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Short Communication

GIS Methods in Monitoring Succession Processes in Limestone and Dolomite Quarries

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Abstract

The complete destruction of primary vegetation and soil cover as a result of human activity is the most drastic example of disturbances in ecosystem functioning. Despite the fact that inactive limestone and dolomite quarries are relatively common in the southern part of the Silesian Upland (the Jaworzno Hills mesoregion), there are not many studies on the processes of transformation of landscape within them. The aim of our paper is to present preliminary results of research on overgrowing processes in the select objects using applied GIS methods. The studies show that differentiation of overgrowing processes in investigated quarries depend on the time that passed from the end of exploitation and of the type of surrounding landscapes. The major fragments of quarries were overgrown by species with a wide ecological spectrum, both herbaceous species (e.g. *Calamagrostis epigejos*) and pioneering trees (e.g. *Betula pendula*, *Salix caprea*). Additionally, especially on the edge of investigated quarries, plant communities form class *Rhamno-Prunetea* and grasses from *Cirsio-Brachypodion pinnati* union formed. In total, 145 species of vascular plants were identified, including 2 strictly protected and 7 partially protected taxons. Research is based on archival aerial photographs and the latest orthophotomaps from the 1950s to 2009. All cartographic materials were calibrated and registered in Poland CS92 coordinate system (EPSG: 2180). Registration and digitalization of vegetation patch ranges were conducted with applied MapInfo Professional software.

Keywords: succession processes, inactive quarries, GIS methods, Silesian Upland, Jaworzno Hills

Introduction

Areas under the influence of intense human activity are often characterized by a great degree of their natural environment degradation. Each component of the environment undergoes remodeling. The complete destruction of primary vegetation and soil cover as a result of intensive human activity is the most drastic example of disturbances in ecosystem functioning as a whole [1-3]. One example of such areas is the Silesian Upland [4], along with one of its southern parts – the Jaworzno Hills mesoregion.

Despite the fact that inactive limestone and dolomite quarries are relatively common in the southern part of the upland, there are not many studies regarding the landscape transformation processes within inactive quarries. Most previous studies concerned the geotourist attraction of quarries and its as a objects of natural and cultural heritage [5, 6]. Some information concerning interesting plant species is given by Czylok et al. [4, 7]. Observation of the succession processes and the formation of ecosystems in the modern landscape ecology is an important research problem [1, 3, 8]. Therefore, the authors undertook a study of the changes taking place in quarries located in the southern part of the Silesian Upland.

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The aim of our paper is to present the preliminary results of research on overgrowing processes in the selected objects using applied GIS methods.

Study Area

The investigation was conducted within the complex of 6 inactive limestone and dolomite quarries in the Przemsza river valley (Fig. 1) in the SW part of the Silesian Upland, specifically the Jaworzno Hills mesoregion (341.14) [7, 9]. There are the residues of the limestone small industry, a lime kiln (the so-called Rumford's furnace), in one of the quarries (Penczków quarry). The kiln is not active.

Our paper presents the results of the research in the two selected objects (Fig. 1): the aforementioned Penczków quarry (2), which is located in the open area, and a quarry near Grabina Woods (1), which is completely overgrown with forest.

Materials and Methods

The analysis of changes within identified ranges of vegetation patches was conducted of the basis of archival aerial photographs and the latest orthophotomaps from the 1950s to 2009. All cartographic materials were calibrated and registered in the Polish CS92 coordinate system (EPSG: 2180), on the basis of topographic maps at a scale of 1:10,000. Maximum registration errors did not exceed 0-1 pixels. The registered rasters were digitalization in terms of vegetation patches [10, 11] in MapInfo Professional GIS software (Fig. 2).

The botanical studies in the quarries were conducted in 2012-13 within previously identified vegetation patches. These included the implementation of the floristic lists along the designated transects. Naming the taxons was given after Mirek et al. [12] and Rutkowski [13]. Additionally, the distribution of protected as well as rare and endangered species was analyzed [14, 15]. The soil study included several shallow soil profiles in each of the separated zones, which allowed the evaluation of the stage of their development.

