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Calaminarian grasslands – threats and conservation prospects – 'BioGalmany' project

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Introduction

Post-mining areas where zinc and lead ores were extracted are a novel anthropogenic environment whose most distinctive feature is a high content of heavy metals in its substrate. The presence of metals such as zinc, lead, and cadmium have a significant influence on the composition and diversity of the flora and fauna of these areas. Unique and often entirely new biocenoses with organisms resistant to high concentrations of these metals develop there (Baker et al. 2010, Jędrzejczyk-Korycińska 2011, Rostański et al. 2015). Secondary sites of many protected and rare plant and animal species also emerged there (Prach et al. 2011). Calaminarian grasslands are typical plant communities for habitats with metalliferous soils (Ernst 1974, Ernst 1990, Brown 2001, Matuszkiewicz 2001, Baker et al. 2010, Baumbach 2012).

Calaminarian grasslands have a special place among the European plant communities. They are very rare because their presence is restricted to small patches of ore-bearing land (e.g. Baker et al. 2010, Baumbach 2012, Szarek-Łukaszewska et al. 2015). They are found sporadically on natural metal-rich rock outcrops and occur primarily in old mine excavations and on waste heaps from ore mining and processing with ore-bearing rock fragments. Plants that are able to colonise these heavy metal-rich substrates usually form a short cover of variable density (e.g. Baker et al. 2010, Baumbach 2012, Szarek-Łukaszewska et al. 2015). Its species composition varies depending on variable physical and chemical properties of the soil. In general, the higher its content of available metals, the poorer its species composition. Mine waste, being a mixture of rock fragments varying in size and mineral composition, deposited in different periods of ore mining activities, offers a mosaic of microhabitats where species with different habitat[1]

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[1] A habitat is the abiotic element of an ecosystem; a space and a group of abiotic factors, mostly climatic and soil ones. Habitat

requirements find a home. In addition to plant species showing preference for warm and dry habitats, there are plants of humid and fertile habitats. Grasslands can vary in density. Vascular plants dominate closed grasslands, while lichens are numerous in open grasslands, on exposed soil and stones. Mosses are not very frequent. Calaminarian grasslands are mostly composed of common species but there are also species which are rare for the regional floras present. These grasslands are places of occurrence for unique plant ecotypes, subspecies, or species which are resistant and tolerant to heavy metals (metallophytes). Among metallophytes, one may find species that occur exclusively on heavy metal-rich substrates or species that grow on both metalliferous and non-metalliferous soils in the same region. The former are named obligatory (or absolute) metallophytes, the latter, facultative metallophytes, or pseudometallophytes (Baker et al. 2010, Bemowska-Kałabun et al. – Chapter 6 of this volume). These unique plants (e.g. *Biscutella laevigata* L., the main character of this volume) are the subject of numerous studies on the mechanisms which enable them to survive in extremely adverse habitat conditions on metalliferous soils (Bemowska-Kałabun et al – Chapter 6 of this volume) and studies on their use in phytoremediation of contaminated land (Muszyńska et al. – Chapter 7 of this volume).

Calaminarian grassland sites are scattered over almost the whole of Europe, in regions where zinc and lead ores were once mined and processed. The best known are grasslands in the Harz Mountains in northern Germany, or in the Aachen-Liege industrial region on the border of Germany, Belgium, and the Netherlands (Ernst 1974, Baker et al. 2010, Baumbach 2012). In Poland, calaminarian grasslands can be found in the south of the country, in Silesian-Cracow Upland, in an ore-bearing area (generally named the Silesian-Cracow region) extending from the north-west to the south-east, including Tarnowskie Góry and Bytom, Zawiercie, Olkusz and Chrzanów (Jędrzejczyk 2004, Włodarz – Chapter 1 of this volume). The best-preserved grassland is in the Olkusz region (Szarek-Łukaszewska et al. 2015).

Plant communities associated with zinc-, lead-, and cadmium-rich soils in the Silesian-Cracow region, syntaxonomically[2] represent the association of Armerietum halleri (alliance Armerion halleri, order Violetalia calaminariae, class Violetea calaminariae) (Szarek-Łukaszewska et al. 2015). They are the easternmost sites of grasslands of this type in Europe. The best-preserved Polish grasslands (in the region of Olkusz) are poorer in species than grasslands described from the west of Europe (Szarek-Łukaszewska et al. 2015). *Minuartia verna* subsp. *hercynica* (Wilk.) O. Schwarz, a characteristic species of west-European grasslands, is absent in the species composition of Polish grasslands but there are ecotypes of bladder campion (*Silene vulgaris* (Moench) Garcke) and thrift (*Armeria maritima* (Mill.) Willd.) associated with metalliferous habitats. Polish grasslands are notable due to the presence of buckler mustard, which shows many morphological and physiological adaptations. Its taxonomical position is unclear (Bemowska-Kałabun et al. – Chapter 6 of this volume). Other species which are constant in these communities are compact dock (*Rumex*

is not synonymous with site (locality), which is a location in a geographical context base on Słownik botaniczny – Botanical Dictionary 2013).

[2] Syntaxonomic (phytosociological) units – in phytosociology, a science concerning the description of plant communities, their classification and arrangement into a hierarchical system. A basic unit is association, and higher units are subsequently: alliance, order and class; units are distinguished and arranged on the basis of floristic similarity, characteristic combination of species and characteristic species (base on Słownik botaniczny – Botanical Dictionary 2013).

thyrsiflorus Fingerh.), sand rock-cress (*Arabidopsis arenosa* (L.) Lawalrée), fastigiate gypsophila (*Gypsophila fastigiata* L.), *Potentilla arenaria* Borkh., and common kidneyvetch (*Anthyllis vulneraria* L.). The presence of clump-forming grasses, such as sheep's fescue (*Festuca ovina* L.) and common bent (*Agrostis capillaris* L.), is a common characteristic of all the calaminarian grasslands (Szarek-Łukaszewska et al. 2015).

