

Challenging the practice of biodiversity offsets: ecological restoration success evaluation of a large-scale railway project

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Abstract Large-scale infrastructure development projects are discussed transdisciplinarily in several domains of society. Critics often claim that environmental impact assessments lack real influence on planning, management, and monitoring. We report herein the evaluation of ecological compensation via biodiversity offsets and technical constructions with a secondary compensation function for a new railway in Austria. We asked: (1) where can ecological restoration success be detected, and (2) is our new method of a composite biotope value calculation representative for all criteria we used? We conducted a vegetation inventory on reference areas and all types of measures that created new habitats. Together with a comprehensive, spatially dense habitat mapping, evaluation of six attributes of restoration success and testing of our new method were carried out. Current threats typical for intensive agriculture have been generally reduced. Ecological compensation measures had the highest connectivity but the lowest plant community diversity. Surprisingly, technical constructions provided significantly more plant

communities and hosted most Red List species. The species assemblage characteristics of compensation measures, their biotope type diversity, and their mean biotope values were, although lower, comparable to the reference. Despite the poor performance of technical areas in the final biotope values, our results call for their reconsideration as potential tools for ecological compensation by greening grey infrastructure in the near future. The tested new method provided an overall statement for the ecological restoration evaluation and could also be used for nature evidence inventories and as a valuable decision support tool in landscape planning.

Keywords Ecoengineering · Environmental impact statement · Ecological compensation · Renaturation · Restoration ecology

Introduction

Ecological compensation measures (ECM), including biodiversity offsets, are an important tool in restoration and conservation, fulfilling international directives and laws (Urbanska 2000; Van Diggelen et al. 2001). Implementation, however, often misses the intended goals and is evaluated insufficiently or not at all (Muller et al. 1998; Grayson et al. 1999; Lockwood and Pimm 1999; Tischew et al. 2010). Methods defined in compensation plans are often unsuitable for the natural and socioeconomic conditions of the respective area, or fail to give specific instructions for implementation, monitoring, aftercare, and adaptive management (Bradshaw 1997; Tischew et al. 2010).

Maron et al. (2012) highlighted the need for ecological restoration research to obtain information on offset

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performance. They emphasized the requirement of measuring and monitoring the multiple aspects of an offset's value, including a quantified method to measure the contribution of connectivity at landscape scale. We evaluated the success of biodiversity offsets undertaken in the course of the construction of a new high-speed railway line in eastern Austria. According to Austrian law on environmental impact assessments based on European Union directive 85/337/EEC and its amendments in 1997 and 2003, a broad range of compensation terms under nature conservation law are stipulated.

In the context of this study, “biodiversity offsets” are defined as spatially explicit measures compensating for losses of biodiversity components at an impact site by generating (or attempting to generate) ecologically equivalent or higher gains elsewhere. Studies published on biodiversity offsets have been generated for more than 25 years now, most of them in the USA, but increasingly since 2009 also in Europe (Goncalves et al. 2015). We included greened technical construction areas (TEC) such as dams and ponds in our investigation. They were supposed to have valuable secondary habitat functions contributing to the overall compensation (Tiwarly and Kumar 2014).

MacMahon and Holl (2001) pointed out the importance of carefully selecting variables or indicators to allow evaluation of stated goals in monitoring programs planned in restoration projects. To improve measurability, and in accordance with recent findings (Sætersdal et al. 2003; Sauberer et al. 2004; Ruiz-Jaen and Aide 2005; Gioria et al. 2010; Santi et al. 2010), we chose clear habitat features and vascular plants as surrogate taxa for biodiversity. Hermann and Wrבka (2009) showed that habitat mapping is indispensable to identify biotopes of high conservation value in agricultural landscapes.

Based on a vegetation inventory and habitat mapping, we investigated the performance of habitat (re-)creation measures within an intensive, impoverished agricultural landscape in terms of nature reclamation and reversing the loss of biodiversity. Besides the evaluation using four out of nine well-known attributes of restored ecosystems (SER 2004), this study presents the first test of a composite biotope value calculation to provide a general statement on the restoration success. We further highlight the potential of different restored habitat types including technical constructions and call into question the “no-net-loss” approach.

The main questions addressed by our study are: (1) can restoration success be detected at a rather early stage (between 2 and 7 years), and (2) is our new method of a composite biotope value calculation representative for all criteria we used?

Materials and methods

Study area

The study area is situated in the Austrian federal state of Lower Austria, and belongs to the political districts of Tulln and St. Pölten (Fig. 1). The area is drained by two tributaries of the Danube: Große Tulln and Perschling. Large drainage ditches, which are already depicted on maps from the eighteenth century, have transformed fens and marshland into farmable land. Three out of four investigation areas are part of the Southern Tullnerfeld and belong to the Pannonian Plain: Egelseergraben (ESG) and Hochwiesgraben, both large drainage ditches, as well as the area along the river Große Tulln and dry meadow offsets to the east.

Geomorphologically, the area is characterized by 9–23-m-thick layers of gravel terrace, overlain with sand, loam, and clay sediments. Due to its deep fertile and nutrient-rich Chernozem (black earth) soils, the Southern Tullnerfeld is an impoverished agricultural landscape with mostly intensive land use. The region rates among those with the lowest landscape diversity in Austria (Wrבka et al. 2004). The most commonly cultivated crops are maize, sugar beet, rape, and forage crops. Moreover, there are several intensive pig farms situated in the study area. Thus, the overall picture is that of a flat, nearly treeless “agro-steppe.”

The fourth investigation area, Hankenfeld, is situated in the Perschling River valley, which belongs to the northern Alpine foreland, and is characterized by a rivulet surrounded by hills, woodland remnants, and foothill slopes with field terraces (lynchets), rich in eolian sediments (Loess).

Study design

Each of the four investigation areas contained sensitive remnant landscape elements that were attested to have a specific value for biodiversity in preliminary investigations (Loiskandl 1997; Zechmeister et al. 2003; Schmitzberger et al. 2005). Remnants within 300 m around the impact area were used as contemporary reference (REF), meeting the requirement of comparability (Goncalves et al. 2015). They also included temporary “protection areas” that were designated during the planning process and declared to be untouched by construction processes.

