GeoScience Engineering

CONTROL METHODS OF INVASIVE PLANT SPECIES AND THE INFLUENCE OF CULTURAL VEGETATION ON THE MICROCLIMATE WITHIN THE CENTRAL WASTEWATER TREATMENT PLANT IN OSTRAVA – PILOT RESULTS

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ABSTRACT

This study is a pilot document focusing on two subjects. The first one concerns control methods of invasive plant species in the floodplain of the river Odra, specifically on wooded wetlands with pools. The second presents the influence of cultural vegetation on the microclimate within the Central Wastewater Treatment Plant in Ostrava (CWWTP). The problem is the spread of invasive plant species, especially the Canadian goldenrod (*Solidago canadensis*) and the Himalayan balsam (*Impatiens glandulifera*), which are expanding in the area to such an extent that they create monodominant invasive vegetation. Various methods of controlling invasive species were gradually tested in defined areas in the forested wetland. Both mechanical and chemical methods were used, as well as their combinations, to find out the most effective one. The process includes partial works, such as the selection of areas, the determination of diversity by using phytosociology, the subsequent application of selected interventions, and the monitoring of given invasive plants with growing accompanying species. This research is time-consuming; therefore, longer application, in terms of years, is assumed, which should lead to much more relevant results. The CWWTP area acts as a heated island, where surfaces are regularly overheated, negatively affecting the biota and the working environment. One of the working results will be the design of suitable vegetation composition, effectively reducing extreme surface temperatures, especially in summer. The determination of diversity is linked to this since any vegetation of different diversity can contribute to a favourable microclimate. An area inventory of tree and shrub vegetation and a phytosociological analysis of selected areas are used to evaluate diversity. These surveys were carried out in the wetland ecosystem and the CWWTP area. Another important step is the measurement of surface temperatures of cultural vegetation and built-up areas in the area of the CWWTP, which was carried out by remote sensing. Later, it will be possible to assess which of the existing biotopes contributes more and which less to the cooling function of the urban heat island and, at the same time, how to care for this vegetation so that it fulfills its role. In the article, we present the results of the pilot survey. For the control of the invasive species *Impatiens glandulifera* and *Solidago canadensis*, three control methods were chosen: mechanical (mowing), chemical (herbicide with the active ingredients of triclopyr and fluroxypyr (A.), and herbicide with pelargonic acid (B.)), and combined (A. + mowing, mowing + B.). The initial reactions of these plants to the interventions were visible after about 20–30 days. It was most pronounced in the area with the dead-end river branch with the combination of A. + mowing, where *Impatiens glandulifera* occurred, and then in the forest area with the occurrence of *Solidago canadensis* with the application of herbicide A. When measuring the surface temperatures of the cultural vegetation and built-up areas in the CWWTP area as a heat island, approximate temperatures were recorded: on average, the cultural vegetation ranged from 26.43 to 34.45 °C, the average temperature of the built-up areas was from 47.26 to 58.32 °C, and the water surfaces (CWWTP reservoirs) then around 20.65 °C. As part of the tree and shrub layer inventory, we recorded 17 tree species and 5 shrub species in the wetland ecosystem. The phytosociological analysis showed that due to the massive occurrence

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of invasive plants, the areas in the wetland ecosystem are poorer in species than the areas of the CWWTP with cultural vegetation.

Keywords: Community; Control methods; CWWTP Ostrava; Floodplain of the Odra River; Invasive plant species; Inventory; Microclimate; Ostrava; Urban heat island.

1 INTRODUCTION

1.1 Invasive plants and methods of control

Mainly due to human practices, disruption of the natural species composition by invasive plant species is currently visible in plant communities. The prosperity of invasive species in plant communities lies in their high capability of generative and vegetative reproduction and often allelopathic effects on competing species. These traits lead to a decrease in the biodiversity of original phytocoenoses, of which wetlands are among the most endangered. Invasive plant species use effective strategies to spread through the river bed of the Odra, which has the character of a forested wetland with pools or floodplain forest in the model area and extends along the grounds of the Central Wastewater Treatment Plant. Our attention is focused on the aggressively spreading Himalayan balsam (*Impatiens glandulifera*), which linearly colonizes banks and pools, and the Canadian goldenrod (*Solidago canadensis*), which creates widespread, species-poor phytocoenoses between stands of invasive Black locust (*Robinia pseudacacia*) and also in forestless habitats.

Himalayan balsam (see Figure 1) was primarily found in the western Himalayan region and was introduced as an ornamental plant to Europe in the 19th century and still grows throughout the continent to this day [1]. It is a 3-m tall annual herb that is characterized by its hollow green to purple stem with opposite sharp saw-like leaves. Fragrant, honey-bearing grape-like blossoms of up to 4.5 cm in size that can be colored white, red-purple, or purple are also typical [2]. It reproduces generatively, with seeds up to 30 mm long and stored in large pods of 5 to 10. Once the pods mature during spring, the seeds can shoot long distances up to 4 m [1]. This plant especially prefers moist habitats in partial shade and weakly acidic to weakly alkaline soil rich in nutrients, therefore most often the banks of watercourses, and it is also common in ruderal areas [3]. The control methods of the plant can be carried out in the following ways: mechanical (by digging and persisting during spring in the flowering period or by mowing using manual mechanization, mowing, or grazing); chemical (application of herbicides based on triclopyr and 2,4 D or herbicides with active ingredient glyphosate) and a combination of both methods, when spraying is applied first and after a certain period after mowing [4].