Results and Discussion

The vegetation occurring on different landforms within the surveyed quarries and the vascular flora along the transects were analyzed. In the various sections of the transect in identified vegetation patches, flora differed because of the changes in relief. A general floristic list of both quarries is presented in Table 1.

Vegetation of the Quarry near Grabina Woods

Four zones of different vegetation types were delimited within the quarry. Initially, 45 species of vascular plants were found (Table 1). From the SW the quarry basin is adjacent to the flattened surface of the Triassic anticline [16], which is used agriculturally. In the ecotone zone (zone I) between the agrocenosis and the ecosystem which is being formed in the area of the quarry, the thermophilic edge community from class *Rhamno-Prunetea* developed with almost a full species composition. The shrub layer is built here from *Cerasus avium*, *Corylus avellana*, *Crataegus laevigata*, *C. monogyna*, *Prunus spinosa*, *Rhamnus catharticus*, *Sambucus nigra*, and *Viburnum opulus*. There are also single sucker forms of *Fraxinus excelsior*, *Quercus robur*, and *Ulmus laevis*. Sunny spots are taken by *Brachypodium pinnatum* with the admixture of many other herbaceous species (Table 1).

The NW and SE rock walls of the quarry are surrounded by steeply inclined slopes (zone II). The average slope angle is approximately 70-80º, and their ground is unstable. A frequent phenomenon in this zone is shearing of the

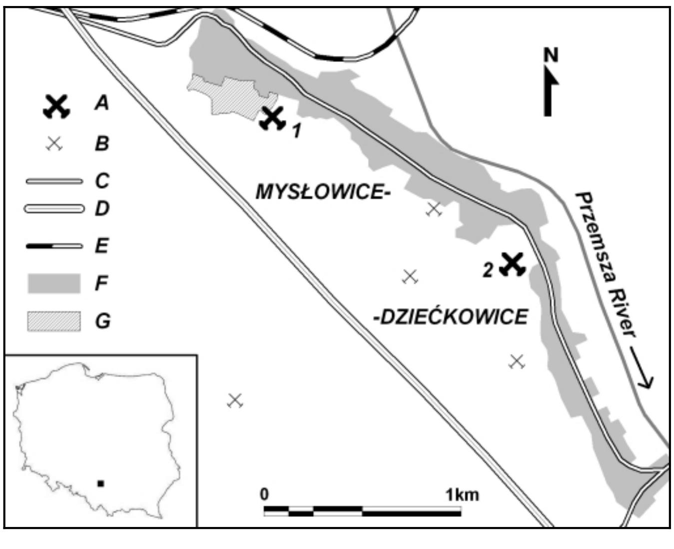

Fig. 1. Location of investigated quarries. (A – investigated quarries: 1 – quarry near Grabina Woods, 2 – Penczków quarry, B – other inactive quarries, C – roads, D – motorway A4, E – railways, F – residential areas, G – the Grabina Woods).

Table 1. The vascular flora of investigated quarries.

