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Is the Vegetation Succession a Threat for Rare and Protected Species in a Sand Quarry? Case Study of the Kuźnica Warężyńska Sand Quarry (Southern Poland)

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Abstract. The work focuses on analyzing and reason of occurrences of rare and protected species by European and Polish low. These species are growing in the areas of former sand exploitations quarry and have different ecological requirements. The origin of such quarries is strictly connected strictly connection with development of coal mining in the Silesian Upland (Southern Poland). From the end of exploitation the processes of spontaneous vegetation ecosystems have been observed. The research was conducted in Southern Poland in the area of the Kuźnica Warężyńska sand quarry with an area of approximately 8 km^2, exploited in the years 1972 - 2003. In results of work has been confirmed by 2 types of habitats which are included in I Annex Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora forms in zone of groundwater outflow. They are 7140-transition mires and quaking bogs and 7230 – alkaline fens. In these communities, numerous population of 22 protects spiecies as *Dactylorhiza maculata*, *D. majalis*, *Epipactis atrorubens*, *E. helleborine*, *E. palustris*, *Malaxis monophyllos*, *Lycopodiella inundata*, *Pinguicula vulgaris*, including *Liparis loeselii* found in Annex II of the Habitats Directive occur. These are early-successional species, whose numbers in next successions phases decrease or after several years completely disappear. The analyzed flora differs in terms of life forms, ecological requirements related to the habitat mosaics. The fragments of sand quarry that were where are not reclaimed can play important role in nature conservation not only in local level but even on supra-regional scale. Hence, this object is a place for many rare, threatened with extinction species and plant communities as substitute habitats. The conservation of such species and plant communities in sand quarry needed active protection. It consists in maintaining the initial stages of succession and preventing the formation of the forest.

1. Introduction

To date, the extraction of various minerals has affected the environment of approximately 1% of the world's land area [1]. Sand from quarries is among the most commonly used mineral resources on Earth [2]. The industry related to the extraction of mineral resources is one of the strongest factors which distort the natural environment globally [3,4,5]. In Europe, including Poland, the area of land degraded as a result of sand quarrying rapidly increased in the 20th century, which was associated with the development of coal mining centres. This environmental damage often amounts to the complete destruction of existing ecosystems, consisting in the destruction of the vegetation and soil cover, the mother rock being exposed or the surface being covered with fresh rock material [6,7]. Landforms, water conditions and even the microclimate are transformed as well.

The use of sand to fill the underground voids left by coal mining resulted in the emergence of extensive sand workings with areas ranging from a few to 30 km^2 and up to 30 m deep. In the 20th century, the Silesian Upland in southern Poland was among the largest coal mining centres in Europe and worldwide. Currently, it is also one of the regions with the highest concentrations of disused sand workings in Europe. In the region, these cover a total area of approximately 115 km^2. On the Silesian Upland, the most significant environmental transformations associated with intensive quarrying of sand for backfilling took place between 1965 and 1985 [8].

After the mining had ceased, the problem of sustainable development of areas degraded in this manner arose. The law in Poland and most European countries imposes an obligation to reclaim such areas on their owners. Reclamation in this case is understood as endowing the degraded land with functional or natural values or restoring such values through proper landform shaping, improving its physical and chemical properties, regulating water conditions, restoring soils and strengthening slopes.

In Poland, reclamation measures have most frequently resulted in such areas being afforested or transformed into water bodies [9]. Thus, more than 40 km^2 of former workings were reclaimed by transforming them into water bodies, forest was planted on around 40 km^2, and only around 5 km^2 were turned to agricultural and other uses. However, some of the former sand quarries or parts thereof were not reclaimed at all and their biocoenoses regenerated naturally.

Meanwhile, increasingly numerous studies indicate that in comparison to reclamation, spontaneous succession results in the development of more diverse plant communities whose species composition is more similar to the natural one; moreover, this is a cheaper option [10,11,12]. Additionally, in most cases the effect of reclamation is achieved in a similar period of around 20 years [12]. In many locations worldwide, the presence of plant species and phytocoenoses of interest to nature conservationists [13,14,15,7] and of significance to ecological processes [16,17,18] has been recorded in former mineral workings. Similar patterns have been observed on the Silesian Upland.

