropogenic origin was more likely. The water body was in the residential area and many non-native species were planted: *Picea pungens* Engelm., *Liriodendron tulipifera* L., *Catalpa bignonioides* Walter, *Pinus nigra* Arnold, *Abies concolor* (Gordon) Lindl. ex Hildebr. and *Thuja* spp.

L. The Akacjowa Street – Niepołomice

Around the water body 40 plant species were recorded on 17/08/2009 by D. Hruševar and A. Wagner. There were two archaeophytes: *Lactuca serriola* L. and *Echinochloa crus-galli* (L.) P. Beauv., as well as three neophytes in the area: the bur marigold *Bidens frondosa* L., black locust *Robinia pseudoacacia* L. and horseradish *Armoracia rusticana* G. Gaertn., B. Mey. & Scherb. The latter is a cultivated plant, invasive, but not harmful.

M. Zalew na Piaskach

The place selected for the survey on 31/07/2009 (by D. Hruševar, U. Ljubobratović and A. Wagner) was in the area where the pond was shallower and overgrown by macrophytes such as *Typha latifolia* L. There were 40 vascular species and a moss – *Sphagnum*. There was one neophyte there: *Erigeron annuus* (L.) Pers.

The study showed the presence of alien plants, including neophytes in each location. Many of them are invasive, although only in few localities they were dominant or even made a significant proportion in the land cover. The most commonly found species (in terms of the number of locations) - *Solidago canadensis* - never covered more than 25% and often less than 5%. This can confirm an interesting study done by Orczewska [15] suggesting that some native species (such as *Urtica dioica* L. and *Galium aparine* L.) can be more dangerous for the habitat than neophytes (such as *Solidago gigantea* Aiton).

The study also confirms the data suggesting higher presence of non-native plants in human-influenced areas [4] [14]. The lowest number was scored in Zabierzów Bocheński and Zalew na Piaskach, places relatively distant from residential areas. On the other hand the presence of non-native species in the areas with already strong human influence is not so harmful. The real danger for biodiversity is the presence of invasive plants in protected areas. The eastern part of the study area is situated near the Niepołomice Forest, a place with some amount of strictly protected areas. Fortunately in a nearby place like Zabierzów Bocheński the influence of invasive species is small (two species of *Solidago*), nevertheless cannot be neglected.

IV. CONCLUSIONS

Although alien species occurred in every location in the study area, they never dominated. Among the alien species particular attention should be paid on invasive transformer species: the ash-leaved maple (*Acer negundo*), black locust (*Robinia pseudoacacia*), Canadian golden rod (*Solidago canadensis*), giant goldenrod (*Solidago gigantea*), bur marigold (*Bidens frondosa*) and small-flowered touch-me-not (*Impatiens parviflora*). The Canadian golden rod was the most common of them.

In the residential areas many alien tree species are grown. Apart from two species (the ash-leaved maple and black locust) they are not invasive and most of them can only sporadically found in the wild.

Further monitoring of invasive plant species is necessary, also because of the perspective of climatic changes. Warming the climate will provide better conditions for the reproduction of southern species so that they could become invasive. The example can be the common walnut (*Juglans regia*), which was found in one location, but, according to literature [11] this species is in the initial phase of invasion, so it is likely to extend its range.

