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Restoration prioritization for industrial area applying Multiple Potential Natural Vegetation modelling

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Short title: Restoration prioritization for industrial area

Abstract

Scaling up ecological restoration demands the involvement of private sector actors. Experience regarding science-based habitat restoration programs in the sector should be made available to support further joint projects. In our case, hierarchical restoration prioritization was applied to select best target for habitat reconstruction at a Hungarian industrial area. Multiple Potential Natural Vegetation Model (MPNV), a novel approach supported restoration prioritization satisfying both ecological (sustainability and nature conservation value) and other needs (feasibility, rapid green surface, amenity and education value). The target that met all priorities was the open steppe forest that has a mosaic arrangement with open and closed sand steppes. The potential area of this xero-thermophile oak wood is expected to expand in Hungary with climate change, therefore the selected target has a likelihood of long-term sustainability, if established. A matrix of sand steppes was created first at the factory area in 2014-2015, and tree and shrub saplings were planted in this matrix. The seeding induced rapid changes in vegetation composition: the second year samples became close to reference sand steppes in the PCA ordination space. Tree and shrub survival was species dependent, reaching a maximum of 52 and 73% for tree and shrub species, respectively. One tree and two shrub species did not survive at all. Altogether 53 of 107 target species have established. So far, restored vegetation development confirmed the suitability of the applied hierarchical prioritization framework at factory scale.

Keywords: private sector actors; forest steppe; grassland restoration; restoration planning; target setting

Implication for Practice

- Non-built up industrial areas provide good opportunities as native biodiversity refuges if restored, and may contribute to achieve no net loss and restoration targets.
- Multiple Potential Natural Vegetation models with adequate spatial resolution provide a range of ecologically relevant restoration targets and allow the consideration of technical constraints and social preferences in goal setting.
- In highly transformed landscapes a range of potentially self-sustainable target communities instead of a single pre-disturbance, historic composition provides better ground for restoration planning.

Introduction

The need for ecosystem restoration is acknowledged at the policy level by now (Aronson & Alexander 2013; Suding et al. 2015) and as a result, large-scale restoration efforts are launched (Jacobs et al. 2015). This scale of restoration remains a symbolic policy without the active contribution of private sector actors (Holl & Howarth 2000; Telesetsky 2012). The growing corporate concern about biodiversity loss and intention for mitigation goes beyond offsetting direct adverse industrial impacts (GPBB 2015). Attempts aim for no net loss and even net gain of biodiversity (Rainey et al. 2015). Marketization of biodiversity offsetting endeavors are debated because of high expectations towards ecologists (Benabou 2014) and inadequate supporting policies (Maron et al. 2012; Gordon et al. 2015; Quétier et al. 2015; Bull & Brownlie 2016). Despite the broad literature on offsetting, restoration cases are mainly described for mining activities (Maron et al. 2012) and not for greening industrial areas. Great impediment for private sector actors is the lack of competence on habitat restoration, maintenance, costs and outcomes (Spurgeon 2014; Rainey et al. 2015). At the same time, there is a major concern that in the lack of scientific rigor during the planning and implementation of private sector driven projects the outcomes can be challenged (Cairns 2000; Gardner et al. 2013). Therefore examples of collaboration among private sector actors and scientific institutions for implementing habitat restoration programs should be made available to support further joint projects. The professional certification program in ecological restoration of the Society for Ecological Restoration may open further possibilities for increasing the quality of performance (Nelson et al. 2017).

Restoration ecology has made great progress during the last few decades in applying ecological knowledge to amend or restore the ecological integrity of degraded land (Higgs et al. 2014). Support for planning restoration projects by developing conceptual frameworks and guiding principles have been published (e.g. Balaguer et al. 2014; Meli et al. 2014; Jacobs et al. 2015; Suding et al. 2015; McDonald et al. 2016; SERA 2016). These concepts are not fully applied during the practice of restoration (Wortley et al. 2013; Török & Helm 2017). The potential natural vegetation (PNV) concept provides a useful tool to guide scientific target setting (Miyawaki 1998; Moravec 1998; Loidi & Federico-González 2012; Somodi et al. 2012), and has been exploited in restoration projects (Miyawaki 1998; Rice & Toney 1998). PNV is often not separated from pre-human or pre-settlement vegetation in this context (e.g. Brown et al. 2004, Jiang et al. 2013). We believe it is important to differentiate between the two in restoration target setting as well (Somodi et al. 2012).

PNV in the traditional sense determines a single vegetation type as potential for any location (Tüxen 1956). However, neither our estimation ability is perfect, nor is the vegetation development deterministic, thus multiple stable states may exist in undisturbed environments as well (e.g. Suding & Gross 2006; Choi et al. 2008). Thus the PNV of a single location should be characterised by more than one vegetation type, either because of estimation uncertainty or because the site conditions would allow the persistence of several different vegetation types even if with differing likelihoods. The concept of multiple potential natural vegetation (MPNV) was introduced to provide a framework for handling this multiplicity (Somodi et al. 2012). MPNV may be estimated by expert knowledge or by automatic methods, such as predictive vegetation modelling. Such a model-based estimation is available for Hungary for all broad vegetation types in a resolution of 35 hectare hexagons (for overviews visit www.novenyzetiterkep.hu/node/1411; estimated values are available as a database through the gateway of the MÉTA database; Somodi et al. 2017). The MPNV estimation can be considered as a multilayer map depicting the suitability of present conditions regarding individual vegetation types, as it formalises on the relationship of vegetation with a synthesis of climate, hydrology, soil and terrain variability.