Canadian goldenrod (see Figure 1) is originally from North America and was introduced to Europe as an ornamental plant in the 17th century, reaching the Czech Republic in the 19th century [5]. Canadian goldenrod is a perennial herb that grows to a height of up to 2 m. It is characterized by straight stems of greenish to purple color, with the upper part densely hairy. Its leaves are alternate, lanceolate, and sessile, dying quickly in the lower tiers and shrinking in the upper tiers. Yellow anthodium in the lats is its dominant feature [6]. It reproduces both vegetatively using rhizomes and generatively using seeds [7]. The seeds (achenes) are brown, 1.2 mm long, hairy, and with pappus [6]. Goldenrod produces large biomass – whether dense stands with more than 300 individuals per 1 m^2 or seeds numbering over 10,000 per individual. Its successful invasion is also due to its ability to act as a transformer, as it can change the conditions in the natural ecosystem thanks to allelopathic properties [8]. It prospers best in sunny habitats that may not be rich in nutrients and is quite resistant to drought. Ruderal or slightly nitrophilous habitats can be included among these habitats, such as burial grounds, the surroundings of cemeteries, gardens, city edges, and habitats along roads or drier river banks [7]. Control methods of the Canadian goldenrod can be mechanical, like mowing at least twice a year in spring and late summer, or chemical, by applying chemical sprays based on 2.4 D, flazasulsufuron, fluroxypyr or pelargonic acid, or herbicides with the active ingredient glyphosate. In the combined method, mowing is applied first, spraying after some time [4].

*Figure 1. Selected invasive plant species (*Impatiens glandulifera *on the left,* Solidago canadensis *on the right), own photo*

1.2 Phytosociological analysis

Phytosociological analysis or phytosociology represents the study of plant communities (a set of populations of all types of plants growing in a certain place), which classifies and maps their occurrence. All plant species (a set of populations that have a common origin, morphology, characteristics, and functions) are recorded in the phytosociological relevés, which indicates the list of species found and their coverage on a pre-selected area. Found plants are always divided in the list according to layers (tree, shrub, herb, and juvenile stages of trees). Coverage (the percentage of area occupied vertically by all above-ground parts of the population) can be determined according to different scales: Braun-Blanquet, Domino, or Zlatníkov. The Braun-Blanquet coverage scale with 7 levels, or with the modification of Westhoff and van der Maarel with 9 levels, is the most often used one (Zurich-Montpellier school [9]) [10] (see Table 1).

Table 1. *Braun-Blanquet coverage scale and coding coverage scale [9]*

Score	Frequency/Coverage of relevés	Coding the scale to mean percentage values
r	very rare species with less than 1 % coverage	1
+	a rare species with a cover of no more than 1 %	2
1	abundant species with 1–5 % coverage	3
2m	abundant species with 5–25 % coverage	
2a	species with 5% coverage and high abundance	13
2b	5–12% cover species	
3	12–25% cover species	38
4	species with 25–50 % coverage	63
5	species with 51–75 % coverage	88

Diversity indices are used to determine diversity (the number of different species that are represented in a given community). Alpha diversity indices such as the Shannon-Wiener index or the Simpson index are used for this in the selected area (at the local level). These two indices differ in how much emphasis they place on species richness or evenness. Species richness means the abundance of species in a given sample, and evenness is the relative

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representation of individual species in a given sample [11]. The Shannon-Wiener index is the most often used one, representing a random selection of individuals (organisms) from a theoretically unlimited number and the occurrence of all community species in a given sample. Its value ranges from 1.5 to 4.5. It can be expressed as evenness, which can also be done with other indices of this type. Evenness here is a value related to the maximum possible evenness of the community and has values from 0 to 1 [10].

Phytosociological relevés are further processed to evaluate diversity. There are also various computer programs for this, such as the TURBOVEG database, where these relevés can be recorded, or the JUICE program, which is used for overall evaluation. Phytosociological relevés can also be processed manually using the recoding of cover levels to mean percentage values (see Table 1) and formulas for calculating the mentioned indixes (see Formula 1 and 2).

Formula 1. *Calculation of Shannon-Wiener diversity index:*

$$H' = -\sum_{i=1}^{n} p_i \times ln(p_i) \qquad p_i = \frac{n_i}{N} \qquad \textbf{(1)}$$

where H' is Shannon-Wiener diversity index, p_i is relative abundance of species i, n_i is number of individuals of i-th species, and N is is the total number of individuals [10].

Formula 2. *Calculation evenness:*

$$E = \frac{H'}{\ln S} \qquad \textbf{(2)}$$

where E is evenness, H' is Shannon-Wiener diversity index, S is total number of taxa (the name of a group of individuals differing in certain characters and characteristics from all other taxa) [10].

1.3 The influence of cultural vegetation on the microclimate of the CWWTP

The urban heat island (UHI – Urban Heat Island) represents a problem that arose mainly in the process of urbanization, when there was a complete change in the physical properties of the natural landscape in the form of land use, the construction of cities and other human activities, which led to the elimination of a large amount of vegetation, and therefore local climate changes [12]. In general, vegetation, together with water bodies, naturally cools the air by evapotranspiration of water from plant leaves and evaporation of surface water. Among other things, vegetation also naturally shades areas. Due to the predominance of land development with hard, impermeable surfaces (such as roofs, pavements, roads, buildings, parking lots), higher air temperatures occur in cities, accumulating more heat above surfaces than e.g. in rural areas [12,13]. All urban structures tend to absorb and re-emit the sun's heat more than forests, permanent grasslands, and bodies of water in natural landscapes. Heat islands can form in or around cities of various sizes, day and night, at any time of the year or in any climate. For example. one of the causes of the heat island is human activity, where heat is produced by vehicles, air conditioners, buildings and industrial equipment [13], which also applies to our area of the Central Wastewater Treatment Plant, where the effort is to ensure a more favorable microclimate, and therefore individual surface temperature of vegetation and urban structures.