To represent the diversity of measure types described in the environmental impact statement, we systematically screened the maps submitted in the approval procedure under nature conservation law. We identified eight ecological compensation measure (ECM) types, five primary technical construction (TEC) types, and six reference

Fig. 1 Main investigation areas south of the Danube in the district of Tulln in the state of Lower Austria. Gray points are sample plots

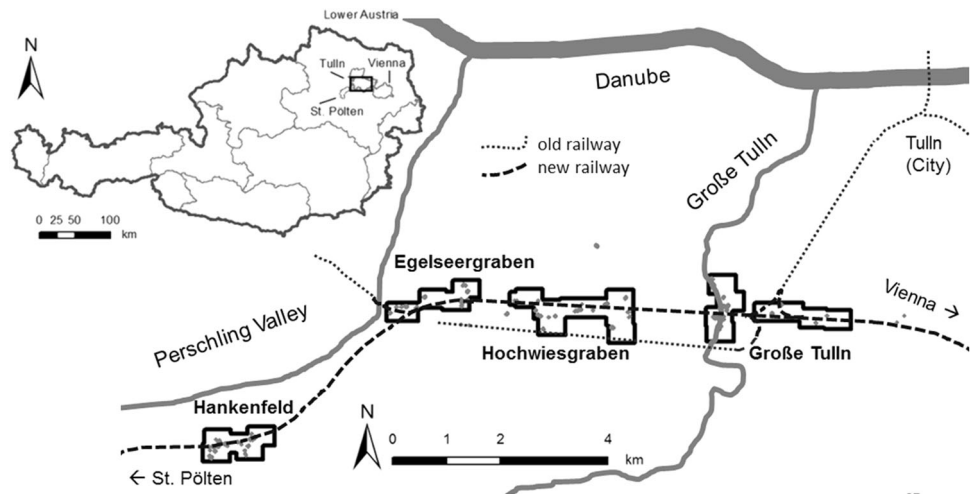


Table 1 Priority classes, measure types, and number of plots

| Priority (<i>n</i>) | No. | Habitat/measure type | <i>n</i> |
|---|-----|--|----------|
| Ecological compensation measures (ECM) (27) | 1 | Fallow-succession | 3 |
| | 2 | Fallow-initial-development: | |
| | | (a) Dry location | 4 |
| | | (b) Moist to wet location | 3 |
| | | (c) River renaturation | 4 |
| | | Dry meadow | 4 |
| | | Mixture hedgerow | 4 |
| | | Wood-grove | 3 |
| Wood-timber | 2 | | |
| Technical construction areas (TEC) (35) | 9 | Ponds, rivulets, and ditches | 8 |
| | 10 | Moist to alternate moist areas of | |
| | | Pond- and ditch-banks | 8 |
| | | Dried pond-beds | 4 |
| | | Dry flood dam slopes and an isolated meadow patch | 4 |
| | | Noise protection dam | 11 |
| Reference areas (REF) (30) | 14 | Lynchet slope | 7 |
| | 15 | ESG rivulet and a river-cutoff | 4 |
| | 16 | ESG flood protection dam | 2 |
| | 17 | Field wood patch and windbreaks | 4 |
| | 18 | Ruderal meadows and dry ones along abandoned railroad beds | 4 |
| | 19 | Woods and forest edges | 9 |

habitat (REF) types. Within these 19 habitat/measure types, 92 sample plots were located in equal share for the three priority classes ECM, TEC, and REF (Table 1). ECM- and TEC-type measures were planned and revised and their construction and planting coordinated by a landscape planning firm. These actions occurred during 2–7 years ahead of the evaluation.

“Fallow-succession” areas were kept completely off management. Fallows with “initial development” aimed at supported succession with punctual planting and facultative management in case of necessity (e.g., occurrence of invasive species). ECM numbers 5–8 were all newly created and consisted of basic standard seed mixtures, varying only in their combinations of woody species. TEC areas varied more in (supported) succession, planting, and seed mixtures also within the types.

Vegetation inventory

Fieldwork was done in 2011, using orthophotos in combination with the maps mentioned above. Twenty-two sample plots were situated at the Große Tulln River and at dry meadow offsets east of it, 23 plots in the area of Egelseergraben, 22 plots around the Hochwiesgraben, and 25 plots in Hankenfeld. The vegetation inventory of these 92 plots included full species lists of vascular plants with abundance/cover values.

The plot size of meadows was 7 m², linear habitats were examined over the whole width and at least 10 m in length, and woody vegetation was investigated with a plot size of 20 m². Vegetation data were stored in a TurboVeg database (Hennekens and Schamineé 2001), and habitats were stored in an Access database.

Habitat mapping

Habitat mapping included and surrounded the 92 inventory plots, resulting in 836 polygons mapped in 2011. For each polygon, we identified the biotope type according to the Red List of Austrian Biotopes (Essl and Egger 2010) and recorded land- use type and intensity. Macro- (e.g., shape of valley, slope or river) and micro-geomorphology (e.g., open soil type, bank shape, clearance cairns, dry stone

walls) were recorded as well as structural attributes (e.g., vegetation height and type, layer composition, cover ratio, availability of old growth or dead wood, water body features).

Attributes defining the socioeconomic and ecosystem relevance and the conservation worth (e.g., area size, network function, species diversity, threatened and rare species or biotope types, “ecosystem services”), current and recommended management activities (e.g., fertilization, grazing, mowing, neobiota treatment, changes in management), as well as current and potential types of endangerment or impairment completed the description of the habitat plot (Wrbka et al. 2002, cf. field survey form in Supplementary Material A).

Data joining, production of field maps, digitization, and analysis were done using MS Access and ArcGIS 10 (ESRI Inc., Redlands, CA).

Data analyses and assessments

The Society of Ecological Restoration International (SER 2004) postulated nine attributes of restored ecosystems, from which we considered the following four as quantifiable within our study: (1) similar diversity and community structure in comparison with reference sites (generating three attributes in this study), (2) presence of indigenous species, (6) integration with the landscape (i.e., connectivity of landscape elements), and (7) elimination or reduction of potential threats.

All data analyses and assessments described herein focused on pairwise comparison of each pair within the three priority classes: biodiversity offsets, i.e., ecological compensation measures (ECM), technical construction areas with secondary compensation functions (TEC), and reference habitats (REF).

