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## Grassland restoration with plant material transfer – bridging the knowledge gap between science and practice

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### ABSTRACT

In Central Europe, species-rich grasslands have strongly diminished over the last century. The transfer of seed-containing plant material from donor sites with a desired species composition to restoration sites is a well-established method to restore species-rich grasslands. Despite a plethora of available literature, restoration projects with plant material transfer often fail or do not reach the planned goals. Practitioners' knowledge is a highly important but underexplored source of information on factors deciding about success of restoration projects. At the same time, it is unclear to which degree scientific findings on success factors are known and considered by practitioners, and if science actually investigates the most relevant aspects for practice. To bridge the gap between practitioners' knowledge and restoration science, we conducted semi-structured interviews with 33 practitioners involved in plant material transfer projects. Using qualitative content analysis, we analysed the interviews for success factors, and compared them to success factors of plant material transfer as investigated in peer-reviewed European studies on the method. We found that science investigated a broad range of practical, technical, and ecological success factors, and that practitioners were generally well aware of this evidence, trying to make use of the knowledge. Failure of practitioners' projects often resulted from organizational obstacles, which were founded in lacking trust and low experience levels among the involved people. We advise unexperienced practitioners to involve more experienced practitioners in their projects if possible. Furthermore, we emphasize the importance of identifying relevant local stakeholders and building trustful regional networks. Interdisciplinary scientific studies considering success factors beyond practical and ecological aspects are required to support widespread effective grassland restoration with plant material transfer.

### 1. Introduction

Semi-natural grasslands of the temperate zones are among the world's most diverse ecosystems (Wilson et al., 2012), providing multiple ecosystem services (Bengtsson et al., 2019; Chapin et al., 2000) and high aesthetic value (Lindemann-Matthies et al., 2010).

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Abandonment of agricultural use, conversion to arable fields, and intensification have strongly decreased the quantity and quality of these habitats in Europe over the last century (Habel et al., 2013; Schils et al., 2022). With the ecological state still deteriorating (EU COMMISSION, 2020), ecological restoration of semi-natural grasslands in Europe is urgent (Török et al., 2011; Waldén and Lindborg, 2018).

Plant material transfer, i.e., the transfer of freshly cut or dried seed-containing hay is a widely used method to restore species-rich grasslands (Kiehl et al., 2010). During seed maturity of target species, the plant material is collected from a species-rich donor grassland and transferred to the restoration site. In the best case, the transferred diaspores provide the basis for a species-rich grassland community similar to the donor community. A major advantage of plant material transfer is its independence from the availability of site-specific regional seed mixtures, whose low availability is still a major constraint in grassland restoration (Dolnik et al., 2022). If freshly cut plant material is transferred, cryptogams and invertebrates may be transferred in addition to vascular plant species, which is considered advantageous compared to other methods, such as sowing of seed mixtures, brushed or threshed seed material (Kiehl et al., 2010; Michalska-Hejduk et al., 2017; Stöckli et al., 2021). The application of plant material transfer is therefore desirable from an ecological perspective.

Spreading knowledge about the advantages of plant material transfer to the public, e.g., via compendiums (Harnisch et al., 2014; Hölzel, 2007) or workshops, has contributed to its relevance in practical grassland restoration today. At a conservation workshop in Germany in late 2020 and in a follow-up interview, two of the authors talked to an employee of a nature conservation authority, to whom we refer as Paul. He had recently been tasked with restoring a species-rich floodplain meadow on a former arable field, and wanted to use plant material transfer. Having little experience, Paul read relevant literature (e.g., Hölzel, 2007) and looked for information in the internet. This way, he learned about success factors, i.e., aspects that, if addressed, can improve the outcomes of plant material transfer projects. Accordingly, as an important condition (Török et al., 2011), he identified a nearby species-rich floodplain meadow as a suitable donor site, and agreed with the farmer to use material from this site for restoration. However, several unexpected difficulties emerged in the course of the project. First, project planning only started in spring, so that the site had already been cut, and Paul decided to use material from the second cut in autumn instead. However, a severe summer drought occurred that year, and there was far too little plant material available to cover the whole restoration site. Thus, Paul, who felt urged to carry out the measure in that year, decided to additionally spread chopped hay on the restoration site, relying on the cooperating farmer's statement that the hay originated from "low-intensively managed" grassland sites. Paul admitted that with this unknown seed source, it is likely that the restoration measure has led to a suboptimal outcome, although no monitoring results were available at the time of our interview.

Given the alarming ecological state of semi-natural grasslands in the European landscape, successful restoration of species-rich grasslands is essential. Despite increasing awareness for the topic as well as growing scientific knowledge on relevant success factors (e.g., Slodowicz et al., 2023; Sommer et al., 2023), practical grassland restoration projects with plant material transfer often deviate from the desired courses of action, as Paul's example demonstrates. At the same time, it is unclear to which degree practitioners base their actions on the existing scientific evidence on relevant success factors, and if science considers the questions relevant to practitioners. We interviewed practitioners who performed restoration projects using plant material transfer and analysed their responses, aiming at answering the following questions with respect to relevant scientific literature:

- 1) To which degree have the success factors of plant material transfer relevant for practitioners been investigated and confirmed by science?
- 2) Which success factors mentioned by the practitioners are beyond the previous scope of science?
- 3) What strategies can practitioners employ to improve future outcomes of grassland restoration projects with plant material transfer?
- 4) How can science contribute to this?