2 METHODS AND STUDY SITE

This study used methodologies that are based on the Memorandum being prepared between Ostrava Waterworks and Sewerage Company of Moravska Ostrava, the Municipal District of Moravska Ostrava and Privoz, the Municipality of the City of Ostrava, and VSB-TU Ostrava, Department of Environmetal Engineering.

2.1 Study site

In this research, 2 areas were selected, which are immediately adjacent to each other and are described in more detail in the following paragraphs.

2.1.1 Wooded wetland with pools in the floodplain of the Odra River

Wooded wetland with pools (terminal of bus 33 – Ostrava Privoz, Oderska) in the floodplain of the Odra River, specifically in the section from river kilometer 15 (Lhotka weir) to approximately river kilometer 13.5., has the character of ruderalized alder forest with the occurrence of Himalayan balsam (*Impatiens glandulifera*) along the banks of ponds. The littoral of the ponds is made up of reeds (*Phragmites communis*), and in drier locations, there are Black locust (*Robinia pseudacacia*) stands with Canadian goldenrod (*Solidago canadensis*) together with the expansive Bush reed (*Calamagrostis epigejos*). Other invasive species are represented with less coverage. In the locality, there is an illegal dump and locally various waste (debris, remnants of cabling, remnants of clothing, etc.). A total of 5 areas were created in this area based on the findings of the most effective control of invasive plants. Plots I6, I7, and I10 (I as an abbreviation for *Impatiens*) had an area size of 5 x 5 m. Areas S8 and S9 (S as an abbreviation for *Solidago*) had an area size of 10 x 10 m (see Table 2 and Figure 2). A phytocenological analysis was carried out on all of them.

2.1.2 The CWWTP Ostrava

The Central Wastewater Treatment Plant is situated in the Moravska Ostrava and Privoz districts on the outskirts of the city of Ostrava. This treatment plant handles 98.7 % of Ostrava wastewater. It has been in operation since 1996 [14]. The CWWTP area consists mainly of permanent grasslands and cultural meadows with varying intensities of mowing with solitary trees or groups of trees. The soils in the territory are loamy, at a depth of about 20 cm, there is often a higher occurrence of skeletons. We have established 5 study areas of 5 x 5 m (A1, A2, A3, A4, A5) to determine surface temperatures and to perform phytosociological analysis (see Table 2 and Figure 2).

Table 2. *Characteristics of study areas and their sizes in both selected areas*

Study area	Area size (m^2)	Biotope	Sunlight
A1	25	northern CWWTP – dry part, near a small alder tree	penumbra
A2	25	northern CWWTP - by the fence, opposite the substrate tank	penumbra
A3	25	northwest CWWTP – near the mast	sunny
A4	25	northwest CWWTP – between the pines	penumbra
A5	25	southeast CWWTP – dry meadow behind the entrance	sunny
I6	25	forested wetland – riparian vegetation, by the pool	shade
I7	25	forested wetland – at the the dead-end river branch	shade
S8	100	forested wetland – behind the fence, Canadian goldenrod	sunny
S9	100	forested wetland – Black locust stands	penumbra
I10	25	forested wetland – transect between the dead-end river branch	penumbra

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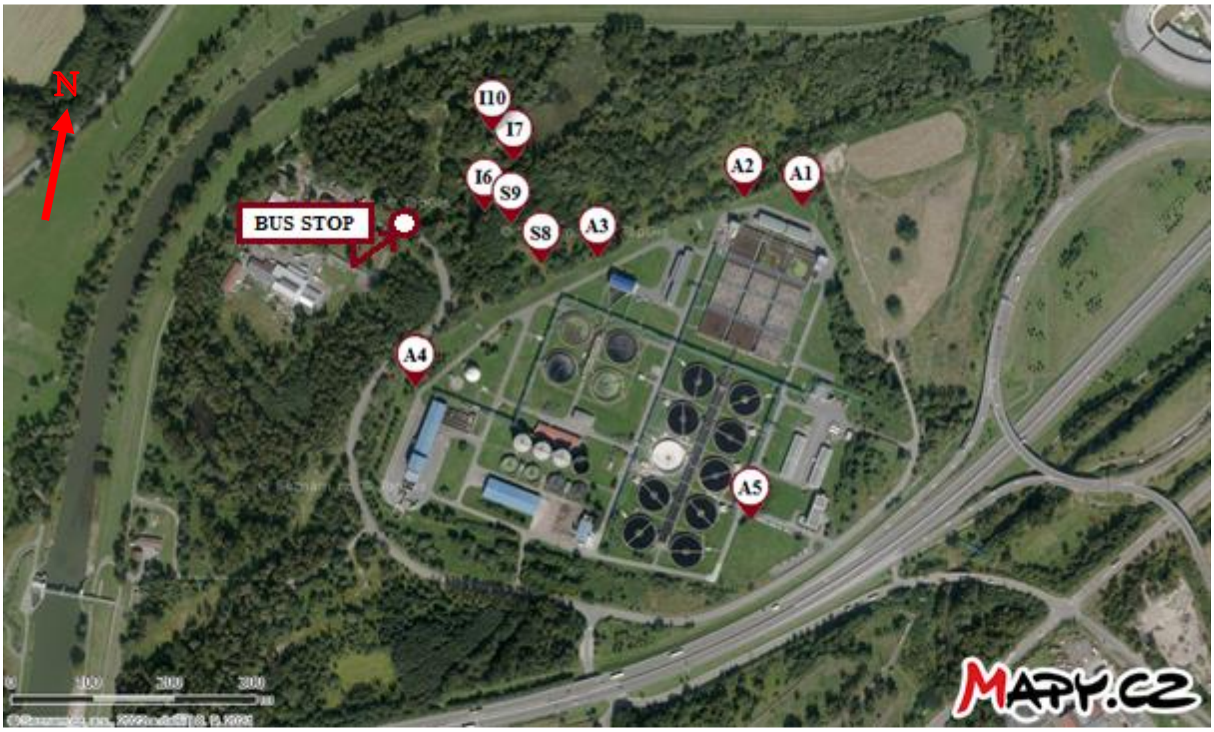