Attributes 1 and 2: diversity, community structure, and rarities

Regarding biotope type diversity (according to the habitat mapping) and plant community diversity (according to the vegetation inventory), we calculated the Shannon index, evenness, variance, *t* test, and degrees of freedom (Magurran 1988). For determination of the 92 vegetation communities, preliminary sorting of vegetation plots was done using the TWINSpan algorithm (Hill 1979) as implemented in the program Juice (Tichý et al. 2011). The vegetation data were then classified following the most recent surveys of the Austrian literature.

To enable an unambiguous and complete classification, we adopted the summarized percentage cover (SPC) approach (Willner 2011). This is a stepwise assignment of sample plots to the hierarchical system of vegetation units

according to the relative cover of diagnostic species. The assignment starts at the highest level of the Braun-Blanquet system (the vegetation class) and proceeds, if possible, down to the most basic units (association) or the next superior level (alliance). To quantify the “characteristic community structure” of a plot, we calculated the SPC of the diagnostic species of the alliance (and the association if applicable).

Restoration success criterion 2 is the presence of indigenous species (SER 2004). We tightened this criterion by focusing on Red List species listed either for the whole of Austria or for the regions Pannonian Lowland and/or Northern Alpine Foreland. For this and all following criteria, significances of differences between priority classes (ECM, TEC, and REF) were calculated using the Kruskal–Wallis test in SPSS 16.0.1.

Attributes 6 and 7: connectivity and threats

For integration with the landscape (attribute 6, SER 2004), we determined connectivity based on our habitat mapping data digitized in ArcGIS. Habitats were classified into four groups (Peterseil et al. 2004):

1. Isolated, most fragmented, no crosspoints—*islands*
2. Minor interlaced, fragmented, few crosspoints—*mostly linear connections*
3. Mean interlaced, wide-meshed network—*several sideways at crosspoints*
4. Highly interlaced, many crosspoints in a dense network

Endangerments and impairments of habitats were detected in the field, distinguishing current ones, which could be perceived in the field, and potential ones, which were most likely to (additionally) become relevant in the future (attribute 7, SER 2004). With the data from habitat mapping, we assessed the current and potential six most abundant threats and the mean degree of endangerment for each main measure category (see Supplementary Material B).

Composite biotope value (BV_C)

To quantify the condition or naturalness of a habitat on an ordinal scale, we applied an approach developed specifically for Austrian agricultural landscapes (Peterseil et al. 2004). A basic biotope type value (BT) was deduced from the generally known reproducibility (restorability), rareness, (structural and resource) complexity, and (species) diversity of each biotope type according to expert knowledge (Wrbka et al. 2002; Zechmeister et al. 2003). In our case study, these basic values ranged from 3 to 9. To adapt them to single biotopes, each value was attuned to the polygon’s

specific composition of “relevance and worth-defining attributes” by adding the (weighted) values from the field survey form (Hermann and Wrška 2009; Supplementary Material A). Weighting factor methodologies received positive quality marks in a recent review on 22 road-corridor planning studies (Loro et al. 2014).

We redefined this biotope valuing system by also adding all values from structural features and from current management measures which are congruent with the ecological target management as well as by subtracting the values of endangerment or impairment. Each feature was weighted according to the significance of the impact on the biotope value as considered from conservation biology expertise (see Supplementary Material A).

The final composite biotope value (BV_C) is therefore defined as the biotope type value (BT) plus the sum of structural features (ST), plus the sum of relevance and value-defining attributes (RW), plus the sum of care and managements that are both current and target [$CM_{(c=t)}$], minus the sum of current endangerments and impairments [$EN_{(c)}$], as determined by the formula

$$BV_C = BT + \sum ST + \sum RW + \sum CM_{(c=t)} - \sum EN_{(c)}.$$

Wortley et al. (2013) reviewed 301 empirical articles regarding methods used in evaluating ecological restoration. Of these, 94 % worked with ecological attributes including vegetation structure, diversity, and abundance as well as ecological processes. They did not mention such an ordinal scaled biotope value attribution, nor did we find any comparable methodologies in our thorough literature research. We therefore regard our method as new.

Results

Biotope type and plant community diversity

In total, 500 of the 836 mapped biotopes were assigned to one of the three priority classes (we excluded settlements, infrastructure, and fields). Two hundred twenty-three polygons were categorized as TEC, 180 polygons as ECM, and 97 polygons as REF.

We found 63 different biotope types. Figure 2 shows an example of biotope types mapped in the Hankenfeld investigation area in summer 2011 (for colored maps of all four investigation areas see Supplementary Material C). Although technical areas (TEC) contributed the most polygons, their biotope type diversity was lower than in the other two classes (Table 2). Reference sites (REF) ranked highest but did not differ that much from ecological compensation measures (ECM).

The 92 vegetation samples were classified into 12 phytosociological classes, 21 orders, and 29 alliances. We found that 65 plots could be assigned to association level, giving 44 different associations. The remaining 27 plots belonged to 15 different alliances. Altogether, 53 different plant communities were found in our investigation area. REF contained the most (25 of 53, see Supplementary Material D), being markedly more diverse than the other two priority classes. TEC ranked, however, also clearly above ECM (Table 3).

The p values of all other results are listed in Table 4.

Connectivity of landscape elements

Most crosspoints with sideways were found in ECM plots (Fig. 3a), which had the highest mean value of connectivity, providing the best conditions for future habitat network development (Fig. 3b). Still, only TEC with the biggest share of isolated and linear connected plots were significantly less interlaced than ECM.

Plant community structure

The mean summarized percentage cover (SPC) of diagnostic species among all plots was 50.1 %. When trisected into categories (low: 3–33 %; medium: 34–65 %; high: 66–96 %), the low and high SPC values were oppositely distributed in TEC and REF (Fig. 4a). The average SPC value of REF was the highest; ECM reached a comparable, yet lower degree (Fig. 4b). (For SPC values for each of the 92 vegetation plots see Supplementary Material E.)

Red List species

In total, 44 Red List species of vascular plants were found in the investigation areas. Water-related TEC measure types, but also REF ruderal meadows, contributed essential numbers (Fig. 5a).

