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Evaluating the transplantation of a meadow in the Harz Mountains, Germany

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Abstract

The transplantation of 0.4 ha of montane grassland in the Harz Mountains was accompanied by evaluating the achievement of declared objectives for 5 years. The project is unique in central Europe with respect to the transplantation technique employed, size of translocated area and intensity of monitoring. The meadow was transplanted to a nearby location using a bulldozer with a special excavating shovel. The preservation of the flora of the whole transplanted area was successful. Disturbance indicator species appeared only to a negligible degree. Of 18 regionally threatened species present, the majority responded indifferently or positively to the transplantation; only two showed a distinct decline in population size, which was probably not caused by the transplantation alone. The preservation of the species composition of the four vegetation types occurring in the study area after a period of 4 years was also successful with all types reverting toward their pre-transplantation state. In contrast, the maintainance of the spatial vegetation mosaic failed completely. Dissection of previously coherent vegetation types and levelling of the ground surface resulted in an artificial vegetation pattern with predominantly geometric patterns.

Keywords: Efficiency control; Habitat translocation; Monitoring; Montane meadow; Threatened species; Vegetation mosaic; Vegetation mapping

1. Introduction

In recent years, translocations have been increasingly applied to preserve ecosystems which otherwise would have been destroyed by human engineering projects, such as the construction of roads, quarries and buildings. To date, most translocation projects seem to have been performed in Great Britain (see Bullock, 1998 for a survey), but there are also numerous examples in central Europe (Schwickert, 1992).

The common principle of all translocation projects is the transfer of a varying portion of all inhabiting organisms at a site from the original site (the donor site) to the target area (the receiving or receptor site). Depending on the type of habitat, the portion of the whole biocoenosis being transferred differs considerably depending on the technique applied (Bullock, 1998). The simplest method is to excavate the vegetation with the underlying soil, to mix the soil and plants, and then to spread them over the receptor area (e.g. Wathern and Gilbert, 1978; Worthington and Helliwell, 1987). Sometimes small turves were transplanted (of about 0.25 m^2) as nuclei for colonisation of bare soil (Wathern and Gilbert). Both methods involve considerable disturbance of soil structure and vegetation.

In other cases the vegetation is lifted as intact turves and laid out carefully at the receptor site. Generally, only the first few centimetres of the uppermost soil layer are translocated with the turves (Bullock, 1998). Rarely, whole soil profiles to a depth of 0.3–0.5 m have been transplanted, e.g. in the project at Thrislington Plantation, Durham, England (Park, 1989; Cullen and Wheater, 1993) or at Twyford Down, Hampshire, England (Ward, 1995; Ward, Snazell and Rispin, 1996). This method has been called *macroturfing* by Bullock (1998).

An 'efficiency control' procedure has been developed in the last few years to judge the success of a nature conservation project (see Marti and Stutz, 1993, Maas and Pfadenhauer, 1994; Weiss et al., 1995). The objective of efficiency control is to evaluate the effort put into a

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project in relation to the results obtained. Unfortunately, methodological standards are still in the process of development (Weiss et al.). In particular, appropriate standards for setting the objectives have yet to be established. Compared to other conservation projects, transplantations have the advantage that objectives can be derived directly from the *status quo* before the transplantation. In other words, a recent reference in time is available; there is no need to refer to a state long ago or to take a nearby location as a reference in space. If the initial state is assessed precisely, the objectives can be defined with the same precision. In consequence, the degree of success in an efficiency control can also be quantified in detail. Unfortunately, most transplantation projects have the character of 'rescue operations', performed under time pressure and thus do not allow proper assessment of the initial state.

A macroturf translocation project in the Harz Mountains provided exceptionally advantageous conditions for such an efficiency control. The planning started one and a half years before the transplantation was actually performed. Moreover, we had worked with the vegetation types to be transplanted even before the transplantation project was conceived. We specified the aims with respect to the different hierarchical levels of monitoring scale, similar to those suggested by Maas and Pfadenhauer (1994) for botanical efficiency controls: the spatial extent of plant communities, the within-community changes, and the population development of target species.

This paper presents the outcome of the efficiency control beginning in the year before the transplantation in 1992 and continuing 4 years thereafter. Details on the mobility of plant species within the population are given by Bruelheide (1999). Furthermore, alternative transplantation techniques were tested (not presented here).

2. Material and methods

2.1. Study site and soil conditions

In the Harz Mountains, a montane meadow had to give way to a bypass road for the city of Braunlage (600 m a.s.l., Lower Saxony). Planned in the 1950s and approved in 1965 by the Ministry of Transport, the proposed road raised objections from nature conservationists because it was to cut through a plateau covered with meadows rich in species considered threatened in Lower Saxony (Bruelheide, Hehlgans, Bergner and Wegener, 1997). A tunnel was proposed to preserve the mountain's shape and, to further minimize detrimental effects, the Lower Saxony Ecology Office (NLÖ) decreed that the most ecologically valuable parts of the meadows affected by the approach road were to be transplanted to a nearby site.

Altogether, a corridor spanning a length of 260 m and width of 40 m was affected by the construction works. To reduce the transplantation costs only approximately half of this area was transplanted. A suitable receptor site was found in the neighbouring vicinity with bedrock of the same geological substrate (diabase) located about 200 m west of the construction site. At the beginning of this century, this area had been covered with grasslands but had been afforested with spruce (*Picea abies*), a tree not native to this altitude.

Soil conditions were examined both at the donor and the receptor site by the Lower Saxony Soil Analysis Office in 1991. All soil horizons were characterized by a high stone content reaching ca. 80 vol% at a depth of 0.5 m. The soil texture was a silt loam. The colour ranged from yellow ochre to deep brown, depending on humus content, which was ca. 20% in the uppermost layer of meadow soils. The groundwater table was located 3–6 m below the surface; the water had a pH of between 7.5 and 7.7. At the receptor site the spruce needle litter had caused the pH(H_2O) in the topsoil to decrease to about 3.7; whereas the soils of the meadows to be transplanted had a pH(H_2O) of between 5 and 6. Therefore, after clearing the spruce forest, the entire soil profile and parts of the bedrock were removed to a depth of 0.5 m leaving only the bedrock beneath. The removed material was used to cover the new road banks. The bottom of the receptor area was levelled.

In contrast to other meadows in this area which are mown for agricultural yield at the beginning of July, the transplanted meadows were cut with a two-wheeled mower in August. This late date was deliberately set to enhance the seed dispersal of plant species.

2.2. Transplantation technique

A total of 4186 m^2 of meadow was transplanted to the receptor site using a bulldozer with a special front-end excavating shovel that allowed the transfer of pieces of 2.2 m in length, 1.25 m in width and 0.5 m in depth directly to the new target area without having to be reloaded onto another vehicle. A special feature of the shovel was a hydraulic device for pushing the blocks of soil and turf from the flat bottom of the shovel, thus allowing an exact set-down at the receptor site. The excavator's shovel size would have allowed a sod width of up to 1.6 m. However, this was not fully utilized because the scientific plan required a grid size of 5×5 m (see below). The smaller sod width had the additional advantage of minimizing soil loss during transport. The distance to the receptor site was between 300 and 600 m depending on the sod's initial position within the road corridor.

