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The introduced population of *Biscutella laevigata* L. on the heap of flotation tailings after lead-zinc ore processing in Piekary Śląskie – current status and future prospects

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Introduction

Biscutella laevigata L. (buckler mustard) is associated with four natural sites in Poland (Rostański et al. – Chapter 3 of this volume). However, the site in Lower Silesia is only of historical importance nowadays. The other three existing sites include one mountain site in the West Tatra Mountains, and two lowland sites: the old mine waste heaps in the Olkusz region where zinc and lead ores were once extracted (Silesian-Cracow Upland) and the grasslands on limestone rock debris in Zagorzyce (the Nida Basin) (Dobrzańska 1955, Grodzińska and Szarek-Łukaszewska 2009, Nowak et al. 2011, Przemyski and Piwowarczyk 2012, Wierzbicka and Rostański 2002, Rostański et al. – Chapter 3 of this volume). The latter site is a result of the recent introduction of the species. It was established in 2009 after buckler mustard seeds were introduced on the flotation waste heap from zinc and lead ores processing in the 'Dołki' (50°21′12″N, 19°00′10″E) region of Piekary Śląskie (Upper Silesia) (Rostański 2014).

The heap in the 'Dołki' region is built of flotation waste from the 'Bleischarley' smelter, formerly 'Orzeł Biały' (producing lead till the 1980s), in Piekary Śląskie. The waste was produced during the initial beneficiation of zinc and lead ores by gravitation methods. It was composed mainly of dolomite sludge, containing large amounts of ore minerals because of the low efficiency of the ore enrichment process (Fajfer et al. 2010). Flotation waste was deposited in the area surrounding the smelters in many elevated heaps. One of them is the 'Dołki' heap which was formed from 1915 to 1930. Now it is an 11 m elevation, covering an area of about 1.2 ha (Fig. 1). Its immediate

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Fig. 1. The 'Dołki' lead-zinc ore flotation tailings heap in Piekary Śląskie (za Mapy Google 2019)
Ryc. 1. Zwałowisko odpadów popłuczkowych „Dołki" w Piekarach Śląskich (base on Google Maps 2019)

surroundings are arable land, wasteland, residential areas, and roads.

Flotation waste presents unfavourable conditions for the growth of plants, mostly because of very high, toxic amounts of heavy metals derived from ore-bearing minerals that remained in the waste material. In the dolomite sludge building the 'Dołki' heap, the following metal concentrations were found: 73,000–89,900 mg/kg of zinc, 17,700–18,300 mg/kg of lead, and 388–447 mg/kg of cadmium (Kucharski et al. 2011, Rostański et al. 2016). These concentrations are many times higher than those acceptable for soils, even in industrial areas, which amount to 2,000 mg/kg for zinc, 600 mg/kg for lead, and 15 mg/kg for cadmium (Brunarska and Szarek-Łukaszewska – Chapter 2 of this volume). Despite this, part of the calamine waste heap (with soils rich in metals from zinc-lead ores) is relatively well vegetated. Vegetation has been developing on the mineral substratum of the heap for more than 80 years as a result of both reclamation activities and natural plant succession (Rostański et al. 2016). The slopes of the heap are almost completely covered by herbaceous plants forming a grassland community. There are also single trees and shrubs that remained after reclamation plantations, but they are in poor condition. The top part of the heap is mostly unvegetated (Fig. 2).

In order to devise an effective method for the revegetation of the top part of the 'Dołki' heap, and also to mitigate wind and water erosion, a field experiment was performed (Rostański et al. 2012, 2016, Rostański 2014). Several techniques promoting plant succession on mineral substrates of abandoned mine land were applied. Studies on spontaneous succession on this type of land have shown that this process enables the development and

survival of plant communities, which are well-adapted to the difficult habitat conditions in the area, without human interference (Prach and Walker 2011, Szarek-Łukaszewska 2015). However, spontaneous revegetation is a long process, mainly because of the small pool of diaspores of the appropriate species, the poor dispersal abilities of these plants and the unfavourable properties of the substratum. It is possible to accelerate this process on unvegetated substrates by introducing seeds of the selected species, spreading hay (biomass of cut plants with seeds), or transplanting fragments of turf with soil containing a seed bank and microorganisms (Kirmer and Tichew 2006, Řehounková et al. 2011). It is important that the introduced material is derived from sites where habitat conditions are similar to those where the plant cover is to be restored.

