Spontaneous Establishment of Woody Plants in Central European Derelict Sites and their Potential for Reclamation

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Abstract

The performance of woody plants was analyzed in 15 successional seres starting at bare ground in central European manmade habitats. The total cover of woody species after 10 years of succession was significantly related neither to initial soil moisture nor to nitrogen (expressed using Ellenberg indicator values). But the comparison of seres indicates that establishment of woody plants was easier under moderate environmental conditions and retarded in extreme habitats (dry, nutrient-poor, or acid). The arrival of the first woody plants was delayed in dry sites. No significant differences were found between primary and secondary seres, either with respect to the total cover of woody plants reached after 10 years of succession or considering the time of their arrival. In total, 24 woody species (10 shrubs and 14 trees) appeared in the series investigated. Their successional performance (in terms of the number of seres in which the species occurred and maximum cover reached in any sere) was not related to species traits (life strategy, type of mycorrhizae, mode of dispersal, diaspore weight), except for the regeneration strategy: species with seasonal regeneration by seeds were capable of creating higher cover. *Betula pendula* **(European birch) was the most successful species in spontaneous succession, especially on moist sites. Practical suggestions for the management of particular habitats (sites disturbed by mining, sites reclaimed after acid rain deforestation, urban sites, abandoned fields) are provided regarding the establishment of woody plants.**

Introduction

Spontaneous establishment of woody plants is a crucial step in succession in the temperate zone, being the first indication of gradual return of ultimately closed forest to a disturbed site (Ellenberg 1988; Woodwell 1992). Afforestation of derelict sites also represents a frequent goal of restoration and reclamation efforts, especially in sites disturbed on a large scale, such as by coal mining (see Bradshaw & Chadwick 1980). The spontaneous succession involving woody plants, both manipulated (Luken 1990) or without intervention, can be envisaged as the cheapest way of reclamation. However, in what kind of habitats and under what environmental conditions is it possible to rely on the spontaneous development of vegetation? This issue is especially urgent in countries of the former eastern block, where damaging economic activity has left vast areas of derelict land and where a shortage of funds to be invested into reclamation represents a serious problem.

In a previous paper, an increase in the cover of particular woody species was roughly compared among various successional seres (Prach 1994). The present study is aimed at analyzing a larger number of seres in more detail and assessing the overall successional role of shrubs and trees important from a successional viewpoint. The most successful colonizers among woody species are evaluated, relationships between their traits and establishment success are analyzed, and some possibilities for the use of these species in reclamation practices are suggested and discussed.

Material and Methods

Both published and unpublished data on percentage cover of particular woody species were gathered for 15 seres in manmade habitats in the Czech Republic (seres 1–14) and Hungary (15). All the seres investigated represented succession starting on bare ground and cover a wide range of habitats with respect to soil moisture and nutrient status (Table 1). The habitats were classified into two categories resembling a distinction between primary and secondary succession, respectively: habitats with (1) organic topsoil absent and (2) organic topsoil present.

Species performances were expressed using cover data obtained by the point-quadrat method (Kershaw

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& Looney 1985) and/or direct cover estimation conducted in permanent plots and transects, or by sampling several differently aged stages under comparable site conditions. The latter approach made it possible to indirectly infer the course of succession (see Table 1 for the sampling method in each seres). For the seres sampled by the relevé method and using the Braun-Blanquet scale (Mueller-Dombois & Ellenberg 1974), the following transformations of cover-class data were used: 5, 87.5%; 4, 62.5%; 3, 37.5%; 2*b*, 18.75%; 2*a*, 8.75%; 2m, 5.0%; 1, 2.5%; +, 0.1%; *r*, 0.02% (van der Maarel 1979).

Species traits were extracted from Grime et al. (1988) and Frank and Klotz (1990). Ellenberg indicator values were used to express the soil conditions (Ellenberg et al. 1991). In this approach, the relationship of a species to particular environmental factors is assessed using an ordinal scale. Indicator values for moisture and nitrogen were calculated for the first five years of succession. Cover values of all plant species for which the indicator values were available and that achieved a cover of at least 1% in one sampling year were included in the calculations, using weighted averages. The mean value for the first five years was used to characterize the initial soil conditions (Prach, et al. 1993*a*); in seres not sampled year by year, the mean value of the years within the five-year period for which the data were available was used instead. The initial soil conditions estimated by this method for each sere are summarized in Table 1.