The excavator allowed the exact horizontal adjustment of the sods within the receptor area, but adjustment of sod height proved to be difficult. Since the entire soil profile was transferred to the receptor site, rocks occurring in the subsoil of the corridor caused deviations from the stipulated standard block thickness of 0.5 m. As a result, gaps and small steps between sod stripes were created in the target area, resulting in an uneven microrelief. This effect was enhanced by later settling of soil. In some cases the turf of one piece of sod was submerged beneath the edge of another. All interstitial spaces were manually filled with subsoil. Ultimately, the receptor area showed a striped pattern with broad strips of grass and narrow strips of bare soil.

The tranplantation was performed between the end of May and beginning of July 1993. It would have been more appropriate to do it outside the growing season (compare Cullen and Wheater, 1993; Park, 1989), but this was not possible because of the altitude; in winter the area is covered with snow from November until April.

2.3. Aims and methods

The transplantation's success was judged according to the following objectives.

1. Preservation of the flora in the affected corridor.
2. Preservation of populations of all threatened plant species.
3. Preservation of the species composition of four vegetation types found in the corridor.
4. Preservation of the spatial extent and mosaic of the four vegetation types.

On this basis, the achievement of each goal was studied separately. The methods employed were adapted to the different scales.

1. A species list of all vascular plants present was made before the road work was started (1992) and 4 years thereafter on the scale of the whole corridor and receptor area. Floristic changes with regard to the initial state were shown by calculating similarity indices according to Jaccard (Wildi and Orlóci, 1990). Nomenclature follows Ehrendorfer (1973).
2. A plant species was considered threatened if it was listed in the Red Data Book of Vascular Plants of Lower Saxony (Grave, 1993; Haeupler, Montag, Wöldecke and Garve, 1983). In total the population size of 18 species was monitored within the largest part of the transplanted meadows. Before the start of the road work in 1992, a 5×5 m grid was established and the populations in each cell were investigated. In 1993, 122 grid cells out of a total of 208 were moved from the corridor to the receptor area. The use of fixed magnets at the corners of cells (see Bruelheide, 1995, p. 25) ensured that the transplanted cells encompassed exactly the same plants as before in the corridor (± 5 cm). For comparability, the 1992 results of the corridor were redrawn in the the grid of the receptor site. Population size was recorded by counting individuals (if $n<20$) or by estimation of cover (if $n>20$). To obtain uniform presentation, counts were converted to cover values by multiplying by a fixed, species-specific average cover for one individual (Table 1) and summing up all 122 cells (total area 3050 m^2). In assessing the success of the project, any short-term fluctuations between 1993 and 1995 were neglected. Such changes could have been due to differences in weather conditions or to internal dynamics.
3. Description of vegetation was based on the records of permanent plots annually investigated from 1992 to 1996. In all four vegetation types (see results) permanent plots of 2×2 m were established before the start of the road work in 1992, marked with magnets and the exact location measured within the 5×5 m grid. All permanent plots were transplanted in two parts of 1×2 m each. Species composition refers to phanerogams and mosses. The change in species composition of each vegetation type was evaluated by calculating similarity indices according to van der Maarel (Wildi and Orlóci, 1990): Similarity $= \frac{\sum x \cdot y}{\sum x^2 + \sum y^2 + \sum x \cdot y}$, with x and y being percentage cover of a species in the two relevés compared.
4. The vegetation mosaic was mapped in the corridor in 1992 and in the target area in 1996. The maps were used to calculate the total cover of the vegetation types. The spatial mosaic existing in the corridor was caused by pits with deeper soils alternating with stony mounds on a scale of ca. 1 m.

Table 1
Average cover values used for calculating the total cover of a species from counts

Species	Unit	Covered area (cm^2)
Polygonum bistorta	Leaf	20
Meum athamanticum	Leaf	10
Nardus stricta	Tussock	100
Arnica montana	Rosette	50
Rhinanthus minor	Shoot	3
Lathyrus linifolius	Shoot	5
Viola tricolor	Shoot	3
Cardaminopsis halleri	Tuft	5
Succisa pratensis	Tuft	100
Dianthus deltoides	Shoot	1
Viola palustris	Leaf	5
Lilium martagon	Shoot	50
Ranunuculus platanifolius	Shoot	50
Polygala vulgaris	Tuft	20
Thesium pyrenaicum	Tuft	50
Lychnis flos-cuculi	Rosette	10
Viola canina	Shoot	10
Hieracium aurantiacum	Rosette	20

3. Results

3.1. Total flora

Out of the 62 vascular species found in 1992, three species had vanished by 1996: *Alopecurus pratensis*, *Gnaphalium sylvaticum* and *Lychnis flos-cuculi*. The last of these was also monitored in detail as a threatened species (see below). In contrast, 17 new species were found by 1996. These were mostly pioneer species occurring only at the edges of the target area and almost never within the transplanted sods, e.g. *Digitalis purpurea*, *Juncus effusus* and trees such as *Betula pendula*, *Sorbus aucuparia* and *Salix caprea*. In total, 76 species were recorded in 1996, amounting to an increase of 23% compared to 1992.

Fig. 1 shows the change in total floristic composition with time. The greatest change in similarity with regard to the initial state in 1992 was observed in the first year after transplantation (1993). Since then, similarity seems to have stabilised at ca. 75%.

3.2. Population size of threatened species

The effect of the transplantation on population size can be best demonstrated with a grid map for the most abundant species, i.e. *Polygonum bistorta* (Fig. 2). This species occurred in all of the 122 grid cells and attained cover values of up to 80%. In almost all cells, cover of the species decreased after transplantation between 1992 and 1993. Cells with previously high values showed the largest decrease. By 1994, the species had recovered considerably, and in 1995 and by 1996 the cover was higher than before the transplantation. It is remarkable that the increase was not only recorded in cells with initial high cover values but also in cells with ⩽5% (Fig. 2, middle of the two bottom rows). The spread of *Polygonum* was due to newly created ditches between sod strips (see below, vegetation mapping). However, the pattern of high and low cover values of this species was very similar in 1992 and 1996. Similarly, *Meum athamanticum* and *Nardus stricta* also occurred with

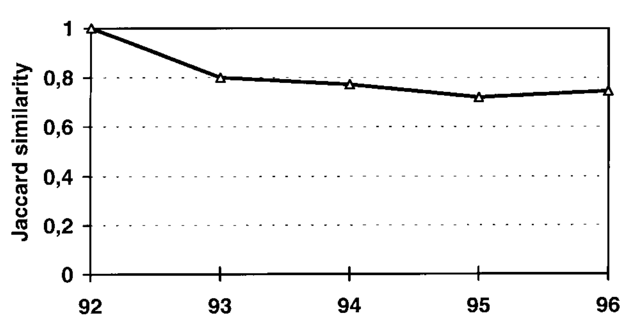

Fig. 1. Similarity of total recorded vascular plant species in the whole area with regard to the year before transplantation (1992), using Jaccard index.