Figure 2. *Map of study areas in both selected areas (Mapy.cz, ©2022 – edited by the authors)*

2.2 Methods and materials

The following partial works were carried out in this initial research:

1. **Phytosociological analysis** was carried out according to the rules of the Zurich-Montpellier school [9], which means that the Braun-Blanquet coverage scale with 9 levels was used (more details in Subsection 1.2 and Table 1). Phytosociological analysis started in the spring of 2022. The imaging was preceded by orientation field trips to determine the basic physiognomy and species composition of the vegetation and the character of the relief. All selected areas were properly marked with wooden stakes in the corners. In total, 10 phytosociological relevés were taken, 5 (A1–A5) are located in the CWWTP area, 5 (I6, I7, S8, S9, I10) in a forested wetland. The size of the relevés corresponds to the area sizes in Table 2. These relevés were further processed manually. They were entered in Microsoft Excel 365, where the scale was recoded to the mean values of percent cover (see Table 1 in Subsection 1.2) in order to determine the values of the Shannon-Wiener index of diversity H´ and evenness E. Formula 1 and 2 are used for calculation.

2. **The inventory of the tree and shrub layer** was carried out based on the registration of individual species in the field only in the forested wetland from the local bus stop to the selected area I10 (see Figure 3), which represents an area of approximately 1702 m^2. After adding all types of trees and shrubs, this list of vegetation will provide detailed information on its biodiversity, distribution, and current status and how it can contribute to the favorable microclimate of urban heat islands in the city, in this case in the premises of the CWWTP.

3. **Control methods of invasive plant species** – management methods have been chosen to affect the local surrounding habitats as little as possible. Areas in the forested wetland were selected based on the highest representation of individual populations of *S. canadensis* and *I. glandulifera*, where selected eradication methods were applied from spring to summer 2022 in 5 areas, 3 of which were for *I. glandulifera* (I6, I7, I10) and 2 for *S. canadensis* (S8, S9). Table 2 shows the size of the areas. Before applying control methods, the vegetative characteristics of both plants were monitored (number of individuals and shoot height per 1 m^2), and then the selected control method was applied:

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1) **Mechanical** – mowing with a brushcutter, applied in area I10 with the occurrence of *I. glandulifera*, 2x per vegetation season.
2) **Chemical –** this method was applied to 2 study areas:
   A. Selective herbicide with the active ingredients of triclopyr 60 g/l and fluroxypyr 20 g/l (commercial name GARLON NEW) – applied to area S9 with the occurrence of *S. canadensis* using a hand sprayer in a mixable solution in the ratio of 60 ml of concentrate and 2 l of water per 100 m^2, 1x per growing season.
   B. Total herbicide with active ingredient pelargonic acid 186.7 g/l (commercial name NEUDORFF FINALSAN) – applied to area I6 with the presence of *I. glandulifera* using a hand sprayer in a mixable solution in the ratio of 200 ml of concentrate and 1 l of water per 25 m^2, approximately 3 times per growing season.
3) **Combined**:
   - **A. + mowing** – carried out in area I7 with the occurrence of *I. glandulifera*, where the herbicide A. was first used in an area of 25 m^2, so the dose was in a smaller ratio of 30 ml of concentrate and 1 l, and after about 20 days it was mowed.
   - **Mowing + B.** – carried out in area S8 area with the occurrence of *S. canadensis*, where it was first mowed and, after about 30 days, spray B was applied with a dose in the ratio of 400 ml of concentrate and 2 l of water.

4. **Measurement of the surface temperature of vegetation and built-up areas (see Figure 3)** – first, there was a test measurement during the spring months in the CWWTP premises using a hand-held non-contact thermal camera type VOLTCRAFT WB-80. Due to irrelevant results, manual measurement was replaced by a drone with a built-in thermal camera, namely Hexacopter DJI Matrice 600 Pro with DJI Zenmuse XT camera in radiometric version. Thermal images were acquired from heights about 15 meters above terrain at 4 selected similar locations that were created for phytosociological analysis on 18 July 2022 at 15:00 (CET). A total of 70 thermal images were created. Thermal image processing was performed by converting pixel values in individual images from raw data to surface temperature values in degrees Celsius. In this part of the development of the study, due to the unfinished analysis of the vegetation, the effect of emissivity of surfaces, background temperature and atmospheric effects has not yet been corrected. Therefore, the emissivity values can only be considered indicative (with an accuracy of approximately 5 °C). Correction of the emissivity of surfaces according to the measured values with respect to the emissivity of the given surface will be carried out after completing a detailed survey and specification of the vegetation type.