Within the priority classes, most Red List species (23) occurred on technical, replanted areas, followed by 16 species in REF and 13 species in ECM. Nearly twice as many incidences were counted for TEC (40 versus 24 in REF and 22 in ECM). This is clearly depicted by the average number of endangered or rare species per habitat type in Fig. 5b.

Threats

Comparing the weighted values of endangerment, a maximum of (minus) 18 was reached in current threats at a REF site, while zero was the minimum in all groups. In contrast to potential (additional) threats in the future, the current values clearly differed between all priority classes (Fig. 6).

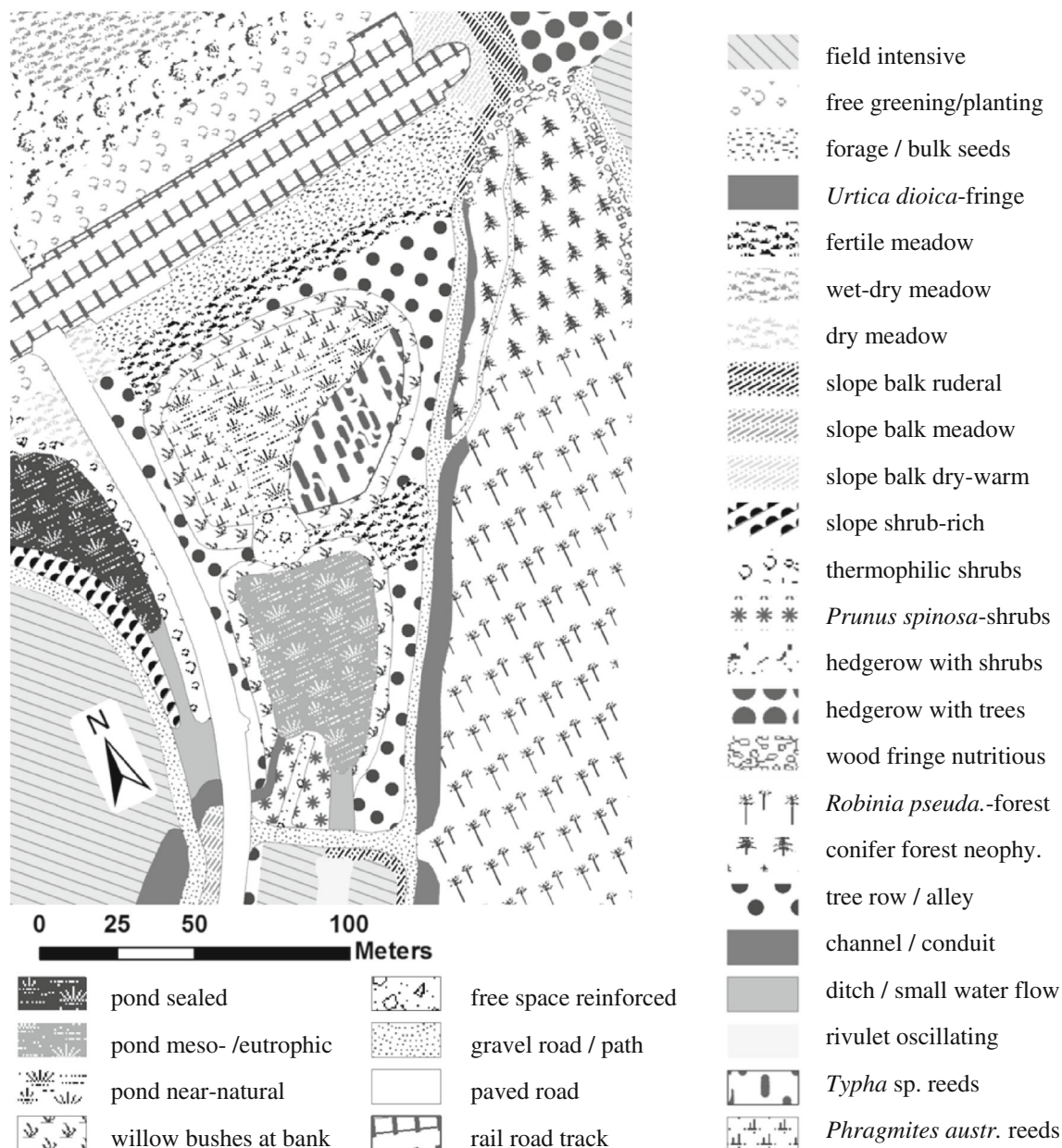


Fig. 2 Biotope type map excerpt: 200 m × 300 m of Hankenfeld substudy area with two sequential retention ponds fed by the hill land rivulet Grubbach

For all priority classes, the two most abundant current threats were biocide input and immission (Fig. 7a). About one-third of the polygons in each class were impaired by mechanical pollution, which was also the most abundant potential future threat (Fig. 7b).

Composite biotope value

The BV_C ranged from 6 to 44. Figure 8a shows the distribution with three classes of biotope values (low: 6–18; medium: 19–31; high: 32–44). The mean for ECM nearly

represents the overall mean of 23.4. Only TEC clearly differed from REF (Fig. 8b).

Discussion

Evaluation of restoration success

Our first criterion for restoration success, i.e., similar diversity and community structure (1), can be considered as fulfilled. The biotope type diversity of ecological

Table 2 Biotope type diversity of priority classes ($p < 0.05$)

| Variable | TEC | ECM | REF |
|------------------------------|-----------------|-------------|-------------------|
| No. of plots (N) | 223 | 180 | 97 |
| No. of biotope types (S) | 40 | 41 | 41 |
| Shannon index (H') | 3.15 | 3.32 | 3.46 |
| Evenness (E) | 0.85 | 0.89 | 0.93 |
| Variance (Var H') | 0.0040 | 0.0037 | 0.0044 |
| Comparison | TEC–ECM | ECM–REF | TEC–REF |
| t -Value | –1.940 | –1.577 | 3.400 |
| df | 401 | 238 | 261 |
| p ($=0.05$) | >0.05 | >0.1 (ns) | <0.001* |

Significant values in bold with asterisks, trends in bold italics ($n = 500$)

Table 3 Plant community diversity of priority classes ($p < 0.05$)

| Variable | TEC | ECM | REF |
|----------------------------|------------------|-------------------|------------------|
| No. of plots (N) | 35 | 27 | 30 |
| No. of plant comm. (S) | 23 | 16 | 25 |
| Shannon index (H') | 2.93 | 2.55 | 3.17 |
| Evenness (E) | 0.93 | 0.92 | 0.98 |
| Variance (Var H') | 0.0089 | 0.0127 | –0.0031 |
| Comparison | TEC–ECM | ECM–REF | TEC–REF |
| t -Value | 2.585 | –6.322 | 3.140 |
| df | 56.7 | 14.7 | 13.2 |
| p ($=0.05$) | <0.02* | <0.001* | <0.01* |

Significant values in bold with asterisks ($n = 92$)

compensation measures (ECM) was similar to that of reference plots (Table 2). While habitats created for technical reasons (TEC) had low SPC values, those of ECM were approaching SPC values of reference (REF) sites (Fig. 4).