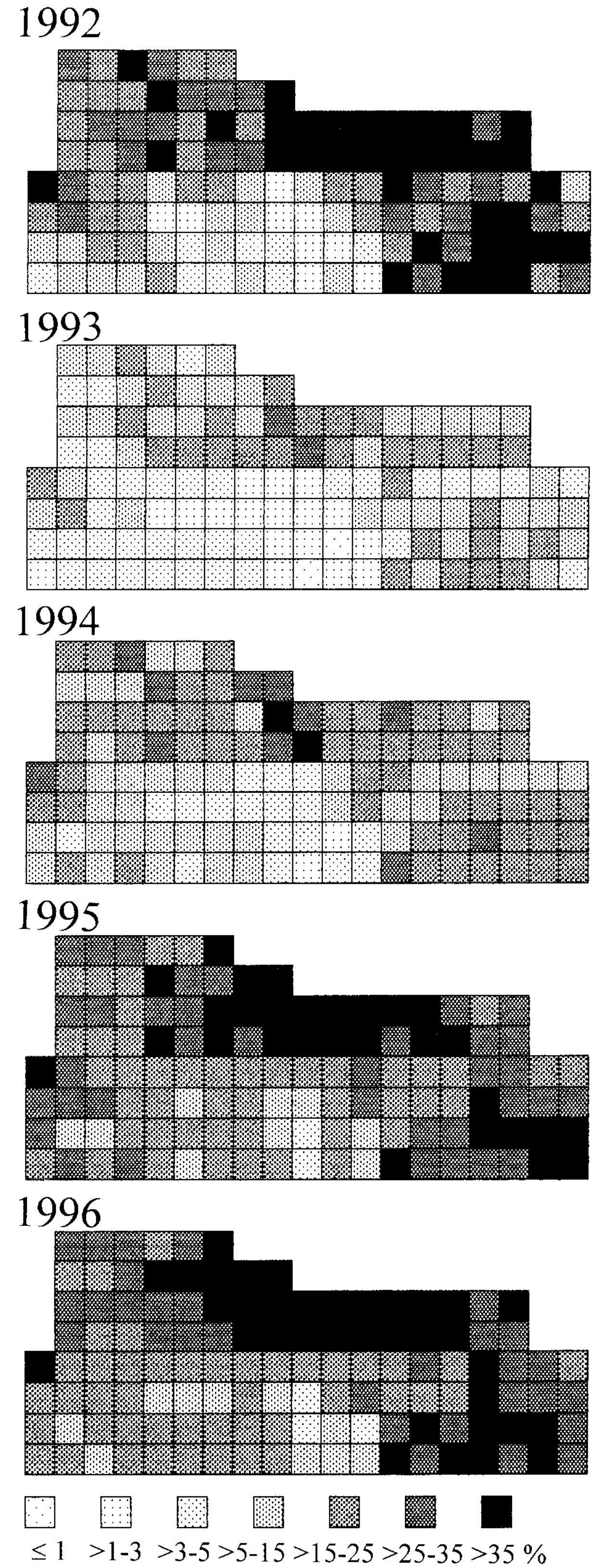

Fig. 2. Cover of *Polygonum bistorta* in all 122 transplanted grid cells from 1992 to 1996. Transplantation was performed before recording in 1993. Observations in 1992 refer to the situation in the road corridor before transplantation and were redrawn to the location of the cells in the target area.

high frequency and also underwent a quantitative decrease immediately after transplantation and a continuous recovery thereafter.

The reaction of some species with intermediate cover is shown in Fig. 3. *Arnica montana* fluctuated by about 20% in relation to 1992 and exhibited no transplantation effect. In contrast, cover of *Rhinanthus minor* and *Viola tricolor* decreased to 21 and 5% of cover in 1992, respectively. A positive effect was encountered for *Lathyrus linifolius* which increased continuously to 221% in relation to 1992.

Among those species that had low total cover, a negative reaction was found for *Viola palustris* (Fig. 4), *Thesium pyrenaicum* and *Lychnis flos-cuculi*. This last species occurred in only two cells in 1992 and had disappeared completely by 1995. A positive response similar to that for *Lathyrus linifolius* (Fig. 3) was also found for *Lilium martagon*, *Succisa pratensis* and *Ranunculus platanifolius* (Fig. 4). Another positive aspect were new occurrences of *Viola canina* and *Hieracium aurantiacum*, which appeared for the first time in 1995.

All other rare species either did not respond to the transplantation or fluctuated in some years in a positive or negative direction, while attaining cover values approximately equal to the 1992 values by 1996, namely *Cardaminopsis halleri*, *Dianthus deltoides* (Fig. 4), and *Polygala vulgaris*.

Table 2 gives a summary of the general trends by listing the frequencies of all species during the study period and the increase or decrease between 1992 and 1996. Nine species increased in cell number with *Lathyrus linifolius* being the species with the largest