The performance of woody plants in each successional sere was evaluated using the following criteria:

(1) Total cover calculated as a sum of covers of all woody species present in a given year. Although four of the seres provide insight into the course of succession over a long time (Table 1, seres 11, 12, 14, 15), it was not possible to compare the long-term development among all seres because of the relatively short duration of most of the others. The performance of woody plants was thus compared for year 10 of succession (±2 years because some of the seres were not sampled annually).

(2) Year of the first recorded occurrence of a woody species. To investigate the possibilities of predicting woody plant performance based on initial envi-

Table 1. Overview of successional seres included in the analysis.

	Locality	*Region*	*Habitat type*	*Initial M*	*Initial N*	*Top soil*	*Period of Succession*	*Sampling Interval*	*Type of Observation*	*Method*	*Plot Size*	*Source*
1	Dřínov	NWB	acidic emergent bottom[1]	7.45	5.42	+	9 yrs	1 year	PT	PQ, Rel	5 × 5	Frantík, Osbornová, Prach
2	Dřínov	NWB	emergent bottom[1]	7.97	5.70	+	10	1 year	PT	PQ, Rel	5 × 5	Frantík, Osbornová, Prach
3	Nový rybník fishpond	SB	peaty barrier[2]	8.83	4.95	+	10	1 year	PT, PP	PQ, Rel	5 × 5	Prach
4	Nový rybník fishpond	SB	sandy barrier[2]	7.00	3.16	−	10	1 year	PT, PP	PQ, Rel	5 × 5	Prach
5	Krušné hory Mts.	NB	bulldozed plots[3]	6.11	2.68	−	15	1, 4, 5, 15	I	Rel	5 × 5	Pyšek 1992
6	Krušné hory Mts.	NB	mounds[3]	6.27	3.77	+	15	1, 4, 5, 15	I	Rel	5 × 5	Pyšek 1992
7	Halámky	SB	abandoned sand pit	4.06	5.04	−	18	2, 6, 12, 18	I	Rel	5 × 5	
8	Plzeň	WB	urban sites-poor[4,5]	4.56	6.60	+	12	1 year	PP, I	Rel	v	Pyšek 1977
9	Plzeň	WB	urban sites–moderate[4,5]	4.57	7.40	+	12	1 year	PP, I	Rel	v	Pyšek 1977
10	Plzeň	WB	urban sites–rich[4,5]	5.14	7.44	+	12	1 year	PP, I	Rel	v	Pyšek 1977
11	Bohemian Karst	CB	abandoned oldfields—xeric	4.71	6.55	+	67	1, 4, 6, 8, 13, 32, 55, 67	I	PQ, Rel	5 × 5	Osbornová et al. 1989
12	Bohemian Karst	CB	abandoned oldfields—mesic	5.69	6.51	+	47	1, 2, 15, 28, 36, 47	PP, I	PQ, Rel	5 × 5	Osbornová et al. 1989
13	Bohemian Karst	CB	abandoned oldfields—wet	7.02	6.61	+	13	1, 2, 4, 5, 13	PP, I	Rel	5 × 5	Osbornová et al. 1989
14	Most	NB	spoil heaps I[6]	4.75	5.95	−	37	± 1 year	PP, I	Rel	1 × 1, 5 × 5	Prach 1987
15	Vissonta	H	spoil heaps II[7]	5.03	5.45	−	20	1–10, 16–20	PP, I	Rel	1 × 1	Bartha 1990

Note: CB, central Bohemia; NB, northern Bohemia; SB, south Bohemia; WB, western Bohemia; NH, northern Hungary. Soil conditions are characterized by Ellenberg indicator values (Ellenberg et al. 1991) calculated on the basis of species covers; mean value for the first 5 years was used to express the initial situation in a given sere. M, moisture; N, nitrogen. Presence (+) or absence (−) of organic top soil is indicated. Sampling years are given for those seres in which the annual sampling was not carried out. PP, permanent plots; PT, permanent transect; I, course of succession was inferred from comparison of differently aged sites. PQ, point quadrat; Rel, relevé method (v, various plot size).