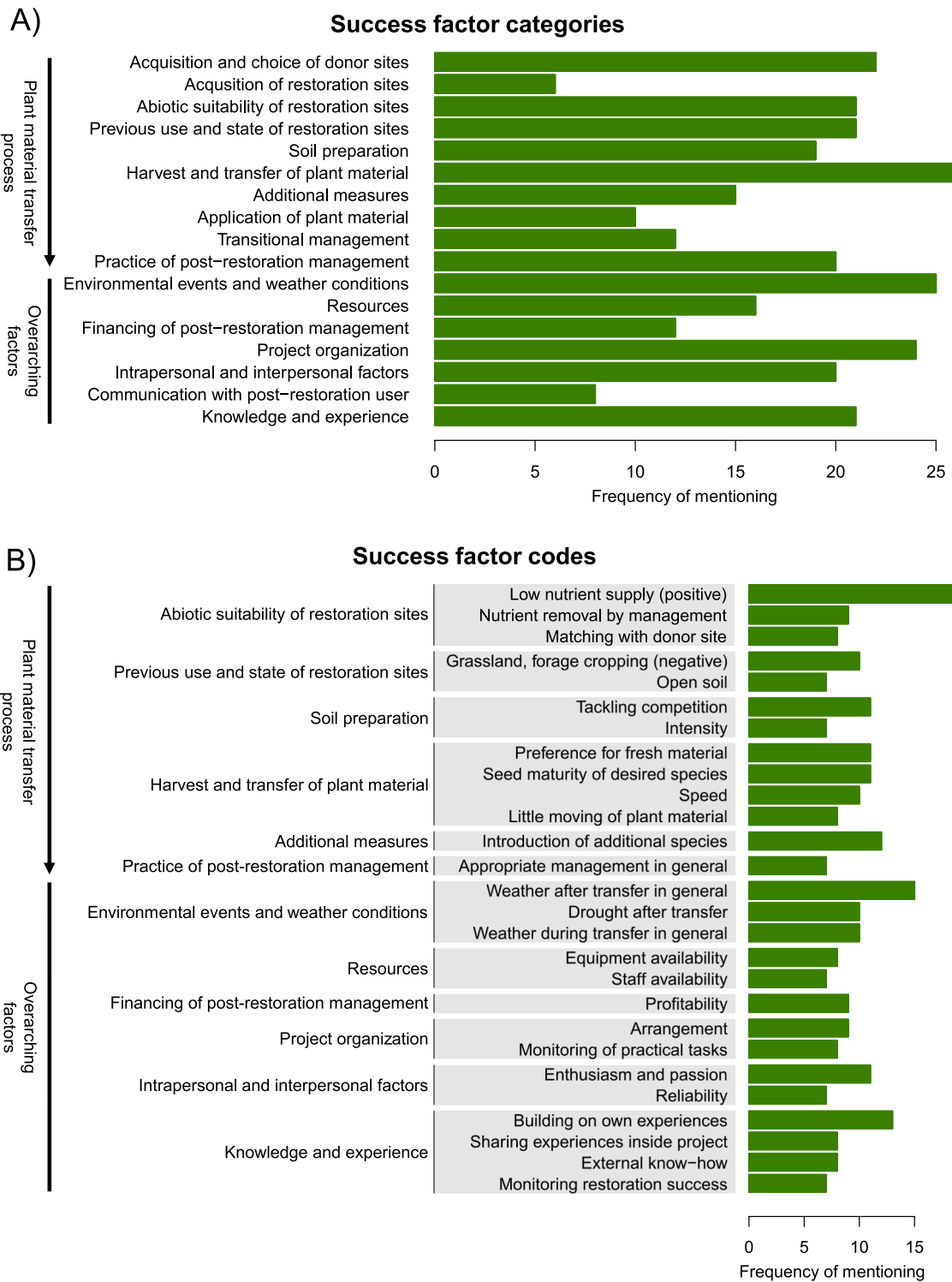
## 2. Methodology

To better understand the process of plant material transfer and relevant success factors from the practitioners' perspective, we conducted semi-structured interviews with 33 practitioners between November 2020 and September 2022. Qualitative content analysis (Kuckartz, 2018) was used to systematically analyse and code the data from the interviews.

### 2.1. Selection of interview partners

Initially, we contacted and interviewed 18 practitioners involved in plant material transfer projects. At the end of each interview, all initial partners were asked to name further practitioners using plant material transfer. From these, 15 could be engaged for an interview. Two of the 31 interviews were performed with two practitioners, 29 with one practitioner.

The final panel comprised practitioners from nature conservation and road construction authorities (9), landscape planning offices (7), publicly funded project offices (7), farms (5), landscaping agencies (3), and compensation agencies (2) (Table A1). They were involved at different stages of the projects, i.e., in planning or organization (28 practitioners), realization (9), monitoring (13), or post-restoration management (5). The practitioners had different experience levels and were involved in the restoration of a range of grassland types (Table A1 in the Supplementary material). The restoration projects were located in Germany, Switzerland, and Luxembourg.



**Fig. 1.** Frequencies of success factors as mentioned in the interviews with the 33 practitioners. Number of practitioners who addressed each of the 17 success factor categories (A) and each of the 27 most frequent success factor codes (B, category names to the left of the grey-shaded codes). The process-related factors/ categories are ordered accordingly in (A) and (B), the plant material transfer process is indicated by the black arrow on the left, respectively. Below, the frequencies of the overarching success factors/ categories, i.e., those affecting the restoration process as a whole, are given. Frequencies of all success factors are given in [Table A2](#).

## 2.2. Conduction and content of interviews

The semi-structured interviews were conducted via video call (25 partners) or in person (8 partners). Interview length ranged between 43 and 127 min per partner, and the interviews were recorded. This resulted in 44 h of audio material. We started each interview by asking for the practitioners' understanding of the term "plant material transfer" (German "Mahdgutübertragung") and their experiences with the method. As there were different attitudes if the term "Mahdgutübertragung" refers only to the transfer of fresh or also of dried mown plant material, we asked the interview partners to talk about both approaches. If applicable, we also asked to talk about the transfer of raked plant material (German "Rechgutübertragung"), which was done in the restoration of calcareous sandy grasslands. If the practitioners did not cover the following topics comprehensively by themselves, we asked about them directly:

- reasons for choosing the method of plant material transfer
- aims of the project(s), financing, organization, setup of the project(s)
- practical implementation of plant material transfer (when and how), complementary restoration measures
- post-restoration management
- evaluation of success, decisive factors for success, options for improvements of success
- used sources of information on plant material transfer, sharing of know-how and experiences
- further need for research

By covering these different aspects, we made sure to get a detailed understanding of how the practitioners' projects were set up on the practical and organizational level, and we got a sense of the involved people's attitudes towards their projects.