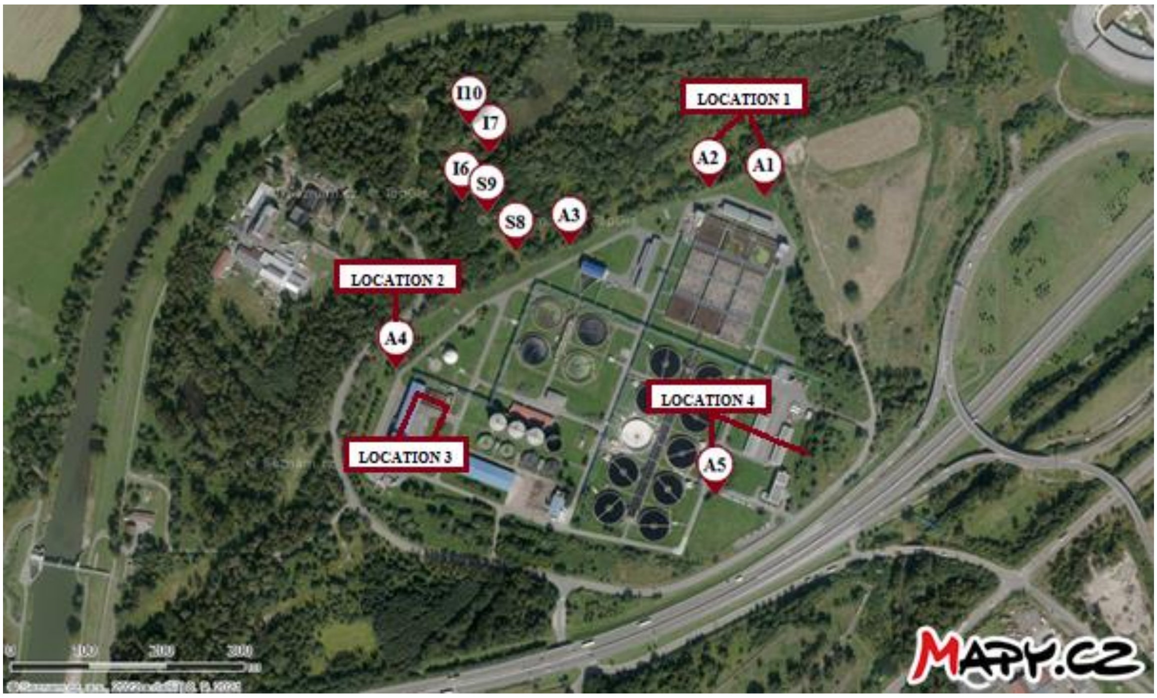

Figure 3. *Map of 4 locations for thermal imaging in the CWWTP area (Mapy.cz, ©2022 – edited by the authors)*

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3 RESULTS

3.1 Phytosociological analysis

Phytosociological analysis was carried out mainly during the spring and summer months. In all 10 phytosociological relevés, 5 invasive plant species (*Prunus cerasifera, Impatiens glandulifera, Robinia pseudoacacia, Galinsoga parviflora, Solidago canadensis*) were found. In our work, we focused on the problematic species *Solidago canadensis* and *Impatiens glandulifera*. Expansive species *Calamagrostis epigejos* and *Cirsium arvense*, which accompany communities with *Solidago canadensis*, were also found. No specially protected species were found. The results of the Shannon-Wiener index of diversity (H') and evenness (E) of all relevés are shown in Figure 4. The Shannon-Wiener index reaches an average value of 2.05 ± 0.67 with a minimum value of 0.43 (relevé on I6) and a maximum of 2.71 (relevé on A5). The evenness reaches an average value of 0.71 ±0.18, there is a minimum value of 0.22 (relevé on S8), and the maximum is 0.84 (relevé on A4).

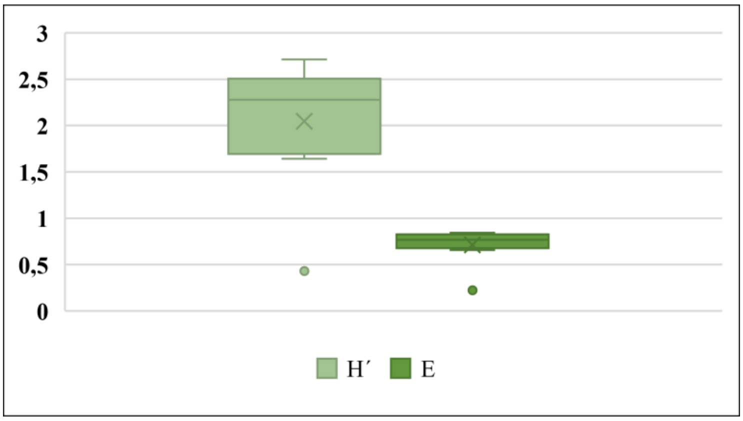

***Figure 4**. Results of the Shannon-Wiener diversity index and species evenness on all areas*

3.2 Vegetation inventory

The vegetation inventory took place during the summer when only representatives of the tree and shrub layer occurring in the vicinity of the defined areas (I6 to I10) were recorded. The results collected so far are shown in Table 3, where 17 species of trees, including juveniles, and 5 species of shrubs are listed. Of the 17 trees, the invasive species *Robinia pseudoacacia* predominates, while willows (*Salix* sp.), poplars (*Populus* sp.), and oaks (*Quercus* sp.) also appear. Fruit trees, such as *Prunus cerasifera*, were also found. *Cornus sanguinea, Sambucus nigra*, and *Crataegus monogyna* were particularly dominant among the shrub representatives. According to the potential vegetation map, the entire area (including our defined section) is classified as an elm-oak forest [15]. It belongs to floodplain river communities, where *Quercus robur, Fraxinus excelsior, Prunus padus, Tilia cordata*, and *Ulmus laevis* or *Alnus glutinosa* predominate [16].

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Table 3. *Indicative list of tree and shrub species recorded in the vegetation inventory in the defined section of the Odra River floodplain*

Inventory record of the tree layer				Inventory record of the shrub layer	
Number	**Species name**	**Number**	**Species name**	**Number**	**Species name**
1	*Acer campestre*	**10**	*Prunus cerasifera*	**1**	*Cornus sanguinea*
2	*Acer negudo*	**11**	*Prunus padus*	**2**	*Crataegus monogyna*
3	*Acer platanoides*	**12**	*Quercus robur*	**3**	*Prunus spinosa*
4	*Acer pseudoplatanus*	**13**	*Robinia pseudoacacia*	**4**	*Rosa canina*
5	*Alnus glutinosa*	**14**	*Salix alba*	**5**	*Sambucus nigra*
6	*Betula pendula*	**15**	*Salix fragilis*		
7	*Carpinus betulus*	**16**	*Tilia cordata*		
8	*Fraxinus excelsior*	**17**	*Ulmus laevis*		
9	*Populus tremula*				

3.3 Control of invasive plant species

The determination of the most effective control method for the invasive species *I. glandulifera* and *S. canadensis* will be carried out during the next 2 growing seasons when a time series of responses of the invasive species to the given type of control is available. Here, we present the vegetative characteristics of the invasive plants mentioned before the application of the chosen control method, and their response to the interventions during one growing season. In the forested wetland, before the start of the control (in June 2022), individuals were counted, and the heights of the shoots were measured in a square of 1 m^2 in the specified areas. Measurements of *I. glandulifera* took place on plots I6, I7, and I10 and for *S. canadensis* on plots S8 and S9. See Table 2 for the total area size.