[1] Exposed muddy bottom of a water reservoir, altitude 260 m. a.s.l.; sulphur accumulation and its subsequent oxidation caused a decrease in pH value in sere 1 during the first years of succession.

[2] Recently (1983) constructed pond about 1 ha in the size at 430 m. a.s.l.; barriers of allochtonous material (3—peat, 4—sand) surrounding the pond were studied.

[3] Reclaimed plots were created by bulldozing away the upper humus soil layer to make spruce replanting in areas deforested by air pollution easier; mounds were built by accumulating the material removed from plots.

[4] Succession in urban habitats of the town of Plzeň (175,000 inhabitants, altitude 300 m. a.s.l.) was inferred from series of permanent plots (each 6 years of duration) starting at different successional age (poor: 1,10; moderate: 2,11; rich: 3,12 in Pyšek 1977).

[5] Visually assessed; no soil analyses were carried out prior to the study.

[6] Spoil heaps after brown coal mining at the altitude of 250–270 m. a.s.l., built predominantly by uniform tertiary gray clay.

[7] Spoil heaps after brown coal mining located in drier climatic district; two differently aged sites were sampled annually.

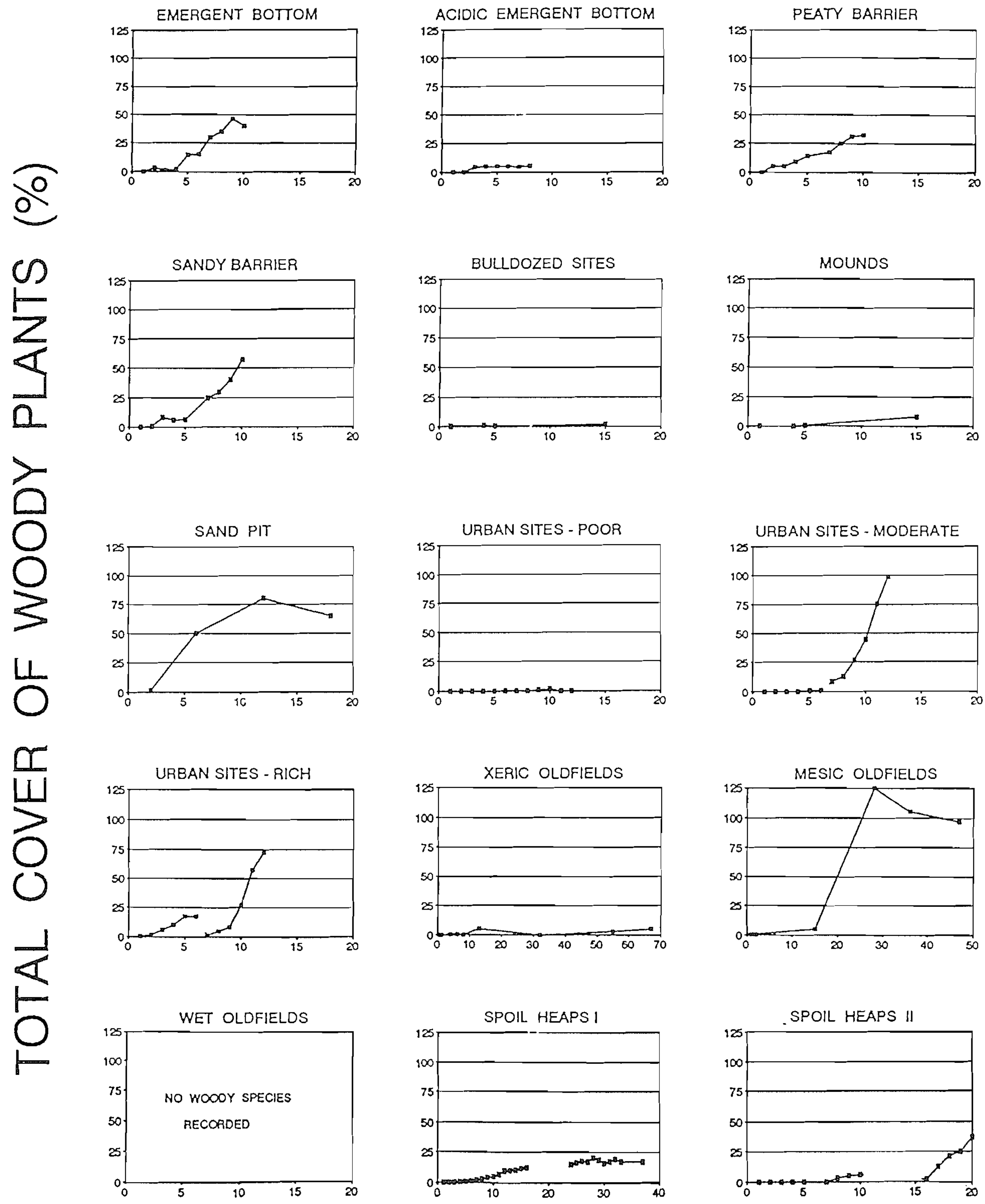

Figure 1. Changes in total cover of woody plants (expressed as sum of covers of all woody species present in a given sampling year) in the seres investigated. Direct comparison between seres is possible because the same scale used on the Y axis. A time scale of 20 years was used in all seres but those for which long-term data were available (11, 12, 14). The seres compiled from repeated recordings of differently aged permanent plots are indicated by the break. Sites 1–15 are shown from left to right; Emergent Bottom, Site 1; Spoil Heap II, Site 15.

