# EFFECT OF AUSTRIAN PINE ON NATURALNESS AND SUCCESSION OF VEGETATION IN RECLAIMED BAUXITE QUARRIES

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**Abstract:** Phytosociological and nature conservation assessment of the herb layer of 6-, 15- and 20-year-old post-mining Austrian pine stands was conducted in reclaimed bauxite quarries in Hungary. Great differences among the vegetations were found. Disturbance-tolerant species were dominant, subdominant and subordinated in the youngest, middle-aged and oldest pine stand, respectively. In parallel, proportion of the species characteristic for natural habitats increased gradually, leading to growing diversity and naturalness. The increasing pine cover reduced the species number and the coverage of herb layer. Post-mining flora differed significantly from both the potential mature oak forest vegetation of the areas and from the associations developed through regenerative succession on clear-cut areas of oak forests. Vegetation of the reclaimed quarries had lower naturalness: relative abundances of disturbance-tolerant and ruderal species were higher, but ratio of natural broad-leaved forest's species was smaller than in the potential vegetation. Similar differences were shown by comparison of the flora of bauxite quarries with the same-aged stages of regenerative succession of oak forests. In pine stands the repression of weeds parallel to the spreading of natural competitors was slower, and natural geophytes and protected species remained absent. Deficiency of propagule sources in reclaimed areas could contribute to the retentive effect of Austrian pine on vegetation succession.
**Keywords:** *Pinus nigra, bauxite quarries, phytosociological succession, naturalness value, reclamation*

## Introduction

At present, an area of 67 200 hectares is covered by the monodominant stands of the alien Austrian pine (*Pinus nigra* Arn.) in Hungary (source: NFCSO, Hungarian Forest Management Inventory, 2013). Although these plantations occupy only 3.7% of the total forested lands of the country, *P. nigra* is responsible for some serious ecological and nature conservation problems (Tamás, 2003). Several studies called the attention to the various aftermaths of the creation of pine stands, such as to the effects on the soil and ground layer including serious impoverishment of the species-rich native grassland vegetation (Bódis, 1993; Csontos et al., 1997, 2012, Szalai et al., 2012), the promoted spreading of other alien plants (Török et al., 2003; Cseresnyés and Csontos, 2012a), as


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well as the highly increased fire risk as a consequence of the considerable accumulation of resinous needle litter (Cseresnyés et al., 2011).

Austrian pine has been widely used for biological reclamation of various degraded areas in several European countries since the 1950s (Fettweis et al., 2005; Zagas et al., 2010). In Hungary, successful afforestations were executed on open-pit dolomite, bauxite, lignite and brown coal mines, waste-rock piles, rubbish dumps, slag heaps and red sludge reservoirs (Szerémy, 1981; Baranyi, 1986; Horváth, 2002; Károly et al., 2006). The good applicability of Austrian pine is presumably related to its wide scale habitat tolerance. The cover substrate deposited through the technical reclamation is generally characterized by physical and chemical conditions improper for plant cultivation, such as low nutrient supply, extreme acidity or basicity, as well as high spatial heterogeneity in texture and subsequently in water-holding and water-conducting capacity (Jochimsen, 2001). Materials of dead rocks, but particularly of slag and red sludge usually contain high level of mobile and easily mobilizable toxic heavy metals and compounds, *i.e.* sulphides (Liu et al., 2011). Austrian pine is quite tolerant to dry and nutrient-poor soils as well as to high concentration of toxic metals (*i.e.* Al, As, Cd, Cu, Sb, Sn, W) and pyrite (Pratas et al., 2005). The intensive early root expansion enables the species to uptake water and nutrients from the soil efficiently, even if unfavourable environmental conditions prevail (Richardson, 1998; Baumann et al., 2006). Soil melioration effect of the pine proved to be unsatisfactory in many cases, but the dense root system, the quick canopy closure and the intensive litter formation markedly reduce soil erosion (Filcheva et al., 2000; Miletić et al., 2011).

After land reclamation, post-restoration monitoring systems are commonly used both for examining characteristic changes in environmental factors and to study the rate and stage of area regeneration. Such type of research offers good opportunities for improving the land restoration practice. The realized monitoring activities are ordinarily include the investigation of refuse soil as well as surface and subterranean water, but the comprehensive survey of the biota in the reclaimed area is neglected in most cases. Phytosociological studies of the vegetation developed during or after biological reclamation may be of great importance in terms of future planned area utilization, particularly in case when the restoration of the botanically valuable potential vegetation is aimed. Therefore, present study was designed to investigate the vegetation of abandoned bauxite quarries reclaimed with Austrian pine and to assess the naturalness of the flora in order to evaluate the effect of the alien tree on the regenerative secondary succession.

## Materials and methods

Three reclaimed bauxite quarries were chosen for study in Transdanubia, Hungary. Locations of the study sites and percentage cover of *P. nigra* are given in *Table 1*.