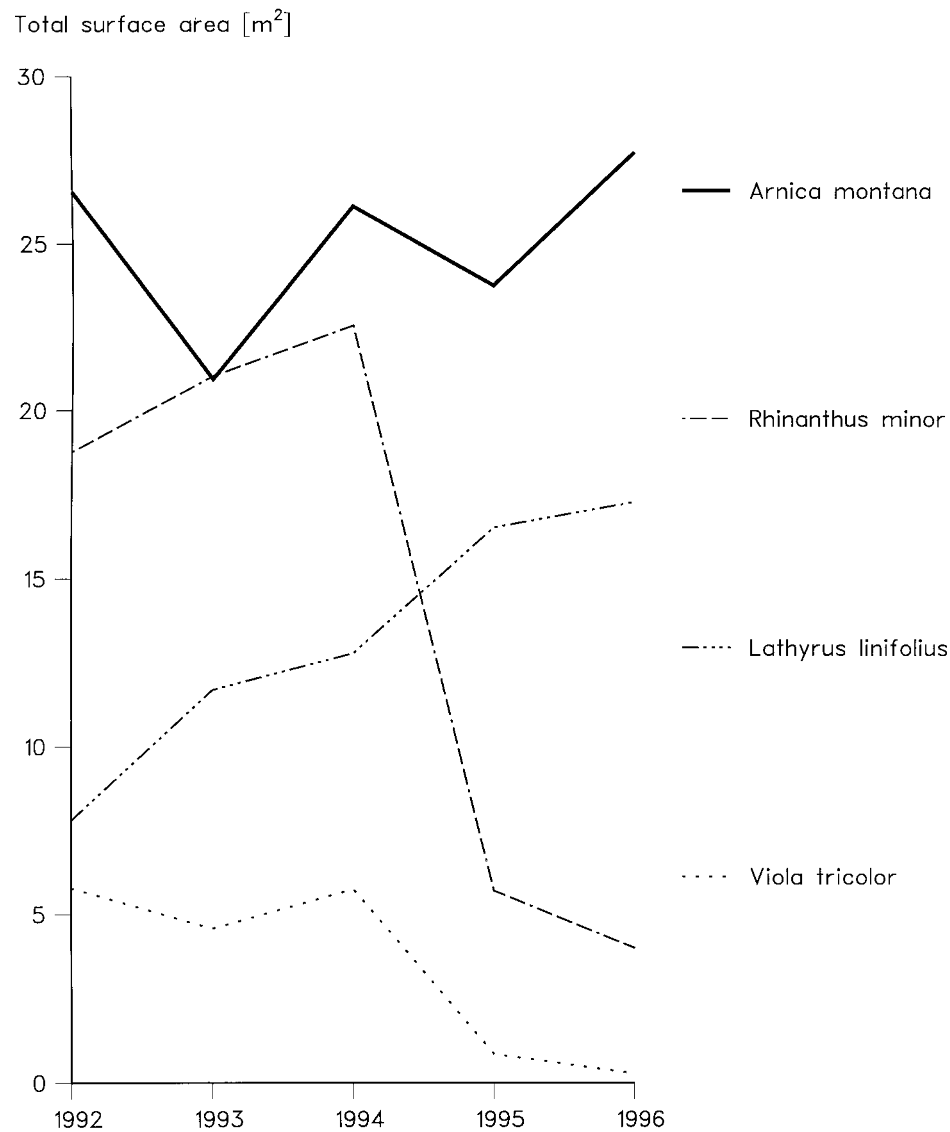

Fig. 3. Total surface area for species with intermediate cover: *Arnica montana, Rhinanthus minor, Lathyrus linifolius, Viola tricolor*; cover summed for all 122 transplanted grid cells (in total 3050 m^2).

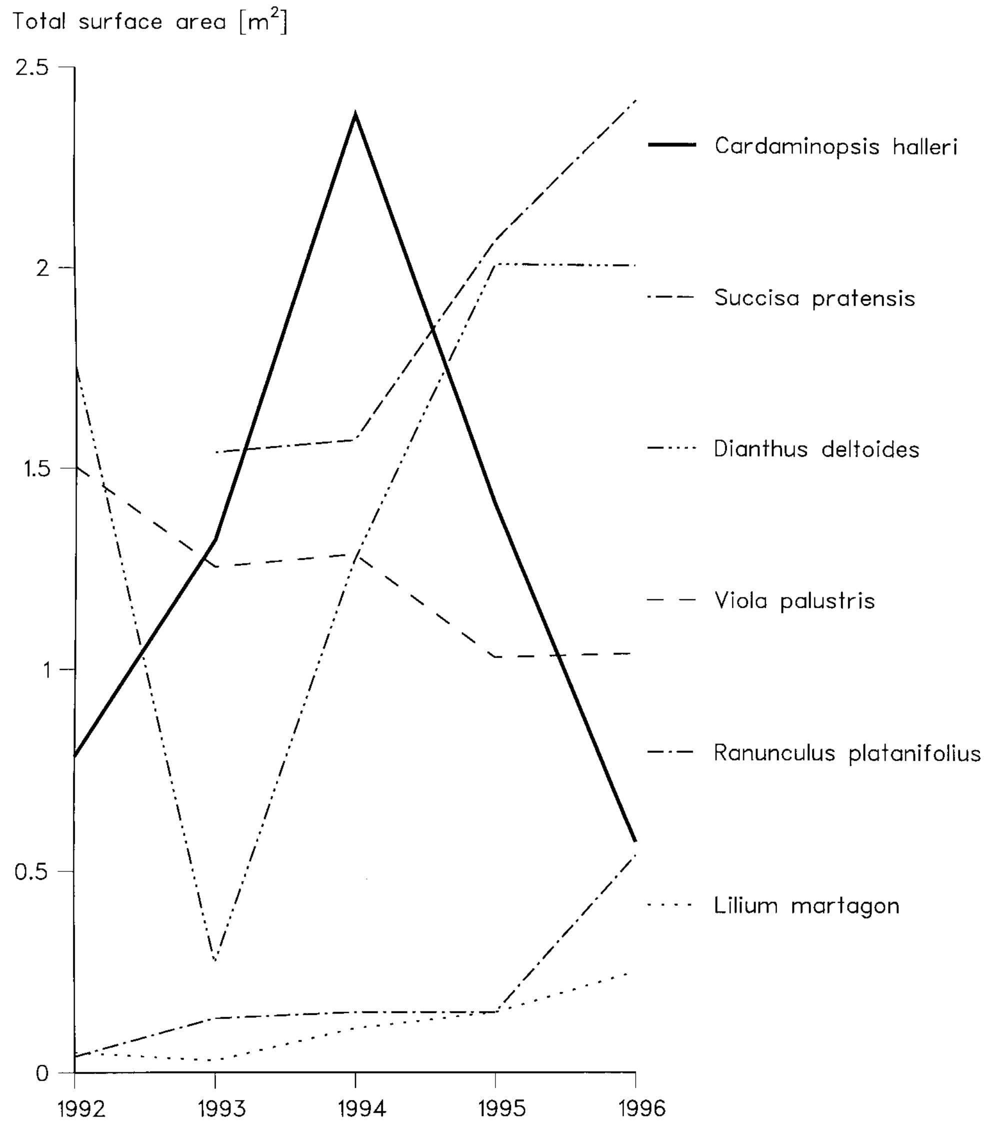

Fig. 4. Total surface area for species with low cover: *Cardaminopsis halleri, Succisa pratensis, Dianthus deltoides, Viola palustris, Ranunculus platanifolius, Lilium martagon*; cover summed for all 122 transplanted grid cells (in total 3050 m^2).

number in newly occupied cells. Six species responded with a decrease in the number of occupied grid cells with *Viola tricolor* suffering the most severe loss.

3.3. Vegetation types

Based on the species composition, four vegetation types were distinguished in the study area (Table 3).

3.3.1. Galium type

The species-poor *Galium* type is mainly composed of grassland species that characterise oligotrophic conditions (*Violion caninae* Basal community according to Peppler, 1992; or Basal variant of *Violion caninae* community according to Bruelheide, 1995). A characteristic feature of this type is the high cover of *Nardus stricta* and *Galium harcynicum*. Meadow species indicating more favourable nutrient and base supply are, for the most part, absent. Furthermore, *Arnica montana* is rare in this vegetation type, although elsewhere this species is very characteristic of mat-grass communities.

Here, transplantation resulted in only slight changes in species composition (Table 3, col. 1–5) except for the proportion of bare soil which increased from 1 to 5% in 1993. Considerable changes were detected in vegetation structure with the average height increasing from 25 cm in 1993 to 40 and 65 cm in 1994 and 1995, respectively. The change was mainly the result of better growth of grass species such as *Avenella flexuosa* and *Poa chaixii*. In this increasingly dense herb layer, cover of the low-growing species *G. harcynicum* and *N. stricta* decreased considerably in 1996, and became no longer dominant.