The experiment on the 'Dołki' heap started in 2009. In the study plots established on the unvegetated top part of the waste heap, plant seeds were sown, hay was spread and fragments of turf with soil were transplanted (details of the methods are given in Rostański et al. 2012). All materials used in the experiment were derived from similar grassland habitats, including grasslands populated with *B. laevigata* at the site of old mine heaps in Bolesław (the Olkusz region) (Szarek-Łukaszewska and Grodzińska 2011, Jędrzejczyk-Korycińska and Szarek-Łukaszewska – Chapter 10 of this volume). Observations of the study plots, carried out in the subsequent vegetation seasons, showed that the methods applied did not produce the expected results (Rostański 2014, Rostański et al. 2016). In 2010, only a few seedlings sprouted in the plots with transplanted turf and in the plots where the seeds of calaminarian grassland plant species had been sown. These were the seedlings of *Silene vulgaris* (Moench) Garcke (bladder campion), *Lotus corniculatus* L. (common bird's-foot trefoil), *Daucus carota* L. (wild carrot), *Reseda lutea* L. (yellow mignonette), and of the buckler mustard. In consecutive years all

Fig. 2. The top part of the 'Dołki' flotation tailings heap in 2017 (photo A. Rostański)
Ryc. 2. Szczytowa część zwałowiska odpadów popłuczkowych „Dołki" w roku 2017 (fot. A. Rostański)

Fig. 3. *Biscutella laevigata* growing on the 'Dołki' flotation tailings heap in 2019 (photo A. Rostański)
Ryc. 3. *Biscutella laevigata* rozwijająca na zwałowisku odpadów popłuczkowych „Dołki" w roku 2019 (fot. A. Rostański)

these plants disappeared, except for the buckler mustard which developed a large population (Figs 3, 4).

Development of the population of *B. laevigata* on the 'Dołki' heap

Monitoring of the buckler mustard population in the top part of the 'Dołki' heap was carried out regularly in each consecutive season from 2009 to 2019. The growth of this population and its spatial expansion were shown in Figure 5 and 6.

At first, the number of *B. laevigata* individuals increased slowly on the flotation waste heaps (Fig. 5). In 2010, of some tens of the buckler mustard seeds, only two vegetative individuals (rosettes) developed in one of the plots. One year later, the rosettes grew and one individual started flowering. In the spring of 2012, all of the individuals entered the full reproductive cycle and produced numerous flowers and fruits (generative phase). In addition, a few young seedlings (tiny rosettes with several leaves) and older individuals of *B. laevigata* were found, some of them developed close to the first maternal individuals and others at a distance from them. In 2013, more than a dozen individuals that flowered and fruited were found. Around them, many young rosettes, new individuals, appeared. Three years later, on the 'Dołki' heap, there were some tens of generative individuals and some hundred vegetative individuals (seedlings and older plants with rosettes of different size). After the three consecutive years, in 2019, several hundred flowering individuals and more than one thousand vegetative individuals (rosettes) were found. Altogether, 304 individuals flowering and spreading seeds, 583 individuals in the form of smaller and bigger rosettes, and 635 seedlings were identified. Ten years after the

seeds were sown and the first two ones germinated, the whole *B. laevigata* population of the 'Dołki' flotation tailings heap amounted to 1,522 individuals in different developmental stages (Fig. 5). Thus, the results of the long-term monitoring of the buckler mustard on the 'Dołki' heap indicate that the further dynamic growth of the population is possible in this newly established locality.