*(1)* 6-year-old site (6.9 ha in area). Pine stand is situated 2.6 km south of village Szőc, on a north-facing slope covered by the materials of former waste-rock piles. The young pine plantation is surrounded mostly by sessile oak – Turkey oak forests, grown in the neighbouring undisturbed areas. Following the open-pit bauxite mining (1977–86), the area was technically reclaimed until 2005 (Kovács, 1998). Sawdust and inorganic fertilizers were used in order to create a more suitable material


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***Table 1.** Data of Austrian pine stands established for reclamation of bauxite quarries in Hungary, and the code of quadrats used for phytosociological studies.*

| Study site age; code of forest management unit | Code of quadrat | GPS coordinates | Cover of *P. nigra* (%) |
|---|---|---|---|
| 6 years old; Sáska 6I, Szőc | A1 | N 46°59'59.9"; E 17°31'33.8"; 282 m | 15 |
| | A2 | N 46°59'59.2"; E 17°31'35.0"; 284 m | 10 |
| | A3 | N 46°59'58.6"; E 17°31'35.3"; 289 m | 10 |
| | A4 | N 46°59'57.9"; E 17°31'34.1"; 294 m | 15 |
| | A5 | N 46°59'57.2"; E 17°31'33.5"; 299 m | 15 |
| 15 years old; Bicske 7A, Nagyegyháza | B1 | N 47°32'38.5"; E 18°32'48.2"; 276 m | 40 |
| | B2 | N 47°32'39.3"; E 18°32'49.4"; 278 m | 70 |
| | B3 | N 47°32'48.6"; E 18°32'56.1"; 297 m | 25 |
| | B4 | N 47°32'47.5"; E 18°32'57.7"; 291 m | 90 |
| | B5 | N 47°32'43.5"; E 18°32'52.1"; 290 m | 70 |
| 20 years old; Sáska 63G | C1 | N 46°59'49.6"; E 17°30'55.8"; 261 m | 20 |
| | C2 | N 46°59'49.1"; E 17°30'54.4"; 260 m | 60 |
| | C3 | N 46°59'48.7"; E 17°30'56.0"; 261 m | 55 |
| | C4 | N 46°59'49.8"; E 17°30'56.5"; 262 m | 20 |
| | C5 | N 46°59'49.3"; E 17°30'58.3"; 263 m | 75 |

for the afforestation, thereafter Austrian pine was cultivated by seed-sowing in 2004. In the study year (2010), pine stand height was 1–1.5 m with a pronounced dominance of *Solidago gigantea* in the herb-layer vegetation.

*(2)* 15-year-old site (3.2 ha in area). Post-mining pine stand is located 3.5 km north of village Nagyegyháza, 9 km northwest of the city of Bicske, surrounded by sessile oak – Turkey oak forests and artificial black locust stands. The abandonment of bauxite mining was followed by the complex reclamation in 1995 (Novák, 2007). Prior to the seed-sowing of Austrian pine, organic fertilizer and chopped bark were added and mixed the cover layer to build soil organic matter. By the study year (2010), a 3–5 m high, dense pine stand (only with local natural thinning) developed in the area predominated by *Calamagrostis epigeios* in the herb layer.

*(3)* 20-year-old site (6.4 ha in area). The area is situated 1 km west of the 6-year-old study site. The neighbouring vegetation was formed mainly by sessile oak – Turkey oak forests except westward where a secondary scrubland was grown (invaded by the alien black locust). Establishment of Austrian pine stands was completed in 1990 by transplanting pine saplings after meliorating the cover layer with addition of sawdust and inorganic fertilizer (Kovács, 1998). In the study year, the 4–6 m high pine stand had great spatial variation in density due to the local decay of trees. Species-rich herb layer was observed especially in the glades of the stand.

For floristic survey, five 10 m by 10 m permanent quadrats were randomly located within each study site at least 20 m from the edge of pine stand then their centres were localized with GPS instrument (*Table 1*). In the quadrats, canopy cover of Austrian pine was visually estimated, afterwards the percentage cover of each herb-layer species (including low shrubs) were recorded three times during the vegetation season (May/June 2010, August/September 2010 and April 2011) in order to get a complete species inventory. Species names were used after Simon (2000). For data processing, each species was considered with its maximum cover value detected during the three sampling occasions. Total number of species, average number of species per quadrat as


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well as dominant and constant species were determined for each study site. Shannon diversity (H') of sample area was calculated by merging the data of the five quadrats and using natural logarithm. In addition, the evenness (E) of the vegetation and the diversity of every single quadrat was also calculated (rare species were considered with 0.1% cover value). Shannon diversity of study sites were compared statistically by performing Hutcheson's t-test (Hutcheson, 1970). Relationships between the cover of Austrian pine and the cover, species number and Shannon diversity of the herb-layer vegetation in quadrats were analysed by using Spearman's rank correlation. For characterizing the vegetation developed since the afforestation two types of plant traits were used: *(1)* social behaviour type (Borhidi, 1995) and *(2)* Raunkiaer life-form (Simon, 2000) of the species. Based upon the mean percentage cover of species (counted by averaging the data of the five quadrats) and their plant traits, group distributions were calculated with the application of the following categories:

*(1)* Social behaviour type: S (specialists); C (natural competitors); G (generalists); NP (natural pioneers); DT + W (disturbance-tolerants and indigenous weeds); RC (indigenous ruderal competitors); AC + I (alien competitors and introduced species). On group distribution graphs, categories are displayed in order of decreasing naturalness value (Borhidi, 1995).

*(2)* Raunkiaer life-form: MM + M (Phanerophyte); Ch (Chamaephyte); H (Hemikryptophyte); G (Geophyte); TH (Hemitherophyte); Th (Therophyte).

The quasi-mean naturalness value of vegetation was computed for each study site, based on the naturalness value of the constituting species weighted with their cover (according to Borhidi, 1995). Vegetation of study sites was compared by applying homogeneity test on the group distributions of *(1)* and *(2)*.