Figure 5 shows that the area most invaded by I. *glandulifera* was I7 (264 psc/m^2). The other two monitored areas I6 and I10 were also heavily invaded. As for the heights of the spikes, the average values are similar on all surfaces (89 cm to 97 cm). From the total recorded data, the lowest individual was measured with a height of 20 cm in area I6, and the tallest individual with a height of 145 cm in area I8. After this measurement, the control methods were carried out in each area (the specific method is recorded in Figure 5 and Figure 6). Since these were areas near pools, a gentler method of extermination using pelargonic acid was chosen. The response of the plant to this herbicide was visible after about 20 days in the I6 area (see Figure 7). On the plants, the upper generative (flower, fruit) and vegetative organs (leaves) were burnt, leaving only half of the stems without leaves. The herbicide was used 3 more times during the growing season. A combination of herbicide A. and mowing was used in area I7, where none of the individuals of *I. glandulifera* appeared after 30 days of spraying, although mowing was still carried out in the area. Mowing applied to area I10, where individuals of *I. glandulifera* regularly regenerated during the growing season, has had the lowest effectiveness so far.

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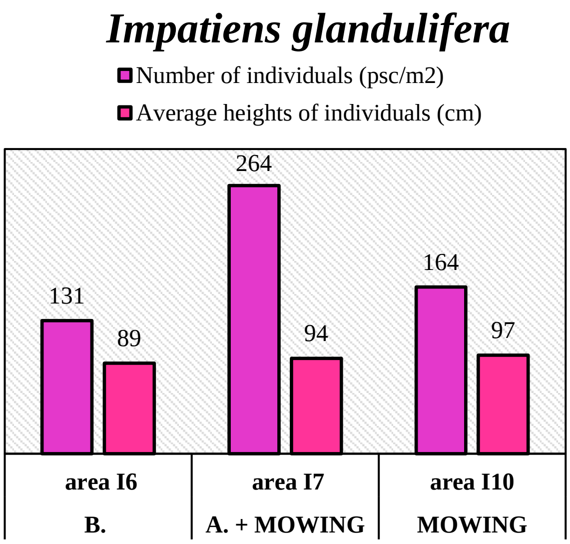

Figure 6. *Vegetative characteristics of* Impatiens glandulifera *before management (**Explanations**: The listed management was applied immediately after the measurement (B. = herbicide with pelargonic acid; Mowing + A. = herbicide with substances triclopyr, fluroxypyr)*

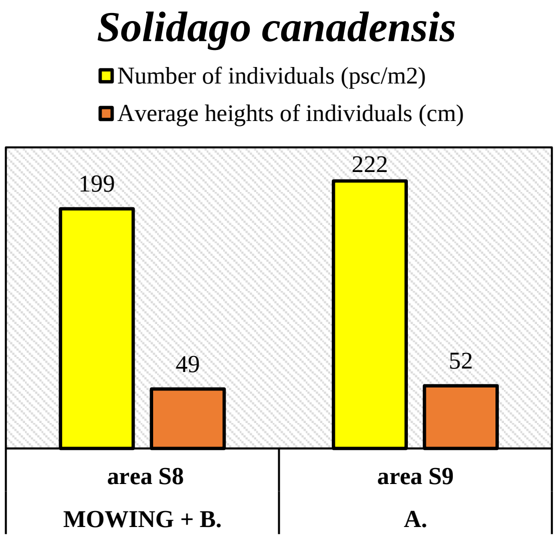

Figure 5. *Vegetative characteristics of* Solidago canadensis *before management (**Explanations**: The listed management was applied immediately after the measurement (Mowing + B. = herbicide with pelargonic acid; A. = herbicide with substances triclopyr, fluroxypyr)*

Before interventions **After interventions** **After interventions**

Figure 7*.* I. glandulifera *on area I6 before and after intervention by herbicide B., onw photo*

Figure 6 shows the results of the number of individuals and the height of the shoots of *S. canadensis*. 222 pcs/m^2 were found in area S9, 199 pcs/m^2 in area S8. The average heights of the individuals in the plots reached 49 cm (S8) and 52 cm (S9). The shortest individual (15 cm) and the tallest individual (85 cm) were recorded at site S9.

The control intervention to reduce *S. canadensis* consisted of a combination of mowing with herbicide B on plot S8 and application of herbicide A. on plot S9. In area S9, the effectiveness of herbicide A. was visible after approximately 20 days, where all individuals had burnt vegetative organs (see Figure 8). In contrast to *I. glandulifera*, the stems did not burn, but the plants did not have the power to form generative organs. The *S. canadensis population* in area S8 with the application of a combination of mowing and herbicide B was not effective for the time being, and after mowing, juvenile individuals appeared again in the entire area.

Before interventions **After interventions** **After interventions**

Figure 8. S. canadensis *in area S9 before and after intervention by combination of mowing and the herbicide A. onw photo*

The impact of selected management on these invasive species may change in the future.

