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Forest planting as a way of species dispersal

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Abstract

Fortuitous introductions of plant species with forestry planting material used in areas deforested by air pollution were studied in the Krušné hory Mountains, Czech Republic. The number and abundance of species of higher plants accompanying spruce saplings were recorded at three stages of the afforestation process: (1) before planting; (2) after planting; (3) after the first growing season. The reduction in the number of species and individuals during these stages of afforestation process was monitored. In total, 39 species were brought into the site with pre-grown saplings and 14 (36%) became successfully established; the corresponding figures for the total number of individuals were 524 (i.e. 1.024 per sapling) and 56 (i.e. 10.7% of the original number), respectively. In terms of the number of species, the planting procedure itself accounted for 72% of total losses, whereas the remaining 28% died during the first year of growth on the site. In terms of the mortality of individuals, the corresponding figures were 90% and 10%. Annuals were reduced to a greater extent than perennials. *Epilobium adenocaulon* and *Betula pendula* were the most successful species in terms of the size of established population. Eight species previously not reported from the area under study were found accompanying the transported saplings. The importance of introductions for the ruderalisation of forest sites is discussed. Considering the extent (millions of saplings being planted each year) and duration (two centuries in Europe) of afforestation efforts, it is suggested that this form of dispersal has caused an important enrichment to the local flora.

Keywords: Afforestation; Dispersal; Establishment; Population reduction; Weeds

1. Introduction

In recent decades, the death of trees caused by acid rain has been a disaster in central European mountain forests (Krause, 1989; Fuhrer, 1990). Vast areas previously covered by Norway spruce are being transformed into spots colonized by aggressive grasses, which were present in the understorey of the original spruce forests and have increased their abundance remarkably after the extraction of dead timber (see, e.g. Pyšek, 1992). Large-scale afforestation procedures carried out in affected areas may, however, act as an important means of introducing other plant species, which are being transported with tree saplings. Surprisingly, the arrival of new species accompanying the forestry planting material has not received much attention so far; no studies are known dealing with the efficiency of this kind of dispersal, and the phenomenon is not even mentioned in recent

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books on forest ecology (e.g. Packham et al., 1992; Watkins, 1993).

The aim of the present study was (1) to provide a quantitative insight into the extent of fortuitous plant introductions associated with afforestation procedures, and (2) to estimate the chance of species introduced in this way becoming established on the planting site.

2. Study site

The study was conducted in the south-western part of the Krušné hory Mountains, Czech Republic (latitude 50°23′, longitude 12°38′), a part of the crystalline complex formed by meta-igneous and sedimentary rocks. The area has a cold climate with a mean annual temperature of 4.5°C and an annual precipitation of about 1100 mm (Böer and Vesecký, 1975).

The study site was located in an area where trees were badly affected by acid rain, at an altitude of 930 m above sea level (a.s.l.). Dense grass cover in the locality under study was removed by bulldozing in 1987 to make the replanting of forest trees easier (Pyšek, 1992); since then it has been colonized by herbaceous species, among which the grasses (*Calamagrostis villosa*, *Deschampsia flexuosa*) are dominant. The substratum consists of coarse sand and fine gravel, originating from the disintegration of the granite bedrock; it is extremely poor in nutrients, with a pH of about 4.5 (O. Rauch, personal communication, 1994).

Saplings of *Picea abies* (Norway spruce) with a proportion (ca. 20%) of *Picea pungens* (Colorado spruce), chosen for the reforestation of the area, were grown in a nursery located 8 km away at an altitude of 780 m a.s.l. In June 1992, at the age of 4–5 years, the saplings were lifted and transported to the study site. For transport, the root system of each sapling was covered by plastic wrapping about 10 cm in diameter, open at both sides. The soil used for packing the saplings for transport was taken from the foothills of the Krušné hory mountain range, 20 km distant from the study site, at an altitude of 430 m a.s.l. The saplings were transported to the study site in plastic containers (10 in each); some were planted in August 1992 and some were left in the containers until September 1992. All these procedures were conducted by the State Forest Agency prior to our study.

3. Methods

To obtain an insight into the changes in populations of species accompanying the saplings, sampling was carried out at three stages of the afforestation process (this term, for the purposes of this paper, is used for the period between the transport of saplings to the site and the end of the first growing season after planting).

(1) In August 1992, 500 spruce saplings prepared for planting were randomly selected and the number of individuals of each accompanying species of higher plants were recorded. This data set is hereafter referred to as the 'transport' stage.