Comparative analyses of the studied vegetations were made in two ways:

*(A)* Vegetations of the reclaimed bauxite quarries were compared to mature stands of oak forests (sessile oak – Turkey oak ass. and pedunculate oak – Turkey oak ass.), the community types considered the natural climax associations of the territories surrounding the studied quarries (Zólyomi, 1989). This type of comparison was dedicated to assess how much the restored vegetations became similar to the theoretical final stage of the succession. In this way, the 15-year-old site was compared to sessile oak – Turkey oak stand relevés from the southern part of Gerecse Mountains (unpubl. data by Z. Barina), whereas the 6- and 20-year-old reclaimed sites were compared to pedunculate oak – Turkey oak stand relevés from the Bakony Mountains (Szodfridt and Tallós, 1964). Since latter authors applied Braun–Blanquet scale in their work, data were converted into percentage cover by van der Maarel transformation (Maarel, 2007).

*(B)* Vegetations of the reclaimed quarries were compared to successional stages of the natural vegetation with comparable age. The idea of this type of comparison was to assess how much slower (or faster) the succession is in the restored vegetation sites than in sites where a spontaneous regenerative succession takes place. Csontos (2010) studied regeneration cycle of sessile oak – Turkey oak forests and identified four stages along time since clear-cutting of the stands. These stages were: I= 1–3 years old; II= 4–11 years; III= 12–21 years and IV= 22–28 years. Relevés from stage II were compared to the 6-year-old reclaimed vegetation, whereas the 15 and 20 years old reclaimed quarries were compared to relevés from stage III of the oak forest regeneration succession.


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The comparative analyses *(A)* and *(B)* were based on distributions of plant functional groups, namely social behaviour types and Raunkiaer life-forms of the vegetation, since this approach is often provides an excellent supplementation to the analysis of vegetation based only on species composition (Woźniak et al., 2011). *Statistica* software package (ver 9, StatSoft Inc., OK, USA) was used for the statistical analyses.

## Results

Altogether 170 vascular plant species were listed in the reclaimed areas (for detailed floristic data, see Cseresnyés and Csontos, 2012b). The total number of species increased with the age of pine stand, as it was the lowest (83) in the 6-year-old stand and the highest (108) in the 20-year-old stand (Table 2). Average number of species per quadrat ranged from 48.3 (15-year-old stand) to 55.2 (20-year-old stand), while the herb layer cover varied between 39% and 95% in the 15- and 6-year-old stand, respectively. The Shannon diversity (H') and also the evenness (E) increased along with the increasing age of pine stand: both index proved to be the lowest in the 6-year-old stand (H'= 2.220; E= 0.502) and the highest in the 20-year-old forest (H'= 2.914; E= 0.622). Hutcheson's *t*-test showed significant ($p< 0.05$) differences in diversities only between the youngest and the oldest sampling areas, while the 15-year-old study site had an intermediate position (*Table 2*). Number of constant species varied considerably from 6 to 19 in the 15- and 20-year-old site, respectively.

***Table 2.*** *Characteristics of the vegetations developed in bauxite quarries reclaimed with Austrian pine 6, 15 and 20 years ago, in Hungary. Superscript letters after diversity values indicate groups distinguished by Hutcheson's t-test.*

| | **6-year-old** | **15-year-old** | **20-year-old** |
|---|---|---|---|
| Total number of species | 83 | 106 | 108 |
| Average number of species per quadrat | 50.8 | 43.8 | 55.2 |
| Average cover of herb layer (%) | 95 | 39 | 73 |
| Shannon-diversity (H') | $2.220^{a}$ | $2.538^{ab}$ | $2.914^{b}$ |
| Evenness (E) | 0.502 | 0.544 | 0.622 |
| Number of constant species | 19 | 6 | 17 |

Characterization of the herb layer of study sites in association with dominant and constant species (*Table 3*):

*(1)* 6-year-old stand: Vegetation of the former waste-rock pile was dominated by the abundant *Solidago gigantea* (48%), *Calamagrostis epigeios* (12%) and *Erigeron annuus* (4.4%). Besides, the flora was determined by the composition of the leguminous *Trifolium pretense*, *T. repens*, *T. alpestre* and *Medicago lupulina* (4–6% cover by each) as well as the grasses *Holcus lanatus* and *Dactylis glomerata*. The high spatial homogeneity and the high number of constant species of the herb-layer vegetation observed in the area was due to the combined effect of the evenly low (10–15%) canopy cover of Austrian pine and the young age of the stand. Each of the nine species


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***Table 3.*** *Mean percentage cover of dominant and constant species in the vegetation of reclaimed bauxite quarries of different ages.*