Calaminarian grasslands growing on soils with a high content of heavy metals are one of the natural habitat types[3] that are of community interest. Their conservation requires the designation of special areas of conservation within the Natura 2000 European Ecological Network (Natura 2000). They are classified as a natural habitat type 6130 Violetalia calaminariae (Journal of Law of 2014 item 1713). According to the report on the conservation status of the habitat type 6130, the conservation status of this habitat is generally unfavourable (inadequate and bad) in the EU (Anonymous 2020). Poland reported the unfavourable status of calaminarian grasslands. This status will deteriorate if appropriate conservation measures are not established (Anonymous 2019). The effective conservation of ecosystems representing the natural habitat type 6130 requires active site management (Anonymous 2015, 2019). Management activities should be focused on the maintenance of grasslands at a desirable developmental stage (stage of succession) and the reclamation of degraded ones to restore their favorable structure and functions, including the characteristic species composition of the plant community. The planned measures should primarily assist the natural development of these specific ecosystems associated with heavy metals. To this aim, the monitoring of changes occurring in these ecosystems and the regular assessment of their conservation status is needed, as well as the elaboration and implementation of long-term conservation plans. The existing long-term cooperation between scientists, administrations responsible for environmental protection, local governments and landowners makes these tasks easier. In 2018, thanks to this cooperation, the first Polish project aimed to develop methods of calaminarian grassland conservation was launched. The project entitled 'Best practices for enhancing biological diversity and conservation of calaminarian grasslands in the Silesian-Cracow region – BioGalmany' (further referred to as 'BioGalmany') is carried out by the University of Silesia in Katowice, municipalities: Jaworzno and Tarnowskie Góry, with the support of the Bolesław Mining and Metallurgical Plant S.A. (Zakłady Górniczo-Hutnicze 'Bolesław' S.A. – ZGH Bolesław) and the commune of Bolesław. The project is supervised by the Regional Directorates for Environmental Protection in Kraków and Katowice. It is financed from EU funds.

In this chapter, based on the 'BioGalmany' project objectives, threats to calaminarian grasslands and proposed management activities aimed to maintain or restore favorable conditions for conservation of the biological diversity of these communities, with particular reference to metallophytes (including *B. laevigata*), are presented. The selected sites of calaminarian grasslands are also described. The duration of the project is four years. Its results[4] will show the effectiveness of the applied management

[3] Habitats Directive introduced the concept of 'natural habitat types', which means 'terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural'; this concept is close to the concepts of 'biocenosis', or 'ecosystem' in biology (base on http://www.natura2000.edu.pl/siedliska-przyrodnicze/).

[4] Tasks planned in the project are already underway. Information on their progress is presented here: www.biogalmany.us.edu.pl.

measures for the conservation of calaminarian vegetation and valuable metallophytes. The results of the project will also be used to outline the long-term management plans.

Threats to calaminarian grasslands

Current threats to calaminarian grasslands are the same as those identified for other grasslands (especially xerothermic grasslands[5]) in Poland and other European countries. They are both natural processes and human activities (Barańska and Jermaczek 2009, Jędrzejczyk-Korycińska 2009, Baumbach 2012, Anonymous 2015, 2019).

In the course of natural succession, the diversity and species composition of plant communities, as well as habitat conditions, undergo gradual changes. In our geographical latitude, semi-natural plant communities (originating as a result of human activity), i.e. grasslands and meadows, normally turn into forest communities (Falińska 2004). In calaminarian grasslands, the process of succession is generally slow because the pool of species that can adapt to extreme conditions prevailing on heaps of calamine waste (drought, full insolation, scarcity of nutrients combined with large amounts of heavy metals in the soil) is small (Winterhalder 1995, Baker et al. 2010, Baumbach 2012). However, we are currently observing a very quick encroachment of shrubs and trees on calaminarian grasslands, mostly belonging to species which abundantly occur in the surroundings (Baumbach 2012, Anonymous 2015, 2019). They may be both native and alien species, easily propagating and quickly growing, which are usually planted on the abandoned and degraded mine area during its reclamation. An example of a native species is Scots pine (*Pinus sylvestris* L.). It propagates by wind-disseminated seeds and has a wide ecological scale and high adaptive capacities. It readily and quickly colonizes metalliferous substrates and is one of the most frequently planted species in degraded areas (Pietrzykowski 2019). As it encroaches on grasslands, pines cast shade, produce large amounts of needles (which remain on the soil surface for a long time) and acidify soil, which makes the growth of many species impossible, mostly light-loving, thermophilous and calciphilous ones (Kapusta et al. 2014). Once Scots pine trees cover increasingly larger areas over time, only a few species (e.g. the buckler mustard) characteristic of grasslands can survive, for a limited time only, in loose Scots pine stands or in their periphery (Kapusta et al. 2014) (Fig. 1). Grasslands are also being invaded by alien species growing in their surroundings, such as black cherry (*Padus serotina* (Ehrh.) Borkh.), Siberian peashrub (*Caragana arborescens* Lam.), and black locust (*Robinia pseudoacacia* L.) (Anonymous 2015, 2019). In a short time, the expansive plants can form a thicket. Under its dense canopy, the light conditions, microclimate, and soil properties undergo changes, making the existence of most herbaceous plants, and above all light-loving species, impossible (Vítková et al. 2017).