We report on a project initiated by a private company committed to caring for the environment, where best available scientific knowledge was applied during target setting and implementation. The LEGO Group has decided to reconstruct native habitat around the factory buildings in Hungary, at about 20 hectares. The main task of scientific planning was to define a target habitat type that is sustainable with low management input in the long term, has nature conservation value and is feasible to restore. Main challenges of feasibility include: i) to find the most suitable target habitat providing nature conservation value in a highly modified landscape; ii) to provide rapid green cover with amenity value; iii) no detailed historic record of previous native vegetation exists for the factory area; iv) threat of invasive ragweed (*Ambrosia artemisiifolia,* nomenclature Király 2009) dominance after construction works; v) restricted market of native seeds in Hungary; vi) limited availability of natural habitats as donor sites in the area; vii) short term contract as a start. With so many aspects to consider, a hierarchical prioritization for target selection was applied with the Multiple Potential Natural Vegetation Model (MPNV) providing the ecological basis. The paper describes how the model was used for target setting and how the challenges presented by the industrial collaboration have been met along the prioritization framework process. We evaluated the success of target setting by reporting on the early establishment of vegetation. No similar case of vegetation restoration in a factory yard was found in the literature, therefore report on success could help spreading the idea that there are further opportunities for native vegetation restoration in urban-industrial areas.

Methods

Site description

The new factory of the LEGO Group is situated at Nyíregyháza, N-E Hungary in the acidic inland sand dune region of Nyírség (lat 47° 57'N; long 21° 39'E). Annual average temperature is 9.8ºC, average precipitation is 550-600 mm. Major land use types are arable farming, orchards and forest plantations (mainly non-native Black locust *(Robinia pseudoacacia)* and poplar *(Populus spp.*). Native steppe vegetation is scarce in the region, and missing from the surroundings of the factory (Fig. S1). The construction of the factory was carried out at previous apple orchards and arable fields, and included the destruction of the local relief. The area provided for the restoration project is divided into parcels (between 1 and 4.5 ha) around the buildings (Fig. 1). The sandy soil is loose, with very low water holding capacity, low calcium, humus and nutrient content. The pH is close to neutral on the top and generally acidic in the lower soil layers (Table S1). The parcels were obtained for planting at different times according to release from construction works and were initially covered by weeds or were left bare after construction.

Hierarchical prioritization for target habitat selection

The selection of the target habitat type was based on multiple criteria. Priorities were arranged to three tiers. First, the most important priority was assigned to the self-sustainability and the nature conservation value of target habitat. Second level priorities included feasibility of restoration and the production of rapid green surface to avoid sand blow. Amenity and education value were considered contributing to the third trier. Feedback was used among these tiers to find the best solution. The conceptual framework for prioritization is demonstrated in Fig. 2. The idea was to search for the best solution within the most important tier and if the next tiers were compromised, to go back to identify a target fulfilling all tier priorities, best as possible.

Tier 1 priority

The search for the probable vegetation type at the factory area was based on the assumption that the vegetation type adapted to the given combination of environmental variables has the highest potential to survive, when restored. To find this vegetation type the Multiple Potential Natural Vegetation Model (MPNV) was applied (Somodi et al. 2012; 2017). The MPNV estimation was carried out covering the full country in a previous project. In the course of the modelling Gradient Boosting Models (Elith et al. 2008) were used to relate the abiotic conditions to the observed presence of natural vegetation types. The statistical relationships identified were used to estimate presence probabilities of vegetation types as defined in the national habitat classification system (Bölöni et al. 2011) for the whole country including areas currently devoid of natural vegetation (Somodi et al. 2017). The same 35 ha resolution (of adjacent hexagons) was used for the predictions as the input vegetation data were available in this scale (MÉTA database; Molnár et al. 2007). Half of the vegetation data of a particular habitat was used for training the model, the other half for testing model outputs. Raw probabilities provided by models underlying MPNV cannot be compared across vegetation types, because absolute probability values depend not solely on environmental suitability but also on the data characteristics per vegetation type, which is an undesirable property. Habitats with few occurrences due to specific environmental requirements but not due to human intervention and widespread zonal types achieve high probabilities in absolute, but those with few occurrences due to conversion by humans have lower probabilities even where they are relatively probable compared to their own distribution. To be able to assess the range of habitats belonging to PNV at one location (in our case within one hexagon), probabilities of different habitats needs to be standardised. A rescaling procedure was applied yielding an ordinal scale of 5 ranks (0, 1, 2, 3, 4, the last being the highest probability). Rescaling ensures that habitats with equal ranks are equally likely members of MPNV at one location.

The obtained categories are as follows (the applied algorithm can be found in the Supporting information Fig. S2):

0- lower probability than the minimum probability within hexagons with observed presence

   Lowest probability: Only possible in hexagons where there is no observation of the habitat.

1- higher probability than the minimum probability within hexagons with observed presence, but lower than the average probability within hexagons without observed presence

   Low probability: It is lower than the average predicted probability for hexagons with absence observations.

2- higher probability than the average probability within hexagons without observed presence, but lower than the average probability within hexagons with observed presence

   Medium probability: higher than probabilities in hexagons, where the vegetation type was not observed, but lower than probabilities in hexagons with observations.

3- higher probability than the average probability within hexagons with observed presence, but lower than the highest value within hexagons without observed presence

High probability: the highest achievable score for hexagons without observation of the habitat.

4- higher probability than the highest value within hexagons without observed presence.

Extreme high probability: high probability even within hexagons, where the habitat was observed.

Eight hexagons overlap the respective territory of the factory regarding the MPNV units, but the surrounding was also considered by altogether 21 hexagon data. Habitats that require different soil type from that of the restoration parcels (Table S1) were rejected: halophytic vegetation, types directly influenced by water and those that develop on loess base rock. The most probable vegetation types for the average of the 21 hexagons were: closed and open sand steppes, closed lowland oak forests and open steppe oak forests on sand (Table S2, Fig. 3). All these habitat types are protected under the EU Habitat Directive as priority habitats (HD: 6260, HD: 9110 Council Directive 1992), therefore no further selection was required regarding nature conservation priority. For the description of the habitat types see Table S3.