Species		Quarry near Grabina Woods	Penczków quarry
1	*Acer platanoides* L.	+	+
2	*Acer pseudoplatanus* L.	+	-
3	*Achillea millefolium* L.	-	+
4	*Aegopodium podagraria* L.	+	+
5	*Agrimonia eupatoria* L.	+	+
6	*Agrostis canina* L.	-	+
7	*Alopecurus pratensis* L.	+	+
8	*Anthoxanthum odoratum* L.	+	-
9	*Anthyllis vulneraria* L.	-	+
10	*Arrhenatherum elatius* (L.) P.Beauv. ex J.Presl & C.Presl	-	+
11	*Artemisia vulgaris* L.	-	+
12	*Berteroa incana* (L.) DC.	-	+
13	*Betula pendula* Roth	+	+
14	*Brachypodium pinnatum* (L.) P.Beauv.	+	-
15	*Briza media* L.	-	+
16	*Calamagrostis epigejos* (L.) Roth	+	+
17	*Carduus* sp. L.	-	+
18	*Carex digitata* L.	+	-
19	*Carlina acaulis* L.	-	+
20	*Carlina vulgaris* L.	-	+
21	*Carpinus betulus* L.	+	-
22	*Centaurea jacea* L.	-	+
23	*Centaurea scabiosa* L.	-	+
24	*Centaurium erythraea* Rafn	-	+
25	*Cerastium arvense* L.	-	+
26	*Cerasus avium* (L.) Moench	+	+
27	*Chamaecytisus ratisbonensis* (Schaeff.) Rothm.	-	+
28	*Chamaenerion angustifolium* (L.) Scop.	-	+
29	*Chamomilla recurita* (L.) Rauschert	-	+
30	*Chelidonium majus* L.	+	-
31	*Cichorium intybus* L.	-	+
32	*Cirsium rivulare* (Jacq.) Scop.	-	+
33	*Convallaria majalis* L.	+	-
34	*Convolvulus arvensis* L.	+	+
35	*Cornus sanguinea* L.	-	+
36	*Coronilla varia* L.	-	+
37	*Corylus avellana* L.	+	+

Table 1. Continued.

Species		Quarry near Grabina Woods	Penczków quarry
38	*Crataegus laevigata* (Poir.) DC.	+	+
39	*Crataegus monogyna* Jacq.	+	+
40	*Crepis tectorum* L.	-	+
41	*Dactylis glomerata* L.	+	+
42	*Daucus carota* L.	-	+
43	*Deschampsia caespitosa* (L.) P.Beauv.	-	+
44	*Dianthus carthusianorum* L.	-	+
45	*Dianthus deltoides* L.	-	+
46	*Dipsacus sylvestris* Huds.	-	+
47	*Dryopteris filix-mas* (L.) Schott	-	+
48	*Erigeron annuus* (L.) Pers.	-	+
49	*Euphorbia cyparissias* L.	-	+
50	*Euphorbia esula* L.	-	+
51	*Euphrasia stricta* D.Wolff ex J.F.Lehm.	-	+
52	*Fagus sylvatica* L.	+	-
53	*Fragaria viridis* Duchesne	+	+
54	*Frangula alnus* Mill.	-	+
55	*Fraxinus excelsior* L.	+	+
56	*Fraxinus pennsylvanica* Marsh.	-	+
57	*Galium aparine* L.	+	-
58	*Galium mollugo* L.	-	+
59	*Galium verum* L.	+	+
60	*Geranium pratense* L.	-	+
61	*Geranium robertianum* L.	+	-
62	*Geum urbanum* L.	+	-
63	*Hedera helix* L.	-	+
64	*Helianthemum nummulari-um* (L.) Mill.	-	+
65	*Hieracium pilosella* L.	-	+
66	*Holcus mollis* L.	-	+
67	*Humulus lupulus* L.	-	+
68	*Hypericum maculatum* Crantz	-	+
69	*Hypericum perforatum* L.	-	+
70	*Knautia arvensis* (L.) J.M.Coult.	-	+
71	*Leontodon hispidus* L.	-	+
72	*Ligustrum vulgare* L.	-	+
73	*Lotus corniculatus* L.	-	+
74	*Malus sylvestris* Mill.	-	+

Table 1. Continued.