| | Dominant species | % | Constant species | % |
|---|---|---|---|---|
| **6-year-old stand** | *Solidago gigantea* | 48 | *Solidago gigantea* | 48 |
| | *Calamagrostis epigeios* | 12 | *Calamagrostis epigeios* | 12 |
| | *Trifolium pratense* | 6.2 | *Trifolium pratense* | 6.2 |
| | *Medicago lupulina* | 5 | *Medicago lupulina* | 5 |
| | *Trifolium repens* | 5 | *Trifolium repens* | 5 |
| | *Trifolium alpestre* | 4.6 | *Trifolium alpestre* | 4.6 |
| | *Erigeron annuus* | 4.4 | *Erigeron annuus* | 4.4 |
| | *Holcus lanatus* | 1.8 | *Holcus lanatus* | 1.8 |
| | *Dactylis glomerata* | 1.64 | *Dactylis glomerata* | 1.64 |
| | *Fragaria vesca* | 1 | *Fragaria vesca* | 1 |
| | | | *Galium verum* | 0.64 |
| | | | *Achillea collina* | 0.46 |
| | | | *Astragalus glycyphyllos* | 0.46 |
| | | | *Tussilago farfara* | 0.46 |
| | | | *Cirsium arvense* | 0.28 |
| | | | *Lotus corniculatus* | 0.28 |
| | | | *Prunella vulgaris* | 0.1 |
| | | | *Sanguisorba minor* | 0.1 |
| | | | *Scabiosa ochroleuca* | 0.1 |
| **15-year-old stand** | *Calamagrostis epigeios* | 20 | *Calamagrostis epigeios* | 20 |
| | *Solidago gigantea* | 3.8 | *Erigeron annuus* | 1.02 |
| | *Erigeron annuus* | 1.02 | *Achillea collina* | 0.84 |
| | *Achillea collina* | 0.84 | *Daucus carota* | 0.82 |
| | *Daucus carota* | 0.82 | *Crataegus monogyna* | 0.68 |
| | *Fraxinus ornus* | 0.82 | *Medicago lupulina* | 0.66 |
| | *Festuca rupicola* | 0.8 | | |
| | *Crataegus monogyna* | 0.68 | | |
| | *Medicago lupulina* | 0.66 | | |
| | *Asclepias syriaca* | 0.64 | | |
| **20-year-old stand** | *Fragaria vesca* | 16 | *Fragaria vesca* | 16 |
| | *Brachypodium sylvaticum* | 13.2 | *Brachypodium sylvaticum* | 13.2 |
| | *Calamagrostis epigeios* | 10 | *Calamagrostis epigeios* | 10 |
| | *Solidago gigantea* | 6.2 | *Trifolium alpestre* | 4.82 |
| | *Trifolium alpestre* | 4.82 | *Securigera varia* | 2.6 |
| | *Securigera varia* | 2.6 | *Clinopodium vulgare* | 2.24 |
| | *Clinopodium vulgare* | 2.24 | *Dactylis glomerata* | 1.82 |
| | *Dactylis glomerata* | 1.82 | *Crataegus monogyna* | 1.8 |
| | *Crataegus monogyna* | 1.8 | *Medicago lupulina* | 1.6 |
| | *Salix caprea* | 1.8 | *Trifolium repens* | 1.42 |
| | | | *Agrimonia eupatoria* | 1.26 |
| | | | *Galium mollugo* | 1.24 |
| | | | *Daucus carota* | 0.86 |
| | | | *Achillea collina* | 0.66 |
| | | | *Picris hieracioides* | 0.28 |
| | | | *Sanguisorba minor* | 0.28 |
| | | | *Rosa canina* | 0.1 |


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mentioned above with high cover values were also members of the constant species group (see *Table 3*).

*(2)* 15-year-old stand: Flora developed in the reclaimed mine-pit was dominated by disturbance-tolerant and invasive plants. The ubiquitous *C. epigeios* and the alien *S. gigantea* represented 20% and 3.8% mean cover, respectively, and their joint cover exceeded 50% in some places. Among woody species, saplings of *Fraxinus ornus* and *Crataegus monogyna* appeared densely in the area. As regards for constant species *Erigeron annuus, Achillea collina*, *Daucus carota, C. monogyna* and *Medicago lupulina* can be mentioned beside the dominant *C. epigeios*.

*(3)* 20-year-old stand: High spatial variability and species richness of the herb-layer vegetation was observed with the dominance of *Fragaria vesca*, *Brachypodium sylvaticum*, *C. epigeios* and *S. gigantea* mixtured with other 11 plant species exceeded 1% in coverage. Juvenile shrubs and trees (*C. monogyna*, *Salix caprea*, *Prunus spinosa*, *Ligustrum vulgare*, *Pyrus pyraster*) were also found sporadically. Altogether 17 constant species were encountered in this study site (*Table 3*).

Increasing canopy cover of Austrian pine had significant ($p< 0.05$) negative effect on the cover and the species number of herb layer (Spearman's $r_{rank}$= –0.897 and –0.662, respectively; *Figure 1*), whereas had no influence on Shannon diversity (Spearman's $r_{rank}$= 0.113).