Therefore, the purpose of our work is to: (1) analyse the occurrence of protected plant species in non-reclaimed parts of the Kuźnica Warężyńska former sand quarry; (2) attempt to answer the question on what factors determine the occurrence of valuable phytocoenoses and protected species and how their numbers change during succession; (3) attempt to answer the question of whether forgoing costly reclamation procedures, at least in some cases, would be acceptable from the point of view of ecosystem restoration and whether the development of such areas may serve the broadly understood purpose of nature conservation.

2. Material and methods

2.1. Study area

The research was carried out in non-reclaimed parts of the Kuźnica Warężyńska former sand quarry in southern Poland (50°21’– 50°24’N, 19°11’– 19°13’E). The sand quarry, with an area of 8 km^2, operated between 1972 and 2003. Parts thereof were later reclaimed (transformed into water bodies and forests) [19]. In the years 2003–2005, a flood control reservoir with an area of 560 hectares, total capacity of 51.16 million m^3, flood capacity of 8.07 million m^3, maximum water level of 265 m a.s.l., maximum depth of 23 m and circumference of 13 km was constructed in the former quarry [20].

2.2. Analyses of flora

An inventory of species present was compiled for each succession stage [18]. Taxonomy was adopted after Mirek et al. [21]. Populations of protected species were determined as well (according to the Regulation of the Minister of the Environment of 9 October 2014 on the protection of plant species) using Raunkiaer's method [22]. Categories of threats to protected species are stated in the IUCN Red List of Threatened Species version 2018 *(*https://www.iucnredlist.org) and in the Polish Red Book [23].

Using ecological indicator values [24], the species composition of the flora was subjected to ecological analyses. The flora was grouped into 10 categories depending on individual species' soil reaction requirements. Shares of individual life forms in the flora were also determined.

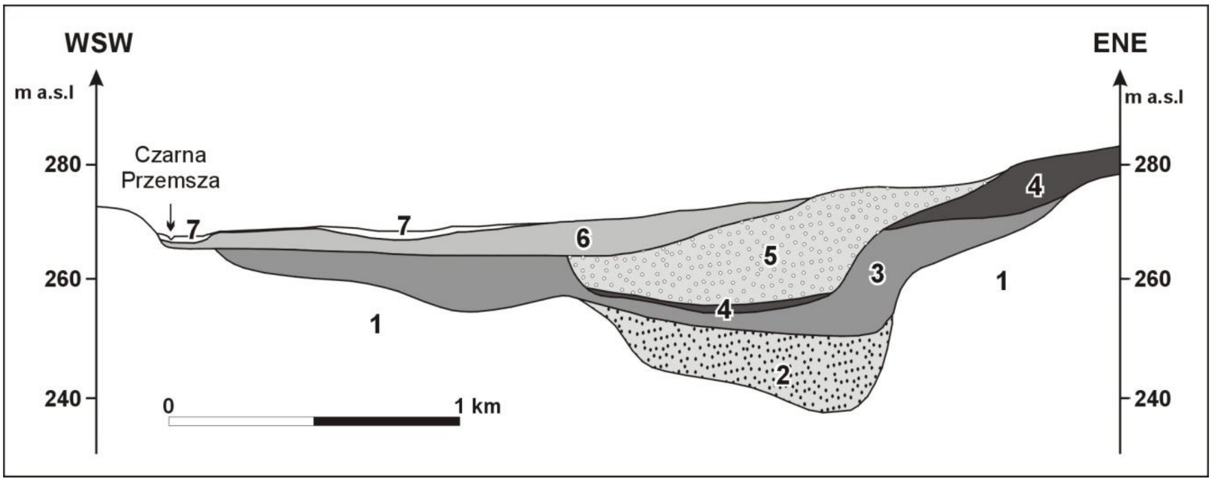

Figure 1. Geological cross-section of the Kuźnica Warężyńska former sand quarry: 1. Permian and Triassic formations; 2. Fluvial gravels and sands; 3. Fluvial sands and gravels with erratic boulders; 4. Fluvial gravels; 5. Fluvial sands and muds; 6. Gravels, fluvial sands and muds; 7. Alluvial soils

3. Results and discussions

3.1. Vegetation

In non-reclaimed parts of the sand quarry, plant communities included in Annex I of the Habitats Directive (Table 1) were found. These are phytocoenoses typical of early stages of succession. These develop mostly in wet and moist habitats with an acidic (All. *Caricion nigrae* and *Rynchosporion albae*) or neutral and alkaline character, which are rich in $CaCO_3$ (All. *Caricion davallianae*).

Table 1. Natura 2000 habitats in the Kuźnica Warężyńska quarry.