Species		Quarry near Grabina Woods	Penczków quarry
75	*Medicago falcata* L.	+	+
76	*Medicago lupulina* L.	+	+
77	*Medicago sativa* L.	+	+
78	*Melampyrum pratense* L.	-	+
79	*Melandrium rubrum* (Weigel) Garcke	-	+
80	*Melilotus alba* Medik.	-	+
81	*Melilotus officinalis* (L.) Pall.	-	+
82	*Nardus stricta* L.	-	+
83	*Ononis spinosa* L.	-	+
84	*Origanum vulgare* L.	-	+
85	*Padus avium* Mill.	+	+
86	*Phleum pratense* L.	-	+
87	*Pimpinella saxifraga* L.	-	+
88	*Plantago lanceolata* L.	-	+
89	*Plantago media* L.	-	+
90	*Poa compressa* L.	-	+
91	*Polygonatum multiflorum* (L.) All.	+	-
92	*Potentilla alba* L.	-	+
93	*Potentilla anserina* L.	-	+
94	*Potentilla argentea* L.	-	+
95	*Potentilla erecta* (L.) Rausch.	-	+
96	*Potentilla heptaphylla* L.	-	+
97	*Potentilla tabernaemontani* Aschers.	-	+
98	*Primula veris* L.	-	+
99	*Prunella vulgaris* L.	-	+
100	*Prunus spinosa* L.	+	+
101	*Pyrus communis* L.	+	+
102	*Quercus robur* L.	+	+
103	*Quercus rubra* L.	-	+
104	*Ranunculus acris* L.	-	+
105	*Rhamnus catharticus* L.	+	-
106	*Rhinanthus minor* L.	-	+
107	*Rosa canina* L.	-	+
108	*Rubus caesius* L.	-	+
109	*Salix caprea* L.	-	+
110	*Salix cinerea* L.	+	-
111	*Salix purpurea* L.	-	+
112	*Sambucus nigra* L.	+	+
113	*Sanguisorba minor* Scop.	-	+
114	*Sanguisorba officinalis* L.	-	+

Table 1. Continued.

Species		Quarry near Grabina Woods	Penczków quarry
115	*Scabiosa ochroleuca* L.	+	+
116	*Sedum acre* L.	-	+
117	*Sedum maximum* (L.) Hoffm.	-	+
118	*Senecio jacobaea* L.	-	+
119	*Senecio vernalis* Waldst. & Kit.	-	+
120	*Senecio viscosus* L.	-	+
121	*Silene vulgaris* (Moench) Garcke	-	+
122	*Solidago gigantea* Aiton	-	+
123	*Sorbus aucuparia* L. em. Hedl.	-	+
124	*Thymus pulegioides* L.	-	+
125	*Tilia cordata* Mill.	+	-
126	*Tragopogon dubius* Scop.	-	+
127	*Tragopogon pratensis* L.	+	+
128	*Trifolium arvense* L.	-	+
129	*Trifolium montanum* L.	-	+
130	*Trifolium pratense* L.	-	+
131	*Tussilago farfara* L.	-	+
132	*Ulmus laevis* Pall.	+	-
133	*Urtica dioica* L.	-	+
134	*Valeriana sambucifolia* Mikan fil.	-	+
135	*Verbascum nigrum* L.	-	+
136	*Verbascum phlomoides* L.	-	+
137	*Veronica chamaedrys* L.	-	+
138	*Veronica spicata* L.	-	+
139	*Viburnum opulus* L.	+	+
140	*Vicia cracca* L.	+	+
141	*Vicia sativa* L.	-	+
142	*Vicia sepium* L.	-	+
143	*Vicia tetrasperma* (L.) Schreb.	+	-
144	*Vinca minor* L.	+	-
145	*Viola tricolor* L.	-	+

weathered limestone rock rubble. Instability of the ground does not facilitate the entry of plants. Slopes are covered with single young specimens of *Carpinus betulus*, *Acer platanoides*, *Betula pendula*, *Quercus robur*, and, rarely, *A. pseudoplatanus*, *Pyrus communis*, and *Rhamnus catharticus*. In the lower parts of the slope a belt of juvenile specimens of *Fraxinus excelsior*, of the height of about 25 m, is found. In the lowest parts of the slopes there is *Brachypodium pinnatum* with the admixture of *Galium aparine*, *Geranium robertianum*, *Geum urbanum*, and *Scabiosa ochroleuca*. The vertical walls of the quarry are not covered by dense vegetation. Only in the cracks do shoots of *Betula pendula*, *Fagus sylvatica*, and *F. excelsior* develop. This zone of quarry was overgrown in the first stage (Fig. 2). The vegetation patch in this zone is the oldest at the quarry area.