Tier 2 priority

For the second tier, propagule availability was estimated based on the survey of national seed market and on local knowledge for donor sites suitable for seed or hay collection. The species composition of the identified target habitat types provided the basis for the selection of target species to be used in the restoration intervention. A list of 107 target species was compiled to serve the search for propagules according to descriptions of species composition of the respective habitats (e.g. Bölöni et al. 2011) and local expert knowledge (Table S4). Relatively good provision of saplings of native tree and shrub species exists, but the native seed market is very limited in Hungary for steppe species. Only 15 target species could be purchased from wild collections or cultivation. To increase diversity, we carried out seed collection by hand, plus a seed mixture of generalist species from Hungary of cultivated origin was purchased. Altogether the seeds of 50 plant species were purchased or collected in 2014 (Table 2). In the lack of appropriate seed market, hay transfer as an alternative method to introduce species was also considered.

Tier 3 priority

There was no preference among native habitat types expressed by the contractor, except to ensure leisure-time activities and education near the entrance area. Therefore general amenity and social preference (Staats et al. 2003) were considered. Previous studies found preference for forest – grassland mosaic habitats around built up areas (Van den Berg & Van Winsum-Westra 2010; Martens et al. 2011; Hauru et al. 2012). Closed lowland oak forest does not fulfil this view, and was neglected as a target habitat. The potential value for environmental education was also considered during the prioritization to promote the bioliteracy of local population (Cruz & Segura 2010). There is a great potential in the project for environmental education, as the factory is highly attractive to visits for the sake of LEGO toys. As an outreach, local school groups were involved in tree planting in 2014 for whom information about the restoration project and the factory were provided. A demonstration garden was also constructed for visitors with a number of representative plant species and information boards on the role of biodiversity, target communities and the ecological restoration program (Fig. S3).

Target vision

Based on the outcome of the hierarchical prioritization, altogether three habitat types were selected as restoration targets: closed and open sand steppes and open steppe oak forests.

Open steppe woodlands dominated by the Pedunculate oak (*Quercus robur*) contain smaller groups of trees and have a mosaic arrangement with dry grasslands, including open and closed sand steppes that gives a parklike appearance. We used this habitat type as a kind of vision with a goal to reconstruct the physiognomy rather than the total historic species pool (Fig. 4). The goal therefore was not to reconstruct a single past habitat type, but to focus on the introduction of wooded and open ecological mosaics with the help of character and available species and by adequate planting and management techniques to ensure the survival of as many native, late seral species as possible.

Field work

Parcels became available for planting according to the factory construction phases, sometimes in seasons unsuitable for restoration. Therefore preparatory plants, lucerne and rye commonly used in the region were selected to provide green cover and control of weeds and invasive species (mainly ragweed, *Ambrosia artemisiifolia*). Soil compaction was treated by ploughing, deep soil loosening and seedbed preparation before sowing and hay distribution, equally carried out at previous nurse plant parcels. Restoration parcels differed in seed introduction methods and seeding rates according to the availability of species at the time of release from construction (Fig. 1, Table 1). We present in detail the 2014 seed introduction (Table 2). Altogether 50 grass and forb species were seeded in 2014. Four basic types of seed introduction were applied: 1) a general biodiverse mixture of native cultivated seeds (parcel NW1); 2) seeds collected by our staff (parcels N, S); 3) seeds originating from wild collection (parcels N, S); and 4) the distribution of seed containing hay (parcels SE, SW). All seeds were sown by hand evenly to the whole parcels (Fig. S4), except for seeds collected by our team that were distributed to less than 0.5 ha in patches, due to low amount of seeds. Dried hay was obtained from three donor sites within a 60 km distance from the factory. Early summer hay containing Fescue seeds (cc. 30 bales/ha; one bale about 250 kg) and bales from late harvest containing mainly forb seeds (cc. 4 bales/ha) were distributed to whole parcels by hand and pitchfork as evenly as possible, at about 5 cm cover. We used hay also as mulching on seeded parcels (N, NW1, NW2, S) to control erosion by wind and for weed suppression (cc. 10 bales/ha).

Forest patches (sizes 300-3000 m^2) were planted after seed introduction. The desirable proportion of forested patches was between 20-30% (similar to natural values). Trees were not planted in rows, but followed an irregular design that considered both ecological and amenity requirements (Fig. S5). More than 16,000 specimen of 2-year-old undercut tree and shrub saplings belonging to 23 species were planted in late autumn of 2014 and 2015 (Table 3). Severe drought and game damage impacted 2014 plantings resulting in more than 70 % die off. Only species with relatively good survival (17 species) were planted in 2015 with the share of *Quercus robur* increased and 735 bigger oak samplings (3-4 years old) added. Composted sewage sludge was given to each hole (0.1 kg) and rabbit mesh applied in winter to increase survival. Post-treatment management implied machine mowing twice per year, including the forested area, where hand mowing was applied.

Monitoring

The success of seed introduction was monitored against pre-treatment baseline, control and reference areas. Multiple controls replace the usual no-treatment type as there was no option to leave open surface within the factory area at a sufficient size. These included a low diversity, traditional lawn within the factory area (6 ha) and a non-seeded control on a clear-cut orchard where only tree plantations were allowed (parcel E, 7.5 ha in Fig. 1). Reference grassland habitats included primary open and closed sand steppes from three locations (Bátorliget 23 ha, Martinka 185 ha, Magy 6.5 ha). We applied the same sampling protocol for control, reference and restoration sites. We estimated visually the cover of each vascular plant species on percentage scale in 5 randomly placed phytosociological plots (2 m x 2 m) in each restoration parcel in June 2014, 2015 and 2016. As for species sown into discrete patches, the whole patch was surveyed and the total area of each species was given per patch. Control areas were sampled only in June 2015 and 2016 and reference areas were sampled either in June 2015 or in June 2016. Survived planted trees and shrubs were counted in 2015 and in 2016 as well.