The higher diversity of plant communities in TEC compared with ECM can be partially explained by the water level dynamics of hydraulic constructions (Table 3). These create many variable biotope structures serving as a starting point for wetland sites and their inhabitants. The strong influence of these qualitative aspects of hydrology leading to small-scale heterogeneity and chronological and spatial transitions of species and plant communities was

Table 4 p -Values of significance ($p < 0.05$, Kruskal–Wallis test) for differences between average (mean \pm CI) attribute values

| Comparison | Red List sp. | Threats current | Threats potential | Connectivity | SPC value | Biotope value _c |
|------------|---------------|-------------------|-------------------|---------------|-------------------|----------------------------|
| TEC to ECM | 0.015* | <0.001* | 0.213 | 0.016* | 0.008* | 0.323 |
| ECM to REF | 0.511 | 0.009* | 0.705 | 0.105 | 0.157 | 0.246 |
| TEC to REF | 0.098 | <0.001* | 0.703 | 0.390 | <0.001* | 0.047* |

Significant values in bold with asterisks, trends in bold italics. Threats: $n = 500$, others: $n = 92$

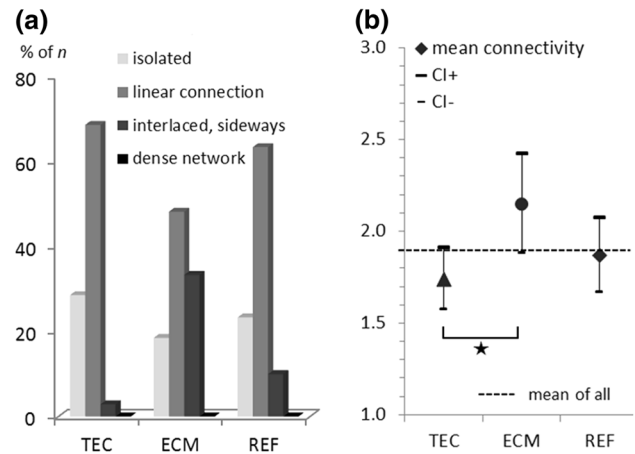


Fig. 3 Connectivity of landscape elements: **a** distribution of four categories, **b** average value of connectivity in priority classes. Asterisk indicates significant difference ($p < 0.05$, Kruskal–Wallis test, $n = 92$)

recently validated by Nishimoto and Hada (2013) and could also be observed at some of our sample ponds at follow-up visits.

In natural wetland habitats which are still connected to source areas of species dispersal, drift of plant parts (hydrochory) and particularly the availability of plant propagules both play major roles in the resettlement of aquatic, semiaquatic, and swamp vegetation (Schneider et al. 2008). In isolated retention, evaporation, and seepage ponds, as in our study area, initial planting (anthropochory) and input from animals (zoochory—especially by water birds) serve as surrogates for these missing migration corridors.

Integration into the landscape (attribute 6) was attempted by “hiding” the railroad behind huge noise protection dams and copying landscape structures from the nearby foothills. The good performance of ECM in landscape connectivity can be recognized as a direct success of the landscape planning design. Establishing linear structures to guide wild animals, providing regular series of underpasses, and connecting all biodiversity offsets among each other and with the surrounding remnant corridors do have positive effects.

On a higher scale, the geomorphological impoverished landscape of the Southern Tullnerfeld is surrounded by

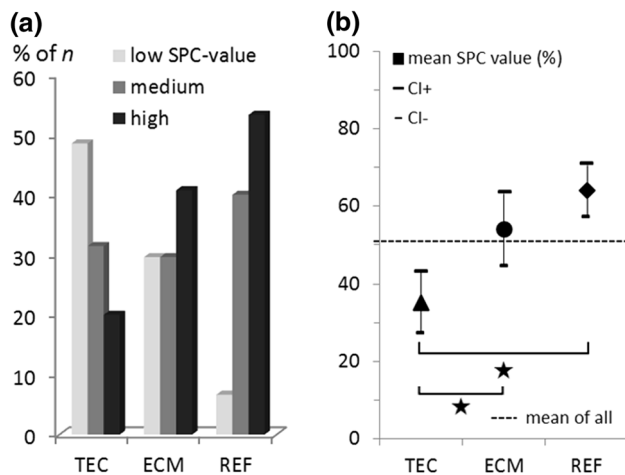


Fig. 4 Compared plant community structure between priority classes: **a** distribution of summarized percentage cover (SPC)-value categories, **b** mean SPC value of all plots. Asterisks indicate significances ($p < 0.05$, Kruskal–Wallis test, $n = 92$)

ecologically high-valued landscape regions of Lower Austria and Vienna, i.e., wetlands and riverine forests of the Danube, the outskirts of the northern Alpine foreland, the Vienna Woods (biosphere park region), and the Wachau [a water gap valley, ecologically the most western part of the (Hungarian) Pannonian steppe and a United Nations Educational, Scientific, and Cultural Organization (UNESCO) world culture and nature heritage site].

Hence, two centuries ago, the Southern Tullnerfeld was, and now again is—only due to the increasing landscape connectivity enabled by the biodiversity offsets—an important hub zone which connects very different landscapes and provides corridors for population fluxes, especially for macrofauna. This “in-kind” shaping of the landscape in line with the major preference of the local people, as well as the choice of ECM location “on-site,” in direct proximity to the impact area, correspond to the recent status quo of biodiversity offsets (Goncalves et al. 2015).