3.4 Surface temperatures of vegetation and built-up areas

Out of a total of 70 thermal images taken at 4 locations in the CWWTP area (for locations, see Figure 3), only 18 of them were processed; images showing the same area areas outside the model area, were deleted. Scanned surfaces:

a) unmown cultural grasslands (meadows) – measured areas of phytosociological relevés were used (for area sizes, see Table 2); they were left without human intervention;
b) mowed cultural grasslands – surrounding vegetation;
c) groups of trees – deciduous, coniferous, mixed and shrubs;
d) roofs of buildings;
e) roads;
f) water tanks – within the CWWTP, these are settling tanks and aerated sand traps.

All these surfaces were compared with each other, the air temperature on July 18, 2022 between 2 and 3 p. m. ranged from 25.1 °C to 25.6 °C according to the Ostrava-Vyskovice weather station [17].

Table 4 shows the results of surface temperatures in 4 selected locations according to surface type – their maximum, minimum, and average temperature according to sunshine and shading.

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The sunlit surfaces of cultural vegetation (grasslands, trees, shrubs) reached a maximum of 51.21 °C (area with mowed grassland) and a minimum of 20.85 °C (area with a group of deciduous trees). The average temperatures of grassland (i.e., without tree vegetation) were above 30 °C. In the case of shaded cultural vegetation, the highest temperature was measured in the unmown lawn – meadow at 30.05 °C, as well as the minimum temperature (22.89 °C). In the case of technical surfaces (building roofs, roads), the maximum was 66.89 °C on a building roof and the minimum was 51.21 °C on the road. The minimum temperatures of technical surfaces do not differ much from the maximum. The difference between surface temperatures and the air temperature is considerable. It differs from the building roofs by 42 °C and from the mowed grasslands by 26 °C. The most optimal surface type was water reservoirs with an average of 20.65 °C, together with a group of mixed trees with an average of 26.43 °C.

The non-sunlit sites compared to the sunny sites yield interesting results, where, for example, the mowed grasslands had a difference in maximums of 22.73 °C, while the minimum temperatures were approximately the same. A 15 °C difference can be seen in the maximum values of the road and the mowed lawn.

Table 4. *Results of the surface temperatures of individual sites in the sun and in the shade in the CWWTP area*

SURFACE TYPE	T – max [°C]	T – min [°C]	T – average [°C]
SUNLIT LOCATION			
Mowed grasslands	**52.21**	23.77	35.45
Uncut grasslands (meadow)	44.21	22.57	30.09
A group of deciduous trees	38.65	**20.85**	27.21
A group of coniferous trees	30.73	23.49	27.19
A group of mixed trees	30.53	25.29	**26.43**
A group of bushes	33,97	25.13	29.61
Roofs of buildings	**66.89**	65.33	58.32
Roads	54.97	**51.21**	47.26
Water tanks	25.33	17.21	**20.65**
LOCATION IN THE SHADOW			
Mowed grasslands	28.49	25.97	**24.27**
Uncut grasslands (meadow)	**30.05**	**22.89**	27.05
Roads	43.85	24.93	35.08

4 DISCUSSION

4.1 Vegetation and diversity survey evaluation

Based on the tree and shrub layer inventory in the forested wetland habitat, Black locust communities (*Robinia pseudoacacia*) prevail, which is a significant deviation from the natural vegetation of the floodplain forest with *Quercus robur, Fraxinus excelsior, Prunus padus, Tilia cordata, Ulmus laevis, Alnus glutinosa* (elm oak forest) [15,16]. Vegetation in the CWWTP area corresponds to common cultural urban ecosystems [18].

The average value of the Shannon-Wiener diversity index (H´) in both model areas is 2.05 ± 0.6. The lowest average value of 0.43 was found in area S8 (forested wetland), dominated by *S. canadensis* with only 7 species. This is consistent with the results of Huang et al. [19], who confirmed the high-competitive ability of Canadian goldenrod against other species in the habitat. The areas with the occurrence of *I. glandulifera* had a Shannon-Wienerov index in the range of 1.64–2.25, which probably means that, despite the creation of populations with up to 90 % coverage, there is not a rapid reduction in the number of species in invaded stands but a change in species composition, which corresponds to the conclusions of Pyšek et al. [20]. According to Divíšek and Culek [10], the Shannon-Wienerov index in Czech ecosystems varies between 1.5 and 4.5. It may even have a higher value, according to Malý [21]. More species-rich areas were recorded in the areas of the CWWTP complex, where the

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number of species ranged from 16 to 27, and the Shannon-Wiener index reached a value of 2.71 in area A5, which is evaluated, according to Malý [21], as moderately rich diversity.

The evenness reaches an average value of 0.71 ± 0.18 in both areas. The lowest value again falls in area S8, so it is a very poorly balanced community. The opposite was area A4 in the CWWTP area with a value of 0.84, which indicates an almost species-balanced community. The evenness ranges between 0 and 1, and the closer it gets to 1, the more balanced the community is in abundance [22].

4.2 Evaluation of the First Control Interventions on Selected Invasive Plant Species

As already mentioned, in this article, we do not provide a final evaluation of the effectiveness of control interventions on the invasive species *I. glandulifera* and *S. canadensis*, but even after the 1st year of interventions, it is already possible to preliminarily evaluate their effect on the populations of the monitored invasive plants.

In our three selected areas with the invasive species *I. glandulifera*, the number of individuals was determined together with their heights. The largest number of individuals per m^2 was found in area I7, with 264 psc/m^2. The height was around 89–97 cm, but during the growing season it can reach 2.5 to 3 m [20, 2]. According to Kiełtyk and Delimat [23], this invasive species mainly inhabits coastal habitats, where it is dominant in nitrophilous herbaceous edges of lowland rivers or in a reed vegetation, which corresponds to our habitats. As part of the control, a gentler version of the herbicide based on natural pelargonic acid (B.) was selected in area I6. An herbicide with the active substances triclopyr and fluroxypyr (A.) was used in area I7. In area I10, a mechanical method was chosen. Švehláková et al. [4] recommend chemical spraying substances, such as triclopyr and 2,4 D. The herbicide A. contains one of these substances, which was visible in area I7, where this plant was suppressed this year. The effects of pelargonic acid on this plant have not yet been significant, but Švehláková et al. [4] report good results.