Data analyses of vegetation development

Relationship between herbaceous species composition and study sites (restoration parcels, reference, and control sites) was explored by successional trajectories drawn on indirect ordination (Principal Component Analysis, PCA) (Legendre & Legendre 1998; Podani 2000). Restoration parcels and control sites were grouped based on elapsed time from intervention: baseline (before treatment, T0, N=35), 1st (T1, N=35) and 2nd year-old (T2, N=20), lawn (L1, N=5; L2, N=5) and non-seeded control (C1, N=5; C2, N=5). Reference data included 15-15 samples for open and closed steppe (RO, RC). PCA ordination was based on species cover data, transformed by log transformation. Because of uncertainties in distinguishing young Furrowed fescue *(Festuca rupicola),* Hard fescue *(F. pseudovina)* and Valesian fescue *(F. valesiaca)*, the three species were grouped under the name *Festuca spp*. The PCA was centered by species, and centroids of groups were calculated to draw the trajectories along the 1st and 2nd axis in the ordination space. Multivariate analyses were carried out with Canoco for Windows 4.5 (Ter Braak & Smilauer 2002).

Results

Grassland development

Restoration of the grassland matrix can be considered successful based on 2nd year data. The total coverage achieved by seeding was similar to sand steppes (parcels S: 58% and NW1: 115%). The dominant fescue species reaching 27-38% average cover, comparable to the open sand steppe (max 30%, Fig. S6). Out of the 50 seeded species, 38 established by the second growing season (Table 2). Hay addition resulted in a lower total coverage (43%) comparable to that of the open sand steppe. Lucerne, grasses and target species amounted up to 70% of total cover.

PCA ordination proved an accelerated development of vegetation as a result of seed introduction compared to control areas (Fig. 5). The seeding induced rapid changes in vegetation composition, the second year samples became closer to closed sand steppes as the trajectory moved along the first axis (Fig. 5a). The second axis separated non-seeded control from restoration parcels and reference plots, indicating that without seed introduction the succession gets stuck at an annual dominated phase. The distribution of the most abundant species in the ordination space provides clarification on the differences. Drooping brome *(Bromus tectorum)*, Hairy vetch *(Vicia villosa)* and Horseweed (*Conyza canadensis)* dominate the unseeded control samples, while *Festuca pseudovina* and Plantain *(Plantago lanceolate)* dominate reference and second year restored samples (Fig. 5b). Invasive ragweed (*A. artemisiifolia*) also belongs to the annual dominated phase (2%), and the shift of treated plots along axis 1 demonstrates that treatment was successful in suppressing this invasive species, resulting in a coverage of 0.01% by 2016.

Tree and shrub survival

The trees and shrubs of 2014 autumn plantation were impacted by severe dieback due to drought, only 22 and 17% of woody species survived on average, respectively (Table 3). Re-planting by only less sensitive species next year was more successful, and resulted in 30 and 49% average survival for trees and shrubs. Tree and shrub first year survival was species dependent, reaching a maximum of 52 and 73%, respectively (*Ulmus minor*, planted 2014; *Prunus spinosa*, planted 2015). Young and elder oak saplings had similar survival rate (28%)

regarding second year planting. Survival rates at forest patches ranged from 11 to 70% (not detailed by patch in Table 3).

Discussion

The novel prioritization framework with hierarchical tiers representing different importance proved to be a viable concept, resulting in a pragmatic and operational decision support for restoration planning at site scale. The three tier prioritization model reflects all four principles of successful restoration as defined by Suding et al. (2015). In their model they advocate for the following principles that restoration planning should take into consideration: increase of ecological integrity; sustainability in the long term; planning to be informed by the past and future and results should benefit and engage society. Our approach follows the logic of first selecting a range of habitats best fitting to the ecological requirements, in the hope of ensuring ecological integrity and sustainability. The set of target species were selected according to historical and contemporary records of species composition of the respective habitat. The estimation of climate change tolerance of the target community type was included as estimation of future changes. Next step was narrowing down this range of community types according to social preference and feasibility (e.g. availability of propagules). This process included considering the benefits of local people as cultural ecosystem services by providing amenity and education values. Our approach can be considered as a possible way for the implementation of the principles articulated by Suding et al. (2015).

The success of the approach at site level cannot fully be evaluated yet, but the development of the seeded parcels towards the reference steppes in two years is encouraging. Restoration sites became similar to closed sand steppe references and the invasive species cover decreased as expected. The amount of survived trees and shrubs gives hope to achieve a forest steppe-like community in the long term. This kind of prioritization can be easily adapted to other restoration projects, with a few considerations in mind.

In the heart of the prioritization was the MPNV modelling used for the first time for selecting restoration target. MPNV provides multiple vegetation types, all of them suitable for the site conditions, though with differing probabilities (Somodi et al. 2017). Its use allows for a wider starting set of suitable vegetation types before weighting of natural versus technical constraints and social preferences. A variety of targets for restoration has been long advocated (Walker & del Moral 2009; Thorpe & Stanley 2011, Stanturf et al. 2014), however, these multiple targets appeared at a higher hierarchical level, i.e. aiming at restoring pre-settlement vs. sustainable vegetation (Thorpe & Stanley 2011) or targeting habitat of a flagship species vs. targeting restoration of vegetation (Fraser et al. 2017). If PNV was considered, it was typically considered as a single option (e.g. Miyawaki 1998; Moravec 1998; Řehounková & Prach 2008). State-and-transition models and approaches (Westoby et al. 1989; Briske et al. 2005) are somewhat similar to MPNV in their basic principle, however they include vegetation sustainable under human management and allow for a change in abiotic conditions (soil erosion) in transitions. Similarly, Prach and del Moral (2014) implicitly argues for the relevance and importance of allowing for multiple stable states in restorations. A difference of both alternative approaches compared to MPNV is that their reference to multiple stable states includes PNV and potential replacement vegetation (PRV; sensu Chytry 1998) together, i.e. self-sustainable vegetation and vegetation stable under human management only and achieves variation in targets this way. In contrast, our scheme allows for variation within PNV member vegetation types offering a variety of potentially self-sustainable vegetation types (even if self-sustainable to a different, but quantified degree). Our results suggest that a flexible potential natural vegetation scheme can effectively support restoration if PNV is viewed as a probability distribution of vegetation types. Current criticism of potential vegetation maps being too coarse scale for restoration targeting (Siles et al. 2010) is also resolved by MPNV as it is based on 35 hectare units.