Like arborescent plants, expansive herbaceous plants may also have a negative impact on the condition of calaminarian grasslands (Anonymous 2015, 2019). An example is purple moor-grass *Molinia caerulea* (L.) Moench. It is a high grass which forms dense clumps and propagates easily, vegetatively and generatively, by seeds (Taylor et al. 2001). It occurs primarily in fertile habitats. In poor habitats it grows in places with more fertile soil and in conditions with an increased atmospheric nitrogen supply

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[5] Xerothermic grasslands are 'thermophilous grassland communities of a steppe character, whose occurrence is determined by climatic, soil and orographic conditions. They are found mostly in southeastern and southern parts of Europe. They occur extrazonally in the whole continent on calcium carbonate-rich substrates on slopes of the large river valleys or limestone outcrops' (base on Barańska et al. 2010, Perzanowska and Kujawa-Pawlaczyk 2004).

Fig. 1. Buckler mustard in coppices on abandoned mine land in the Olkusz region, 2019 (photo G. Szarek-Łukaszewska)

Ryc. 1. Pleszczotka górska w zadrzewieniach na nieużytku górniczym w rejonie olkuskim, rok 2019 (fot. G. Szarek-Łukaszewska)

(Taylor et al. 2001). The purple moor-grass has many adaptations which enable this plant to colonize bare, dry, and heavy metal-rich flotation tailings (formed after processing zinc and lead ores) (Turnau et al. 2012). In the Olkusz region, this grass also grows on relatively fertile, humid, metalliferous soils, in places where the abandoned mine land was covered with foreign and fertile soils during its reclamation (Szarek-Łukaszewska and Grodzińska 2010, Holeksa et al. 2015). In recent years, the gradual colonization of poor calaminarian grasslands habitats by purple moor-grass has been observed in this region (Fig. 2). Precious plant species of calaminarian grasslands are also ousted by invasive herbaceous plants, such as Canadian goldenrod (*Solidago canadensis* L.) and Symphyotrichum novi-belgii (*Aster novi-belgii* L.), as well as large-leaved lupine (*Lupinus polyphyllus* L.) (Anonymous 2015, 2019). The negative impact of these plants on native plant communities has frequently been described (e.g. Weber 1998, Hejda et al. 2009). Expansive perennial plants with a large biomass quickly form a dense, permanent cover, making the existence of other species impossible.

Inappropriate human activities also pose a threat to calaminarian grasslands. It is not commonly known that calaminarian habitats are of special conservation and cultural interest, as a result they are still perceived as degraded industrial areas and often reclaimed (planted with trees, or grasses) (Szarek-Łukaszewska 2015). The applied reclamation techniques stem from forestry or agriculture. Shrubs and trees from commercial nurseries and seed mixtures containing cultivars are planted on levelled and often fertilized (organic matter, or inorganic fertilizers) substrates. The plant species used for reclamation are both native, sometimes not representing local varieties, and alien to the native flora. In this way, uninteresting

Fig. 2. Purple moor-grass in calaminarian grassland in the 'Armeria' Natura 2000 site, 2019 (photo M. Jędrzejczyk-Korycińska)

Ryc. 2. Trzęślica modra w murawie galmanowej obszaru Natura 2000 „Armeria", rok 2019 (fot. M. Jędrzejczyk-Korycińska)

homogenous plant communities are formed, built mostly by common, synanthropic species (associated with man), including invasive ones (Prach et al. 2011, Szarek-Łukaszewska 2015). With time, because of a lack of natural assets, they may be destined for urban and rural development. Another reason why calaminarian grasslands disappear from the landscape is due the use of associated rock material as aggregate for construction of local roads (Baumbach 2012, Anonymous 2015, 2019). Other heaps of mine waste, distinguished by varied surface features, are damaged by quads, motorcycles, and off-road vehicles. Their routes are deprived of vegetation and soil, and the exposed mineral substratum is strongly compacted. The revegetation of such damaged areas is difficult and takes time. Metalliferous areas are also seen as waste disposal grounds and often become illegal municipal waste dumping sites, which are difficult to shut down (Anonymous 2015, 2019).

Monitoring of natural habitat types, including special areas of conservation (Natura 2000 sites), was carried out as part of the State Environmental Monitoring from 2013–2014 and 2017–2018 and it has shown that the conservation status of the natural habitat type 6130 in the whole Silesian-Cracow region was unfavourable: inadequate or bad (Anonymous 2015, 2019). The overall result of the assessment was determined by assessment of the poor structure and functions, due to the gradual transformation of calaminarian grasslands into meadow and forest communities and the intrusion of alien species. On account of the results and the rare occurrence of calaminarian grasslands in Poland, monitoring specialists proposed to extend protective measures to all, even very small sites of these communities. Otherwise, the ongoing processes of succession and inappropriate human activities will result in the disappearance of calaminarian grasslands and associated valuable plant and animal species. It should be stressed that calaminarian grassland sites are also an important relic of the old industrial culture, therefore their protection is important in the context of not only the conservation of the natural environment conservation but also of cultural heritage.

Conservation measures applied to calaminarian grassland sites as part of the 'BioGalmany' project