ronmental conditions, both measures were related to Ellenberg indicator values characterizing initial moisture and nitrogen level.

Results

Differences among Seres in the Performance of Woody Species. The development of cover of woody plants in all seres investigated is presented in Figure 1. The performance of woody plants varied greatly among the seres. The woody plants were less successful in extremely nutrient-poor sites (bulldozed plots, mounds), the acid site (acidic emergent bottom), and both xeric and excessively wet oldfields. Low woody plant cover was also recorded in spoil heaps that represent other relatively dry and harsh environments. On the other hand, establishment of shrubs and trees was successful in some seres under moderate environmental conditions (mesic oldfields, moderate and nutrient-rich urban habitats). However, the relationship, between total cover of woody plants after 10 years of succession, soil moisture, and nitrogen did not exhibit any interpretable pattern (Fig. 2*a*). The arrival of woody plants was delayed in some drier sites but did not show any clear response to nitrogen (Fig. 2*b*). Surprisingly, the relationship between the total cover of woody species after 10 years of succession and the year of their arrival in a given sere was not significant ($r = -0.33$, $F_{1,12} = 1.48$, $p = 0.24$).

When the effect of the presence or absence of organic topsoil on the performance of woody plants of succession was analyzed, the seres investigated differed neither in total cover of woody species reached after 10 years (Kruskall-Wallis test, $H = 0.05$, $p = 0.46$) nor in the year of the first occurrence ($H = 0.00$, $p = 1.00$). Total cover in seres with organic topsoil present