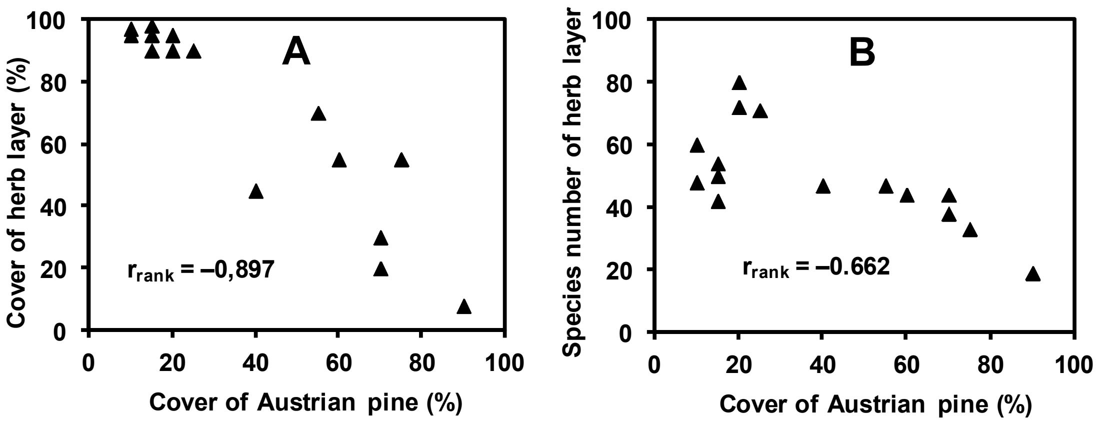


***Figure 1.*** *Change of the cover **(A)** and the species number **(B)** per quadrats of the herb-layer vegetation related to the cover of Austrian pine in the reclaimed bauxite quarries.*
*$r_{rank}$ = Spearman's rank correlation coefficient*

Results of homogeneity tests of group distributions based on social behaviour types and Raunkiaer life-forms for different study sites are summarized in *Table 4*.

In the analysis based on the social behaviour types, homogeneity test showed significant differences among the vegetation of the three bauxite quarries (*Figure 2/A, Table 4 `A`*). In the 6-year-old pine stand, alien plants became predominant (51.6%) mainly due to the strong invasion of *S. gigantea*, but *Erigeron annuus* and *Conyza canadensis* were present as well. High proportion of disturbance-tolerants and


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***Table 4.*** *Statistical evaluation of the vegetations developed in the reclaimed bauxite quarries. Data show $\chi^2$ values and levels of significance obtained from the homogeneity test of group distributions based on the ecological attributes of species.*

| | **Compared study sites of different ages since pine stand establishment** | **Ecological attribute** | |
|---|---|---|---|
| | | **Social behaviour type** | **Raunkiaer life-form** |
| *`A`* | 6-year-old vs. 15-year-old | 43.39*** | 19.37** |
| | 6-year-old vs. 20-year-old | 60.76*** | $10.72^{NS}$ |
| | 15-year-old vs. 20-year-old | 74.01*** | $10.08^{NS}$ |
| *`B`* | 15-year-old vs. Barina [*ined.*] (native oak forest) | 119.2*** | 106.9*** |
| *`C`* | 6-year-old vs. Szodfridt and Tallós [1964] (native oak forest) | 125.6*** | 45.54*** |
| | 20-year-old vs. Szodfridt and Tallós [1964] (native oak forest) | 49.86*** | 24.36*** |
| *`D`* | 6-year-old vs. Csontos [1996] II stage (oak forest regeneration) | 98.38*** | 18.01** |
| *`E`* | 15-year-old vs. Csontos [1996] III stage (oak forest regeneration) | 118.2*** | 23.12*** |
| | 20-year-old vs. Csontos [1996] III stage (oak forest regeneration) | 52.08*** | 15.20** |

****= p< 0.001; **= p< 0.01; NS= not significant*

weeds as well as of indigenous ruderal competitors (principally *C. epigeios*) were detected. From among the 27 generalist species, *Trifolium alpestre*, *Holcus lanatus* and *Fragaria vesca* attained considerable cover. On the 15-year-old study site, herb-layer vegetation was featured by indigenous ruderal competitors (46.9%) owing to primarily the propagation of *C. epigeios* and secondly the abundance of *Cirsium arvense*. Alien invaders (*S. gigantea*, *Asclepias syriaca* and *Ambrosia artemisiifolia*) as well as 62 species classified as native disturbance-tolerants or weeds also formed important groups with 23.2% and 18.4% proportion, respectively. Natural competitors (9 species) and generalists (20 species) formed relatively small groups in cover. The flora of the 20-year-old bauxite quarry was mainly composed by generalist colonizers (35 species with 51.1% group mass) with the predominance of *Fragaria vesca* and *Brachypodium sylvaticum* and the relatively high frequencies of *Trifolium alpestre*, *Clinopodium vulgare* and *C. monogyna*. However, the disturbance-tolerants and weeds (48 species, *e.g. Securigera varia*, *Dactylis glomerata*, *Salix caprea*) and also the indigenous ruderal species (*C. epigeios*, *Cirsium arvense*) and adventive plants (*S. gigantea*, *Erigeron annuus*, *Robinia pseudoacacia*) were still abundant. Small percentage contribution (below 0.3%) of both natural pioneers and specialists were obtained for each of the three reclaimed areas. The quasi-mean naturalness value calculated for the vegetations of the 6-year-old and the 15-year-old plantations proved to be very low (–0.87 and –0.55, respectively) clearly due to the high cover degree of species having small naturalness value, while for the 20-year-old study site considerable higher (2.18) naturalness value was obtained.

Considering Raunkiaer life-form distributions significant difference was shown only between the herb-layer vegetations of the 6 and the 15 years old stands (*Figure 2/B, Table 4 `A`*). Outstanding percentage ratio (68.5–85.2%) of hemicryptophytes was found in each study site. Phanerophytes represented notable group mass (17.8%) in the 15-year-old site owing to the dense regrowth of *Fraxinus ornus*, *C. monogyna* and *Quercus petraea*. Not more than 4.6–11.2% relative coverage of therophytes was found, notwithstanding their relatively high species number (16–25) in each site. Each


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reclaimed site was characterized by the low ratio of chamaephyte, geophyte and hemitherophyte life-forms; although from the latter group *Picris hieracioides* and *Centaurea biebersteinii* were relatively abundant.