Sustainability in the long term can be ensured either with focus on appropriate management (Suding et al. 2015) or better by selecting from probable vegetation types suited to the location (our approach) or some combination of these two approaches. A limit to the approach of the target setting at the moment is that estimations are typically available only for the actual conditions at appropriate resolution and the approach does not account for potential future changes, from which climate change appears inevitable. Ideally, a restoration target should be set so that it both complies with actual and future conditions (Battin et al. 2007; Choi et al. 2008). The dominant target species can serve as a proxy when estimating habitat survival under climate change (e.g. Gelviz-Gelvez et al. 2015). Oaks are reported to tolerate well the expected climate change in the Carpathian Basin (Hlásny et al. 2014). Although Hickler et al. (2012) provided an estimate for the future distribution of dominant species in Europe, this estimation is too coarse for local applications. A better target setting would have been ensured by considering MPNV and multiple potential future vegetation (Somodi et al. 2012) together. Potential future vegetation estimations are rare, however, models for expected forest zonation change exist for two climate scenarios for Hungary at a country scale (Mátyás 2006; Czúcz et al. 2011). According to the worse scenario (1,3°C avg. temperature increase and 66 mm yearly precipitation loss), zonal closed forests will shrink, while the forest steppe zone will remain in the lowlands and further expand to the foothills of mountain areas.

In case of threatened and rare habitats, restoration projects might face the problem of scarce availability of local propagules. In similar cases we propose the parallel use of available propagules together with direct seed harvest and the application of seed containing hay material (cf. Kiehl et al. 2010). The approach to introduce as many target species as possible and let the system further develop beside careful, low-intensity management meets the technical constrains often imposed by the short contractual period to create a rapid, but natural-like green surface. Societal benefits are taken into account at lower tiers. High visibility and park-like landscape around built up areas adds to community acceptance.

The open steppe oak forest on sand is one of the most threatened and rare habitats for the Pannonian region (Bölöni et al. 2011), and the sand steppes are also priority habitats (Council Directive 1992). Although there are well-known examples of large-scale steppe (Lengyel et al. 2012) and steppic forest (Verő 2011) restoration efforts in Hungary, this experiment is unique as no example of forest steppe complex restoration is known that commenced on bare soil. Usually forest restoration focuses only on the trees and shrubs and herb layer is modified later (Honnay et al. 2002). In this study we considered the herb layer in the wooded patches as a grassland to be restored parallel with the effort to plant the forest.

Our study demonstrates that MPNV and similar models can help private sector actors to contribute to comply global or European commitments to restore degraded habitats at private land. Non-built up industrial areas can be used as native biodiversity refuges instead of intensively managed, species poor green areas. Widely known good practices that imply lower management costs may have a snowball effect (Wortley et al. 2013) and attract other companies to act similarly.

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Table 1. Summary of seed introduction methods and seeding rates of restoration parcels. Parcels became available for planting according to the factory construction phases. No seed introduction took place at parcel E. 2015 spring seeding had to be repeated in autumn due to summer drought. Codes follow Figure 1. For details on 2014 seeding rates see Table 2.

Code	**N**	**NW1**	**NW2**	**S**	**SE**	**SW**
Restoration area (ha)	1.5	4.5	4	2.6	1	1.7
Preparatory nurse plant						
Timing	2014 summer	2013 autumn		2014 summer	2013 autumn	2013 autumn
Nurse plant (kg/ha)	20	20		20	20	20
Seed introduction with hay						
Timing					2014 summer	2014 summer
Grass (bale)					26	40
Forbs (bale)					5	6
1st seeding					(only 0.03 ha)	
Timing	2014 autumn	2014 autumn	2015 spring	2014 autumn	2015 autumn	
Matrix grass	Festuca rupicola	Festuca pseudovina	Festuca pseudovina	Festuca rupicola	Festuca rupicola	
Cultivated seeds (kg/ha)		45	45			
Hand-collected seeds (kg/ha)	0.6			0.36	0.83	
Purchased collected seeds (kg/ha)	70			60	30	
2nd seeding						
Timing	2015 spring		2015 autumn			
Matrix grass	Festuca pseudovina		Festuca pseudovina			
Cultivated seeds (kg/ha)	45		65			
Nurse plant (kg/ha)	20					
3rd seeding						
Timing	2015 autumn					
Matrix grass	Festuca pseudovina					
Cultivated seeds (kg/ha)	88					
Hand-collected seeds (kg/ha)	10					
Mulching						
Timing	2015 autumn	2014 autumn	2015 autumn	2014 autumn		
Mulch (bales)	8	42	37	26		

Table 2. Seeding rates (2014) and 2nd year survival (2016). Herbaceous species were either purchased from cultivators (parcel NW1) or collectors (parcel N) or collected by the project staff (parcel S). Note: + is less than 0.01 g/ha; * is in %, not m^2

	Parcel Code	**NW1**		**S**		**N**	
	Origin of seeds	Cultivated seeds		Hand-collected seeds+purchased Fescue		Purchased collected seeds	
No.	Species names	seeding rate (g/ha)	mean cover 2016 (%)	seeding rate (g/ha)	total cover 2016 (m^2)	seeding rate (g/ha)	mean cover 2016 (%)
1	*Achillea collina*			250	65		
2	*Achillea millefolium*	370	0.01				
3	*Agrimonia eupatoria*	839	0				
4	*Anthemis arvensis*	730	2				
5	*Anthemis tinctoria*	730	0.4				
6	*Anthyllis vulneraria*	370	1				
7	*Berteroa incana*			2	15		
8	*Centaurea arenaria*			1	24		
9	*Centaurea cyanus*	730	0.2				
10	*Centaurea jacea*	730	1				
11	*Consolida orientalis*	730	0.2				
12	*Consolida regalis*	730	1				
13	*Corynephorus cansecens*			10	0		
14	*Cynoglossum hungaricum*			2	+		
15	*Dianthus pontederae*			4	4		
16	*Erysimum diffusum*			5	13		
17	*Festuca spp.*	30000	38	60000	27*	60000	0
18	*Festuca vaginata*			21	0.1		
19	*Filipendula vulgaris*					1.8	0
20	*Galium verum*	440	0			2.7	0
21	*Gypsophila paniculata*	370	0				
22	*Hieracium pilosella*			1	0.3		
23	*Hypericum perforatum*			14	2	500	0
24	*Hypochoeris radicata*			1	1		
25	*Jasione montana*			7	1		
26	*Knautia arvensis*					100	0
27	*Lathyrus tuberosus*	730	0.3				
28	*Leucanthemum margaritae*	1100	0				
29	*Linum perenne*	1100	1				
30	*Lotus corniculatus*					1.5	0
31	*Onobrychis arenaria*	110	0				
32	*Origanum vulgare*	370	0				
33	*Papaver rhoeas*	730	2				