Habitats	Systematic list of phytocoenoses
Transition mires and quaking bogs (7140)	Cl. *Scheuchzerio-caricetea nigrae* (Nordh. 1937) R.Tx. 1937 O. *Scheuchzerietalia palustris* Nordh 1937 All. *Rynchosporion albae* Koch 1926 All. *Caricion nigrae* Koch 1926 em. Klika 1934
Alkaline fens (7230)	Cl. *Scheuchzerio-caricetea nigrae* (Nordh. 1937) R.Tx. 1937 O. *Caricetalia davallianae* Br.-Bl. 1949 All. *Caricion davallianae* Klika 1934

A characteristic feature of the Kuźnica Warężyńska sand quarry is the presence of adjacent communities with different habitat requirements within very small areas [18]. This is due to the micro-topography of the area which promotes a diverse mosaic of habitats. This was already indicated by earlier studies conducted in this area as well as in other disused sand quarries [7].

As a result of the study, 22 legally protected species (inter alia, *Dactylorhiza maculata*, *D. majalis*, *Epipactis atrorubens*, *E. helleborine*, *E. palustris*, *Malaxis monophyllos*, *Lycopodiella inundata*, *Pinguicula vulgaris*) were identified within the former sand workings, including *Liparis loeselii*, which is found in Annex II of the Habitats Directive. This species, which exhibits high population variability in various regions of the world due to environmental barriers [25], is fairly abundant here (Table 3). These species occur most frequently in Natura 2000 habitats (Table 2,3), but they are also present within other phytocoenoses formed in wet and moist habitats, most often belonging to the *Epilobion fleischeri* complex and the*Betulo-Salicetum repentis* association (Table 2).

Table 2. Shares of protected species in vegetation assemblages in the Kuźnica Warężyńska quarry (in the years 1994–2010)

Syntaxons	Number of protected plant species
Phragmitetum australis (GAMS 1927) SCHMALE 1939	7
Caricetum rostratae RUBEL 1912	1
Salicetum pentandro-cinereae (ALMQ. 1929) PASS 1961	6
Betulo-Salicetum repentis OBERD 1964	10
Epilobion fleischeri BR. -BL. IN. J. ET G. BR.-BL. 1931	10
Molinion caeruleae KOCH 1926	5
Rynchosporion albae KOCH 1926	8
Caricion nigrae KOCH 1926 EM. KLIKA 1934	12
Caricion davallianae KLIKA 1934	11
Dicrano-Pinion LIBB. 1933	8

These are usually early succession species. Long-standing research (Table 1) yielded the observation that the abundance of these species varies with stages of succession. Their numbers either decrease in successive stages of succession or they disappear completely after around a dozen years. Exceptions are *Orthilia secunda* and *Pyrola* species which only emerge after the initial stages of the formation of forests from the *Dicrano-Pinion* complex have begun. A similar pattern was observed in other quarries [26,17,7]. The plant associations highlighted here exhibit specific habitat requirements linked to geological and hydrogeological conditions. The conditions present in the quarry enable specific types of ecological niches to form. Their peculiar character is related to the waters flowing from Triassic formations. These waters exhibit an increased content of calcium ions, which affects the species composition of phytocoenoses forming in the areas which they feed.

The gradual retreat of rare early succession species and of entire phytocoenoses is a natural process resulting from the replacement of species during plant succession. Therefore, their further functioning within the quarry will depend solely on the development priorities adopted in plans. If preserving protected habitats, early succession species and plant communities characteristic of the first stages of overgrowth is a priority, active nature conservation measures will have to be implemented consisting in inhibiting further succession stages.

The inventory of vascular plants conducted in the Kuźnica Warężyńska former sand quarry demonstrated that a total of 367 species of vascular plants are present there, representing different life forms (Figure. 1). The quarry flora is dominated by hemicryptophytes (54%), therophytes (14%) and geophytes (10%). The diversity of life forms is conditioned by the mosaic-like nature of the habitat (macro and micro landforms) and the presence of a potential biochore in the vicinity of former mineral workings.

The dominance of chamaephytes in the initial phases of succession in other quarries [27] is probably related to their more homogeneous surfaces and greater distances from the source of propagules (diaspores).