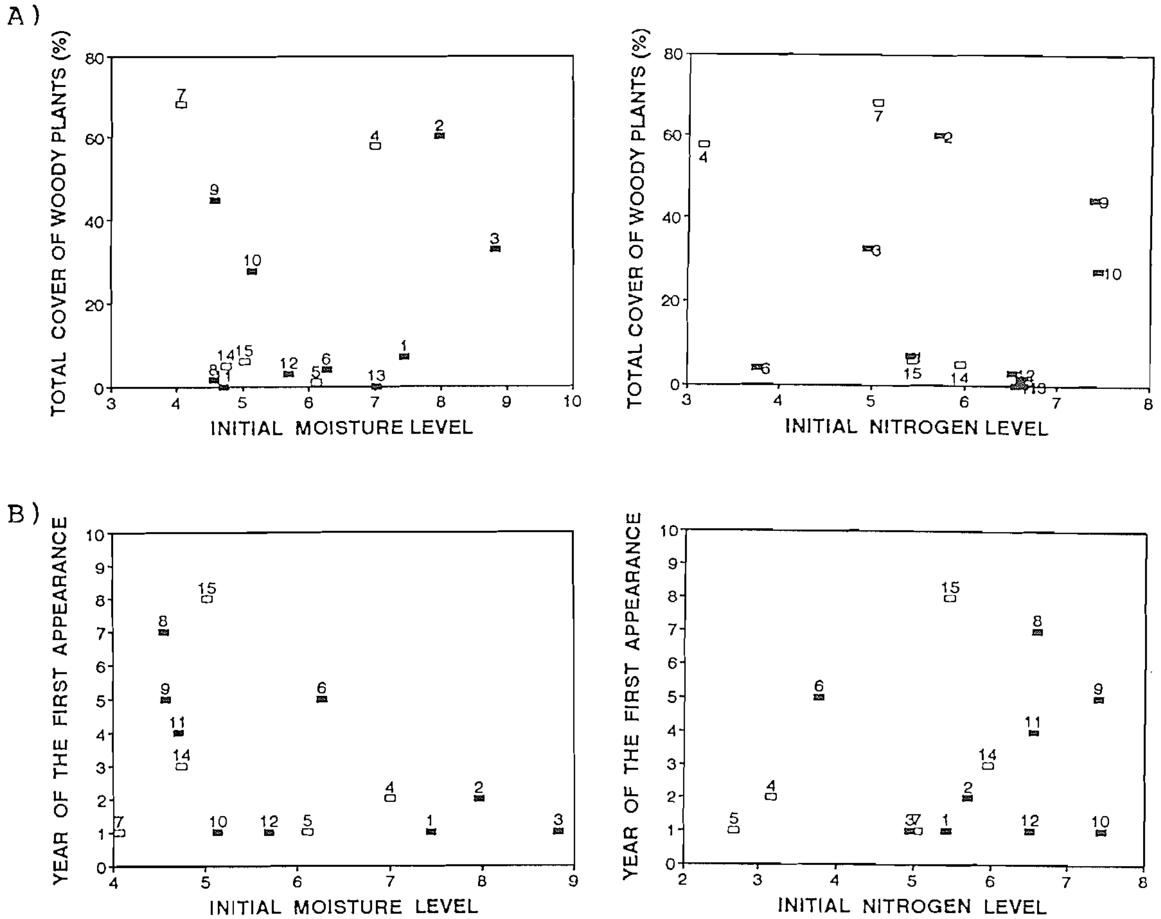

Figure 2. Performance of woody plants after 10 years of succession related to initial soil conditions. (a) Total cover of woody plants (sum of cover values for all woody plants present). (b) Year of the first appearance expressed as the year of arrival of the first woody species to a given sere. Soil conditions were expressed using Ellenberg indicator values (Ellenberg et al. 1991, see Methods for details). Numbers of seres correspond to those used in Table 1. The seres with topsoil present at the beginning of succession (filled square) are distinguished from those with topsoil absent (empty square). All relationships shown were not significant (Kendall correlation coefficient, $n = 15$).

was 18.0 ± 6.9 (mean ± S.E., n = 10) and in those without it 27.5 ± 4.5 (n = 5). The mean year of the first occurrence of woody species was the same regardless of the type of succession (3.0 ± 0.76 for topsoil present and 3.0 ± 1.3 for topsoil absent).

Performance of Particular Species. In total, 24 species of woody plants (10 shrubs and 14 trees) appeared in the seres investigated, and 18 of them (10 shrubs and 8 trees) reached a cover of at least 5% in at least one sere (Table 2). The highest woody species richness (expressed as the number of species recorded) was found in mesic oldfields (9 species) and in moderately rich urban sites (6 species), where several species were dominant. On the other hand, no woody species appeared in wet oldfields, and only one occurred in both types of emergent bottoms and in nutrient-poor urban sites. But the total species number recorded can serve only as a rough measure of the diversity of woody plants due to the differences in sampling techniques used by original authors (transect versus relevé methods).