A partial success for SER criterion number 7 could be derived by dividing the current status of endangerment and impairing for TEC, ECM, and REF into three levels (Fig. 6). Biocide input (contamination from surrounding fields) and eutrophication (input and residues in the ground) have been reduced compared with the reference sites, while immission and mechanical pollution are still present at the same level (Fig. 7a). Potential (additional future) threats such as dredging of water bodies or improper thinning even have a worse prospect. Comparing the priority classes, there is hardly a difference in the endangerment potential (Figs. 6, 7b).

This is possibly due to the surrounding conditions of the landscape and the ongoing human alteration of the

ecosystem, which is not restrained by the boundaries drawn on maps. It is questionable whether additional mitigation measures, such as subsidies for organic farming, were attempted effectively enough or at all. However, management specifications also contribute to the bleak prospects. (Contractually installed) land owners, for example, are free to manage and commercially use ECM wood-timber and wood-grove in exactly the same way.

Last but not least, the composite biotope value was a composite reflecting all the listed criteria. Reference sites had the highest values, though this difference was less conspicuous than with regard to the cover of diagnostic species (SPC values) and plant community diversity. These two variables based on vegetation inventories—but also biotope type diversity—reflected the biotope value trend. They seem to have more influence on the biotope value than the criteria of connectivity, endangerments, and Red List species, and thus have strong indicative ability.

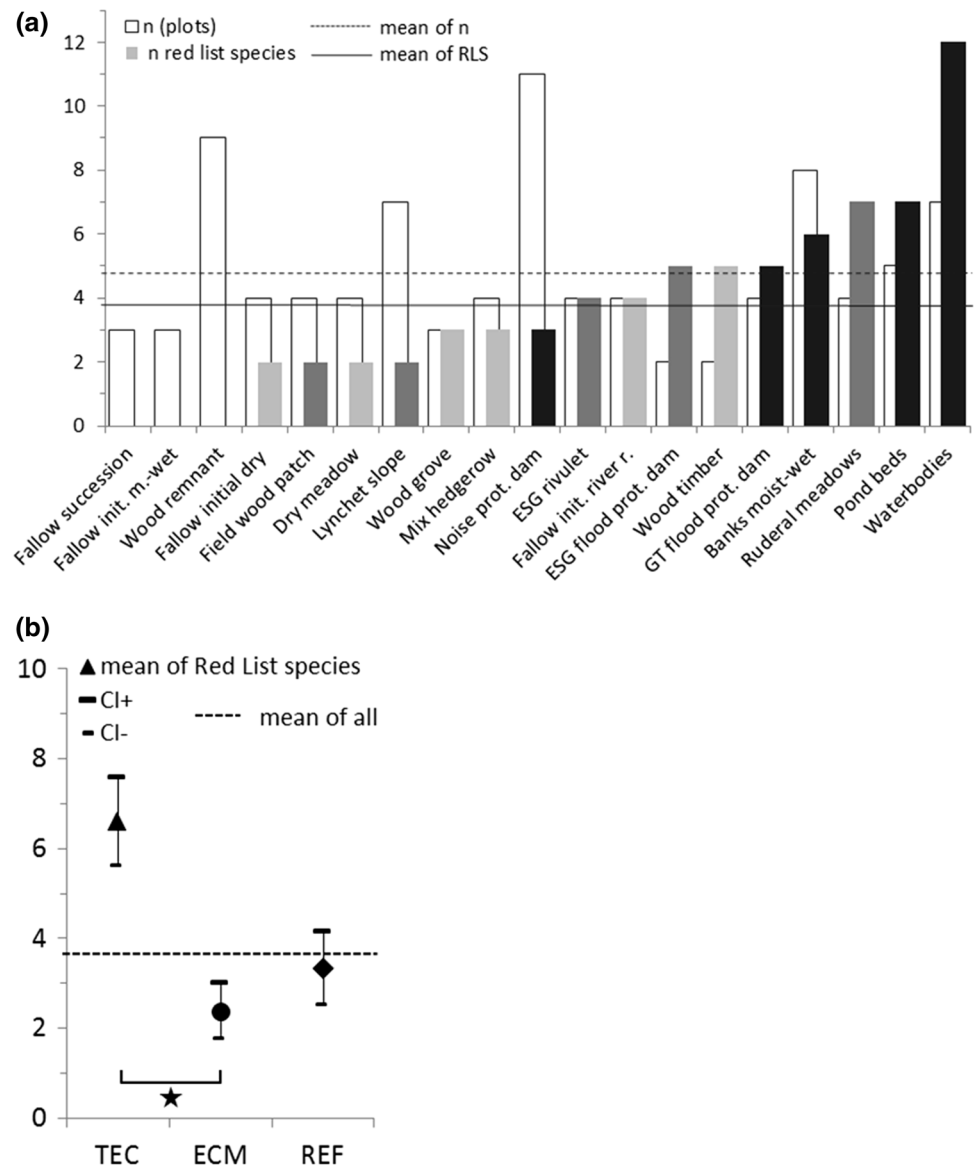
Methods evaluating restoration measures should operate at different scales to account for effects at landscape, habitat, and community level (e.g., Schmitzberger et al. 2005; Tischew et al. 2010; Tambosi et al. 2014). Our new method of a composite biotope value calculation deduced from habitat and vegetation mapping meets this demand. In this case study, it acted well as an overall statement regarding the momentary state of restoration success. Moreover, it would also serve as a supportive tool in landscape planning processes such as variant design development, environmental impact assessment, stakeholder communication, as well as planning of compensation and monitoring.

We want to emphasize here the importance of monitoring and its well-planned financial basis for any kind of ecological compensation. Together with a certain part of the budget reserved for adaptive management, this is essential for sustainable development of the near-natural status of the target ecosystem and additionally provides findings for subsequent projects.

Time scale difficulties

It is generally agreed that compensation measures and biodiversity offsets suffer from crucial risks regarding the improvement or maintenance of their success or even failure over time, and that time lags are important to consider when planning monitoring and evaluation concepts (Bell et al. 2014; Maron et al. 2012; Moilanen et al. 2009; Lake 2001). In this construction project, however, an obligatory long-term evaluation of the measures was not precisely included in the environmental impact statement, nor was it demanded by any regional or statewide political authority.