Table 2
Frequency of occurrences in grid cells for all threatened species, listed in order of net change 1992–1996 n.r. = not recorded in the first year

Species	1992	1993	1994	1995	1996	Change
Lathyrus linifolius	60	63	67	73	77	17
Arnica montana	87	97	98	93	94	7
Lilium martagon	5	3	8	8	11	6
Cardaminopis halleri	27	41	49	54	31	4
Dianthus deltoides	12	16	15	13	14	2
Viola canina	0	0	0	1	2	2
Succisa pratensis	n.r.	18	20	20	19	1
Viola palustris	6	6	7	7	7	1
Hieracium aurantiacum	0	0	0	1	1	1
Polygonum bistorta	122	122	122	122	122	0
Meum athamanticum	122	122	122	122	122	0
Ranunculus platanifolius	3	3	3	3	3	0
Nardus stricta	n.r.	122	121	121	121	−1
Polygala vulgaris	3	4	5	6	2	−1
Thesium pyrenaicum	3	5	5	3	2	−1
Lychnis flos-cuculi	2	2	1	0	0	−2
Rhinanthus minor	70	76	90	76	65	−5
Viola tricolor	53	50	78	58	25	−28

3.3.2. *Arnica type*

The *Arnica* type is characterized by high cover of *Arnica montana*. Also a type of mat-grass community, it is much richer in species than swards of the *Galium* type and is allocated to the milkwort mat-grass community (*Polygalo-Nardetum* according to Peppler, 1992). Apart from *Arnica*, other species typical of oligotrophic grasslands occurred regularly: e.g. *Dianthus deltoides* or *Campanula rotundifolia*, or meadow species, e.g. *Cardaminopsis halleri*. These species, in combination with low cover of *Polygonum bistorta*, can be used to distinguish *Arnica* type from *Galium* type.

In contrast to the latter there were fewer changes in species composition and in dominant species (Table 3, col. 6–10). One direct effect of transplantation was a reduction in cover for some species, e.g. *Arnica*. In the succeeding years, other species not only recovered but also increased in abundance, e.g. *Dianthus deltoides* (Table 3, col. 8–10). Strong fluctuations were detected in meadow species: most species in this group increased from 1992 to 1994 and then decreased in 1996 to initial cover values or even lower, e.g. *Leucanthemum vulgare* agg. (Table 3, col. 6 and 10).

3.3.3. *Rhinanthus type*

The *Rhinanthus* type is distinguished by meadow species attaining high cover values, e.g. *Rhinanthus minor, Veronica chamaedrys* or *Ranunculus acris*. The stands belong to the cranesbill/yellow oatgrass association, typical of montane meadows (*Geranio-Trisetetum* according to Oberdorfer, 1983; *Polygono-Trisetion flavescentis* community, Basal variant, subvariant of *Avenella flexuosa* according to Bruelheide, 1995). In contrast to *Arnica* swards, the meadows had a lower cover of *Nardus stricta* and *Galium harcynicum*. The *Rhinanthus* type became increasingly similar to the *Arnica* type as a result of new occurrences of sward species and reduction of species with a more pronounced nutrient and base demand, such as *Veronica chamaedrys*.

3.3.4. *Polygonum type*

Meadows belonging to the *Polygonum* type were distinguished by the dominance of a single species, *Polygonum bistorta* covering more than half of the plot's area. In the transplanted meadow, species composition of the *Polygonum* type varied considerably, showing partial resemblance to the *Rhinanthus* type and to the *Galium* type.

After transplantation, the high initial cover of *Polygonum* was drastically reduced (Table 3, col. 17). After 2 years this species recovered to the 1992 levels (Table 3, col. 16–20). Other species showed no conspicuous changes apart from a decrease of some grasses (e.g. *Agrostis tenuis*). Initially species-poor, the species number increased continuously to 21 vascular species by 1996. It is remarkable that the new species belong to different groups, including mat-grass swards, meadows and pioneer species of bare soil. This plot, which was located near the edge of the target area, was the only one where a newly invading disturbance indicator, *Holcus mollis*, became established.

The overall floristic change with time for all four vegetation types is illustrated in the similarity diagrams (Fig. 5). All types were affected by transplantation as indicated by a decrease in similarity from 1992 to 1993. Thereafter, the *Galium* and *Rhinanthus* types continued to decrease to between 60 and 70% while the other two tended to fluctuate around 70–80%. This was mainly due to the decrease in cover of previously dominant species (see Table 3). The shift in dominant species was also the main reason for the strong decline in similiarity of the *Galium* type in the last observation in 1996.

3.4. *Vegetation mapping*

The vegetation pattern of one section of the road corridor before transplantation is shown in Fig. 6(I). While meadows of the *Rhinanthus* type occurred in smooth level sites, *Arnica* swards were located on mounds and *Polygonum* stands in depressions. The transplantation changed this pattern drastically [Fig. 6 (II)]. Because the technique transferred strips of 1.25 m width, the coherence between pieces was maintained in the north–south direction within a strip but each strip was turned by 180° in a west–east direction. As a result, edges of adjacent strips in the road corridor were no longer directly adjacent in the target area [Fig. 6(II)]. In the east–west direction the sod strips were separated by a distance of two times the sod width (2.5 m). Borders between vegetation types, which previously had been curved smoothly, were transformed into jagged lines. In

Table 3
Permanent plots of transplanted meadows, size 2 × 2m[a]