During the first three years of the experiment on the flotation waste heap, the distribution of the *B. laevigata* population was limited to the immediate neighbourhood of the first two maternal individuals (within a radius of 3–4 m) (Fig. 6). Afterwards, plants were observed at larger and larger distances from the centre of the distribution. In 2019, new individuals were spotted at a distance of over

Fig. 4. Different developmental stages of *Biscutella laevigata* on the 'Dołki' flotation tailings heap. A – young rosette, B – first spring flowers, C – numerous young rosettes near maternal individual (photo A. Rostański)

Ryc. 4. *Biscutella laevigata* na hałdzie odpadów popłuczkowych „Dołki" w różnych stadiach rozwojowych. A – młoda rozeta, B – pierwsze wiosenne kwiaty, C – liczne, młode rozety w sąsiedztwie osobnika matczynego (fot. A. Rostański)

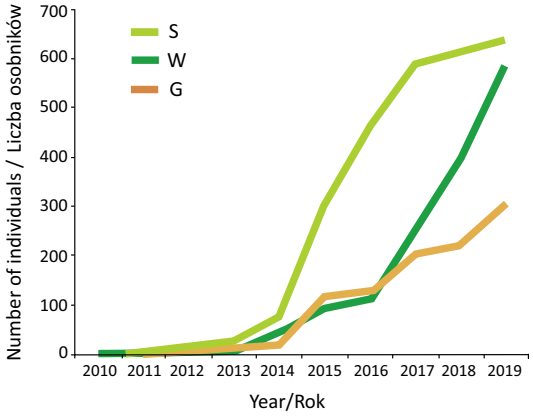

Fig. 5. Changes in the numbers of *Biscutella laevigata* on the 'Dołki' flotation tailings heap from the years 2009–2019. S – seedlings, W – vegetative individuals, G – generative individuals

Ryc. 5. Zmiany liczebności *Biscutella laevigata* w latach 2009–2019 na hałdzie odpadów popłuczkowych „Dołki". S – siewki, W – osobniki wegetatywne, G – osobniki generatywne

20 m from the maternal individuals. Also, the buckler mustard abundantly colonized the south-eastern slope of the heap (which was outside of the study plots). The seeds of *B. laevigata* were found not only in the vicinity of the maternal individuals. Many seeds were transported by wind and water at a big distance, spreading mostly downward, to the base of the heap.

The monitoring of the *B. laevigata* population on the 'Dołki' heap over many years has revealed an important adaptation of this species to particular phenomena occurring there, such as movements of the ground associated with frost (frost heaving). When ground frost occurs, significant movements of the ground surface can be observed (authors' own observation). The surface layer of the waste material can swell upward at a height of even 10 cm