Fig. 5 **a** Red List plant species: distribution in 19 habitat/measure types; *open bars* no. of plots; *filled bars* no. of species, TEC is *black*, ECM *light gray*, and REF *dark gray*. **b** Red List species: mean per habitat/measure type in priority class; *asterisk* indicates significance ($p < 0.05$, Kruskal–Wallis test, $n = 92$)



Our own study project was therefore supported by information and documentation material from the responsible landscape planning company, but not financially and not promoted from any side to have follow-up surveys.

We have to admit here that a rather vague temporal extent of our data deriving from measures undertaken 2–7 years ahead of the evaluation leaves some space for criticism. Anyway, this could not be avoided, because the complexity and variability of the construction process were too great, including several intermediate changes and revisions.

We thus emphasize that our data describe an important first step within a desirable long-term follow-up process and provide a momentary view on an early stage of development.

A closer look

Biodiversity offsets (ECM) for woodland establishment were monitored at still immature stages. Even so, and despite criticisms concerning management, the species compositions chosen for planting modules are remarkable. They consist of a variety of native trees and shrubs, including some rare and threatened species. This would have been a favorable, convenient opportunity to apply thoroughly elaborated seed mixtures in the understory of the young trees. Meadows with scattered fruit trees (orchards) have become rare in Austria and, when carefully maintained, serve as habitats for numerous endangered species.

ECM mixture measures with open land and hedgerows do benefit from the species-rich and interlacing design of

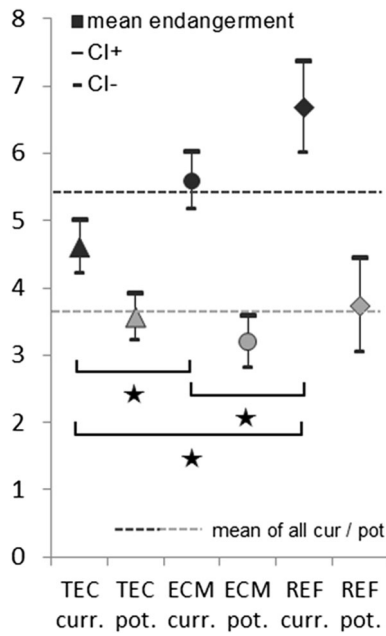


Fig. 6 Average current and potential threat values of priority classes; asterisks indicate significant difference ($p < 0.05$, Kruskal–Wallis test, $n = 500$)

woody planting modules, thus contributing to the relatively good SPC and biotope values. However, similar to the herbal layer of afforestation measures and fallows with initial planting, the low-budget seed mixtures create the same flaw at all other newly created, grassland-dominated habitat/measure types (including banks of water bodies).

Already 15 years earlier, the lack of meadows was grave compared with the historical situation (Loiskandl 1997). The weak performance of both ECM and TEC meadow

Fig. 7 Current (a) and potential (b) endangerments and impairments: percentage abundance of the six most abundant threats in each priority class is shown; $n = 500$

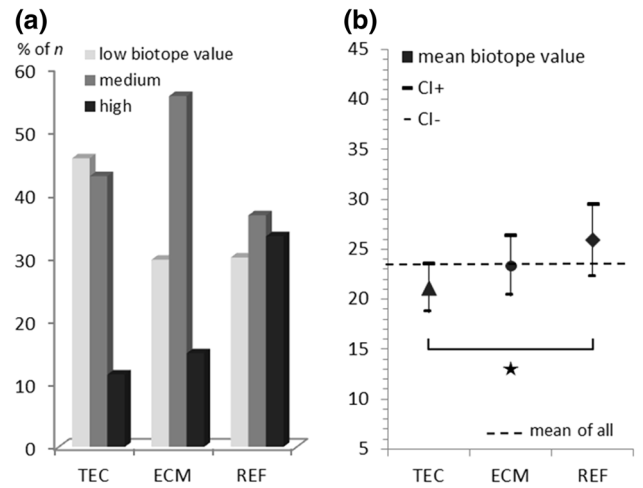
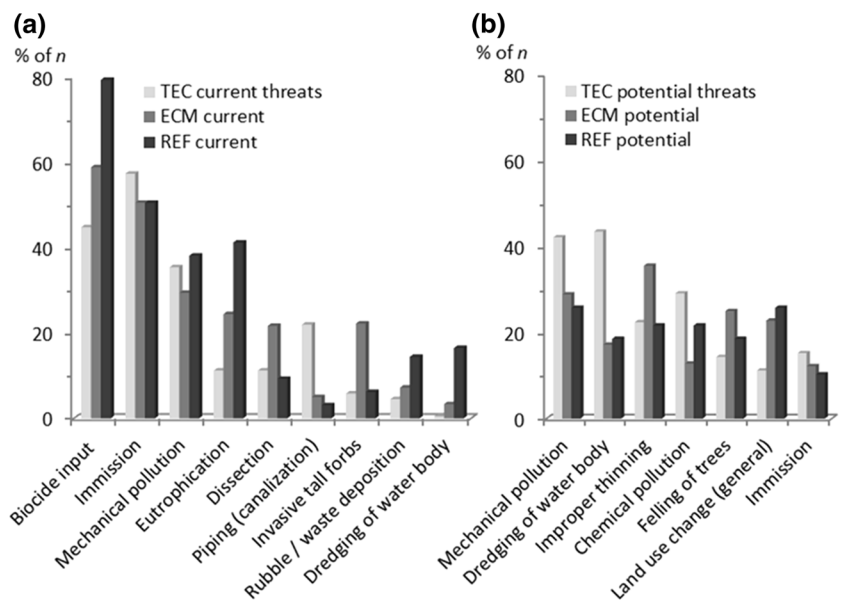


Fig. 8 a Distribution of three composite biotope value categories; b mean biotope value (BV_C) of all plots. Asterisk indicates significant difference ($p < 0.05$, Kruskal–Wallis test, $n = 92$)

types is unquestionably due to wrong decisions made in the planning process regarding the choice of seed mixtures and their establishment. The *Molinio-Arrhenatheretea* plots (pastures and meadows on fertile soils) of both priority classes mostly belong to the *Cynosurion* (park lawns) and *Tanaceto-Arrhenatheretum* (ruderal meadows).