## 2.3. Analysis of the interviews

We transcribed the interviews in the form of detailed notes, i.e., not word for word, but we noted down the gist of every of the practitioners' statements. Memorable or emotional phrases were transcribed word for word. Following the guide of [Kuckartz \(2018\)](#), we then conducted a qualitative content analysis that reflected the aims of our research.

In a first step, we went through the transcripts and coded success-related text segments, i.e., statements on project goals and on factors that seemed decisive for success in the practitioners' minds. We derived a preliminary set of 56 different success factors and attached them to the coded text segments, using the software QDA Miner Lite ([Provalis Research, 2018](#)). In this way, we gained a first overview of the aspects the practitioners considered important, and of typical wordings or phrases they used to describe success factors for plant material transfer. Examples for such wordings are:

- "[...] is/ was important/ decisive"
- "one has to pay attention to [...]"
- "it has to be done like [...]"
- "[...] is/ was a sticking point"
- "I would change [...] next time"
- descriptions of causes and effects with respect to project success

In a second step, we re-read the transcripts, and re-coded them for success factors, which was facilitated by the impressions we had gained from the first round. We coded additional text segments as success factors, removed codes where it became evident that a clear success relatedness was missing, and split success factors into more specific "sub-factors" to facilitate content analysis. In this way, we identified 173 success factors. These were then grouped into 17 categories. While some of the categories represent the different stages of the rather fixed and sequential process of plant material transfer, other categories include success factors that affect the process as a whole (see "Results" section, the complete coding is given in [Table A2](#) in the [Supplementary material](#)).

## 3. Results

### 3.1. Project goals and success factors addressed by the practitioners

While the practitioners had strong overlaps in their project goals and consistently mentioned a range of relevant success factors, we also found a broad variety of aspects to consider. The establishment of rare or regionally typical target plant species and plant communities was the main goal of the practitioners' projects. However, faunistic conservation goals, such as protection of ground-nesting birds or support of invertebrates, also played a role. Depending on the restoration context, ensuring usability as fodder was important, or, in case of dykes and road embankments, erosion control.

Out of the 17 success factor categories, harvest and transfer of plant material, environmental impacts, and project organization were the most frequently addressed ones (by 26, 25 and 24 of the 33 practitioners, respectively; [Fig. 1A](#)). Among the full list of 173 success factors, low nutrient supply on the restoration sites, weather conditions after restoration, and building on own experiences over time were most frequently mentioned (by 19, 15 and 13 practitioners, respectively; [Fig. 1B](#)). The original quotes in German language, the full coding and coding frequencies are given in [Table A2](#).

### 3.2. Process-oriented view on the success factors

We developed a framework in which the various success factors and their complex relationships are ordered according to the process plant material transfer (Fig. 2). In the following, we explain the different stages and aspects of our framework, going into detail about most success factors, supporting our explanations with translated quotes. The success factors linked to each of our statements and of the example quotes are indicated by their abbreviations in brackets, and can be seen in detail in Table A2. Additionally, the practitioners cited are given in italics after the quotes. Success factors that were addressed by only a few partners and appear to be less relevant are not included in the text (but in Table A2).

### 3.3. Acquisition and choice of donor sites

As a main motivation for restoration, practitioners mentioned the drastic losses and, thus, scarcity of species-rich grassland sites in their regions. Accordingly, knowledge and availability of suitable donor sites as plant material sources were often considered a bottleneck, which was met in different ways.

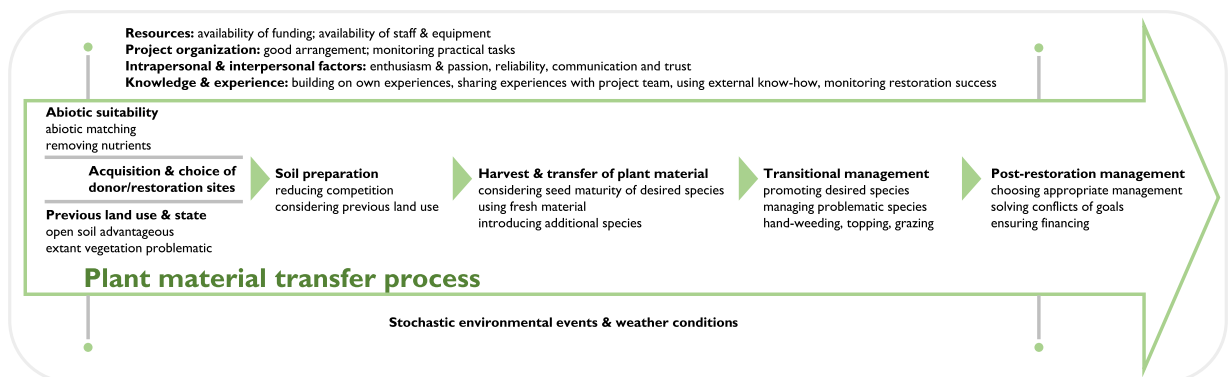
Prominently, donor site quality was considered crucial: “*First, you need enough donor sites. These shouldn't be just species-rich, but also should not contain problematic species. [...] In [our federal state], we hardly have species-rich grasslands in [...] agricultural use any more*” (quote from practitioner PFPO6; success factor DS04; see Table A2). To facilitate material transport, proximity to the restoration sites was considered important (DS01). Furthermore, the practitioners emphasized that donor sites should be sufficiently large to provide enough plant material (DS09). Several times, it was mentioned that great attention should be paid to suitable management of potential donor sites in a region to keep their diversity (DS07). Monitoring donor sites concerning the presence and abundance of desired and undesired species was considered relevant, too (DS06). To this end, sites with poisonous species or weeds should be excluded from harvest, or the plants should be removed: “*You have to take care not to transfer [*Jacobaea vulgaris*] or [*Rumex obtusifolius*]; we weed them before harvest*” (PFPO3; DS05).