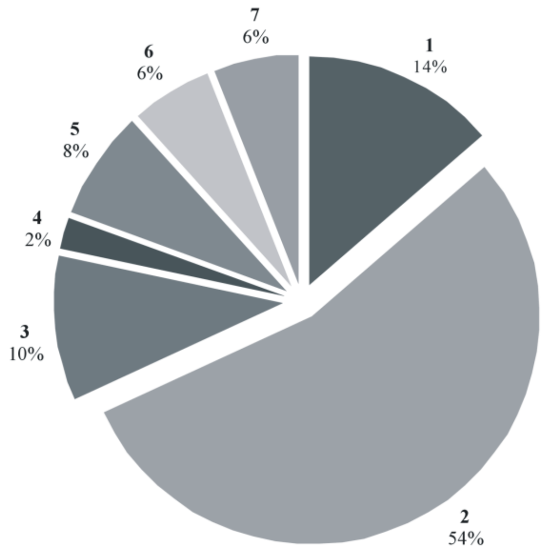

Figure 2. Percentage shares of plant life forms in the Kuźnica Warężyńska quarry (in the years 1994–2010): 1- therophytes; 2 - hemicryptophytes; 3 - geophytes; 4 - chamaephytes; 5 - hydrophytes; 6 – megaphanerophytes and 7- nanophanerophytes.

Table 3. List of vascular plants subject to conservation recorded in the Kuźnica Warężyńska quarry.

Nr	Species	Status by Polish Red Book	Status by IUCN red List (2018)	Abundances of species on the Kuźnica Warężyńska quarry in years	
				1994-2010	2010-2018
1.	*Carex davalliana*	-	LC	+	lack
2.	*Cladium mariscus*	-	LC	+++	++
3.	*Centaurium erythraea*	-	LC	+++	++
4.	*Dactylorhiza incarnata*	-	LC	++	+
5.	*Dactylorhiza maculata*	-	LC	+++	+
6.	*Dactylorhiza majalis*	-	LC	++	+
7.	*Drosera rotundifolia*	-	LC	+++	++
8.	*Epipactis atrorubens*	-	LC	+++	++
9.	*Epipactis helleborine*	-	LC	++	++
10.	*Epipactis palustris*	-	LC	+++	++
11.	*Huperzia selago*	-	LC	+	lack
12.	*Liparis loeselii*	VU	NT/HD	+++	++
13.	*Lycopodium clavatum*	-	LC	+++	+++
14.	*Lycopodiella inundata*	-	LC	+++	+++
15.	*Malaxis monophyllos*	NT	NT	+++	lack
16.	*Orthilia secunda*	-	LC	++	++
17.	*Pinguicula vulgaris* ssp. *bicolor*	CR	LC	+++	+
18.	*Pyrola chlorantha*	-	LC	+++	+++
19.	*Pyrola minor*	-	LC	++	+++
20.	*Pyrola rotundifolia*	-	LC	++	+++
21.	*Tofieldia calyculata*	-	LC	+++	+
22.	*Utricularia australis*	-	LC	++	+

Explanation: LC - Least concern, NT - Near threatenet, VU - Vulnerable, CR - Critically endangered. HD - Habitats Directive. Frequence: + solitary (1- 10 specimens), ++ frequent (10 - 50 specimens), +++ abundant (50 and more specimens).

3.2. Vegetation and pH

The flora of the sand quarry exhibits very variable preferences with respect to soil reaction (Table 4, Figure 3) However, most plant species (24%) are neutral soil species (*Equisetum hyemale*, *Carex panicea C. vesicaria*). The second and third places are occupied by species with a wide range of tolerance for neutral and alkaline soils (*Epipactis helleborine*, *Eriophorum latifolium*, *Equisetum variegatum*, *Thalictrum flavum*, *Triglochin palustre*) and by species with a very wide range of tolerance for soils ranging from moderately acidic to neutral and alkaline (*Pyrola minor*, *Salix rosmarinifolia*) (Table 2).

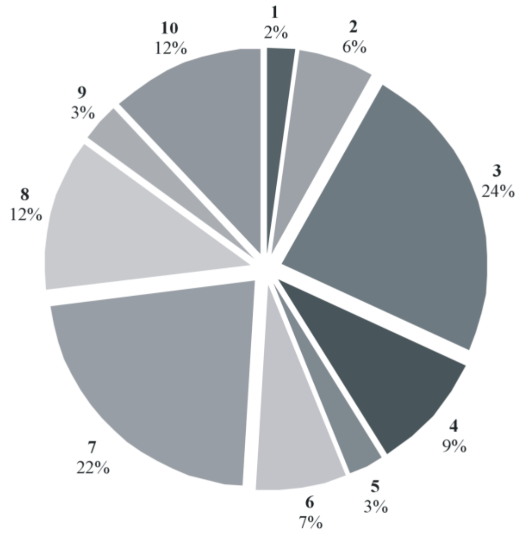

Figure 3. Diversity of flora in terms of soil reaction (in the years 1994–2010): 1. > 4 ph <5; 2. 5 ≤ pH < 6; 3. 6 ≤ pH <7; 4. pH> 7; 5. > 4 pH < 6; 6. 5 ≤ pH < 7; 7. 6 ≤ pH > 7; 8. 5 ≤ pH > 7; 9. 4 > pH> 7 and 10. unclassified.