To counteract the decline of calaminarian grasslands, with their unique components – metallophytes, active management measures are desperately needed. It is necessary to maintain and restore the grasslands in the degraded sites, overgrown with trees and shrubs, even in those whose vegetation is no longer of the desired type. An attempt at the restitution of calaminarian grasslands was undertaken at the end of 1990s in Germany in the post-mining area of Stolberg (Raskin 2008). In the fragments of the metalliferous site (about 4.5 ha in area) overgrown with Scots pine, with scattered grassland species, all the trees were cut down. Next, the upper part of the soil was stripped to uncover its mineral part. Grassland vegetation reappeared after five years of the experiment. At the beginning of the 21th century, in Poland, an experimental tree clearance was performed at a site named 'Pleszczotka' (0.8 ha; approximately 20% of the whole grassland area), part of the calaminarian grassland which was shrinking in area due to the encroachment of Scots pine. This grassland has developed on a heap of mine waste in the Olkusz region which is over 100 years old (a detailed description of the grassland is given in a later part of this Chapter). Studies carried out in the first stage of the experiment (before tree clearance), from 2008–2009, aimed to assess the impact of Scots pine on the species composition of the grassland (Kapusta et al. 2015). The results of these studies showed that the species diversity of the plant community decreased, and valuable light-loving species disappeared in response to the increasing density of trees. Thus, to maintain the grassland, it was necessary to cut down Scots pines. Simultaneously, it is important to maintain the mosaic of microhabitats, including those with bare, mineral, skeletal soil. These include microhabitats of some metallophytes (e.g. buckler mustard). In the second stage of the experiment, in the winter of 2011, all trees were removed from the grassland and monitoring of the effect of this management measure began. After a few years, the frequency of occurrence of grassland species, such as common bent, harebell (*Campanula rotundifolia* L.), Carthusian pink (*Dianthus carthusianorum* L.), purging flax (*Linum catharticum* L.), cream scabious (*Scabiosa ochroleuca* L.) and bladder campion, increased (Jędrzejczyk-Korycińska et al. 2014, Jędrzejczyk-Korycińska and Szarek-Łukaszewska 2017). Some species which were new to the area had also appeared, e.g. sweet vernal grass (*Anthoxanthum odoratum* L.), yellow mignonette (*Reseda lutea* L.), and white clover (*Trifolium repens* L.), as well as seedlings of trees and shrubs (sycamore, *Acer pseudoplatanus* L.; silver birch, *Betula pendula* Roth; common aspen, *Populus tremula* L.; buckthorn, *Frangula alnus* Mill.). In patches where mineral soil was occasionally exposed during tree clearance, characteristic species of calaminarian grasslands emerged, e.g. buckler mustard, bladder campion, broad-leaved thyme (*Thymus pulegioides* L.) and fastigiate gypsophila. In patches where trees were not removed, the number of plant species did not change (Jędrzejczyk-Korycińska et al. 2014, Jędrzejczyk-Korycińska and Szarek-Łukaszewska 2017).

The 'BioGalmany' project, which started in 2018, is the continuation and extension of the small-scale experiment described above. It covers the whole area of the 'Pleszczotka' site in Bolesław and other sites of calaminarian grasslands in the Silesian-Cracow region. In the project, in addition to tree clearance, there are other management activities planned, selected from the list of best practices for conservation and restoration of xerothermic grasslands. These management measures have been established as a result of different projects carried out in Poland over the last few years (e.g. Barańska and Jermaczek 2009, Gawroński 2013). Management measures adopted for the 'BioGalmany' project are in line with recommendations for the conservation of the 6130 natural habitat type within the Natura 2000 sites in Poland (Świerkosz et al. 2013, Anonymous 2019) and other European countries (Simkin 2011).

'BioGalmany' – project goals and objectives

The main goal of the 'BioGalmany' project is to attempt to restore and maintain suitable habitat conditions, so as to maintain the biological diversity of calaminarian grasslands in the Silesian-Cracow region, in selected sites, both protected and not protected within the Natura 2000 network. To achieve this goal, the following tasks are carried out: to assess the present condition of grasslands in the selected sites, to implement management measures aimed to stop the succession of trees, to maintain the diversity of microhabitats in the well-preserved fragments of grasslands, to implement measures aimed to restore grasslands being overgrown with shrubs and trees, to increase species diversity of grasslands and to carry out monitoring of the effect of the measures applied.

'BioGalmany' – characteristics of selected sites

Six sites of calaminarian grasslands have been selected for the 'BioGalmany' project in the Silesian-Cracow Upland. Two of them are in the Olkusz region, in the district of Bolesław, in abandoned mine land belonging to ZGH Bolesław. In 2010, these two sites were included in the Natura 2000 network, one as the PLH120092 'Pleszczotka', the other as the PLH120091 'Armeria'. The 'Pleszczotka' site was declared valuable and worthy of protection by the Bolesław District Council as early as 1997, long before it was included in the Natura 2000 network. It was declared a site of ecological interest (Resolution no. XXIII/196/97 of the Bolesław District Council, 1997). The main justification for this decision was the abundant occurrence of buckler mustard in the grassland, hence the name of the area. The third selected site of calaminarian grasslands included in the project is the mine waste heap of the 'Fryderyk' mine in Tarnowskie Góry, which is also proposed to be included in the established Natura 2000 site – PLH240003 'Podziemia Tarnowsko-Bytomskie' (Tarnów-Bytom Underground System), protecting underground excavations after zinc and lead ore mining, which are important for hibernating bats. The next sites included in the 'BioGalmany' project, which are important for the conservation of calaminarian grasslands, are situated in the former mining area of the Jaworzno District.

The first selected site, 'Pleszczotka', is on the old heap of mine waste at the open-pit ZGH Bolesław mine (Grodzińska and Szarek-Łukaszewska 2002, Włodarz – Chapter 1 of this volume). The site only covers part of the heap (about 4.9 ha in area), lying to the east of the open-pit (Fig. 3). In the whole area of 'Pleszczotka' the ground surface is uneven, marked with hollows and hillocks of different

Fig. 3. Southern fragment of the ‘Pleszczotka’ Natura 2000 site, 2018 (photo M. Jędrzejczyk-Korycińska)
Ryc. 3. Południowy fragment obszaru Natura 2000 „Pleszczotka”, rok 2018 (fot. M. Jędrzejczyk-Korycińska)

sizes, formed as a result of the uneven subsidence of waste material. Soils are mostly dry, skeletal, and shallow with a small content of nutrients and a high content of trace metals (up to 39,000 mg/kg of zinc, 2,600 mg/kg of lead and 180 mg/kg of cadmium; Szarek-Łukaszewska and Grodzińska 2011, Kapusta et al. 2015, Jędrzejczyk-Korycińska et al. 2015).