To get access to suitable donor sites, many practitioners relied on their local knowledge of sites and positive relationships with the managing farmers (DS02; DS08). While donor site databases could facilitate acquisition (DS03), practitioners were also worried about competition: “*The question [is] if we should have a donor site database or not. You get a competitive situation. We already notice that [another practitioner] snaps up the donor sites that we've been using for years*” (LSPO7; DS13). There was agreement that when grasslands managed by farmers are used as donor sites, adequate compensation for the biomass is important: “*We compensate the farmer, that's important for acceptance. [Our payment] is not staggering, but it's a good, fair price*” (PFPO2; DS11).

### 3.4. Acquisition of restoration sites

When acquiring restoration sites, practitioners were often confronted with land use pressure and competition with farmers' interests. If purchase of sites for restoration was not possible, practitioners relied on respectful talks with the managing farmers.

Many practitioners who tried to purchase sites for restoration considered limited availability a big challenge: “*Access to sites would be desirable [...]. There are enough arable fields in the floodplain, but acquiring sites is extremely difficult. The [federal state] government could, for example, buy sites [...] and make them available for restoration*” (FARM3; AR02). If restoration of grasslands managed by farmers were planned, practitioners emphasised the importance of respectful talks: “*[One should] communicate with the farmers early, before displeasure grows and becomes unstoppable. [...] Presenting [restoration] as an offer is very important, that you don't impose anything [and show] appreciation for the farmers' work*” (PFPO4; AR04). Price gradations for restoration sites were mentioned depending on agricultural usability. If grasslands with site conditions unfavourable for intensive agricultural use, e.g., wet meadows, were to be restored, prices of restoration sites were often lower compared to more favourable sites (AR03).



**Fig. 2.** Factors affecting the success of plant material transfer according to the 33 interviewed practitioners. Factors related to a certain step of the process of plant material transfer are placed inside the arrow, their chronological order is from the left to the right. Overarching factors, i.e., factors affecting the plant material transfer process as a whole, are placed outside the arrow.

### 3.5. Abiotic suitability of restoration sites

As practitioners pointed out, suitability of a restoration site to support a target plant community crucially depends on abiotic conditions, which have to be carefully considered in project planning.

Aspects mentioned as decisive for success were suitable nutrient levels (SR04-SR06), soil pH (SR08), hydrological conditions (SR10, SR11), exposure, and slope (SR12). Several practitioners based their assessments on abiotic similarity to the donor sites (SR02), partly underlining the importance of soil analyses (SR03). For example, one practitioner reported problems with restoring grasslands on dykes because of unknown site conditions: *“Ideally, the topsoil is stored separately for different sides of the dyke and re-used accordingly. But sometimes a [highly fertile] sugar beet soil is deposited, then you have a lot of [Mercurialis annua]. And sometimes, the soils are humus-free and do hardly become green”* (LSCG2; SR17). Generally, low nutrient levels were seen as beneficial to restoration success: *“[The restoration sites] have become very rich in flowers, with many forbs and very low vegetation cover. But this was due to the poor [nutrient level]”* (PFPO7; SR04). To reduce nutrient levels, practitioners mentioned topsoil removal as an effective and quick tool (SR18), while management (SR07) was often seen as a time-consuming and less effective instrument:

*“We wanted to remove the topsoil from the field. [...] We’ve calculated that [otherwise], with 10 mg phosphorus per 100 g of soil, from which we wanted to get down to 5 mg/ 100 g, at least ten years of intensive use with high N fertilization would be required to get somewhat in that direction. So saying that you do one year of intensive arable use [...] and do plant material transfer in the following year, that’s eyewash, a myth”* (LSP07; SR07).

In some cases, successful outcomes were observed on initially nutrient-rich sites, possibly because of N-limitation due to nitrogen leaching (SR06). However, nutrient-poor site conditions are not always desirable, as low productivity may negatively affect post-restoration use and development of target grassland communities. One practitioner warned: *“There is that idea [...] that the site should be as nutrient-poor as possible, and then plant material transfer projects are planned on pure gravel sites. As if any low-productive meadow would grow on washed gravel”* (LSCG1; SR05).

### 3.6. Previous use and state of restoration sites

Previous use of a restoration site determines the level of competition that transferred species are confronted with, and is therefore another decisive success factor.

Closed swards of grasslands or multiannual fodder crops were considered particularly challenging (PR06), and restoration without topsoil removal even seemed pointless to some practitioners: *“I’ve said goodbye to the idea of introducing species into existing grassland. If so, you need [...] a successional restart. If I was dealing with floodplain meadows, I would do it like [another practitioner who applied topsoil removal]”* (AUTH9; PR14). Due to lacking competition, raw soils, e.g., in mining areas were generally seen as advantageous (PR15). In restoration of calcareous sandy grasslands, substrate application was considered very effective to create raw soils, with the additional opportunity to regulate abiotic conditions: *“We only take sand from a depth of more than 2 m, because above that, it can contain root pieces [of undesired species], and can be decalcified. We had bad deliveries [...], which contained e.g., root pieces of [Ailanthus altissima], which grows very quickly then”* (FARM5; SR15, PR18). Sometimes the expression “raw soil” (German “Rohboden”) was used colloquially, actually referring to humus-containing open soil, e.g., on arable fields (PR01, PR02) rather than to minimally developed soils. These also offer conditions with low competition by existing vegetation: *“Over the last years, we’ve almost exclusively [restored] cleared arable fields, so that [we’ve hardly needed] any site preparation.”* (AUTH3).