Vegetation type	Galium type					Arnica type					Rhinanthus type					Polygonum type				
No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year	92	↓ 93	94	95	96	92	↓ 93	94	95	96	92	↓ 93	94	95	96	92	↓ 93	94	95	96
Cover herb layer [%]	85	80	85	85	80	60	60	70	75	80	70	60	75	85	80	95	70	80	90	90
Height herb layer, mean [cm]	10	10	15	30	20	5	5	5	20	20	10	10	10	30	25	25	10	20	30	30
Height herb layer, max. [cm]	25	25	40	65	35	15	15	50	50	30	20	20	45	65	50	40	25	60	80	60
Cover moss layer [%]	15	20	20	20	20	20	15	5	5	10	20	10	10	10	10	1	1	2	5	10
Cover litter [%]	30	5	50	40	70	70	50	50	70	80	70	40	40	50	50	70	40	60	70	70
Cover bare soil [%]	1	5	3	< 1			20	10	5	< 1		30	15	5	3		25	15	1	1
Number of phanerogams	14	15	15	16	15	25	28	27	28	27	21	24	29	30	27	15	16	20	20	21
Number of cryptogams	3	2	3	4	4	4	6	7	9	10	2	2	3	3	3	2	2	4	4	4
Species of Mat-grass swards																				
Nardus stricta	3	3	2	2	1	1	#	#	#	#	1	#	+	#	#	.	r^{2}	r^{2}	r^{2}	r^{2}
Avenella flexuosa	1	2	2	2	1	1	#	2	2	1	+	#	#	2	2	.	.	r^{9}	+	r
Luzula campestris	#	#	+	r	r	#	#	#	+	r	#	+	+	+	#	r	r	r	r^{7}	r^{13}
Veronica officinalis	r^{1}	r^{1}	r^{5}	r^{5}	r^{4}	r^{2}	r^{4}	.	r^{4}	r^{6}	.	.	.	r^{1}	r^{5}	r^{4}	+	+	+	+
Galium harcynicum	2	3	3	3	#	2	3	3	2	1	1	1	1	2	1	+	1	1	1	#
Thesium pyrenaicum	.	.	.	.	.	r^{1}	r^{2}	r^{2}	r^{5}	r^{4}	.	.	.	.	.	.	.	.	.	.
Lathyrus linifolius	.	.	.	.	.	r^{4}	r^{11}	r^{22}	$+^{52}$	$+^{66}$	.	.	.	.	.	.	.	.	.	.
Dicranum scoparium	r	.	.	.	.	r	+	r	r	r	.	.	.	.	.	.	.	.	.	.
Pleurozium schreberi	.	.	.	.	.	r	r	r	r	r	.	.	.	.	.	.	.	.	.	.
Potentilla erecta	.	.	.	.	.	+	+	#	+	+	$+^{20}$	#	#	#	#	.	.	.	.	.
Dianthus deltoides	.	.	.	.	.	r^{10}	r^{10}	r^{59}	r	r^{58}	.	r^{1}	r^{11}	r^{20}	r^{5}	.	.	.	.	.
Arnica montana	.	.	.	.	.	+	r^{10}	r^{15}	r^{15}	r^{16}	$\#^{27}$	$\#^{25}$	$\#^{35}$	$\#^{52}$	$\#^{49}$	.	.	.	.	.
Campanula rotundifolia	.	.	.	.	.	r^{3}	r^{35}	+	r	r	r^{30}	r^{30}	r^{30}	r^{7}	r^{29}	.	.	.	.	.
Hypericum maculatum	.	.	.	.	.	$+^{40}$	+	r^{22}	r^{17}	r^{13}	.	r^{1}	r^{8}	r^{12}	r^{35}	.	.	.	.	.
Hieracium laevigatum	r^{1}	r^{1}	.	.	.	r^{3}	r	r^{8}	r^{7}	r^{7}	r^{2}	.	r^{1}	r^{1}	r^{3}	.	.	.	.	.
Carex pilulifera	.	.	r^{2}	r^{1}	r^{1}	.	.	.	.	.	.	.	r^{1}	r^{1}	r^{2}	.	.	.	.	r^{1}
Species of meadows																				
Leucanthemum vulgare	.	.	.	.	.	+	+	#	#	r^{33}	.	.	.	.	.	.	.	.	.	.
Cardaminopsis halleri	.	.	.	.	.	r^{1}	.	r^{7}	r^{1}	.	.	r^{5}	r^{4}	r^{3}	.	.	.	.	.	.
Trisetum flavescens	.	.	.	.	.	r^{5}	r^{9}	r^{15}	r^{10}	r^{3}	.	r^{7}	r^{14}	r^{14}	r^{10}	.	.	.	.	.
Veronica chamaedrys	.	.	.	.	.	+	+	#	#	+	1	1	1	#	r	.	.	.	r^{4}	r^{1}
Rhinanthus minor	.	.	.	.	.	r^{20}	r^{86}	$+^{132}$	r^{42}	r^{39}	#	+	$+^{81}$	r^{50}	r^{74}	r^{13}	r^{3}	r^{3}	r^{1}	r^{1}
Ranunculus acris	.	.	.	.	.	r^{3}	r^{12}	r^{13}	r^{7}	r^{8}	$+^{20}$	#	#	#	r^{46}	.	.	.	.	.
Plantago lanceolata	.	.	.	.	.	.	.	.	.	.	r^{1}	r^{1}	r^{1}	r^{1}	r^{2}	.	.	.	.	.
Cardamine pratensis	.	.	.	.	.	.	.	r	.	r^{1}	.	.	.	.	.	.	.	.	.	.
Poa pratensis	.	.	.	.	.	.	r^{1}	.	.	.	.	.	.	.	.	+	r^{4}	r^{52}	$+^{33}$	r^{9}
Dactylis glomerata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r^{2}	+	#	+	r^{1}
Leontodon autumnalis	.	.	.	.	.	.	.	.	r^{1}	.	.	.	.	r^{1}	.	.	.	r^{3}	r^{7}	r^{3}
Cerastium holosteoides	.	.	.	.	.	.	.	.	.	.	.	.	r^{1}	.	.	.	.	.	.	.
Trifolium repens	.	.	.	.	.	.	.	.	.	.	.	.	r^{1}	.	.	.	.	.	.	.
Species of montane grassland																				
Polygonum bistorta	2	2	2	2	2	#	#	#	#	#	1	1	#	#	1	6	4	5	6	5
Achillea millefolium	r^{4}	r	r	r^{2}	.	.	.	.	.	.	r^{30}	#	#	#	#	r	+	+	r	r
Meum athamanticum	1	1	1	2	2	2	1	1	1	2	2	1	1	1	2	2	1	#	1	1
Poa chaixii	#	#	#	1	#	r	+	r	r	r	1	#	+	#	#	#	#	#	#	#
Agrostis tenuis	1	1	1	1	1	#	#	#	1	1	1	1	#	1	2	3	2	1	1	1
Festuca rubra	2	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
Anthoxanthum odoratum	+	r	+	r	r	.	.	.	.	.	r^{20}	r^{2}	+	+	+	+	+	+	r	r
Anemone nemorosa	r	r	#	#	#	#	+	#	#	1	1	+	#	#	#	r	r	+	+	1
Rumex acetosa	.	r^{2}	r^{7}	r^{7}	r^{7}	.	r^{12}	r^{18}	r^{13}	r^{22}	r^{3}	r^{30}	+	r	+	r^{2}	r^{1}	r^{7}	r^{16}	r^{20}
Silene dioica	.	.	.	.	.	.	r^{1}	r^{1}	.	.	.	.	.	.	.	.	.	.	.	.
Pioneer species of bare soil																				
Ceratodon purpureus	.	.	r	r	r	.	r	r	r	r	.	.	.	.	.	.	.	.	.	.
Dicranella heteromalla [b]	.	.	.	r	r	.	.	.	r	r	.	.	r	r	r	.	.	r	r	.
Bryum spec.	.	.	.	.	.	.	.	r	r	r	.	.	.	.	.	.	.	.	.	.
Pohlia nutans	.	.	.	.	.	.	.	r	r	r	.	.	.	.	.	.	.	r	r	r
Rumex acetosella	.	.	.	r^{3}	r^{3}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Galeopsis tetrahit	.	.	.	.	.	.	.	.	.	.	.	.	.	r^{1}	r^{1}	.	.	.	.	.