Unlike the majority of the mining waste heaps around the ‘Bolesław’ open pit, where trees were systematically planted, the area of ‘Pleszczotka’ has not been reclaimed. From the beginning of the 20th century, its vegetation has been shaped by spontaneous succession. Professor Zygmunt Wóycicki, a botanist, was the first who showed an interest in this vegetation and in 1913 published its description and photographs (Wóycicki 1913). Later on, its species composition was described in detail (e.g. Dobrzańska 1955, Grodzińska et al. 2000, Jędrzejczyk 2004, Szarek-Łukaszewska and Grodzińska 2011). The most recent inventory (in the 21st century) has shown that the grassland is rich in species. Over one hundred vascular plant species occur there: several dozen lichen species and a few moss species. *B. laevigata* is very numerous. There are also other interesting mountain species present, such as German gentian (*Gentianella germanica* (Willd.) Börner), mountain gold (*Alyssum montanum* L.), smelly wallflower (*Erisimum odoratum* Ehrh.) and stemless carline thistle (*Carlina acaulis* L.). The orchids dark-red helleborine (*Epipactis atrorubens* (Hoffm.) Besser) and broad-leaved helleborine (*Epipactis helleborine* (L.) Crantz) may be spotted as well. Dominating grass species are sheep’s fescue and creeping bentgrass (*Agrostis stolonifera* L.). Other species that are found in most patches, with various abundance, are common yarrow (*Achillea millefolium* L.), sand rock-cress, Carthusian pink, cinquefoil, dock, broad-leaved thyme and fastigiate gypsophila. Lichens are an important component of the grassland and the most frequent species are terricolous cup lichens (e.g. *Cladonia furcata* (Huds.) Schrad.), rim lichens (e.g. *Lecanora dispersa* (Pers.) Röhl.) and rock-inhabiting crustose lichens of the genus Verrucaria (e.g. *Verrucaria muralis* Ach.) (Bielczyk et al. 2009, Bielczyk 2015).

For many years, only single trees were found in the 'Pleszczotka' grassland (Grodzińska and Szarek-Łukaszewska 2002). Until the 1950s, their growth was restrained by goat and sheep grazing (Dobrzańska 1955). Later on, air pollution (sulphur dioxide and metallic dust) from high levels of industrial emissions hampered their growth (Kapusta et al. 2014). In the 1980s, a considerable decrease in the emissions of pollutants resulted in a quick, unrestrained growth of tree seedlings, mostly Scots pine seedlings. The Scots pine trees continued to spread over larger and larger areas of grassland (Kowolik et al. 2010). In 2008, Scots pine occupied almost 90% of the 'Pleszczotka' site (Fig. 4).

The 'Armeria' Natura 2000 site is part of a post-mining area (of about 7.4 ha), extending along the northern border of the zinc smelter of ZGH Bolesław. It is heterogenous in terms of age, origin, the properties of the substrate, and the type of vegetation. It is a mosaic of grasslands and coppices. The oldest western part has never been reclaimed; vegetation has developed

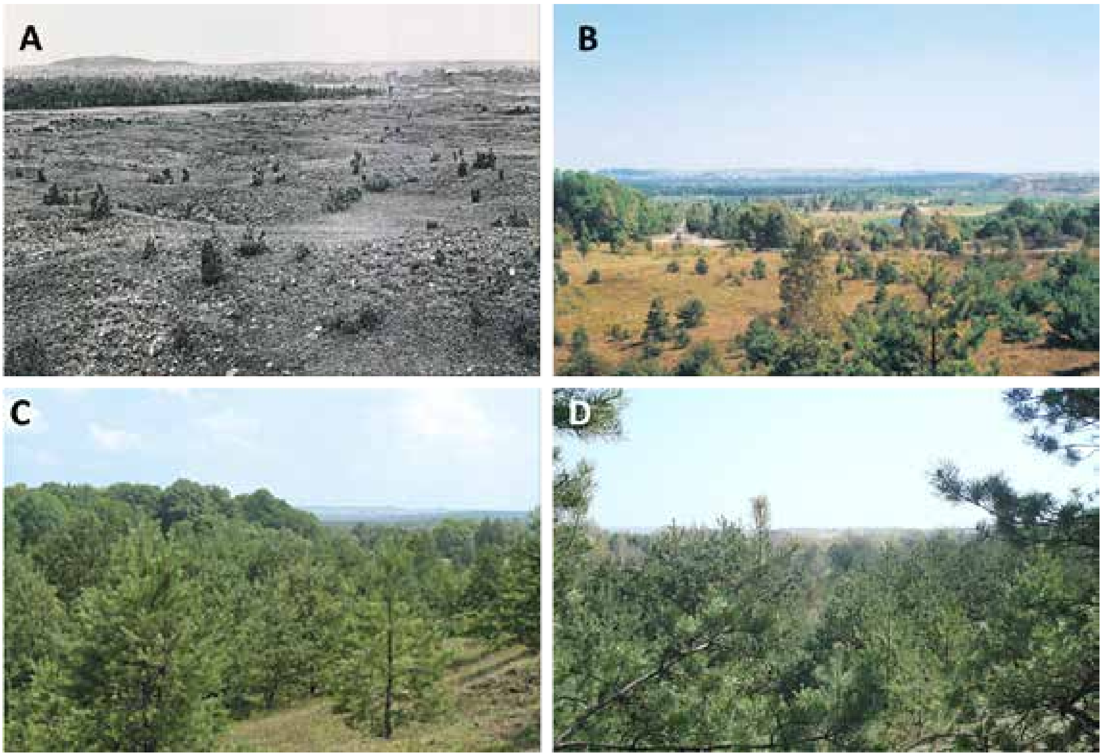

Fig. 4. View of the east fragment of the 'Pleszczotka' Natura 2000 site in the years: 1912 (A), 1999 (B), 2006 (C) and 2008 (D) (photo: A – Z. Wóycicki, B – K. Grodzińska, C – G. Szarek-Łukaszewska, D – M. Jędrzejczyk-Korycińska; A – base on Wóycicki 1913, B, C – base on Grodzińska and Szarek-Łukaszewska 2002)