### 3.7. Soil preparation

Many practitioners advocated soil preparation prior to plant material application, but some concerns and questions regarding necessity and negative side effects were also raised.

While creating a good seedbed for germination was an important goal of soil preparation (SP02), tackling competition by the existing vegetation was very prominent: *“We’ve made the experience that the more intensely you disturb the soil and destroy the competing vegetation, the more successful your measure gets”* (LSPO6; SP03, SP11). However, for some subsequent users of restored meadows, uneven soil surfaces from ploughing were an obstacle: *“Some sites had been ploughed. I had suggested to [the planner] to level them... but no, the seeds wouldn’t sprout so well then. That’s like a mogul field, you ram against those bumps with your mower afterwards”* (FARM2; SP01). Two practitioners reported diminishing effects of soil preparation on species establishment in the long-term (SP15). Furthermore, negative side effects of soil preparation on insects or target plant species already present on existing grassland were mentioned (SP13).

### 3.8. Harvest and transfer of plant material

Practitioners were concerned with transferring as many seeds of desired species as possible when harvesting, storing, and transporting plant material, while affecting germination as little as possible.

Many practitioners aimed at optimizing the harvest date: *“If I harvest [...] in June, I only have grasses. The donor site vegetation must be recorded, you need the right timing. I have to look which species have shed their seeds, which ones are ripe, which ones are flowering”* (PFPO7; HT02, HT07). Having access to different donor sites allows for flexibility: *“The donor site had been mown before [our planned] harvest, as the farmer had forgotten about it. Then you have to react quickly to find an alternative”* (PFPO3; DS10, HT09, HT10). Some practitioners harvested at several dates to transfer more species (HT05), whereas many preferred additional sowing or planting of target species to

make organization less complicated (AM01). In hay transfer on dykes or road embankments, nurse crops such as cereals or *Bromus secalinus* were added to achieve fast sward closure and erosion control (AM04).

There was broad agreement that transferring freshly cut material is, in principal, preferential to transferring dried material, even among practitioners who often applied the latter method: *“Surely, fresh material is better by factor three. Due to withering, windrow and so on you have considerable losses [of seeds] in hay bales. Interestingly, many of the early and late flowering species get established, but surely less than with fresh material”* (LSCG2; HT13). One reason to use hay bales was that seeding on large restoration sites is easier to organize, as material from different donor sites can be combined (HT14). Another practitioner appreciated that hay bales enable hydro-seeding on steep road embankments, as they can be shredded and mixed with moisture holders for adherence, and sprayed on the embankments (AP02).

Mowing during wet conditions, e.g., in the early morning, was recommended several times to increase seed capture (HT12). Many practitioners emphasised that the plant material should be moved as little as possible prior to collection (HT16) and considered rapid transfer of fresh material crucial to minimize seed losses: *“Optimally, we mow and load the plant material onto the silage wagon without any delay”* (PFPO4; HT17). There was uncertainty on the effects of hay storage on seed quality: *“I store [the bales] for two years at maximum, I’ve no idea about the germination ability. The danger of losses is high. The bales are under fleece, but are exposed to weather conditions”* (LSCG2; HT18).

### 3.9. Transitional management

In the first years after restoration, many practitioners were confronted with the emergence of undesired species, which were not part of the target plant communities. To direct plant communities towards the target states, specific transitional management was often considered crucial.

As outlined before, poisonous species or weeds occur on freshly restored sites depending on abiotic conditions, previous state, site preparation, and plant material composition. Eliminating unwanted species is so important that sometimes hand-weeding was performed (TM01). A central transitional management practice was topping (German “schröpfen”), i.e., cutting to weaken fast-growing weeds and prevent them from developing ripe seeds: *“[The initial management in the first years] must not be based on the later regular management. In front of students, I have also advocated not to follow any faunistic arguments or conservation dogmas with late cutting [...]. Mowing, mowing, mowing leads to success”* (LSPO7; TM03). In the eyes of some practitioners, increased nutrient richness and productivity required more frequent topping and biomass removal over longer time periods (TM05, TM06). Intensive grazing was mentioned as another option to suppress undesired species such as *Cirsium arvense* (TM02). Several practitioners recommended monitoring during the first years: *“Finding the optimal management is definitely a permanent issue and very challenging. You have to observe all the time how the vegetation reacts, and then adjust the management, ideally jointly with the farmers”* (LSPO3; TM08).

### 3.10. Post-restoration management

To maintain a stable plant community after transitional management, adapted post-restoration management was an important success factor for many practitioners. However, management often had to make compromises due to limited funding and different, sometimes conflicting conservation goals.

Some practitioners stressed the relevance of management in general, as opposed to leaving restored sites unmanaged (PM01). Others specified the need of low-intensive management, as opposed to intensive agricultural exploitation (PM02). Management that can be refinanced by biomass use, e.g., as livestock fodder, was often seen as the best option to secure the conservational value of restoration sites. However, this was hard to reconcile with low-intensive management: *“If the barn for 200 cows is financed and then you [...] tell [the farmer], ‘Just try low-intensive management’, that’s a complete changeover for the farm. [...] Contractual nature conservation is not sufficient there; the cows have to be fed.”* (PFPO4; FM01, FM02). In some cases, practitioners reported severe failures in post-restoration management. For example, to improve fodder values of restored sites, some farmers tilled and re-sowed restored grasslands with commercial seed mixtures (PM12, PM13).