(continued on next page)

Table 3 (*continued*)

Vegetation type	Galium type					Arnica type					Rhinanthus type					Polygonum type				
Rubus idaeus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r 1	.	.
Holcus mollis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	#
Other vascular plant species																				
Polygonatum verticillatum	.	.	.	.	.	.	r 1	.	r 1	r 1	.	.	.	.	.	.	.	.	.	.
Carex leporina	.	.	.	.	.	.	.	.	.	.	.	.	r 1	r 1	.	.	.	.	.	.
Other moss species																				
Rhytidiadelphus squarrosus	1	2	2	2	2	2	1	#	#	1	2	1	1	1	1	r	r	+	#	1
Brachythecium salebrosum [c]	+	+	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	+
Plagiomnium affine	.	.	.	.	.	.	r	.	.	r	.	.	.	.	.	.	.	.	.	.
Polytrichum formosum	.	.	.	.	.	.	.	.	r	r	.	.	.	.	.	.	.	.	.	r

[a] Cover values after Londo (1975), slightly modified (*r*: < = 1%; +: > 1–3%; #: > 3–5%; 1: > 5–15%; 2: > 15–25%; 3: > 25–35% etc.). Number of individuals is written as an exponent. With a few exceptions, individuals were only counted when less than 20 were present; cover values without exponent always indicate > 20 individuals.

[b] Incl. *Ditrichum heteromallum*

[c] Incl. *Brachythecium albicans*

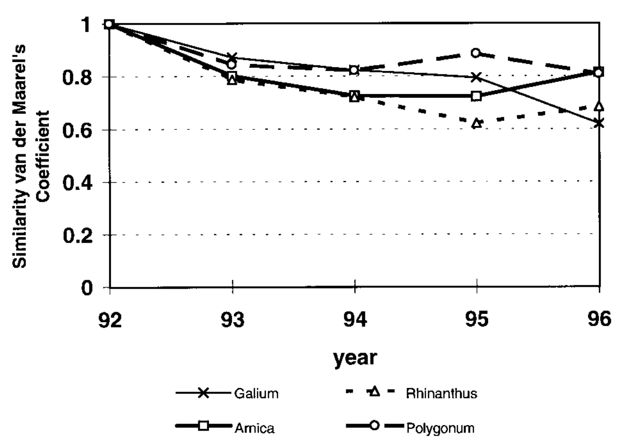

Fig. 5. Similarity of four vegetation types with regard to their initial state before the transplantation (1992), using percentage cover and van der Maarel's coefficient.

total, the pattern was dominated by narrow acute-angled sections.

In 1996, the vegetation presented a completely different picture [Fig. 6(III)]. Rectangular or square patterns prevailed, their size mainly being determined by the shape of the transplanted sod strips. The small section shown in Fig. 6 indicates how the surface area of the *Arnica* type decreased in favour of the *Rhinanthus* type (Table 4). In comparison, the surface area of the *Polygonum* type increased slightly throughout the entire site; whereas the Galium type decreased (Table 4).

4. Discussion

4.1. Judgement of success

Preservation of the total flora was completely successful. This conclusion is also valid in light of the fact that newly appearing disturbance indicator species never occurred in the transplanted sods but only around the edges of the receptor area.

Preservation of populations of all threatened species was generally successful, with some reservations. Of the 18 monitored species, 13 responded indifferently or positively to the transplantation, clearly indicating success. Of the two species with a considerable decrease in population size, *Lychnis flos-cuculi* is not typical of montane meadows or swards although abundant in wet grasslands in the Harz. The decrease of *Viola tricolor* was probably not caused by the transplantation; like *Rhinanthus minor* and *Cardaminopsis halleri*, this species colonizes patches of bare soil within meadows. Owing to mowing of the target area in late August, the transplanted meadows developed a dense herb layer, which also promoted a higher nutrient supply, and a thick litter layer. The species which decreased are not able to germinate on litter and are inefficient competitors for light.

Preservation of species composition of the vegetation types after 4 years was also reasonably successful, with some reservations concerning the shift in dominant species in the *Galium* type in 1996. The accumulation of species with time especially in the *Rhinanthus* and *Polygonum* type is not considered to be a severe drawback. With a few exceptions, all newcomer species were typical members of meadow communities. It is a general observation that disturbance in grasslands activates the seedbank, and thus results in increasing species number (Ward and Jennings, 1990). This has already stabilised and can be expected to decrease in the following years.

A medium-term effect was the immense increase in biomass in 1994 and 1995, evidenced by an increase in height of the herb layer. This was probably the result of a higher nutrient supply in the soil caused by the slight disturbance of soil structure and consequently increased

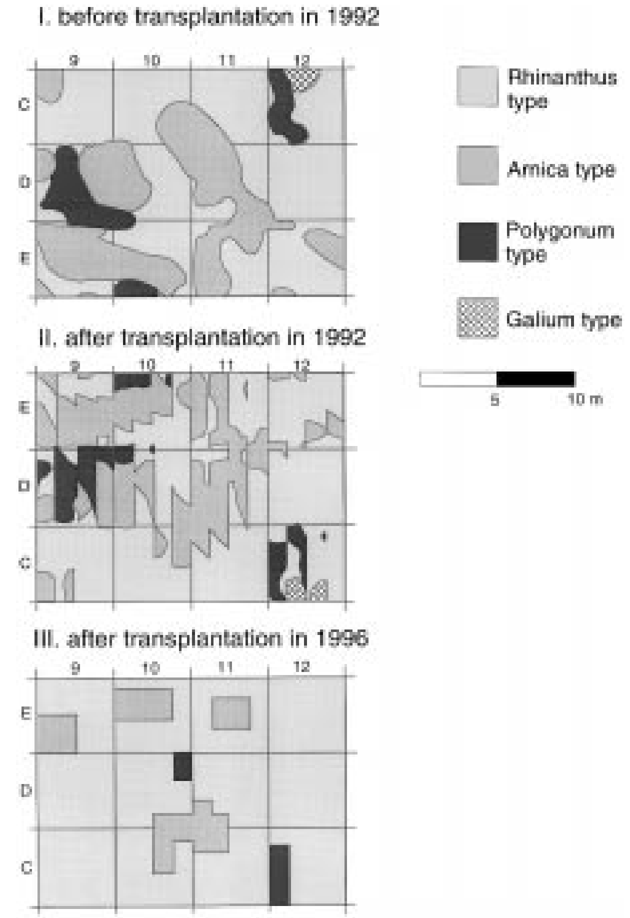

Fig. 6. Part of the vegetation map. Only 12 out of the total of 122 cells of 5×5 m are shown. I: before transplantation in 1992; II: after transplantation in 1992, as in I, but after transplanted strips were redrawn according to their later position in the target area; III: after transplantation in 1996.

oxygen access and enhanced microbiological activity with higher mineralisation of organic matter. Although we made no measurements of nutrient supply following the transplantation, this assumption is supported by observations of increased nitrogen mineralisation rates when soil disturbance is caused by the measurement process itself, e.g. when filling soil in incubating bags (Haynes, 1986). Since all techniques measuring mineralisation have the problem of causing soil disturbance, their value for monitoring transplantation disturbance is very limited. A similar increase in biomass and a decrease of low-growing species were also observed in translocated litter meadows and mires near Zurich (Klötzli, 1975, 1980, 1987) and transplanted chalk grasslands in the Lech valley in Bavaria (Müller, 1990).