Ryc. 4. Widok na wschodni fragment obszaru Natura 2000 „Pleszczotka" w latach: 1912 (A), 1999 (B), 2006 (C) i 2008 (D) (fot. A – Z. Wóycicki, B – K. Grodzińska, C – G. Szarek-Łukaszewska, D – M. Jędrzejczyk-Korycińska, A – za Wóyciki 1913, B, C – za Grodzińska i Szarek-Łukaszewska 2002)

Fig. 5. Western fragment of the 'Armeria' Natura 2000 site, 2018 (photo M. Jędrzejczyk-Korycińska)
Ryc. 5. Zachodni fragment obszaru „Armeria", rok 2018 (fot. M. Jędrzejczyk-Korycińska)

there spontaneously from the beginning of the second decade of the 20th century. The area is notable for its surface features. It is strongly undulated with numerous hollows, evidence of the former prospecting activity (Fig. 5). Soil with a thick, poorly decomposed organic layer (in places even 20 cm thick) is characterized by a very high content of heavy metals (e.g. up to 75,000 mg/kg of zinc, 7,600 mg/kg of lead and 510 mg/kg of cadmium; Szarek-Łukaszewska and Grodzińska 2011). In spite of this, it is densely overgrown in some places. Vegetation is mostly composed of sheep's fescue. Among its clumps, other characteristic species of metalliferous habitats are scattered (Szarek-Łukaszewska and Grodzińska 2011). For example, some lichen species, e.g. *Cladonia foliacea* (Huds.) Willd., *Cladonia pyxidata* (L.) Hoffm., *Cladonia glauca* Flörke, grow abundantly (Bielczyk 2015). The remaining part of the 'Armeria' site is the former opencast mining area, active in 1953–1969, named 'Hałda Michalska' (Włodarz – Chapter 1 of this volume). The mostly shallow soil, formed chiefly on strongly fragmented dolomite mine waste, contains smaller amounts of metals than soil in the older part of the 'Armeria' site (e.g. about 15,000 mg/kg of zinc, 2,100 mg/kg of lead and 90 mg/kg of cadmium; Szarek-Łukaszewska and Grodzińska 2011). In the mid-1990s, during reclamation, the area was planted with trees and shrubs, e.g. silver birch, European larch (*Larix decidua* Mill.), Scots pine, black locust, sea-buckthorn (*Hippochaë rhamnoides* L.) and Russian olive (*Eleagnus angustifolia* L.), forming patches of different sizes. In the whole of the 'Armeria' site, in addition to sheep's fescue, some other important species of calaminarian grasslands are also present: sea thrift, buckler mustard, fastigiate gypsophila, dock, common rock-rose (*Helianthemum nummularium* (L.) Mill.), cinquefoil, stemless carline thistle (*Carlina acaulis* L.), bladder campion and sand rock-cress, as well as orchids: dark-red helleborine and broad-leaved helleborine. Branched St Bernard's-lily

(*Anthericum ramosum* L.) and spiny restharrow (*Ononis spinosa* L.), which are also found there. Large fragments of the area are overgrown with purple moor-grass (Szarek-Łukaszewska and Grodzińska 2011). From the end of the 1990s, it has been observed that Scots pine and black locust spread very quickly in the 'Armeria' site, similar to the 'Pleszczotka' site.

The flotation tailings heap in the 'Podziemia Tarnogórsko-Bytomskie' Natura 2000 site is located on the site of the former washery of the 'Fryderyk' mine. It is surrounded by arable fields. The heap is formed of ore-bearing dolomite, remaining after the washing and separating of zinc and lead ores (also containing an admixture of silver) and iron ores. The washery operated for 120 years and the waste grew taller over time. Deposition of the waste was finished in 1926 (Lamparska-Wieland 1997). Currently, the heap has a wide flat top part and steep slopes (Fig. 6). It covers an area of about 6.5 ha. The soil is dry and contaminated by heavy metals. It contains up to 46,000 mg/kg of zinc, 1,500 mg/kg of lead and 500 mg/kg of cadmium (Jędrzejczyk 2004, Jędrzejczyk-Korycińska and Rostański 2015). The slopes and the top part of the heap are dominated by grass species, e.g. sheep's fescue and Boehmer's cat's-tail (*Phleum phleoides* (L.) H. Karst.). Species such as Nottingham catchfly (*Silene nutans* L.), common milkwort (*Polygala vulgaris* L.), cream pincushions, lesser burnet (*Pimpinella saxifraga* L.), bladder campion, sand rock-cress, and common carline thistle also grow there. Other important species are stemless carline thistle, dark-red helleborine, and broad-leaved helleborine. In recent years, the spontaneous encroachment of Scots pine and silver birch on the flotation tailings heap in Tarnowskie Góry has been observed.

Sites of calaminarian grasslands, situated in Jaworzno, have not yet been given legal protection within the Natura 2000 network. Zinc and lead ores were extracted in this area from the Medieval times to the beginning of the 20th century (Molenda 1972, Sas-Gustkiewicz et al.