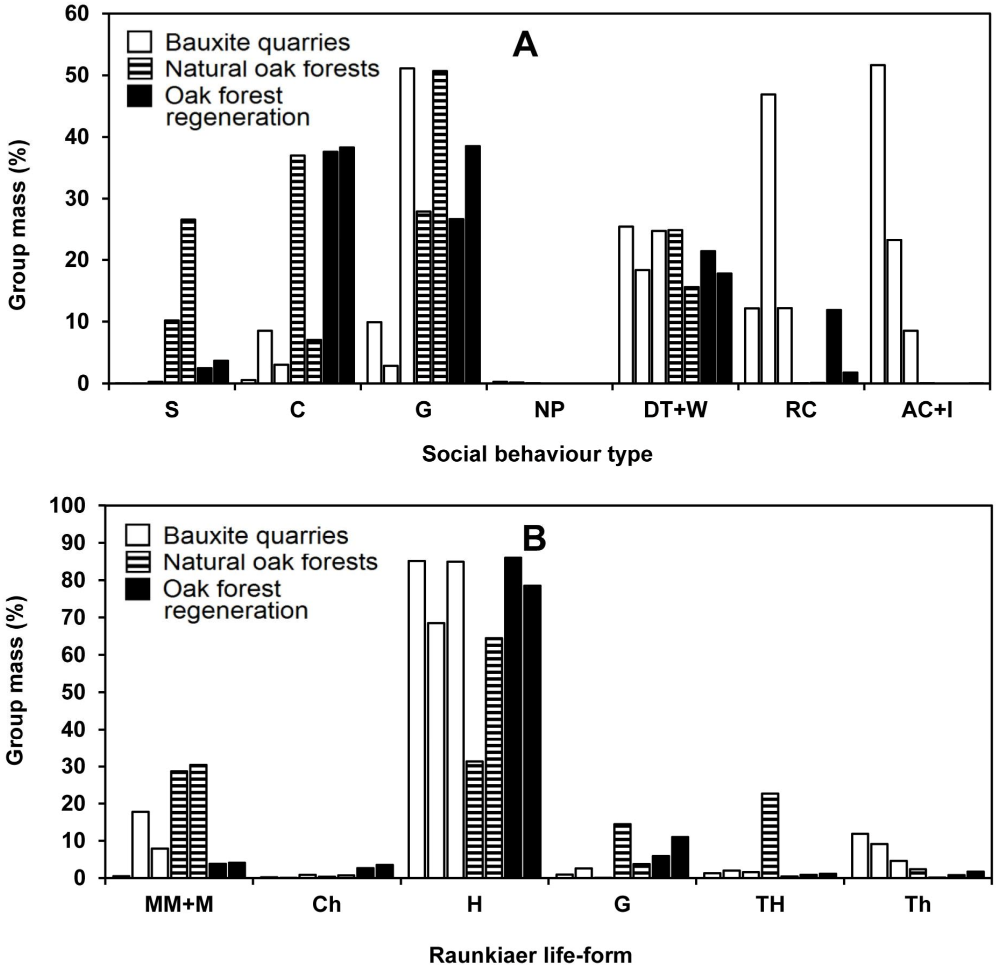


*Figure 2. Group distributions of social behaviour types* (A) and Raunkiaer life-forms (B) for the herb-layer vegetation of the (i) reclaimed bauxite quarries of different ages (empty bars from left to right: 6, 15 and 20 years old stands), (ii) the natural oak forests (striped bars from left to right: Gerecse and Bakony Mts.) and (iii) oak forests regenerated after clear-cutting (filled bars from left to right: regeneration stage II and III).* S= specialists; C= natural competitors; G= generalists; NP= natural pioneers; DT= disturbance-tolerants; W= indigenous weeds; RC= indigenous ruderal competitors; AC= alien competitors; I= introduced species*

Further comparative evaluation of the vegetation formed in the reclamation areas was completed by employing the published (Szodfridt and Tallós, 1964; Csontos, 2010) and unpublished (Barina, *ined.*) data described earlier. Homogeneity tests showed significant differences in each case when group distributions calculated on the post-mining flora was compared with those of generated on the basis of literature data derived from native or regenerated forest associations.

Distributions concerning the herb layer of native sessile oak – Turkey oak forests were examined at first (*Figure 2*). Considerable differences appeared between the flora


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of the 15-year-old reclamation area and the herb layer of *Quercetum petraeae–cerris* stands from Gerecse Mountains (*Table 4 `B`*). As regards the reclaimed bauxite quarry, the distribution of social behaviour types shifted markedly towards species groups having lower naturalness values. Oak forests were dominated by natural competitors and generalists and characterized by a remarkably higher percentage cover of specialists, whereas plenty of indigenous ruderal competitors and alien species as well as several natural pioneers featured the flora on the reclaimed site. Concerning the Raunkiaer life-forms, lower proportion of phanerophytes and geophytes as well as higher ratio of hemicryptophytes and therophytes were observed in the reclaimed areas than in the native sessile oak – Turkey oak stands. (The outstanding proportion of hemitherophytes in the oak forests of Gerecse Mts was due to the high cover of *Alliaria petiolata*, a species with ambiguous classification between TH and H life forms.)