Given that low-intensive management could be implemented, the decision for mowing or grazing management was a big topic. Mowing was often advocated with regard to certain target plant communities: *“My impression is that [in our federal country] too little attention is paid to [management]. For reasons of cost [reduction], people try to maintain systems by grazing that have actually evolved from mowing”* (LSPO6; PM03, PM09). If mowing was chosen, adaptation of the cutting regime to the needs of certain target species or species groups was important (PM06). This often resulted in conflicts between different restoration goals: *“The cutting date [...] was postponed [...] to protect ground-nesting birds. That’s not favourable with regard to [the invasive plant species *Solidago canadensis*].”* (LSPO2; PM07). Grazing was advocated for different reasons, e.g., for its potential to suppress undesired species, to achieve higher structural diversity, and to create germination gaps for target plant species:

*“The thistles have almost disappeared because of the sheep [grazing]. [...] We observe decline of [*Peucedanum officinale*] after plant material transfer [if there is only mowing]. [This target species] certainly needs regular soil disturbance. [...] Perhaps, one would have to go in there with larger grazers. [...] Certainly, a richer mosaic would be good in the sites”* (FARM5; PM04, PM08, PM10).

### 3.11. Stochastic environmental events and weather conditions

Environmental conditions before, during and after restoration affected the outcomes of many projects, with major impacts by stochastic events. The practitioners’ main strategy of dealing with this problem was repetition of plant material transfer.

Several practitioners mentioned negative consequences from flooding for plant material transfer in floodplain meadow restoration: “If you have a donor site in the active floodplain which is flooded over the summer, your measure is already dead for that year” (AUTH7; EN02, EN04). The main instrument to deal with such impacts was repetition and temporal diversification: “Once, we had heavy rainfall with 40 litres [per m<sup>2</sup>] in 25 min, which partly washed away the soil at the slopes. The excavator re-located [the soil] and we re-sowed [these areas]” (LSPO5; EN06). Droughts were another frequent obstacle, partly seen as an increasing problem due to climate change. In some cases, this lowered the possibility for farmers to forgo haymaking for plant material harvest: “Many farmers tell us that they have less yield due to climate change. The hay is getting limited” (PFPO2; EN03). Many practitioners reported lower species establishment due to drought after plant material transfer (EN05). In some cases, damages by wild boars, mice or deer occurred (EN01), but did not lead to the complete failure of restoration projects.

### 3.12. Resources

Limited resources were mentioned in relation to finances, personnel, and machinery. As a result, acquisition of these resources was sometimes time-consuming for the practitioners, and required a wide search radius.

Although insufficient financial resources were not frequently mentioned, some practitioners talked about such problems (RE04). However, external staff and suitable machines were hard to acquire in some regions. In terms of personnel, there were complaints of limited experience and dependence on farmers who have little time for restoration tasks: “We have to find [farmers] who will engage in [plant material transfer], no one has experience. [...] If only one will not do the work, you have a problem, then the plant material lies around somewhere [waiting to be transferred]” (COAG2; RE01). Lack of machinery was sometimes linked to the agricultural structure of a region: “The first problem is that we are not a grassland region. [...] Therefore, there are no silage wagons” (AUTH8; RE02). In such cases, more time had to be invested for acquisition, and the search radius often had to be extended: “If [the farmer] does not have the proper loader wagon, you may have to acquire a contractor 70 km away... then it gets more complicated and expensive” (LSPO7; RE02).

### 3.13. Project organization

While plant material transfer is, in principal, a simple method, the variety of tasks, short timeframes, and the different people involved make organization inherently challenging. Practitioners, thus, had to ensure good planning, task arrangement, and monitoring.

Timing was considered crucial in project organisation. Plant material transfer projects should be planned early in the eyes of many practitioners, which was not always realised (OR09). The complexity of plant material transfer projects, often with many involved people (OR6), requires good organization with close arrangement and communication (OR05). Combining tasks was suggested by several practitioners, particularly with respect to coordination: “One person has to coordinate this. [...] In my eyes, good coordination is key [...], so that you can create the required conditions. When do you have access to the site, when is the farmer available for soil preparation, and so on” (LSPO1; OR01). Accordingly, having own personnel was deemed beneficial (OR03). For dykes or road embankments, schedules determined by construction works increased the organizational challenge (OR10).

Practitioners often mentioned that monitoring practical tasks, e.g., by attending plant material harvest and application, was an important success factor (OR08). Several practitioners said that their projects were successful because they could implement their own ideas, while others criticised that decisions were taken from them: “Sometimes we are now forced by the commissioner to use secondary donor sites. Then [the result] doesn't become so great, obviously” (LSCG1; OR04).

### 3.14. Intrapersonal and interpersonal factors

Intrapersonal experience is the internal experience of an individual's mental and emotional processes, while interpersonal experience is the experience of an individual's interactions with other people. Practitioners underlined the relevance of both aspects for the outcomes of their restoration projects.

As an important intrapersonal factor, many practitioners mentioned the attitudes among the people involved in the restoration project. Openness towards the project idea was considered important, and disinterest strongly affected success of some restoration projects: “The responsible person [in the commissioning company] had no interest in proper application [of the plant material], this was all done by the construction company. The sites were totally neglected [...], you almost don't want to look at them any longer” (LSPO5; IF02). In contrast, enthusiasm and passion could be pivotal for successful outcomes (IF05). When technicians or farmers became interested in the projects, reliability increased greatly (IF06), and even motivated proactive involvement after longer collaboration: “We have a contractor who is able to do things on his own by now [and] makes own proposals. This collaboration is the reason that many things work out very well [in our county]. In other regions, it's harder” (LSPO7; IF03).

As a decisive interpersonal factor, getting familiar with each other and building trust with partners raised openness to the project ideas:

“We had farmers who [...] raised their hands and said ‘No, we won't do [plant material transfer], that's too complicated for us!’ They know that they have a conservation authority breathing down their necks. [...] For [plant material transfer], you need trust between conservation and agriculture. While you may build trust with something like this, trust is also a pre-condition for success” (AUTH7; IF07).

Increased trust and experience levels reduced necessity of close-meshed monitoring and controlling: “[This farmer] [...] knows why he does what he does. He's a lucky find. There are also other farmers with whom we cooperate, where we have to monitor a lot [more]”

(AUTH9; IF07, OR08, KE01, KE05). Building trust and acceptance was not only important concerning people directly involved in the restoration process, but also concerning farmers that manage sites: “A good relationship with the farmers is important to us, so that the farmer knows what happens on his site, where the [plant] material is from and where it is applied” (AUTH1; CU01, CU02).