Table 1
Plant introductions with spruce saplings to the study area

	T	*P/T*	*P*	*E/P*	*E*	*E/T*
Number of species in the sample	39	0.538	21	0.667	14	0.359
Annuals	20	0.550	11	0.364	4	0.200
Perennials	19	0.526	10	1.000	10	0.526
Number of species per sapling	0.078		0.042		0.028	
Total number of individuals	524	0.181	95	0.589	56	0.107
Annuals	182	0.132	24	0.250	6	0.032
Perennials	342	0.208	71	0.704	50	0.146
Individuals per sapling	1.048		0.190		0.112	

Figures are shown for particular stages of the afforestation process: *T*, after the transport of tree saplings to the site (transport stage); *P*, after planting (planted stage); *E*, established after the 1st year of growth (established stage). Sample size = 500 spruce saplings.

(2) At the same time, another 500 saplings which were already planted at the study site were randomly selected and sampled in the same way (termed the 'planted' stage). Saplings were planted with the plastic wrapping in which they were transported so it was possible to distinguish plants introduced with saplings from those emerging from the surrounding disturbed spot.

(3) A year later, in August 1993, 500 spruce saplings growing on the study site were again randomly selected and the number of accompanying individuals were recorded by species (this data set is termed the 'established' stage). Only plants rooting inside the area delimited by the plastic wrappings were considered. Plants that had obviously penetrated from the surroundings (usually a vigorous nearby population was taken as an indication) were not considered.

The data set made it possible to express the loss in the number of species and individuals between particular stages of the afforestation process. The change in the population size of a particular species, however, does not represent its rate of survival as we used a different set of saplings for each sampling and hence did not follow the fate of individual plants over time. Direct comparison of the 'planted' and 'established' stages is further biased by the fact that some plants may have emerged from the soil seed bank during the first year of growth. However, such cases also represent an introduction with forestry planting material, so they must also be viewed as a consequence of the afforestation procedure.

Nomenclature of plant species follows Rothmaler (1987).

Table 2
List of species introduced to the locality with tree saplings. Only those species with at least ten individuals are shown

Species	N_T	N_P/N_T	N_P	N_E/N_P	N_E	N_E/N_T
Epilobium adenocaulon	125	0.416	52	0.462	24	0.192
Betula pendula	95	0.126	12	0.833	10	0.105
Juncus effusus	39	0.051	2	1.000	2	0.051
Viola arvensis	34	0.059	2	0.000	0	0.000
Conyza canadensis *	31	0.000	0	–	0	0.000
Polygonum lapathifolium	24	0.333	8	0.125	1	0.042
Poa annua	22	0.273	6	0.500	3	0.136
Polygonum hydropiper *	17	0.235	4	0.000	0	0.000
Lycopus europaeus *	17	0.000	0	–	1	0.059
Sagina procumbens	14	0.000	0	–	2	0.143
Juncus bufonius	13	0.000	0	–	0	0.000
Spergularia rubra	12	0.000	0	–	0	0.000
Carex spp.	12	0.167	2	0.000	0	0.000
Rorippa palustris	10	0.100	1	1.000	1	0.100

Sample size = 500 spruce saplings. N_T, number of individuals present after the transport of spruce saplings into the area (transport stage); N_P, number of individuals recorded after the planting procedure was carried out (planted stage); N_E, number of individuals established after the first year of growth (established stage). Population changes between the particular stages of the planting process are also shown. Species not previously recorded in the area under study are marked with asterisks.

Species with fewer than 10 individuals present at the transport stage (those recorded at the establishment stage are marked +): *Ajuga genevensis, Atriplex prostrata* *, *Calamagrostis villosa* +, *Capsella bursa-pastoris, Cerastium holosteoides* +, *Chamomilla suaveolens, Chenopodium album, C. rubrum* *, *Echinochloa crus-galli* *, *Epilobium angustifolium* +, *Gnaphalium sylvaticum, G. uliginosum, Hypericum perforatum, Matricaria maritima* +, *Plantago major, Polygonum aviculare* s.l., *Rumex acetosella* +, *Salix* spp. +, *Senecio vulgaris, Stellaria longifolia* *, *S. media, S. uliginosa* *, *Tussilago farfara, Urtica dioica, Veronica arvensis*.

4. Results

In total, 39 species of higher plants were introduced to the locality with the spruce saplings sampled, and 14 (36%) became established by the end of the first growing season (Table 1). Of the total reduction in the number of species between the 'transport' and 'established' stages, 72% were accounted for by the planting procedure itself and 28% by elimination during the subsequent growing period. Both annuals and perennials were equally reduced in terms of number of species by the planting procedure itself. However, perennial species all survived the following year whilst the number of annual species was reduced by 64.6% (Table 1).

Of the species introduced to the locality, eight had not previously been reported from the area, i.e. the Rolava River catchment of about 40 km^2 (Table 2). Only one species (*Lycopus europaeus*) new to the area has become successfully established.