34	*Petrorhagia prolifera*			3	16		
35	*Peucedanum oreoselinum*			9	0		
36	*Plantago lanceolata*	730	7			1.5	0
37	*Poa angustifolia*			1	+		
38	*Potentilla argentea*			1	3.8	500	0
39	*Pseudolysimachion spicatum*					100	0
40	*Rumex acetosella*			7	3.5		
41	*Salvia austriaca*	150	0				
42	*Salvia nemorosa*	1000	0.1				
43	*Salvia pratensis*	1100	0				
44	*Securigera varia*	730	0.01			1.5	0
45	*Silene alba*	370	2				
46	*Silene nutans*					250	0
47	*Silene vulgaris*	730	0.5				
48	*Taraxacum officinale*	90	0.01				
49	*Teuchrium chamaedris*			22	0		
50	*Verbascum densiflorum*			1	0		
	TOTAL	45809	57%	60362	149 m^2	61459	0%

Table 3. Number of planted trees and shrubs and rate of survival by species at the total planted area. Second year survival was counted from first year survived specimen.

	Tree species	**2014 plantation (No.)**	**2014/2015 survived (%)**	**2015/2016 survived (%)**	**2015 plantation (No.)**	**2015/2016 survived (%)**	**total survived (%)**
1	*Acer campestre*	94	36	62	200	41	35
2	*Acer tataricum*	176	22	55	100	31	19
3	*Betula pendula*	260	0	0			0
4	*Malus sylvestris*	60	13	38	50	8	6
5	*Populus xcanescens*	316	20	29	300	23	14
6	*Pyrus pyraster*	64	30	47	50	10	12
7	*Quercus robur* (1-2 year)	1,296	15	43	6,600	28	25
8	*Quercus robur* (3-4 year)				735	28	28
9	*Tilia cordata*	126	2	100			2
10	*Tilia tomentosa*	354	23	47	400	44	28
11	*Ulmus laevis*	66	30	60	80	44	32
12	*Ulmus minor*	64	52	64	250	45	42
	Total tree planted	2,876			8,765		
	Average tree survival		22%	54%		30%	20%
	Shrub species	**2014 plantation (No.)**	**2014/2015 survived (%)**	**2015/2016 survived (%)**	**2015 plantation (No.)**	**2015/2016 survived (%)**	**total survived (%)**
1	*Cornus sanguinea*	618	12	47	550	13	9
2	*Corylus avellana*	406	3	64			2
3	*Crataegus monogyna*	440	38	56	250	41	28
4	*Euonymus europaeus*	353	36	78	350	54	41
5	*Frangula alnus*	169	0				0
6	*Ligustrum vulgare*	481	22	51	150	49	20
7	*Prunus spinosa*	189	15	21	100	73	27
8	*Rhamnus catharticus*	219	19	34	150	50	24
9	*Rosa canina*	268	15	78	200	65	35
10	*Sambucus nigra*	272	7	0			0
11	*Viburnum lantana*	12	17	17			17
	Total shrub planted	3,426			1,750		
	Average shrub survival		17%	45%		49%	19%
	Total tree & shrub	6,302			10,515		
	Average tree & shrub		19%	50%		40%	19%

Figure Captions

Figure 1. Map of treatments within the LEGO factory. Restoration parcels are named according to cardinal points. For details on restoration parcels see Table 1.

Figure 2. Concept of restoration prioritization and selection of methodology for target setting. Priority is constant within a tier. The selection procedure followed the arrows with feedback loops.

Figure 3. MPNV hexagon map of factory area and surroundings. Hexagons (35 ha each) are colored according to the most probable vegetation types (probability rank ≥ 2). Habitat codes are G1: open sand steppes, H5b: closed sand steppes, L5: closed lowland oak forests, M4: open steppe oak forests on sand. Colors are chosen so as darker ones to represent more woody vegetation presence in the MPNV.

Figure 4. Picture of open steppe oak forest remnant, model for restoration (Álló-hegy, Hungary, Photo: M. Halassy).

Figure 5. PCA trajectory of restoration plots compared to control and reference plots (a) and scatter plot of species (b). Axis 1 and 2 explain 19 and 15% of variance respectively. For better transparence, species composition is represented for only the 20 dominant species. T0 = baseline; T1 = 1st year after seed introduction; T2 = 2nd year after seed introduction, C1 = non-seeded control 2015; C2 = non-seeded control 2016; L1 = lawn 2015; L2 = lawn 2016; RC: closed sand steppe reference and RO: open sand steppe reference. Species codes: ambart: *Ambrosia artemisiifolia*; antrut: *Anthemis ruthenica*; brohor: *Bromus hordaceus*; brotec: *Bormus tectorum*; carste: *Carex stenophylla*; conarv: *Convolvulus arvensis*; concan: *Conyza canadensis*; cyndac: *Cynodon dactylon*; equram: *Equisetum ramosissimum*; fespse: *Festuca pseudovina*; fesvag: *Festuca vaginata*; lolper: *Lolium perenne*; medsat: *Medicago sativa*;

plalan: *Plantago lanceolata*; seccer: *Secale cereale*; thysp: *Thymus sp*.; torrur: *Tortula ruralis*; triarv: *Trifolium arvense*; tristr: *Trifolium striatum*; vicvil: *Vicia villosa*.