### 3.15. Knowledge and experience

Knowledge and experience are considered crucial success factors. While practitioners were able to accelerate their learning by acquiring external information and support by experts, the ability to succeed reliably in plant material transfer appears only to grow with performing more projects. Many practitioners emphasised the importance of building on own experiences and knowledge over time:

“Reading some advice and thinking that you can just start now, it’s not like this. Plant material transfer looks like a very simple method, and it is simple in principle. [...] Somehow learning it is quickly done. But if you want to get really good at it, it’s very challenging. Then you need much experience... good practical, but also theoretical and botanical knowledge” (LSCG1; KE03, KE05).

Less experienced practitioners often acquired external knowledge through exchange with experienced practitioners or scientists. In the best case, practitioners involved them in their projects: “You need an expert who tells you when the time point [for harvest] is there, [...] otherwise the probability of failure is just too high” (AUTH1; KE01).

Some practitioners considered monitoring of restored sites a key tool to learn from their own projects (KE06). Knowledge exchange between involved people and joint learning over time was mentioned several times as an important success factor (KE07). Local knowledge and regional networks were considered very helpful to achieve successful outcomes:

“I think if you have a good network in a region, if you know the donor sites and the farmers who can do the management [of the restored sites], [plant material transfer] is a very good method. If [landscape planning] offices work in a new region, it is a tedious task in the first year. Things depend on our experience and the trustful collaboration with [the implementers]” (LSPO7; KE08).

## 4. Discussion and conclusions

The goal of our study is to contribute to improving practical grassland restoration outcomes with plant material transfer in the future. To achieve this, we have related relevant success factors from the practitioners’ point of view to the existing scientific literature. We find many overlaps between scientific findings and practitioners’ views, but also remarkable research gaps (Table 1 gives an overview; see Table A3 for the literature list, along with a detailed comparison of the practitioners’ views and the scientific findings, and Information A1 for the method of literature search). In the following, we discuss our findings with regard to the four research questions (RQ) from the Introduction.

### 4.1. The scientific evidence supports the practitioners’ views (RQ 1)

According to our literature review, science has almost exclusively investigated the rather process-related practical, technical, and ecological success factors of plant material transfer. Most prominently, scientific studies considered quality and composition of the donor sites (e.g., Kiehl et al., 2006; Wagner et al., 2021), abiotic conditions (e.g., Sengl et al., 2017; Sommer et al., 2023) and previous

**Table 1**

Number of studies found in our literature review (total of 37 studies) considering the 17 success factor categories of plant material transfer identified in the practitioner interviews. For each category, the number of studies supporting or contradicting the practitioners’ views is given, along with the number of studies investigating further success factors unmentioned by the practitioners. See details on this comparison and the studies in Table A3 and on the literature search methodology in Information A1.

Category	Number of studies		
	supportive	contradicting	success factors not mentioned
Acquisition and choice of donor sites	7	0	3
Acquisition of restoration sites	0	0	1
Abiotic suitability of restoration sites	12	0	2
Previous use and state of restoration sites	3	0	0
Soil preparation	5	1	2
Harvest and transfer of plant material	6	0	3
Application of plant material	0	0	0
Additional measures	4	0	3
Transitional management	1	0	0
Practice of post-restoration management	3	0	1
Communication with post-restoration user	0	0	0
Financing of post-restoration management	0	0	0
Environmental events and weather conditions	3	0	0
Intrapersonal and interpersonal factors	0	0	0
Project organization	0	0	0
Resources	0	0	0
Knowledge and experience	0	0	0

use of the restoration sites (e.g., Donath et al., 2007; Harvolk-Schöning et al., 2020), soil preparation (e.g., Bischoff et al., 2018; Szymura et al., 2022), plant material harvest (e.g., Bischoff et al., 2018; Kiehl et al., 2006), additional introduction of desired species (e.g., Hofmann et al., 2020; Slodowicz et al., 2023), and post-restoration management (Coiffait-Gombault et al., 2011; Rasran et al., 2007). Our analyses of the interviews show that all these aspects were considered relevant and mentioned frequently by the practitioners. Concerning the way these factors influence restoration success, there is a strong consensus between scientific findings and practitioners' views. For example, many practitioners underlined the importance of low nutrient supply of the restoration sites. This is supported by scientific studies where the panels of restored sites varied in nutrient richness (Schmiede et al., 2012; Sommer et al., 2023). However, some statements of the practitioners also indicate the existence of misleading narratives in practice. For example, LSCG1 reported attempts to develop low-productive meadows on pure gravel sites, which were unsuitable to support any meadow plant community due to very low nutrient supply (Section 3.5).

Some questions investigated by our reviewed studies have not or barely been mentioned by the practitioners. For example, extensive research has been carried out on the optimal thickness of the plant material layer and the size ratio of the donor and restoration sites (e.g., Donath et al., 2006; Scotton, 2018), but the practitioners hardly mentioned this as a decisive success factor. It is likely that limitations such as the availability of donor sites and narrow time frames for plant material transfer and application do often times not allow for targeted decisions on the layer thickness. This is in accordance with some practitioners, such as Paul whose example we present in the introduction, mentioning limited availability of high-quality plant material as a problem. Generally, the layer thickness might just not be a crucial success factor in many cases, as the moisture-keeping effect only becomes relevant during droughts, and too thick layers only affect a subset of species, i.e., small-growing (Hansen et al., 2022) and small-seeded ones (Eckstein and Donath, 2005). Another success factor considered by science but not mentioned by practitioners was the removal of unwanted species on the restoration sites prior to plant material application (Hansen et al., 2022; Szymura et al., 2022). According to our interviews, in practice, such species were removed from restoration sites after plant material transfer as part of the transitional management. As overall, practitioners knew about the relevance of managing undesired species, this supports the conclusion that practitioners are generally aware of the important success factors as identified by science.