In total, 524 individuals accompanied the spruce saplings when they were transported to the study site (i.e. 1.024 per 1 spruce sapling). By the end of the first growing season, 56 (10.7% of the initial number) successfully established individuals were found. Planting caused 91.6% of the reduction in the number of individuals between the 'transport' and 'established' stages, whereas 8.4% were accounted for by losses during the first season of growth.

At the beginning of the afforestation process, the proportion of individuals of perennial species (65.3%) was approximately double that of annuals (34.7%). The loss in the number of individuals due to the planting procedure was similar for both groups (Table 1). However, after the first year of growth, the number of successfully established individuals of perennial species reached 70.4% of those that had survived the planting procedure, whereas the corresponding figure for annuals was only 25.0%. Consequently, population reduction during the whole afforestation process was almost five times higher for annuals than for perennials (Table 1). After the first year of growth, there were only six individuals (10.7% of those that survived planting) of annual species established in the whole sample, compared to 50 (89.3%) of perennials (Table 1).

The extent of population reduction differed remarkably between species (Table 2). In the majority of species, the planting itself eliminated most individuals (Fig. 1). *Epilobium adenocaulon* and *Betula pendula* were the only species with more than three individuals established by the end of the first growing season. The population size of the former species was reduced remarkably both by planting and during the first year of growth, whereas losses in the latter were mainly due to the planting only (Fig. 1).

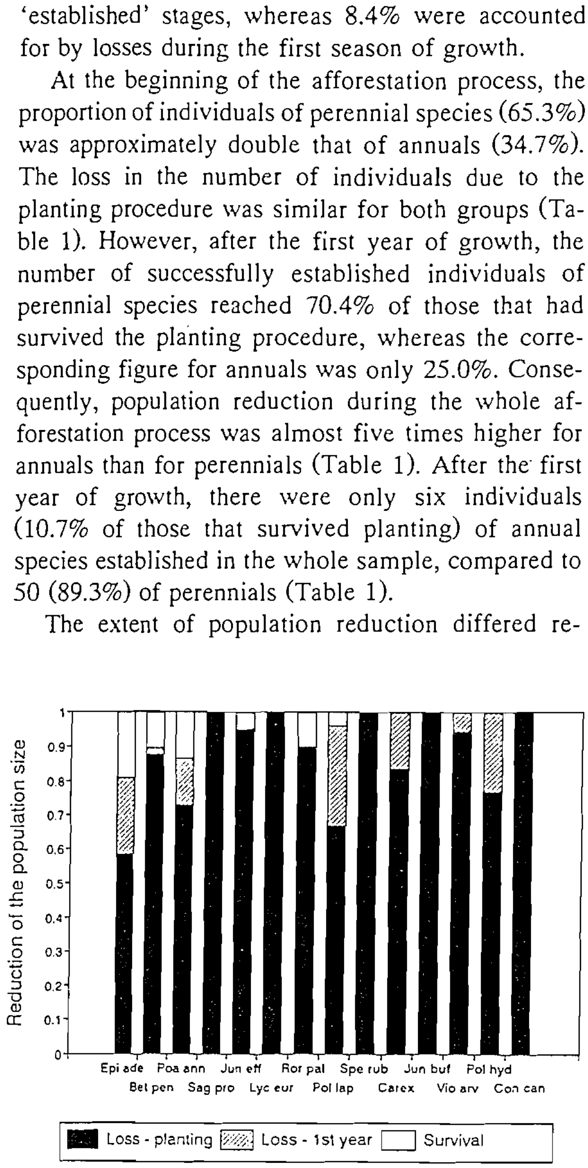

Fig. 1. Population reduction during the three steps of afforestation considered. Only species whose abundances at the transport stage were at least ten individuals are displayed. The proportion of losses accounted for (a) by planting procedure, and (b) during the first year of growth are shown. Species are ranked according to the abundance of individuals established after the first year of growth (see Table 2 for values). The first three letters of species names listed in Table 2 are used as abbreviations.

5. Discussion

Although there was a remarkable reduction in the number of individuals during the afforestation process and resulting absolute numbers of established individuals are rather low, introductions with forestry planting material can certainly play an important role. This is apparent especially on a large scale. The forestry agency responsible for the study site has been handling an area of about 260 km^2; in 1992, there were 1.6 million spruce saplings used for afforestation. Provided the estimates given in our study (i.e. 0.112 established individuals per 1 sapling) are representative, there would be 179 200 successfully established individuals of higher plants introduced annually into the area due to the afforestation procedures. The importance of the phenomenon can be highlighted even more if we consider which species are most successful in surviving afforestation: the highest figures would be obtained for *Epilobium adenocaulon* (76 800 plants $year^{-1}$) and *Betula pendula* (32 000). The former is an invasive alien and the latter represents an early successional woody plant, undesirable from the viewpoint of afforestation.