The bottom of the quarry (zone III) is covered with rubble, which is the remains of the pit operation. This area is also littered. Consequently, the processes of the vegetation development are much more difficult. Moreover, the significant thickness of the existing wood prevents the entrance of new species. Layer A (coverage 5.5) is dominated by *Carpinus betulus*, *Betula pendula*, and *Fraxinus excelsior*. Among the shrubs there are large and multi-sprout specimens of *Corylus avellana* and *Sambucus nigra*, as well as numerous young specimens of *Padus avium*. In large numbers *F. excelsior* and *Tilia cordata* are reintroduced. In the undergrowth there is *Polygonatum multiflorum* and single specimens of *Convallaria majalis*, while *Vinca minor* creates patches of up to 10 m^2. The bottom of the quarry was overgrown at the final time (Fig. 2).

The NE margin of the quarry (zone IV) has a varied surface with the presence of numerous small and shallow ravines and micro-basins. The substrate, which is limestone residuum with an admixture of anthropogenic material, is impermeable. This modifies the habitat conditions due to periodic water stagnation in micro-basins. The area directly adjacent to the disused quarry basin is overgrown with a belt of patchy forms of *Ulmus laevis* and *Corylus avellana*. A characteristic feature is a complete lack of undergrowth under compact crowns of *C. avellana*. The remaining margin fragments of the forest stand are dominated by *Fraxinus excelsior*, with single specimens of *Carpinus betulus* and *Tilia cordata*. Individual specimens of *F. excelsior* grow up to about 30 m and their diameter reaches about 15 cm. The effects of the struggle for light are clearly visible. Leaves are only found in the upper crown, while lower crowns are