#### 4.2. Many success factors are beyond the previous scope of science (RQ 2)

The different technical-ecological, process-related success factors considered by science and practitioners will, if taken into account, likely contribute to successful restoration outcomes in many cases. However, it has become evident that practitioners were only able to set up their projects accordingly if a range of additional conditions were met. Most prominently, trustful relationships between the involved people and good organization of tasks were key for many practitioners. The higher the practitioners' experience levels, the better they were able to take the different factors into account. For example, AUTH1 was aware of the importance of the right harvest date. However, they did not feel confident about defining it, but felt the need for an "expert" to do this (Section 3.15).

Restoration science, mainly with regard to stakeholder relations in large-scale restoration projects, has identified the importance of good communication and trust-building (e.g., Druschke and Hychka, 2015; Gamborg et al., 2019; Strauser et al., 2020) and given advice on how to gain trust and foster interest and involvement of different stakeholders (Gornish et al., 2021). Most of the projects of the practitioners we interviewed were small-scale projects with one or few restoration sites. However, the importance of communicating and building trust with relevant stakeholders is also transferable to such small projects and can be facilitated by the smaller number of people involved (Metcalfe et al., 2015). If practitioners can build on local networks, plant material transfer is more likely to succeed as key stakeholders do not have to be identified in advance. This aspect is also known from ecological restoration in other contexts (Buitenhuis and Dieperink, 2019; McGuire and Ehlinger, 2022). While trustful relationships can be helpful, organizing plant material transfer projects remains very challenging due to their inherent complexity, as pointed out by Latacz-Lohmann et al. (2022). Good organizational skills are therefore another key for practitioners, but will probably only grow with experience over time.

#### 4.3. Knowledge acquisition and trust-building are key for practitioners (RQ 3)

Our findings indicate that the most promising bases for successful plant material transfer projects, such as good local networks and broad ecological and practical knowledge as well as organizational skills, will hardly ever be available to practitioners from the outset. Long-term restoration activities by established regional networks are therefore more promising compared to isolated short-term projects like Paul's, which is presented in the Introduction. We advise practitioners who have little or no experience with plant material transfer to level their expectations, be patient, and not to give up if initial restoration attempts are not successful. To improve chances of success, we recommend integrating experienced practitioners in restoration projects. When this is not possible, talking to experts and acquiring knowledge from compendiums may be the second-best option. Accordingly, we encourage expert practitioners of plant material transfer to share their knowledge and experiences.

In many cases, it will be crucial to collaborate with local farmers, authorities, and various other stakeholders. Practitioners must recognize the significance of cultivating positive and trustworthy relationships with these local partners. It is important to acknowledge that fostering trust and cultivating interpersonal connections requires deliberate effort and cannot be established instantaneously. By proactively convening different stakeholders and staff before commencing a project, a sense of community can be fostered, and potential sources of conflicts or mistrust can be identified. To achieve this objective, collaborative solutions can be developed to address specific concerns. For instance, during the process, it may become apparent that a farmer responsible for managing the site after restoration exhibits disinterest in the project and may consider re-sowing the area with commercial seeds, posing a risk to the restoration efforts. In such instances, strategies for appropriate management following the transfer of plant material

to avoid weed dominance and improve acceptance can be openly discussed among stakeholders. Alternatively, if financial resources are available, a contractual arrangement might be explored to address this issue.

#### 4.4. Interdisciplinary work and targeted communication are key for science (RQ 4)

Although scientific focus has primarily revolved around technical and ecological research pertaining to plant material transfer, recent studies have yielded novel and valuable insights in this domain such as into the transfer of invertebrates (Stöckli et al., 2021) or the long-term success factors of restoration (Harvolk-Schöning et al., 2020; Sommer et al., 2023). While some success factors examined by scientific research were not explicitly mentioned by practitioners, we encourage scientists to explore aspects that might extend beyond the immediate concerns of most practitioners. For example, the roles of functional connectivity provided by management (Klinger et al., 2021) or of soil organisms, such as earthworms (Buisson et al., 2021) or mycorrhizal fungi (Kozioł et al., 2022), have rarely been investigated. Additionally, science could support practitioners by systematically investigating reasons for failure or success in restoration practice. As factors linked to project organization may strongly influence project outcomes, information on the inter-personal, intrapersonal, and organizational setups of the projects should be considered in addition to technical and ecological data. To this end, interdisciplinary studies of natural and social scientists on restoration success are needed. Further, science could support targeted spread of knowledge on plant material transfer by studying the distribution of practitioners' experience levels across regions and countries in Europe.

Our analysis did not provide a definitive answer regarding the specific means by which practitioners acquired their knowledge and formed their perspectives on success factors related to plant material transfer. Nevertheless, certain practices have shown promise in this regard. These include conducting literature reviews (e.g. Kiehl et al., 2010; Török et al., 2011), publishing compendiums and guidelines in national languages (e.g., Harnisch et al., 2014 and Hölzel, 2007 in German or Johansson et al., 1991 in Swedish), and organizing collaborative workshops with practitioners. Notably, the alignment between practitioners' views on success factors and the available scientific evidence suggests the effectiveness of these approaches. Generally, it is crucial that science communicates its results broadly using all these tools, potentially focusing on regions or countries where knowledge gaps are largest, once these have been identified.

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#### CRediT authorship contribution statement

**Leonhard Sommer:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Bente Castro Campos:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization. **Sarah Harvolk-Schöning:** Conceptualization, Methodology, Supervision, Project administration, Funding acquisition. **Tobias W. Donath:** Conceptualization, Writing – review & editing, Funding acquisition. **Till Kleinebecker:** Conceptualization, Writing – review & editing, Resources, Supervision, Funding acquisition. **Yves P. Klinger:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

As agreed with the interviewed practitioners, we have anonymized their responses in the supplied Appendix (Table A2).

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#### Appendix A. Supporting information

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