S. canadensis was monitored in two plots; the highest number was recorded in S9, with 222 individuals per m^2. Some authors also state 309 pcs/m^2 [19]. In both areas, the average height was in the range of 49–52 cm in June. Canadian goldenrod is not strongly bound to wetland, moist humic biotopes [7]. In our case, this species occurred in drier biotopes and in moist floodplain forest. The same types of herbicides were selected for *S. canadensis* as for *I. glandulifera*. Švehláková et al. [4], in this case, recommend the following herbicides: 2,4 D, flazasulsufuron; with less effectiveness they rate preparations based on fluroxypyr or pelargonic acid. In our case, a substance was not chosen to contribute to the elimination of the species, but the pelargonic acid shows its effectiveness in the case of *S. canadensis* after some time, most often in combination with mowing.

4.3 Evaluation of Relative Surface Temperatures of Cultural and Built-up Areas

The sunlit mowed grassland reached a maximum temperature of around 51.21 °C. Nováková [24] measured similar grasslands on August 1, 2020, between 9 a.m. and 10 a.m. (CET) in a different location using a FLIR E60 thermal camera and found a maximum value of 31.90 °C. From the overall results on the sunlit surfaces in the CWWTP, it can be determined that the most optimal effect in the area is not only water bodies with an average temperature of 20.65 °C but also a group of mixed trees with an average of 26.43 °C. As for the cause of artificial surfaces, the average for roofs was around 58.32 °C and for roads 47.26 °C, which is unacceptable for workers, as breaks are mandatory when the temperature exceeds 36 °C [25]. As mentioned above, the US EPA [13] claims that vegetation generally provides much more shade than built-up areas, which we can agree with in the case of the CWWPT. The cultivated grasslands in the CWWPT reached an average surface temperature of 24.27 °C, and the average road temperature was 35.08 °C. For now, we can say that an uncut grassland (meadow) has a better cooling function than, for example, cut grass. It must be added that these initial results may still change after correction to the absolute values.

Corrections for conversion to exact absolute surface temperature were not made due to a lack of data. Total data will be available during the next two growing seasons. We are going to calculate the emissivity coefficient (ε), which is expressed according to Engineering ToolBox [26] as heat radiation from a "gray body" according to the Stefan-Boltzmann law compared to heat radiation from an ideal "black body" with an emissivity coefficient of ε = 1. Emissivity of some types of surfaces can be found in relevant tables [26]. These will be recalculated for cultural vegetation and built-up areas or water bodies in the next steps of the research.

5 CONCLUSION

The article presents partial results, especially the vegetation inventory and phytosociological survey in the Odra River floodplain and the CWWTP area. The inventory took place in the form of a listing of tree and shrub layer species in an area of approximately 1702 m^2 in a part of the wetland ecosystem in the floodplain of the Odra River (the area selected near the areas for phytosociological analysis). 17 species of trees and 5 species of shrubs were recorded here. The invasive species *Robinia pseudoacacia* was the most represented. A total of 10 relevés were created for the phytosociological analysis, 5 of which were located in a forested wetland and 5 in the CWWTP territory. Study areas in the wetland ecosystem, due to the prevailing invasive plants, have lower diversity and lower evenness (area S8 with index H' = 0.43 and evenness E = 0.22) than areas in the CWWTP area, where vegetation can be assessed as moderately rich and almost optimally balanced in terms of species (area A5 with index H' = 2.71 and area A4 with evenness E' = 0.84). The number of species here ranged from 16 to 27, while in the wetland, it ranged from 7 to 22.

Control methods leading to the reduction of the population of *Impatiens glandulifera* and *Solidago canadensis* were also evaluated. Mechanical (mowing), chemical (using herbicide with active ingredients triclopyr and fluroxypyr (A.), and herbicide with pelargonic acid (B.)), and combined (A. + mowing, mowing + B.) methods were used. From the point of view of control effectiveness, selected vegetative characteristics were monitored: the number of individuals per m^2 and the height of the shoots. The highest number of individuals of *I. glandulifera* was in area I7, with 264 individuals/m^2 and for *S. canadensis* in area S9, with 222 individuals/m^2. The average height of Himalayan balsam stems reached 89–97 cm, while the height of Canadian goldenrod stems was around 49–52 cm. These characteristics were recorded during June as the first measurement before the application-chosen control method. The reaction of plants to the control was visible after about 20–30 days, most pronounced in area I7 with a combination of A. + mowing for *I. glandulifera* and in area S9 with a combination of mowing + A for *S. canadensis*.

The last part of this research was the measurement of the surface temperatures of cultural vegetation and built-up areas in the CWWTP area as heat islands. Surfaces in CWWPT are repeatedly overheating, and one of our aims is to propose a suitable composition of vegetation using local natural and cultural plant species, which will effectively reduce extreme temperatures. This aim will be carried out in the next steps of the research. Using a drone with a built-in thermal camera proved to be a suitable method. A total of 70 thermal images were created, 18 of which were processed. On average, the temperature of the surface of cultural vegetation (mown grasslands, unmown grasslands – meadows, groups of trees and bushes) ranged from 26.43 °C to 34.45 °C. The average temperature of the technical surfaces (roads, building roofs) was in the range of 47.26 °C to 58.32 °C, and the average temperature of the water surface (water treatment plant tanks) reached 20.65 °C. However, there were no corrections to the emissivity of the surfaces, so these are indicative values.

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