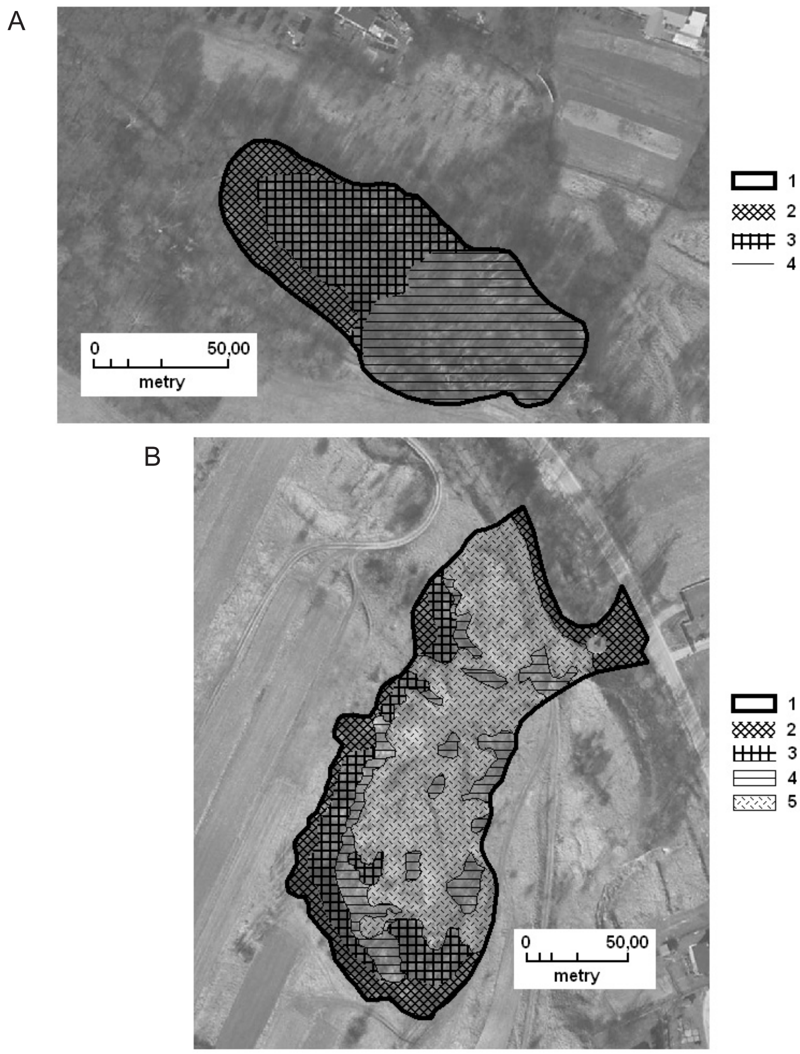

Fig. 2. Changes of selected vegetation patch ranges within investigated quarries (on the background of latest ortophotomaps from 2009) (A – the quarry near Grabina Woods: 1 – marginal line of quarry, forest vegetation: 2 – from the 1960s, 3 – from the 1970s, 4 – from the 1980s/90s; B – the Penczków quarry: 1 – marginal line of quarry, 2 – forest vegetation from the 1960s/70s, 3 – forest-scrubs vegetation from the 1970s/80s, 4 – the youngest scrubs vegetation from the 1990s, 5 – plant association *Calamagrostietum epigeji*).

entirely devoid of them. In the undergrowth *Brachypodium pinnatum*, *Fragaria viridis*, *Galium verum,* and *Geum urbanum* are found, with single specimens of *Carex digitata*. The zone of small gullies is associated with a massive reintroduction of *F. excelsior* and *Fagus sylvatica*.

From the E and NE the quarry is adjacent to an old farmland area at the residential premises of Dziećkowice village. In the zone of the ecotone a narrow belt of scrub with *Carpinus betulus*, *Corylus avellana*, *Fraxinus excelsior,* and *Tilia cordata* is being formed. Its physiognomy refers to communities of the class *Rhamno-Prunetea*. The open areas are taken by patches of common species (*Aegopodium podagraria*, *Chelidonium majus*).

From the north side the studied object is adjacent to a complex of dry ground mixed forest, the so-called Grabina Woods [7] (Figs. 1 and 2), but any herbaceous species typical for this plant association are not found in the quarry. This may be conditioned with the increased anthropopressure and the struggle for light within the existing dense cover of woody vegetation. However, the results obtained by analysis of aerial photographs and ortophotomaps by GIS tools showed that the overgrowing processes within the investigated quarry followed from the direction of this forest complex (Fig. 2).

Vegetation of the Penczków Quarry

Within the Penczków quarry three morphologically distinct vegetation zones were distinguished. In total, 127 species of vascular plants were identified (Table 1). Zone I is the ecotone between the edge of the quarry and an adjacent cultivated field. A scrub of young specimens of *Cerasus avium*, *Prunus spinosa*, *Quercus robur*, and *Q. rubra* is under formation. The share of herbaceous plants is diverse (Table 1), in accordance with the relief, the neighbouring farmland, and the supply of organic matter of anthropogenic origin (municipal waste). Initially, about 60 species were found in this zone, and therefore it shows greatest biodiversity. Most of the plants growing in this zone also enter the rock shelves and cracks within the walls of the quarry. Similar results were obtained by Czylok et al. [4].

The wall of the quarry (zone II) is almost vertical (the slope is about 80-90º), and it represents active processes of rock weathering and fall. In spite of this, *Acer platanoides*, *Cerasus avium*, *Crataegus laevigata*, *C. monogyna*, *Fraxinus excelsior*, *F. pennsylvanica*, and *Padus avium* enter here, with single specimens of *Malus sylvestris* and *Pyrus communis*.