The above figures might seem rather low when expressed in terms of density: the total estimate would be 6.9 successfully established newcomers ha^{-1} $year^{-1}$. However, one must bear in mind that the possibility of establishing a vigorous reproducing population is enhanced after successfully surviving the initial period (Harper, 1977). Those species that manage to do so may act as foci for further spread, which is especially important in the case of invasive aliens (see, e.g. Moody and Mack, 1988).

However, the extent of infestation (in terms of the number of individuals) is not the only important aspect of introductions with forestry planting material. At the species level, the simple fact that a species reaches the area is important, especially if we consider that the reduction in species numbers during the afforestation procedure (mainly due to mechanical damage or intentional removal) is not so severe as is the case for the number of individuals. Further, it should be stressed that rather extreme site conditions were typical of the study area. The low annual temperature, short growing season, extremely low nutrient content and high acidity of the soil were probably responsible for the failure of thermophilous ruderal species that occurred at the transport stage but were eliminated later on (*Atriplex hastata*, *Chenopodium rubrum*, *Conyza canadensis*, *Echinochloa crus-galli*). Under less extreme conditions, the rate of successful establishment would probably be higher in terms of both species numbers and abundance.

The means of dispersal reported in this paper may contribute significantly to the ruderalization of the treated habitats (Kirby, 1988, 1993). Of the total number of species recorded at the transport stage, 21 (54%) are ruderals (sensu Grime et al., 1988) or weeds; five of them survived. However, the phenomenon has not been paid major attention so far. This is surprising, as it represents a striking example of direct unintentional introduction of plant species by man. At present, as ecologists are becoming aware of the global threat imposed by changes in local floras due to the activities of man (see, e.g. Soulé, 1990), we should be extremely cautious of any fortuitous introductions of plants, especially into relatively undisturbed (in terms of the composition of local flora) habitats such as those at higher altitudes. This present paper, being a short-term case study restricted to only one locality, has certainly recorded only a small part of the potential for introductions of plants with forestry planting material. The total variability (viewed at the landscape level) in terms of species pool, abundance and survival rates, associated with this human-induced dispersal vector would undoubtedly be much higher. Nevertheless, the results provide a hint of its importance, which is further stressed if we take into account that this afforestation process has been practiced in Europe for about two centuries.

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References

Böer, W. and Vesecký, A. (Editors), 1975. The climate of the Krušné hory Mountains. Český hydrometeorologický ústav, Praha (in Czech).

Fuhrer, E., 1990. Forest decline in Central Europe. Additional aspects of its cause. For. Ecol. Manage., 37: 249–260.

Grime, J.P., Hodgson, J.G. and Hunt, R., 1988. Comparative Plant Ecology. Unwin Hyman, London.

Harper, J.L., 1977. Population Biology of Plants. Academic Press, London.

Kirby, K.J., 1988. Changes in the ground flora under plantations on ancient woodland sites. Forestry, 61: 317–338.

Kirby, K.J., 1993. The effects of plantation management on wildlife in Great Britain: Lessons from ancient woodland for the development of afforestation sites. In: C. Watkins (Editor), Ecological Effects of Afforestation. Studies in the History and Ecology of Afforestation in Western Europe. C.A.B. International, Wallingford.

Krause, G.H.M., 1989. Forest decline in Central Europe: The unravelling of multiple causes. In: P.J. Grubb and J.B. Whittaker (Editors), Toward a More Exact Ecology. Blackwell, Oxford.

Moody, M.E. and Mack, R.N., 1988. Controlling the spread of plant invasions: The importance of nascent foci. J. Appl. Ecol., 25: 1009–1021.

Packham, J.P., Harding, D.J.L., Hilton, G.M. and Stuttard, R.A., 1992. Functional Ecology of Woodlands and Forests. Chapman and Hall, London. 407 pp.

Pyšek, P., 1992. Dominant species exchange during succession in reclaimed habitats: A case study from areas deforested by air pollution. For. Ecol. Manage., 54: 27–44.

Rothmaler, W., 1987. Exkursionsfora für die Gebiete der DDR und der BRD. Volk und Wissen Volkseigener Verlag, Berlin, 752 pp.

Soulé, M.E., 1990. The onslaught of alien species, and other challenges in the coming decades. Conserv. Biol., 4: 233–239.

Watkins, C. (Editor), 1993. Ecological Effects of Afforestation. Studies in the History and Ecology of Afforestation in Western Europe. C.A.B. International, Wallingford.