Fig. 6. Western slope of the 'Fryderyk' mine heap in Tarnowskie Góry, 2017 (photo M. Jędrzejczyk-Korycińska)
Ryc. 6. Zachodni stok hałdy kopalni „Fryderyk" w Tarnowskich Górach, rok 2017 (fot. M. Jędrzejczyk-Korycińska)

Fig. 7. Fragment of the operational area of the 'Fryderyk' mine in Długoszyn, 2018 (photo M. Jędrzejczyk-Korycińska)
Ryc. 7. Fragment obszaru działalności kopalni „Fryderyk" w Długoszynie, rok 2018 (fot. M. Jędrzejczyk-Korycińska)

2001). At first, the prospecting and mining of ores was carried out by shallow digging. Over time, better tools and machinery were used and ores were extracted from deeper and deeper deposits. As a result, the area was covered by an irregular network of gallery workings and tens of small shafts, 2.20 m deep (Molenda 1972). To the present day, in the Długoszyn city district of Jaworzno, in Ciężkowice, and in the surroundings of the Sadowa Góra Hill, one may spot the signs of past ore mining and processing activity, such as piles of earth, pits, hollows, sinks and spoil heaps. Soils of these areas have high levels of heavy metals, considerably exceeding concentrations of these metals in the soils of neighboring areas (Pasieczna 2011).

In Długoszyn, the fragment of a site (5.6 ha), where prior to the 20th century several small mines operated, was included in the 'BioGalmany' project. The last closed mine was 'Fryderyk' (Cabała and Sutkowska 2006). At present, this area comprises a mixed forest, small sites of grassland, and arable fields (Fig. 7). The forest is composed of Scots pine, northern red oak (*Quercus rubra* L.), and silver birch. Among the trees one may spot heath false brome (*Brachypodium pinnatum* (L.) P. Beauv., bladder campion, common carline thistle and stemless carline thistle, for example. In the grassland stands, species such as sheep's fescue, Timothy grass, Carthusian pink, sea thrift, sand rock-cress, common rock-rose, common sorrel (*Rumex acetosa* L.), burnet-saxifrage, and broad-leaved thyme are found.

In Ciężkowice, a site of ecological interest (ca. 5.6 ha in area) situated on the Góra Wielkanoc Hill has been selected for the project (Fig. 8). The site was established in 2015, pursuant to the Resolution of the Jaworzno City Council (no. V/36/2015), to protect xerothermic grasslands and landscape values. Within the borders of this site there are also excavations that are traces of past zinc and lead ore mining and processing. Some of them can be spotted on the northwest periphery of the site, and some other shallower ones in its

Fig. 8. Western fragment of Góra Wielkanoc Hill, 2018 (photo Jędrzejczyk-Korycińska)
Ryc. 8. Zachodni fragment Góry Wielkanoc w 2018 r. (fot. M. Jędrzejczyk-Korycińska)

central-southern part. According to historical sources, there was a mine of the same name on the Góra Wielkanoc Hill, where ores were probably extracted from the Medieval Ages to the latter part of the 16th century (Leś-Rudnicka 2000, Cabała and Sutkowska 2006). The site encompasses small fragments of calaminarian grasslands with sheep's fescue, bladder campion, sand rock-cress, common rock-rose, common sorrel, common carline thistle (*Carlina vulgaris* L.), burnet-saxifrage, broad-leaved thyme, and cinquefoil *Potentilla arenaria*. Recently, silver birch has been encroaching on the site.

The last site included in the 'BioGalmany' project is adjacent to a limestone, dolomite, and marl quarry on the Sadowa Góra Hill. Currently, it is partly covered by a birch-pine forest where the relics of mining operations still remain on the forest floor (Fig. 9). In the small fragments of a loose forest, single individuals of some grassland species are found, e.g. heath false brome, common carline thistle, and stemless carline thistle, as well as an abundance of branched St Bernard's-lily and expansive eagle fern (*Pteridium aquilinum* (L.) Kuhn). In the forest surroundings, on cultivated meadows, one may also find traces of former mining operations (skylights, shafts). Grassland species such as sheep's fescue, Carthusian pink, sand rock-cress, common rock-rose, common sorrel, burnet-saxifrage, cream pincushions, bladder campion, and broad-leaved thyme occur there.

'BioGalmany' – selected management measures

As previously mentioned, management measures planned within the framework of the 'BioGalmany' project stem from the best practices established for xerothermic grasslands. The main management measure aimed to maintain these seminatural communities is grazing, which arrests plant succession and contributes to the maintenance of the mosaic of microhabitats and species (Barańska and

Jermaczek 2009, Barańska 2013). Grazing is not, however, an appropriate conservation measure for calaminarian grasslands, considering the animals' welfare. Feeding on metal-rich plants (plants containing large amounts of heavy metals), and consuming dust from metalliferous soil along with the plants, herbivores may be exposed to high concentrations of heavy metals, which is dangerous for their health (Wilkinson et al 2003). Therefore, it has been decided that management measures aimed to improve the conservation status of calaminarian grasslands will be performed, if possible, without heavy machinery, only manually with simple tools. The intrusion of bushes and trees will be limited by removing their seedlings and saplings, and the development of expansive high grasses will be limited by mowing (with removal of cut biomass). The loosening of dense sward and dead plant remnants is aimed to maintain a variety of microhabitats suitable for grassland species. Open spaces among perennials are a suitable habitat for less competitive annual plants, biennials, and lichens. On open bare soil, xerothermic and light-loving species may come back, while patches of bare mineral substrate may be colonized by metallophytes (particularly those showing preference for a high concentration of heavy metals, e.g. buckler mustard; Bemowska-Kałabun et al. – Chapter 6 of this volume). Disturbance of the continuity of the plant cover should also increase the frequency of natural disturbances, e.g. landslides, exposing fresh bare metalliferous substrates. There are also plans to rake and remove the thick layer of dead plant remains to decrease soil fertility, and consequently, to limit the intrusion of woody species, expansive grasses, weeds, and invasive species. Their appearance is often associated with an increase in the amount of nutrients in the soil; the source of these elements is decomposing organic matter (Pärtel and Helm 2007). Dead leaves piled up around high grasses will be removed as well. The open spaces may constitute supplementary microhabitats, which are suitable for metallophytes that are generally poorly competitive (Baker