The flora developed on the 6- and 20-year-old study sites was compared with the herb-layer of the native oak forest in Bakony Mountains (*Table 4 `C`; Fig. 2*). Specialist species (having high naturalness value) constituted an insignificant part of coverage on the reclaimed areas, moreover here the natural competitors also represented a smaller ratio than in native oak forest. Conversely, post-mining Austrian pine stands were colonized by several natural pioneer plants as well as by the crowds of disturbance-tolerant, indigenous ruderal competitor and adventive species. Phanerophyte and geophyte life-forms proved to be less frequent on reclaimed sites than in oak forest, whereas hemikryptophyte, hemitherophyte and therophyte species had higher proportion in the reclaimed sites.

In a subsequent analysis, we compared the herb layer vegetation of the reclaimed areas to the herb layer of oak forests' clearings regenerated after clear-cutting (*Figure 2; Table 4 'D'*). Vegetation of the 6-year-old study site was compared with the 4–11 years old successional stage of oak forest regeneration (stage-II in Csontos, 2010). Group distributions of social behaviour types showed just slight differences in proportion of either the disturbance-tolerants or the indigenous ruderal competitors. On the other hand, post-mining vegetation was predominated by adventive plants, but the regenerated forest clearings were mainly characterized by the intensive propagation of natural competitors and generalists as well as the relatively high cover degree of specialists. Apart from the uniformly high ratio of hemikrytophytes, some fundamental disparities appeared between the graphs of Raunkiaer life-forms: the reclaimed bauxite quarry seemed to be abound in therophytes and hemitherophytes, whereas was rather poor in phanerophytes, chamaephytes and geophytes.

Regarding the 15- and 20-year-old pine stands, comparison was made with the 12–21 years old successional stage of oak forest regeneration (stage-III in Csontos, 2010), (*Table 4 `E`*). According to the distribution of social behaviour types, species groups with low naturalness values were expressing considerable cover ratios in the reclaimed areas. In the same-aged successional stage of oak forest regeneration, natural competitors and specialists accompanied the generalist species; alien plants played an insignificant role and natural pioneers were absent. Graph of Raunkiaer life-forms (*Figure 2/B*) shows the higher proportion of phanerophytes, hemitherophytes and therophytes in the reclaimed bauxite quarries, whereas the higher abundance of chamaephytes and geophytes was observed in the regenerating oak forests.


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## Discussion

Post-mining vegetations of different ages were clearly distinguished by the dominant species and the group distributions of social behaviour types and Raunkiaer life-forms. Herb layers of the 6, 15 and 20 years old Austrian pine stands could be considered as a successional chronoseries. In the youngest (6-year-old) stand, the small species number, low Shannon diversity and evenness values were mainly caused by the dominance of *S. gigantea* and *C. epigeios* that formed altogether 60% of the vegetation cover. The remaining part of the species-pool belonged principally to disturbance-tolerants and ruderal competitors, similarly to the findings of other successional studies in the literature (Kompala-Baba and Baba, 2013). Consequently, the calculated quasi-mean naturalness value (–0.87) was the lowest among the study sites. In the 15-year-old pine stand, a smaller cover ratio of alien plants were observed, but the vegetation was still predominated by disturbance-tolerants and indigenous ruderal competitors, leading to a similarly low naturalness value (–0.55). The species number, diversity and evenness of the herb layer proved to be the highest in the 20-year-old pine plantation, where the role of native broad-leaved forests' species was already important. Indigenous and alien ruderal competitors were still present, but generalists prevailed over other social behaviour types, resulting in a more favourable spectrum of the naturalness value (with the quasi-mean of 2.18). The increasing pine canopy cover reduced the cover and species number of the herb layer but no change in Shannon diversity was detected. The independence observed between pine cover and herb layer diversity can be explained by the excessive spreading of *C. epigeios* and *S. gigantea* in the open quadrats, causing a reduction of both evenness and diversity. Rapid propagation of *C. epigeios* through the early stage of regenerative succession, as well as its penetration to various forest communities were also observed in Central Europe (Sierka and Chmura, 2005; Mudrák et al., 2010). Házi et al. (2011) suggested an artificial control of *C. epigeios* by regularly repeated mowing in order to promote the appropriate course of succession. Negative effect of Austrian pine cover on species number and fine-scale structural complexity of the herb-layer vegetation was reported earlier as well (Bartha et al., 2004; Mudrák et al., 2010).

Indigenous ruderal and alien competitors as well as natural pioneers were nearly absent from the native sessile oak – Turkey oak associations, furthermore habitat-indifferent plants were substituted by species of broad-leaved forests. According to the social behaviour types, these species mainly belonged to the specialists, natural competitors and generalists, contributing to a much higher naturalness of sessile oak – Turkey oak forest. As for Raunkiaer life-forms, both the species number and relative coverage of phanerophytes exceeded the values determined for the reclamation areas and the proportion of therophytes were lower in oak forests due to the subordinate role of weeds. Conspicuous difference appeared between group masses of geophytes as well. Geophytes amounted to 5–15% cover ratio in the native oak forests, whereas they were absent from the reclaimed sites. Extreme low colonization ability and slow propagation of geophytes was also demonstrated during various secondary succession studies (Schmidt, 1988; Hayashi, 1991).