Although required in the nature conservation restrictions, neither regional, wild plant seed mixtures nor green hay from nearby donor sites were used. Even meadow types important for nature conservation target species [e.g., the Lycaenidae butterfly *Phengaris nausithous* (syn. *Maculinea n.*, dusky large blue)] that resisted extinction in the affected area—explicitly described in the submission report under nature conservation law—were dropped. The

international literature is full of excellent case studies, guidelines, and reviews pointing out best practice for grassland restoration (for a summary of recommendations see Supplementary Material F).

Most of the recorded Red List plant species were found at TEC plots related to water (Fig. 5a). Our results correspond to those of Morris et al. (2006), who concluded that highly dynamic or transient conditions are typical for relatively re-creatable habitats such as fluvial communities or freshwater wetlands. To achieve restoration success in a reasonable time, biodiversity offset planners should target habitats with natural dynamic regimes.

The other measure types conducted on wetlands show that a relatively high occurrence of Red List species (Fig. 5b) alone is insufficient to create (near-)natural habitats. The technical restrictions are too great a hindrance; e.g., the beds of most of the TEC ponds are isolated from groundwater to prevent potential chemical contamination after traffic accidents. Seepage can only take place in certain ponds and only through nonisolated banks.

In the long run, another factor is the necessity to dredge water bodies when they have accumulated a level of biomass and organic matter at which their technical function can no longer be guaranteed. If management options, however, allow time-lagged and spatially scattered dredging of only minor proportions of water bodies in one area, this may even mimic the mosaic cycle of dynamic ecosystem processes. Technical constructions with the likelihood of successfully mimicking or initializing near-natural processes should be considered as a chance to create a variety of secondary habitats.

The segments of river renaturation that were conducted under the ECM type “fallow initial development” ranged in the top three regarding characteristic plant community structure (SPC value) and biotope value. They are on a similar level to the REF Egelseergraben drainage ditch and its flood protection dam, which Loiskandl (1997) described as the most diverse and most natural landscape element of his study area. Ecological compensation within impoverished landscapes should always include protection and/or enhancement of remnant biotopes of relatively high natural value within a biotope network system. A combined approach involving nature conservation and ecological restoration must be aimed for (Urbanska 2000; Young 2000; Walker et al. 2007).

A gain for the fauna

The general but very obvious enhancement of habitat diversity in this otherwise mainly intensive agricultural landscape as well as some of its new features mimicking the original state of a heterogeneous wetland were also

recognizable in the flourishing fauna. Despite a total lack of monitoring of any animal taxa, 40 Red List animal species were observed during the botanic fieldwork.

These included six Lepidoptera species such as the Geometridae *Ennomos autumnaria* (large thorn) listed as endangered (EN) in Austria, 15 bird species such as *Actitis hypoleucos* (common sandpiper) (EN), *Recurvirostra avosetta* (pied avocet) (EN), and *Tringa ochropus* (green sandpiper)—all correlated to TEC water bodies, the last one being even critically endangered (CR). Furthermore, the list includes five grasshoppers (Caelifera and Ensifera), four mammals, four amphibians, three dragonflies, a lizard, a longhorn beetle, and a mussel (Jäch 1994; Zulka et al. 2005, 2007).

Regarding their habitat demands as described in the most recent Austrian books on Red List animal species and the location where they were observed, 12 of the 40 species were associated mainly with ECM areas, 8 with REF areas, and 18 with TEC, again showing their potential. According to some occasional conversations with local hunters and residents, the area around the new railway line even became an “insiders’ tip” for birdwatchers.

Policy implications

The ecological compensation measures evaluated in this case study have attributes where they both outstrip and fall short of the reference habitats, but overall they approach them. This can be seen as a preliminary restoration success.

Hughes et al. (2011) state that evaluation and monitoring of large-scale, “open-ended” habitat creation projects should focus on restoration impacts and benefits that change over time. As dynamic landscapes shift in structure and connectivity, so do species in their abundance and composition, thus conservation goals and values need to adapt accordingly.

This study demonstrates the importance of including long-term monitoring and adaptive management approaches in any biodiversity offset project, as also emphasized by MacMahon and Holl (2001). A mandatory detailed description of aftercare and corresponding financial backing are key elements for a successful restoration outcome. However, legal support is also necessary to correct failures made and make up for neglect.

Morris et al. (2006) also described the difficulties in responding to failures at later stages with additional measures without legal support. Restoration ecologists also need to use positive results of restoration research for proactive communication with stakeholders and politicians, and amongst rural communities. All this has to be solidly covered by financial backing, and therefore predefined in the original project plan. This has to be argued in future projects processed through environmental impact

assessment, generally prone to lack of compensation (Villarroya and Puig 2013).

Targeted, precisely defined, and conceptually elaborated conservation value has to be thoroughly considered and promoted among all parties involved in the early stages of conception and planning. Based on the precaution principle (Wiegleb et al. 2013), a sound prestudy on their feasibility, time lags, as well as uncertainties should be included in any loss–gain calculation (Maron et al. 2012). The whole process from planning to the management of compensation measures should be obligatorily evaluated (Tischew et al. 2010), ideally by project-accompanying ecological consulting and control with management capacity.

Given the often impaired ecological condition of both the impact area and local reference sites, plus the levels of uncertainty over the eventual quality of restored areas, we also argue that an evaluation of biodiversity offsets using the “no-net-loss” approach may be difficult to justify. “Loss” areas with low natural value (such as intensive agricultural landscapes) could justify “gain” areas with moderate biodiversity value (Quétier et al. 2014).

Humans have altered the Earth’s richness and resources so much that robustly fair offset ratios are needed, producing at least as much biotope value in the offset areas as is lost from the development site (Moilanen et al. 2009). As a basic principle, high-value biodiversity areas should not be destroyed at all (Pilgrim et al. 2013). Furthermore, ecological compensation measures for the loss of low- or medium-value biodiversity areas should be planned more ambitiously (Rainey et al. 2014), always aiming for a “net gain,” even in the worst scenario. Thus, we suggest that the gain should be equivalent to twice the loss, as an absolute minimum.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards The experiments comply with the current laws of Austria.

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