The bottom of the quarry (zone III) is characterized by varied microrelief. It includes both pits and ramparts of fine-grained overlay, which was the waste material during the quarry operation. Most of the area is covered by the plant association *Calamagrostietum epigeji* – single species aggregation. Thanks to its considerable ecological plasticity, the grass grows very well in such extreme environments [3]. Within this association there are other rare species of vascular plants, such as only single specimens of *Agrimonia eupatoria*, *Briza media*, *Coronilla varia*, *Melilotus alba*, and *M. officinalis*. Within the cavities, which are often wetter, there are patches of *Corylus avellana*, *Crataegus laevigata*, *C. monogyna*, and *Malus sylvestris*.

The Penczków quarry has overgrown from banks to bottom (Fig. 2). The vegetation patches connected with quarry banks can be classified as the oldest within the area. The youngest vegetation patch is the plant association *Calamagrostietum epigeji* in the central part of the investigated quarry. In contrast to the quarry near Grabina Woods, the vegetation of Penczków quarry has grass-scrubs character, which is conditioned by its open landscape location.

Protected, Rare, and Endangered Species

Two species of strictly protected vascular plants were found (*Carlina acaulis*, *Centaurium erythraea*), as well as seven partially protected taxons: *Convallaria majalis*, *Frangula alnus*, *Hedera helix*, *Ononis spinosa*, *Primula veris*, *Viburnum opulus*, and *Vinca minor*. In addition, 5 species are endangered at the regional-scale – V category (*C. erythraea*, *Ononis spinosa*, *Potentilla alba*) and R category (*Carlina acaulis* and *Primula veris*) [14]. Endangered species at the country level were not recorded [15].

Soil

Within the studied quarries a mosaic soil cover is observed. The quarry bottoms include small fragments of anthropogenic *Technosols* and *Anthroposols* associated with building rubble [17]. Plant species on such ground show diverse habitat requirements, as shown by other studies [3].

Initial rendzinas are being formed directly at the foot of the steep walls of the quarries and have an evolving nature. The profiles contain a distinct humus level (A) lying directly on the variously grained fraction with the dominance of the coarse one (limestone and dolomite grains). The thickness of the humus level is conditioned by the nature of relief, especially meso- and microrelief, which in turn influences the type of vegetation. The share of calcareous species was observed (based on ecological numbers by Zarzycki et al. [18]). The direction of the soil-forming processes and the type of parent rock indicate the formation of rendzinas.

Conclusion

The studies showed that differentiation of overgrowing processes in investigated quarries are conditioned by the time that passed from the end of exploitation and of the type of surrounding landscapes. The results of the research show a clear relationship between vegetation and the degree of soil formation, the influence of microrelief and individual tree species on the formation of specific landscape mosaic. As a result, such areas could serve as model objects for investigation and monitoring of landscape transformation. In the area of the quarries the formation of new ecological systems is observed. Documenting these types of processes can help to predict the time of the formation of mature landscapes in the future.

The overgrowing process both in the quarries and at their fringes, besides the natural ecological succession, are significantly influenced by anthropogenic factors. The process of the supply of organic matter primarily are increased by washing the material away from the farmland located at higher levels. Moreover, the use of such sites as illegal municipal waste dumps also has some relevance. Despite the significant degree of anthropogenization, the tested objects are characterized by the diversity of habitats and micro-habitats, species richness, and the occurrence of rare and protected vascular plant species.

The use of GIS methods makes research on the basis of old aerial photographs and contemporary ortophotomaps and their comparative analysis easier. The GIS analysis was very helpful for the identification of changes of the vegetation patch ranges that are identified in period from the end of exploitation. GIS systems allow for easy collection, processing, analysis, and visualization of vegetation data. The databases created in this way will be able to be used in the future for studies of investigated quarries and their comparison with other similar objects, not only within the area of the southern part of Silesian Upland.

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