The diversity in the pH of the soils on which ecological succession takes place is conditioned by many environmental factors such as the mineralogical composition of sand, soil particle size distribution and carbonate debris admixture; however, in the case of the Kuźnica Warężyńska, this diversity is driven mostly by landforms and the presence/absence of carbonates in the waters. The dominance of species associated with neutral and alkaline soils is due to the fact that most wetland habitats are fed with $CaCO_3$ rich waters from cut aquifers. Weakly acidic and acidic soil reaction is found in areas where water is supplied mostly by precipitation. These are generally elevated sandy patches or areas with a layer of impermeable clay or clayey sands which isolate the soil surface from groundwater.

Table 4. Classification of flora in relation to soil reaction (pH).

Nr	Types of category	range of pH
1.	Species of highly acidic and acidic soils	> 4 pH <5.2
2.	Species of moderately acidic soils	5 ≤ pH < 6
3.	Species of neutral soils	6 ≤ pH <7
4.	Species of alkaline soils	pH> 7.5
5.	Species with a wide range of tolerance, acidic and moderately acidic soils	> 4 pH < 6.6
6.	Species with a wide range of tolerance, moderately acidic and neutral soils	5 ≤ pH < 7
7.	Species with a wide range of tolerance, neutral and alkaline soils	6 ≤ pH > 7
8.	Species with a very wide range of tolerance (from moderately acidic to neutral and alkaline soils)	5 ≤ pH > 7
9.	Species with a very wide range of tolerance (from highly acidic and acidic to neutral and alkaline soils	4 > pH> 7
10.	Unclassified	-

3.3. Development possibilities

After the mining has ceased, the issue is how to develop the former workings in a sustainable manner. European and Polish law [28] imposes an obligation on the area owner to reclaim their areas, which is costly. To date, such areas both in Poland [10, 9, 7] and in other Central European countries [16, 12] have mostly been transformed into forests or water bodies. In Poland, the assumption has often been that forest productivity should be restored in degraded areas as quickly and cheaply as possible. In accordance with the priority adopted, the main criteria for the selection of tree species planted included their resistance to pests, rapid growth, properties which accelerate the formation of soils (enriching soil with nitrogen, high biomass production) and often phytomelioration properties. These conditions were most often met by species of alien origin such as *Pinus nigra*, *Quercus rubra*, *Robinia pseudoacacia* and others [7].

However, monocultures and mixed plantings of alien species, although they do accelerate the restoration of soil cover and generate relatively rapid economic gains, also result in the impoverishment of the emerging biocoenoses, which exhibit reduced biodiversity [29]. Therefore, it is increasingly claimed that planned reclamation of quarries, especially by afforesting them, is not always the most beneficial solution from the point of view of nature conservation and sustainable development of the region.

The problem remains: how should former quarries be developed? Should we forgo expensive reclamation works? The studies conducted demonstrate that non-reclaimed former sand quarries may play an important supra-regional role in nature protection both as places where rare plant communities are present and as substitute habitats for plant species which are threatened with extinction in Europe. In sustainable planning, biocoenotic functions can and should be attributed to such areas.

5. Conclusions

Numerous populations of rare and protected plant species as well as plant communities of European significance are present in non-reclaimed parts of the former sand quarry. The natural succession occurring in disused sand workings results in the development of ecosystems with special natural values, which are often of supra-regional importance. The natural capacity of the environment to regenerate should be appreciated to a greater extent when making decisions concerning the development of such areas, and spontaneous succession should be allowed more frequently in such locations instead of costly technical reclamation measures.

Mineral workings left to natural regeneration are important from the point of view of maintaining and enhancing diversity at the genetic, species and ecosystem levels. Such areas should be adequately protected and biocoenotic functions should be attributed to them in sustainable management plans. Owing to the replacement of species which takes place in the course of natural succession, the preservation of protected species sites will require the implementation of active nature conservation measures to inhibit succession.

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