Fig. 9. Fragment of the flat-topped Sadowa Góra Hill in Jaworzno, 2018 (photo Jędrzejczyk-Korycińska)

Ryc. 9. Fragment wierzchowiny wzgórza Sadowa Góra w Jaworznie, rok 2018 (fot. M. Jędrzejczyk-Korycińska) et al. 2010). The management measures mentioned, and primarily those aimed to maintain the mosaic of varied microhabitats, should be conducive to the long-term survival of calaminarian grasslands (Simkin 2011).

In cases of advanced successional changes and grasslands declining due the gradual overgrowth of shrub and tree species, attempts at their restoration are undertaken in the 'BioGalmany' project. The first stage of work included the clearance of trees and shrubs and the removal of their biomass. This work was performed in winter, in the first year of the project. Next, the offshoots that appear are cut off twice a year. Other methods are used for the invasive black locust. It is useless to simply cut down the black locust trunk because the plant may still spread, even quite vigorously, through underground shoots. The mechanical destruction of roots or trunks often results in the development of new trunks and a considerable increase in the area covered by the species (Vítková et al. 2017). Therefore, black locusts was cut down to a height of 11.5 m, next the trunks will be girded, a ring of bark and phloem will be removed, which should result in the death of trees. After the clearance of trees and bushes, the dead parts of plants (needles, leaves, twigs, fruits) accumulated on the soil surface, were removed as well. At certain sites, a thick soil layer was also stripped to expose the mineral substratum. Along with the soil, the soil seedbank was also removed. The seedbank may contain the seeds of unwanted species, and infrequently the seeds of metallophytes because most of them do not produce a long-term seedbank (Baker et al. 2010). It is expected that the exposed surfaces will be colonized by grassland species originating from the nearby sources of their diaspores: fragments of well-preserved grasslands (Grodzińska et al. 2000). To accelerate the process of grassland restoration, the sowing of seeds from the selected species, collected in their local populations, is planned. In addition, rare and endangered species will also be introduced in the form of seedlings (grown *ex situ*). In case of the intrusion of expansive species (e.g. bushgrass) or invasive species (e.g. Canada goldenrod) on the exposed surfaces, their removal and/or mowing is planned over the whole duration of the project.

The management measures mentioned are carried out with varied intensity on metalliferous sites depending on the results of a detailed natural inventory, the initial site condition, and the assessment of the local species pool, with particular reference to metallophytes. The inventory will cover groups of organisms such as vascular plants, lichens, mosses, ants, spiders, and pollinating insects. Species censuses carried out in the first year of the project will be repeated in the subsequent years to assess the effects of the applied conservation measures. These monitoring results will help to formulate guidelines for the long-term conservation of calaminarian grasslands.

Summary

Calaminarian grasslands are composed of unique plant species, tolerating drought, strong insolation, scarcity of nutrients and simultaneously, excessive amounts of heavy metals (mainly zinc, lead, cadmium) in the soil. These plants are an excellent example of the operation of microevolutionary processes, a subject of studies on the functioning of organisms in extremely adverse habitats and their use for phytoremediation purposes. Among them there is *B. laevigata*, a characteristic species of calaminarian grasslands, developing on metalliferous mine waste in the Olkusz region. These grasslands are the best preserved and best-known communities of this type in Poland. Other, not so well-known sites

of calaminarian grasslands are scattered over the Silesian-Cracow Upland, in places where zinc and lead ores were mined and processed in the past. Calaminarian grasslands are, however, increasingly less visible islands in the landscape. Trees and bushes, along with other expansive or invasive plants, are encroaching there. Due to inappropriate human activities, these sites of great natural value are being turned into land for development and refuse dumps. The same process takes place throughout the whole of Europe. Due to the unique character of calaminarian grasslands, their important contribution to the biodiversity of various regions, and their quick decline, they are listed as a natural habitat type of community interest, whose conservation requires designation as part of the special areas of conservation within the Natura 2000 European Ecological Network. Following the recommendations for calaminarian grasslands conservation in the Natura 2000 sites, the project 'Best practices for enhancing biological diversity and conservation of calaminarian grasslands in the Silesian-Cracow region – BioGalmany' (2018–2021) foresees the use of active management measures to maintain or restore these unique ecosystems with their precious species. Such large-scale activities were undertaken for the first time in our country. The project covers a number of extensive calaminarian grasslands, almost 20 ha of zinc and lead waste heaps in total. In each site, depending on the results of their initial state assessment (natural inventory), the suitable habitat conditions and species diversity will be maintained, improved, or restored through management measures, carried out with varied intensity. This will include loosening of dense turf and dead plant remains, exposing the mineral layer of metalliferous soil, mowing expansive herbaceous plants, the clearance of trees and bushes, and then sowing seeds and/or planting seedlings (grown in cultivation) of the selected species from the local calminarian communities. The effects of the measures applied will be closely monitored. Monitoring data will allow us to assess the effectiveness of the implemented conservation plans and to outline the long-term conservation measures for calaminarian grasslands and precious metallophytes, including *B. laevigata*. They also will contribute to the knowledge of ecosystems associated with heavy metals.

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