Figures

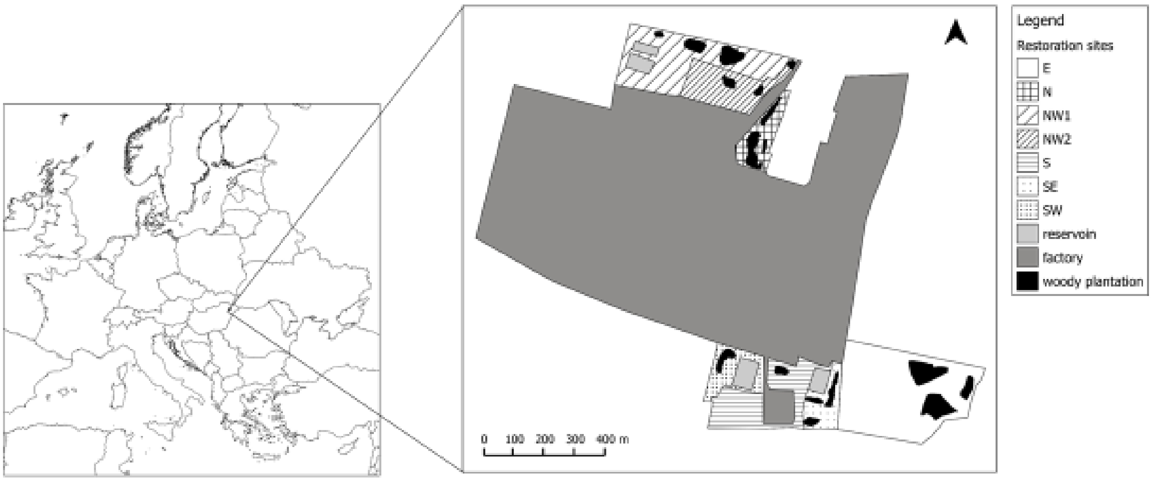

Fig. 1

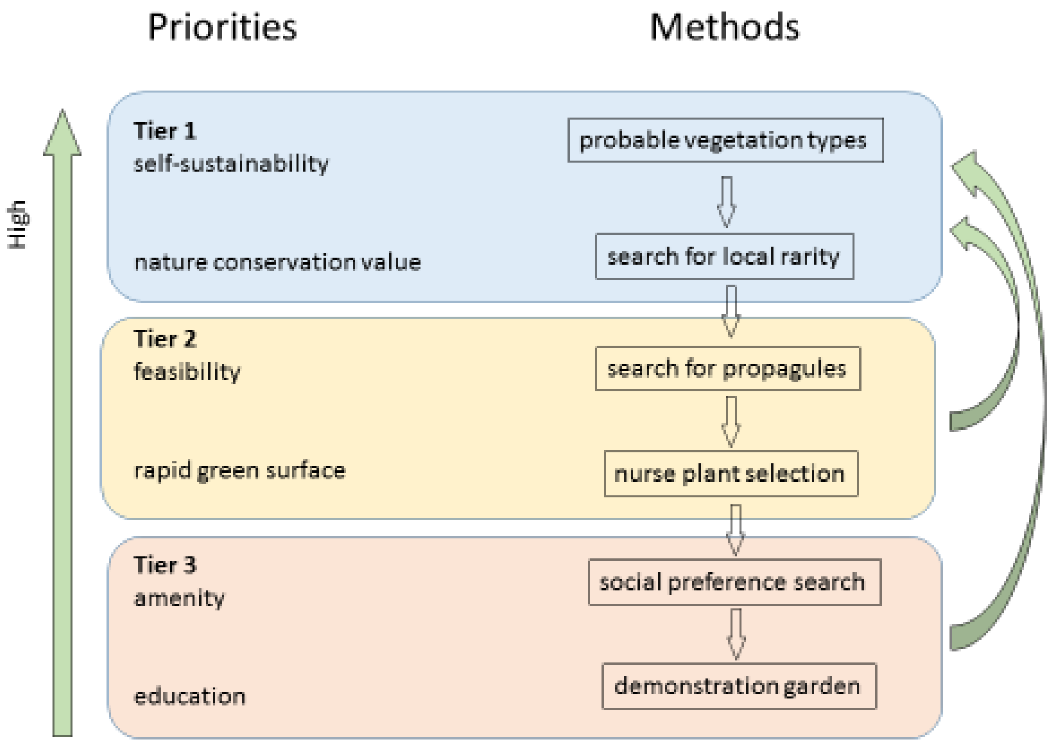

Fig. 2.

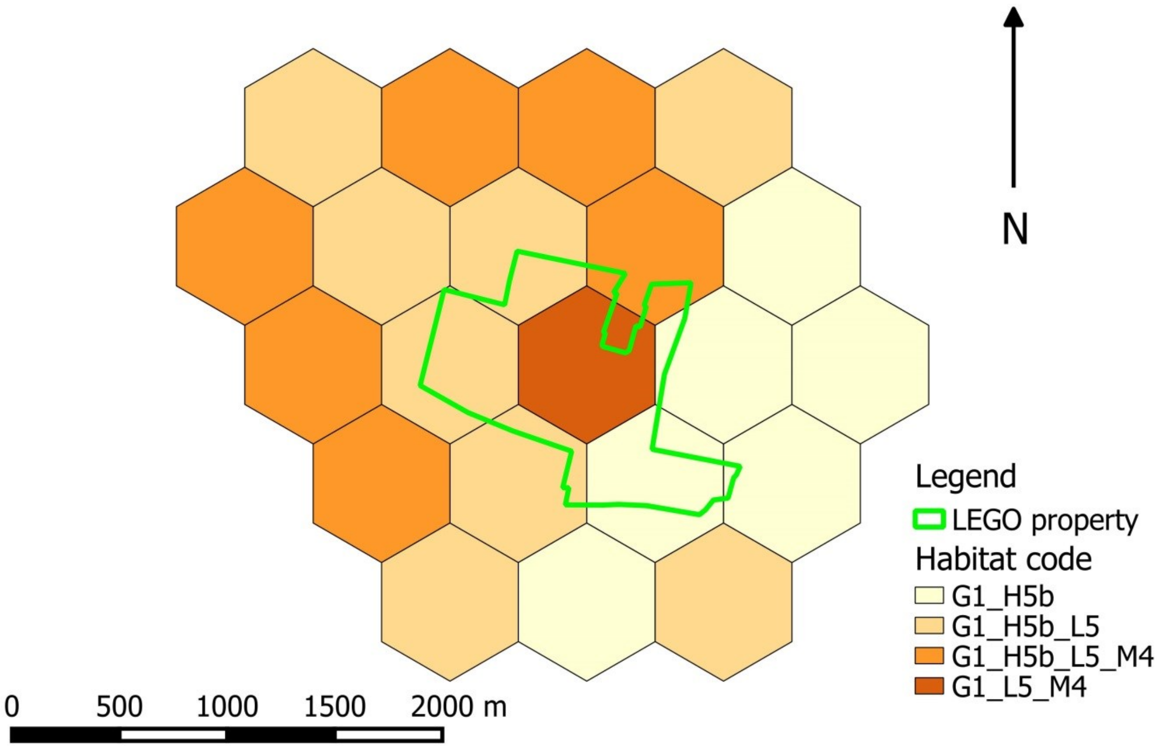
N
Legend
LEGO property
Habitat code
G1_H5b
G1_H5b_L5
G1_H5b_L5_M4
G1_L5_M4
0
500
1000
1500
2000 m