Tab. 1. NON-NATIVE (OR SUSPECTED TO BE NON-NATIVE) PLANTS OF IN THE AREA OF WATER BODIES NEAR KRAKÓW

N – neophyte, A – archaeophyte

	BG	SP	D	ZK	KA	KU	PR	WB	ZB	ZC	MK	A	ZP	
<i>Acer negundo</i>	+	+	+					+						N, invasive, transformer
<i>Robinia pseudoacacia</i>	+										+			N, invasive, transformer
<i>Juglans regia</i>				+										N, cultivated, in the first phase of invasion
<i>Populus x euroamericana</i>							+							N, not invasive
<i>Pinus nigra</i>											+			N, not invasive
<i>Picea pungens</i>								+			+			N, casual
<i>Abies concolor</i>											+			N, casual
<i>Thuja sp.</i>											+			N, casual
<i>Liriodendron tulipifera</i>											+			N, casual
<i>Catalpa bignonioides</i>											+			N, casual
<i>Fraxinus pennsylvanica</i>		+		+										N, casual
<i>Solidago canadensis</i>	+	+	+	+	+	+	+		+					N, invasive, transformer
<i>Solidago gigantea</i>		+												N, invasive, transformer
<i>Bidens frondosa</i>			+		+			+	+	+		+		N, invasive, transformer
<i>Impatiens parviflora</i>					+									N, invasive, transformer
<i>Conyza canadensis</i>		+				+	+	+		+	+			N, invasive, weed
<i>Veronica persica</i>											+			N, invasive, weed
<i>Phalaris canariensis</i>	+							+						N
<i>Armoracia rusticana</i>												+		N, invasive, not harmful
<i>Medicago sativa</i>	+						+							N, invasive, not harmful
<i>Erigeron annuus</i>	+		+			+	+			+	+		+	N, invasive, not harmful
<i>Oenothera biennis</i>		+					+			+				N, not invasive
<i>Panicum miliaceum</i>								+						A or N, depending on subspecies
<i>Echinochloa crus-galli</i>								+		+		+		A, invasive, weed
<i>Setaria viridis</i>			+							+				A, invasive, weed
<i>Setaria pumila</i>										+	+			A, invasive, weed
<i>Cichorium intybus</i>			+											A, invasive, not harmful
<i>Marticaaria perforata</i>								+		+				A, invasive, weed
<i>Lactuca serriola</i>								+		+		+		A, invasive, not harmful
<i>Capsella bursa-pastoris</i>								+						A, invasive, not harmful
<i>Papaver rhoeas</i>			+											A, invasive, not harmful
<i>Senecio vulgaris</i>			+											A
<i>Melilotus albus</i>	+						+							A
<i>Melilotus officinalis</i>	+													A
<i>Pastinaca sativa</i>	+	+	+											A
<i>Humulus lupulus</i>		+					+							A
<i>Echium vulgare</i>				+										A
<i>Lathyrus tuberosus</i>														A
<i>Odontites verna</i>				+										A
<i>Cirsium vulgare</i>								+	+	+				Uncertain status, invasive, not harmful
<i>Euphorbia virgata</i>							+							Uncertain status, not invasive
<i>Rumex crispus</i>													+	Uncertain status
	BG	SP	D	ZK	KA	KU	PR	WB	ZB	ZC	MK	A	ZP	

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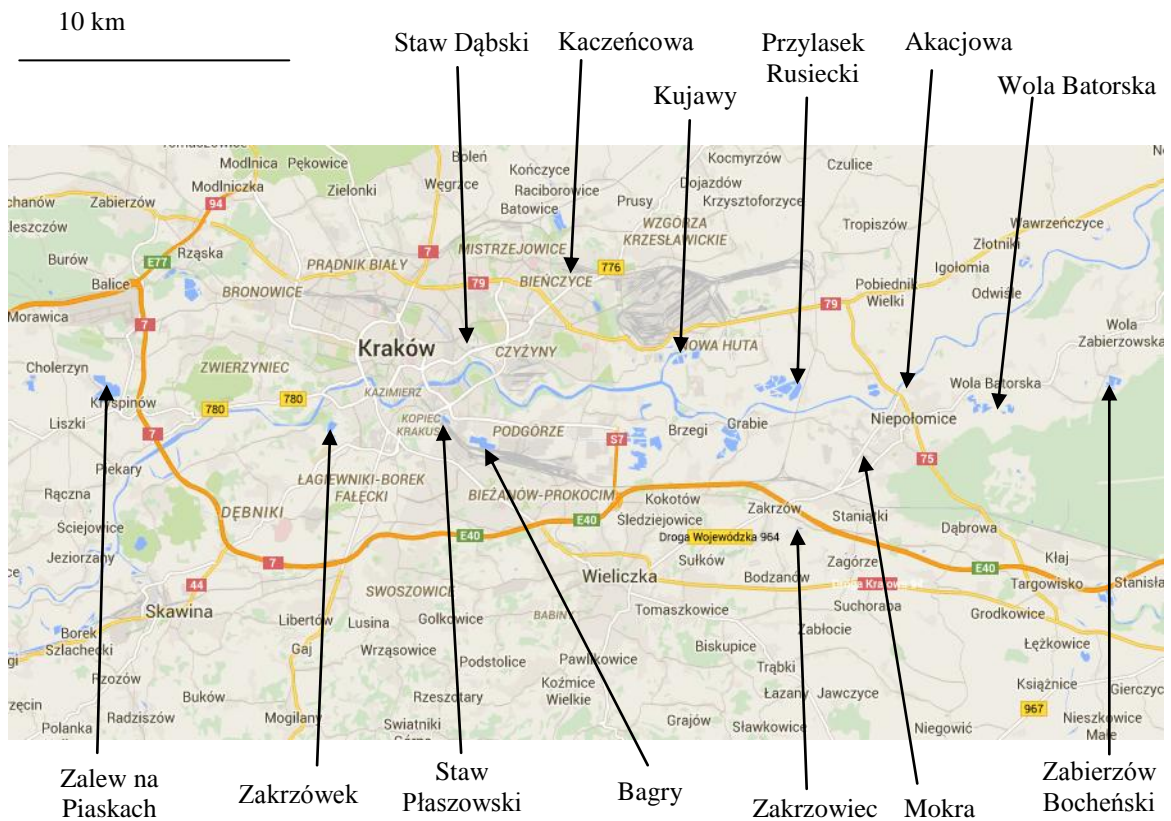


Figure 1. The study area.



Figure 2. The example of vegetation – the area near the Płaszów Pond. On the right-hand side – *Solidago* sp. Photo by A. Wagner.