In general, *Betula pendula* is the most successful woody species in manmade habitats in the area under study, regardless of the presence or absence of topsoil (Table 2). It occurred in 9 of 15 seres, and in 3 of these reached a cover of at least 10%.

Analysis of woody species performance, expressed in terms of maximum cover and the number of seres in which the species occurred (Table 2) with respect to the traits of particular species, did not reveal any significant effects related to life strategy, type of mycorrhizae, mode of dispersal, or diaspore weight. The only marginally significant relationship was with the regeneration strategy (Grime et al. 1988) on the total cover (ANOVA, $F_{1,22}$ = 3.32, p = 0.08). Species with seasonal regeneration by seeds were capable of producing a higher cover than those not possessing this mode of regeneration (mean ± S.E. = 31.7 ± 10.2, n = 11, and 12.9 ± 3.8, n = 13, respectively).

Discussion

Although the ability to predict woody species establishment using estimated initial soil conditions appears to be too weak to provide unequivocal results, some trends are obvious.

Table 2. Overview of woody species occurring during succession in habitats studied.[1]

	Organic Topsoil Present										*Organic Topsoil Absent*					*Total Number of Records*	*Maximum Cover*
Sere	*1*	*2*	*3*	*6*	*8*	*9*	*10*	*11*	*12*	*13*	*4*	*5*	*7*	*14*	*15*		
Acer campestre									15.0							1	15.0
Acer pseudoplatanus						7.5								1.0		2	7.5
Alnus glutinosa			15.0													1	15.0
Betula pendula	5.0	46.0	5.0	8.0		7.5					40.0	1.5	10.0	5.0		9	46.0
Crataegus sp. div.								2.5	98.0							2	98.0
Eleagnus angustifolia															4.5	1	4.5
Frangula alnus			15.0								2.5					2	15.0
Fraxinus excelsior									15.0					1.0		2	15.0
Pinus sylvestris			5.0								10.0		70.0			3	70.0
Populus alba															15.5	1	15.5
Populus tremula					1.5	7.5										2	7.5
Prunus spinosa									50.0							1	50.0
Quercus petraea									0.1							1	0.1
Robinia pseudoacacia															17.0	1	17.0
Rosa canina								2.5	10.0							2	10.0
Rubus caesius						1.3	3.8		0.1			0.2			6.0	5	6.0
Rubus fruticosus								2.5						8.5		2	8.5
Rubus idaeus				7.2								0.1				2	7.2
Salix caprea						37.5						1.5	5.0			3	37.5
Salix cinerea											2.5					1	2.5
Salix fragilis												0.1				1	0.1
Sambucus nigra						38.8	68.8		10.0					8.0		4	68.8
Sorbus aucuparia				0.1												1	0.1
Swida (Cornus) sanguinea									0.1							1	0.1

[1]The occurrence is shown separately for seres with organic topsoil present at the onset of succession and for those starting without it. Maximum cover reached by a species is given for each sere (numbers of seres correspond to those used in Table 1). Total number of seres in which the species was recorded and the maximum cover it reached in any sere are given in the last two columns.

The results indicate that low initial soil moisture often retards subsequent growth of woody plants. But low soil moisture in itself need not automatically prevent successful establishment. If low moisture is combined with a low nutrient level, however, lower performance of woody plants is highly probable. An extremely low nutrient level by itself seems to have a similar effect.

The successful establishment of woody plants can also be retarded in sites with a compact herb layer formed immediately after the onset of plant establishment there, resulting in a high competitive pressure; this may be hypothesized as happening in wet and nutrient-rich abandoned fields (Osbornová et al. 1989). The clear, positive relationship between soil nitrogen content and cover of woody plants, as reported by Inouye et al. (1987) and Tilman (1988), was not confirmed in this study. Poor establishment of woody species has been reported from very dry and very nutrient-poor or toxic substrate (Banásová 1976).

Traditionally emphasized differences between primary and secondary succession, (Glenn-Lewin et al. 1992) were not evident in our study. The distribution between these two kinds of succession seems to be less relevant than suggested. Instead of adopting the usual terms "primary" and "secondary" succession, we classified the seres investigated into two categories based on the presence or absence of organic topsoil regardless of its origin.