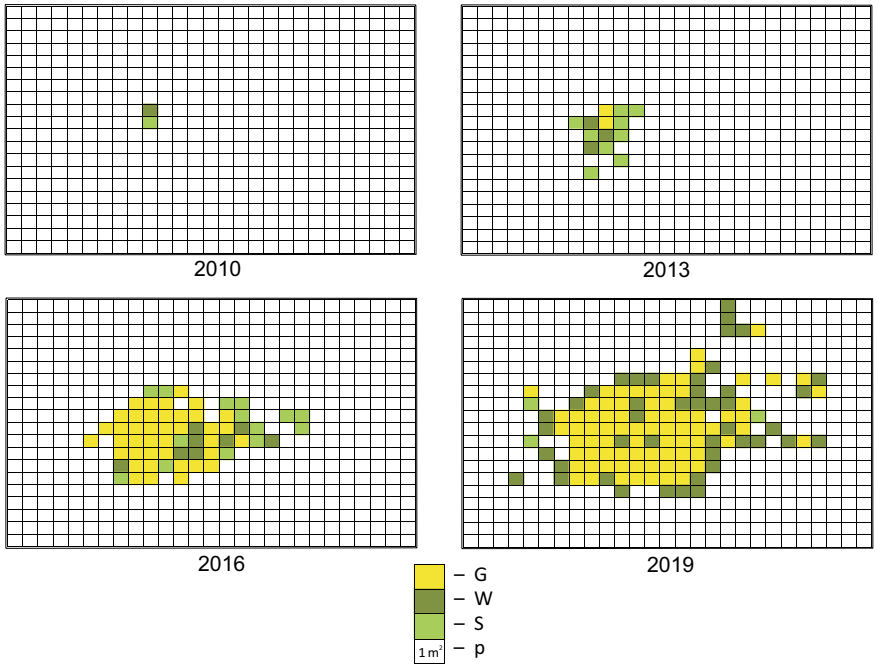

Fig. 6. Spatial pattern of the *Biscutella laevigata* population on the 'Dołki' flotation tailings heap from the years 2010–2019. G – generative individuals, W – vegetative/individuals, S – seedlings, p – study plot 1 m × 1 m

Ryc. 6. Rozwój przestrzenny populacji *Biscutella laevigata* w latach 2010–2019 na hałdzie odpadów popłuczkowych „Dołki". G – osobniki generatywne, W – osobniki wegetatywne, S – siewki, p – poletko badawcze 1 m × 1 m

Fig. 7. The *Biscutella laevigata* seedling (A) on the 'Dołki' flotation tailings heap and images of frost heaving – ice with fragments of the upper ground layer (B) and area affected by ground movements associated with frost (C) (explanation in the text) (photo A. Rostański)

Ryc. 7. Siewka *Biscutella laevigata* (A) z hałdy odpadów popłuczkowych „Dołki" i ilustracja ruchów mrozowych gruntu na tym zwałowisku – lód z fragmentami wierzchniej warstwy gruntu (B) i powierzchnia zwałowiska z efektem mrozowym (C) (objaśnienia w tekście) (fot. A. Rostański)

as a result of the freezing of subsurface water (Fig. 7). Frost heaving may greatly reduce the growth and survival of most seedlings and young plants of different species colonizing the bare substratum of the top part of the heap (Rostański 2014). However, the buckler mustard, with its long and strong roots anchoring the plant firmly in the deeper layers of the substratum, is resistant to ground movements associated with frost and develops normally when spring arises. It seems that frost heaving may be considered a selection factor governing the growth and survival of plants colonizing the waste material, as important as the toxicity of its substratum (Fig. 8).

The development of the large *B. laevigata* population on the flotation waste of the 'Dołki' heap confirms the usefulness of this species for the phytostabilization of metalliferous grounds. This usefulness has already been shown earlier, in the experiments conducted on flotation waste in the Olkusz region (Rostański 2014, Muszyńska et al. – Chapter 7 of this volume). In these experiments, similarly as in the 'Dołki' experiment, the seeds of plants growing on the old mine waste (rich in metals) in the Olkusz region were used. *B. laevigata* shows many adaptations to the difficult habitat conditions prevailing there (Bemowska-Kałabun et al. – Chapter 6 of this volume).

Monitoring of the effects of the buckler mustard introduction on the 'Dołki' heap is planned. The dynamics of this population, as well as the population dynamics of other species accompanying *B. laevigata* (e.g. *S. vulgaris*), will be studied. Now an important question

Fig. 8. Young buckler mustard *Biscutella laevigata* individuals lying on the surface of the 'Dołki' flotation tailings heap. There are visible elongated roots, which are an adaptation to ground movements associated with frost (photo A. Rostański)

Ryc. 8. Młode osobniki pleszczotki górskiej *Biscutella laevigata* „leżące" na powierzchni gruntu hałdy opadów popłuczkowych „Dołki". Widoczne wydłużone korzenie, przystosowanie do ruchów mrozowych gruntu (fot. A. Rostański)

arises as to whether the buckler mustard will initiate the development of dense species-rich vegetation on the lead-zinc ore flotation tailings heap without human interference.

Summary

The dynamic development of the *B. laevigata* population, started from two individuals, emerged from seeds that were sown in 2009 and was observed on the 'Dołki' flotation tailings heap. Year by year the population increases, individuals abundantly flower and fruit, and the current status of the population is promising. The buckler mustard shows resistance to frost heaving, which seems to be an important adaptation which is particularly useful for colonizing mineral, unvegetated substrates.

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