Fig. 3.

Fig. 4.

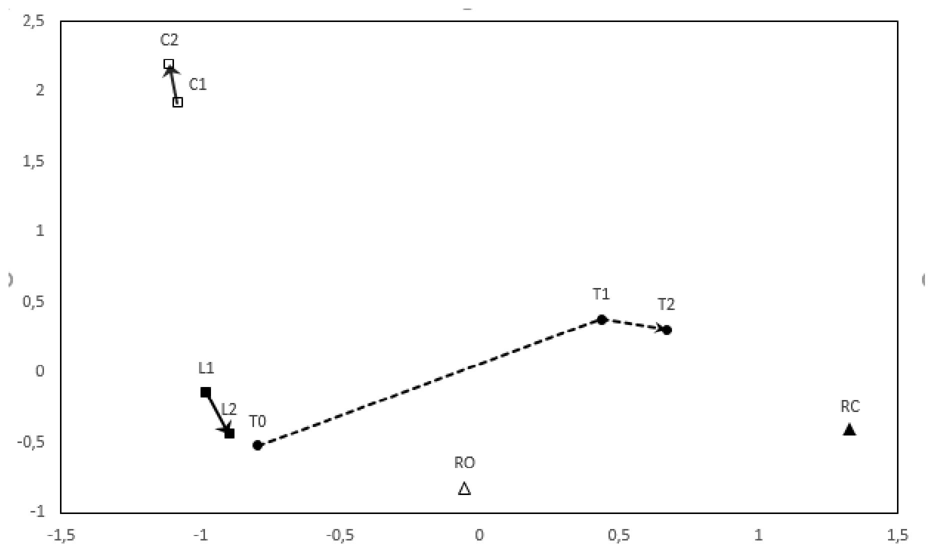
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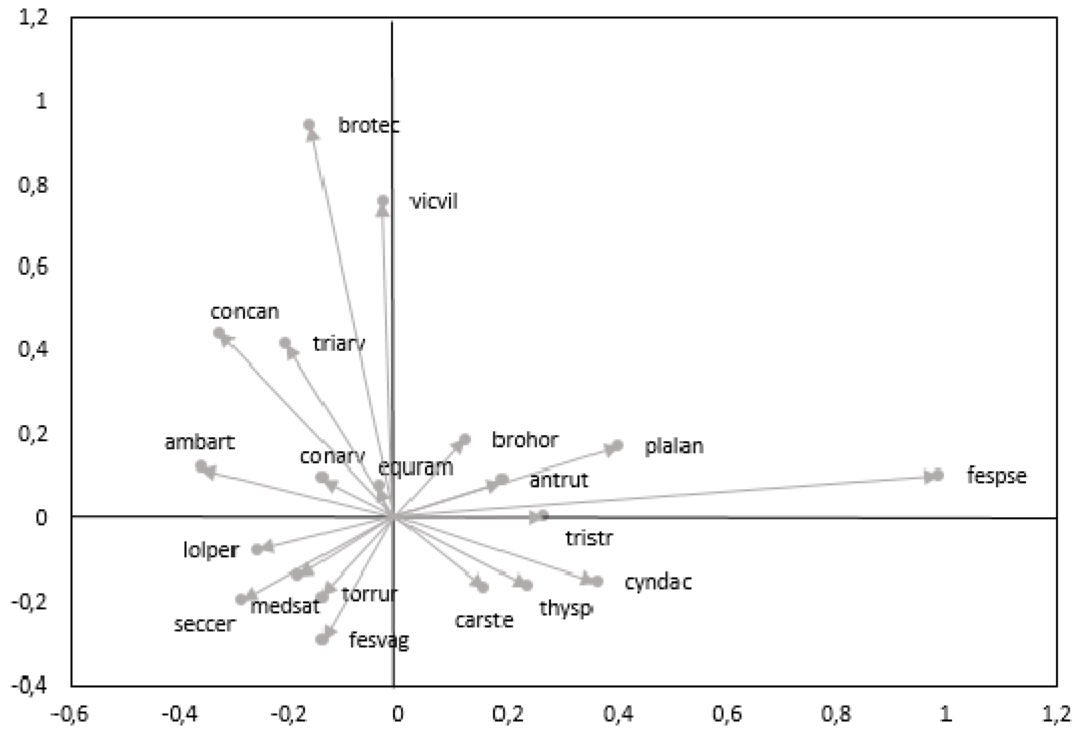
Fig. 5a.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vicvil
concan
triarv
ambart
conarv
equram
brohor
plalan
antrut
fespse
tristr
cyndac
lolper
medsat
torrur
seccer
fesvag
carste
thysp

Fig. 5 b.