Herb-layer vegetation in the reclaimed areas expressed characteristic changes along with the aging of Austrian pine stands. Cover ratio of indigenous ruderal and alien competitors decreased gradually in parallel with the increasing role of the botanically more valuable generalists, natural competitors and specialists. An upward trend for the accompanying forest species group is also established on the reclaimed areas, as their


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initial 2.5% cover rate (at the 6-year-old stand) increased to 29.5% (at the 20-year-old stand). However, even the latter proportion falls far behind the 73% relative cover of this group found in the herb layer of natural sessile oak – Turkey oak forests (Szodfridt and Tallós, 1964; Kevey, 2008). Hemitherophytes and therophytes become repressed gradually parallel to the ageing of the reclaimed areas but the recurrence of geophytes did not occur. Such long-time changes in life-form and phytosociological spectra of the vegetation proved to be characteristic successional trends observed in different types of primary and secondary successions in infertile substrates, as confirmed by several field studies (Schmidt, 1988; Bartha et al., 2004; Frouz et al., 2008). Protected plants were absent from the reclaimed areas although several of them were frequently detected in the surrounding natural associations (Barina, *ined.*; Barina, 2006; Szodfridt and Tallós, 1964; Kevey, 2008).

Vegetation regenerated after the clear-cutting of sessile oak – Turkey oak forests (Csontos, 2010) also differed significantly from the flora formed on reclamation areas. Natural pioneers and adventive species were missing in stage II (4–11 years old) of the regenerative succession, but the latter group contributed nearly 52% of the cover in the 6-year-old reclaimed site. A particularly great inequality was shown for natural competitors representing about 0.5% proportion in the 6-year-old reclaimed site, whereas the herb layer of regenerating forest clearings was predominated (37.6%) by this social behaviour type. The graph of Raunkiaer life-forms clearly shows both the notably higher ratio of geophytes and the low cover degree of therophytes on the regenerating forest clearings. Additionally, vegetation of this early successional stage of clearings was already featured chiefly by the mixture of accompanying species (62%) instead of disturbance-tolerants and ruderal plants which were characteristic on the reclaimed sites.

By comparing the flora of the 15 and 20 years old post-mining pine stands with the successional stage III (12–21 years old) of oak forest regeneration (Csontos, 2010), differences proved to be similar in many respects, and a more pronounced disparity were obtained for the middle aged than for the older reclaimed stand. The herb layer of the regenerating oak forest clearings was richer in specialists and natural competitors, but conversely poorer in indigenous ruderal competitors than the reclaimed areas. Distribution of Raunkiaer life-forms displays the considerable cover rate of geophytes (11%) and the lower proportion of hemitherophytes and therophytes, in relation to reclamation areas. Oak forest clearings were dominated by the accompanying species of broad-leaved forests in this successional stage. Several protected species (*e.g. Doronicum hungaricum*, *Iris graminea*, *Lilium martagon*, *Lychnis coronaria*) were already established in the successional stage II of oak forest regeneration, followed by others (*e.g. Cephalanthera longifolia*, *Epipactis helleborine*, *Neottia nidus-avis*) in stage III (Horváth and Csontos, 1992; Csontos, 2010), whereas protected species were absent from the vegetation of the reclaimed sites.

We can conclude that the herb layer of post-mining Austrian pine stands passes through similar processes of regenerative succession than does the vegetation developed on clearings of formerly clear-cut native sessile oak – Turkey oak forests. However, the revegetation by spontaneous succession takes place more slowly or just partially in Austrian pine stands, thus the naturalness of the post-mining vegetation is always falls behind the same-aged stage of oak forest's regeneration. It corresponds to the characteristic differences between regeneration succession and secondary succession (Maarel, 1988), as the former takes place on oak forest clearings but the latter is the


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governing process on the reclaimed sites. In the reclaimed quarries, adventive plants may become abundant quickly, while the proportion of natural broad-leaved forests' species increases their share slowly. In addition, the major part of the constant oak forest species (particularly the specialists) does not occupy the reclaimed areas even after 20 years. Weak soil ameliorative effect of Austrian pine and its negative influence on the recolonization of native vegetation was formerly observed and silvicultural interventions, mainly small-scale and diffuse gap-opening in pine canopy was proposed for promoting natural succession (Barčić et al., 2006; Jonášová et al., 2006). However, it should be taken into consideration that plant recolonization in the post-mining areas can be strongly prevented by the deficiency of propagules which were presumably available on clearings regenerated after clear-cutting (surviving specimens, soil seed bank, bulbs, rhizomes *etc.*), but obviously absent from the top layer of reclaimed quarries. Spreading of propagules was found to be a crucial factor for plant migration and recolonization in disturbed areas that could strongly determined the course of regenerative succession (Matlack, 1994; Lanta and Leps 2009). For better understanding the consequences of Austrian pine application, long-term ecological monitoring of several reclamation areas should be initiated with involving unforested control sites receiving technical reclamation only. Nevertheless, presented results suggest the obstructive effect of Austrian pine on secondary succession, thus further establishment of pine stands can be reasonable just in case when the unfavourable habitat conditions (water management, nutrient supplying ability) do not make possible the utilization of other tree species in the spoil area. Hodačová and Prach (2003) realized that spontaneous succession could be an advantageous alternative to technical reclamation, leading to more natural vegetation with much higher species diversity. Consequently, existing pine stands have been created for silvicultural reclamation should not be maintained for decades. These plantations can be provisionally effective for preventing both water and wind erosion, but their conversion to the locally native vegetation types should be made as early as possible to achieve a perfect restoration goal.

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