Table 4
Surface area (m^2) of transplanted vegetation types in 1992 and 1996

	1992	1996	Increase/decrease	
Galium type	1709	1522	−187	(−11%)
Arnica type	402	264	−138	(−34%)
Rhinanthus type	1336	1570	+234	(+18%)
Polygonum type	893	984	+91	(+10%)
Total	4340	4340		

Enhanced nutrient supply apparently only exerted an effect during the first 2 years after transplantation because, in 1996, all plots showed a decreasing herb layer height. On a long-term basis, an increase in low-growing species can be expected. In 1996, this trend was already suggested by a distinct increase in typical sward species in plots of the *Arnica, Polygonum* and *Rhinanthus* types, whilst meadow species decreased. In contrast, the *Galium* type exhibited a decrease of low-growing species especially in the last observational year. Future observations will show whether this effect is intermediate or a long-term trend.

After 4 years of observation, the preservation of the four vegetation types with respect to the original proportions of the area covered and to spatial mosaic has to be considered as having failed. The diverse pattern of the road corridor in 1992 had almost completely disappeared in 1996. Because of the relatively equal height of the transplanted sods, the surface was much more even than before, only interrupted by shallow ditches between sods. The geometric patterns prevailing in 1996 are not encountered under natural conditions but subsequent years can be expected to bring further changes, which will probably result in smoother borders between types.

The target area might have been prepared with a more uneven surface. Although this would have allowed for the creation of a microrelief, it would never have been possible to transplant the vegetation types to their corresponding reliefs. We had considered whether we should have additionally levelled the newly created surface sods in the receptor area with machines to avoid the creation of ditches as was done in the Thrislington project where limestone grasslands were transplanted (Park, 1989). We decided against this because it would have severely affected the vegetation development in the spring and summer of 1993.

4.2. Comparison with other projects

The invasion by weedy species into the transplanted sods and their dominance in the first year, are a severe problem in turf transplantation. Most projects have removed weeds manually (e.g. Klötzli, 1978; Park, 1989; Cullen and Wheater, 1993; Ward et al., 1996) or even used herbicides (e.g. Park). *Tussilago farfara*, *Cirsium arvense* and *Rumex* spp. are particularly troublesome because they can spread into the turves. Despite hand weeding, Worthington and Helliwell (1987) recorded a considerable increase of many weeds 6 years after transplantation, including *Bromus mollis, Cirsium vulgare, Galium aparine, Geranium dissectum, Hordeum secalinum, Polygonum* *aviculare, P. lapathifolium, Urtica dioica, Vicia cracca, V. sativa*. In machine-translocated chalk grasslands at the Winchester bypass the number of weeds and problematic species increased from 11 in the initial state to 30, one year after transplantation and stabilized around 20, four years later (Ward et al., 1996). In transplanted peatland meadows close to the Zurich airport rushes (*Juncus articulatus* and *Juncus effusus*) appeared in large quantities (Klötzli, 1975, 1981, 1987; Klötzli and Keel, 1976). Another problem is weed species with runners which intrude from the edges of the receptor area, e.g. *Solidago serotina* and *S. canadensis, Aster* spp. and *Calamagrostis epigejos* (Klötzli, 1978) or *Potentilla reptans* and *Agropyron repens* (Worthington and Helliwell, 1987).

None of these weeds was ever observed in the Harz project. Only species which were already present, such as *Rhinanthus minor, Cardaminopsis halleri* and *Lathyrus linifolius* established themselves in the gaps, either by seed dispersal or by their diaspores buried in the seedbank and brought to the surface during transplantation. We consider this to be an effect of the exclusive use of subsoil material that was free of seeds for filling up gaps between sods. At the edges of the target area, where topsoil from the former spruce stand was used to level the surface, *Juncus effusus* was able to germinate and proliferate. This species was never observed in the transplanted sods. In consequence, we would recommend not using soil with a high seed-burden of undesirable species in transplantation projects. Similar positive results with respect to weeds have been obtained in only a few other projects, e.g. the turf translocation project of flood-meadow grasslands at Hockley Junction, Hampshire (Ward, 1995). Apart from initial removal of thistles and nettles there, no further weed control was necessary to maintain the number of troublesome species below their number before the transplantation.

In contrast to other transplantation projects, the changes in vegetation in the Harz project were only moderate. Many transplantation projects reported a dramatic decline in deep-rooting species, especially umbellifers (Apiaceae) with tap-roots (e.g. Klötzli, 1981, 1987; Worthington and Helliwell, 1987). In prairie transplantation experiments in North America, species with the lowest survival rates were those with thick roots that extend vertically for >0.25 m (Kearns, 1986). Although a strong decrease was also initially observed for the deep-rooting *Meum athamanticum*, the species rapidly recovered.

Despite the decline of some species, most of the whole turf transplantation projects have been successful with respect to maintaining species number and floristic similarity between initial and translocated state (Bullock, 1998). In general, turf transplantations are more successful than spreading techniques (Byrne, 1990, cited in Cullen and Wheater, 1993; Pywell, Webb and Putwian, 1995; Ward et al., 1996). However, the coherence of the transplanted communities has rarely been evaluated. As in the Harz meadows, the disruption of the grassland matrix was also the main criticism in the Thrislington project, which exhibited a quilt-like appearance (Park, 1989). This patchwork pattern was probably less marked than in the Harz meadows because the ground at Thrislington was relatively flat without pronounced topographical features. Park expressed the hope that a detailed turf relocation scheme would minimize disruption effects. Despite the high organisational effort performed in the Harz meadow transplantation, the correct juxtaposition of pieces of turf was not possible there either. In general, without an additional set-down and pick-up during the transfer, cut edges cannot correspond. Apart from being more complicated than the transfer itself, such a transposition of pieces would probably disrupt the turves even more.

5. Conclusion

From our results we can conclude that transplantation of montane meadows is feasible. The Harz meadow project was the first documented example of a successful tranplantation at montane altitude, at least with regard to the populations of threatened species and vegetation types. However, it was clear that this success was only achieved with a vast expenditure of time and money. The use of the special excavator shovel, selection and preparation of the target area were crucial aspects. The Harz meadow project was unique with respect to setting four objectives which were evaluated separately. The approach of defining several but more specified goals and approaching them with different methods proved its merits.

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