Only the influence of soil moisture and nitrogen level were taken into account in the present study (for the discussion on using Ellenberg indicator values, see, for example, ter Braak & Gremmen 1989). The relationship between the establishment of woody plants and soil conditions turned out to be nonsignificant, apparently due to high variation among seres and other factors, especially (1) availability of diaspore sources in the surrounding landscape, (2) intensity of dispersal agents, (3) activities of animals and unintentional human activities, and (4) timing of the onset of succession (Olsson 1987; Skoglund and Verwijst 1989; Sukopp et al. 1990; De Steven 1991). The role of chance factors must also be taken into account (Christensen and Peet 1984). Considering all these possible effects, it is not surprising that the relationship of woody plant performance to initial soil conditions is rather vague, and their establishment generally exhibits a great deal of variation, even within one type of succession in the same region (Osbornová et al. 1989; Prach 1994). These factors are extremely difficult to quantify, however, although it is necessary to do so if their relative importance in the course of succession is to be assessed. Such analysis is urgently needed for a higher number of seres to contribute to our understanding of successional mechanisms, and to provide us with a theoretical basis for more-precise restoration and management of derelict sites.

The high variation in the performance of woody plants corresponds with the relatively low importance of species traits influencing their successional behaviour, as shown above. The only exception—species with seasonal regeneration by seed being more successful—is in accordance with theoretical expectations (Grime 1979).

Remarks on Reclamation Practices

As indicated in this study, we can make use of the spontaneous succession of woody plants, particularly in reclamation of moderate sites (in terms of soil conditions), where trees and shrubs are neither limited physiologically nor by competition from herbs. Among the woody species that attained the cover of at least 5% (18) in any sere (Table 2), there are eight trees. Five of these are already being used for artificial afforestation in central Europe, mainly in the reclamation of sites disturbed by large-scale mining (Štýs 1981): *Acer pseudoplanus* (Sycamore maple), *Alnus glutinosa* (black alder), *Fraxinus excelsior* (European ash), *Pinus sylvestris* (Scots pine), and *Quercus petraea* (dûrmast oak). Only *P. sylvestris* is regularly used for timber production and, in addition, is an important component of the mature "climax" forests in the area. However, timber production is not usually the main goal of restoration efforts in derelict sites. Consequently, the establishment of other tree and shrub species listed in Table 2, with the exception of the alien *Robinia pseudoacacia* (black locust), can be desirable for enhancing biotic diversity.

Betula pendula takes a prominent position among species establishing spontaneously in derelict sites. Despite its rapid growth and the wide range of environmental conditions under which it is able to thrive (Ellenberg 1988), it is still not considered a valuable amelioration species, except for occasional sowing in areas deforested due to air pollution.

Regarding the real situation in central Europe, spontaneous succession can be recommended especially in small disturbed sites without any special interest, and in most large-scale disturbed sites where artificial restoration is difficult due to financial and technical constraints. In some particular cases, spontaneous succession could be directed by inexpensive interventions.

Sites Disturbed by Mining (seres 7, 14 and 15 as examples). The results of the present study and those of published papers (Banásová 1976; Wolf 1985; Szegi et al. 1988) show that the low soil moisture and fertility of many spoil heaps can limit spontaneous establishment of woody plants. Usually, the smaller the disturbed area, the easier its colonization by woody species, if there are seed sources nearby. On large spoil heaps, the artificial planting of woody species is especially desirable on marginal slopes to prevent erosion and create visual barriers. The interior can often be left completely for spontaneous succession, thus creating a base for future use of the site for amenity purposes and providing retreating species with refugia. Similar basic successional trends have been repeatedly recognized in large spoil heaps from brown coal mining throughout central Europe, despite large local variance (Wolf 1985; Prach 1987; Pyšek & Pyšek 1988; Szegi et al. 1988). Unless there are some unusual limitations, such as toxic substrata, the establishment of woody species may be expected to occur before the twentieth year of succession (Wolf 1985; Prach 1987; Bartha 1990; this study). *Betula pendula* is the most common colonizer in this type of habitat (see also Pyšek & Pyšek 1988). Vegetation development can be directed and sped up by artificial sowing and/or nonstandard replanting (Prach 1992). Unfortunately, these practices are still not generally practiced.

The easiest establishment of trees was observed in sites disturbed by sand and gravel extraction (sere 7). These sites were invaded and subsequently dominated by *Pinus sylvestris*. Sites disturbed by peat extraction are usually also easily colonized by woody plants (Prach, unpublished data). There, spontaneous succession may be recommended as an effective reclamation tool, unless timber production is the main goal.

Reclaimed Sites in Areas Deforested by Air Pollution (seres 5, 6). Deforested areas in central European mountains are extensively invaded by the grass *Calamagrostis villosa* (small-seed grass), whose dense cover makes the replanting of conifers (*Picea abies*, [Norway spruce], *P. pungens* [table mountain pine], *Pinus mugo* [mountain pine]) difficult or even impossible. Removal of the top soil layer containing rhizomes of *C. villosa* was carried out, and these plots were then used for planting of spruce saplings. As no special management or effective protection were given to the planted trees, the sites were exposed to natural vegetation development. Some of these sites provide us with a direct comparison of artificial plantings and directed succession. In sites where aerial sowing of *Betula* seeds was applied, successful establishment of this species was observed, whereas planted spruce saplings generally did not grow well due to persistent air pollution and competition from grasses and herbs colonizing the newly exposed areas (Pyšek 1992). In these habitats, SO_2 air pollution is a special factor that makes the choice of suitable woody species extremely important; species resistant to air pollution are selected naturally in the course of succession. Besides *Betula pendula*, listed in Table 2, *Sorbus aucuparia* (European mountain ash), *Alnus glutinosa*, and *Salix caprea* (goat willow) were observed to be successful colonizers in the deforested areas.

Urban Sites (seres 8, 9, 10). In urban sites, succession greatly varies depending on a habitat type, such as ruins, rubbish tips, abandoned railway areas, industrial wasteland (Prach et al. 1993*b*). Most of the sites are of moderate to rich fertility, so the establishment of woody plants is rather fast and often results in formation of a dense cover. *Salix caprea* and *Sambucus nigra* (European elder) are the most common colonizers of derelict sites in central European settlements (Sukopp et al. 1990; Pyšek & Pyšek 1991). But the presence of woody plants in urban sites can also have negative consequences. A high representation of exotic, often invasive aliens (Sukopp et al. 1990, Pyšek & Pyšek 1991) is a distinguishing and undesirable feature. In addition, some species are responsible for pollen allergy (Kopecký 1993).

Spontaneous woods on derelict land in settlements may be used as a basis for artificial improvement; selective cutting and planting can be adopted as measures for improving the quality of a site. Spontaneously established shrubs and trees increase habitat diversity and make a more natural vegetation part of urban greenery.

Abandoned Fields (seres 11, 12, 13). In abandoned fields, great differences in the course of succession occur among sites and from region to region. Generally, the spontaneous establishment of woody plants has been reported to be more successful in moderately wet and fertile sites than in dry sites or wet sites of high fertility (Prach 1985; Osbornová et al. 1989). Long-term prevention of woody plant establishment due to strong herb competitors has been observed (Olsson 1987; sere 13 in this study).

Abandoned fields covered by a spontaneously formed shrub and tree layer can increase the structural diversity of the landscape and, especially in the agricultural regions of central Europe, form buffer zones against various pollutants and serve as important refugia and biocorridors. Locally, they can create visual barriers around various disturbed sites, such as quarries (Rambousková 1989). Artificial afforestation for timber production is recommended after large-scale abandonment of arable land if no "reserved" fields are intended (Jukola-Sulonen 1983). Conversion to meadows or pastures is another possible use of these habitat types. At present, under the changing economies in the countries of the former eastern block, the abandonment of arable land is becoming an urgent problem.

Other seres considered in the present study represent exceptional examples (emergent bottom, barrier surrounding the pond). No particular reclamation procedures are usually necessary, and these sites can be allowed to regenerate naturally.

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