Plant functional composition

as a tool for the assessment of grassland restoration success

Dissertation

zur Erlangung des

Doktorgrades der Naturwissenschaften (Dr. rer. nat.)

der

Naturwissenschaftlichen Fakultät I – Biowissenschaften –

der Martin-Luther-Universität

Halle-Wittenberg,

vorgelegt

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geboren am 25.08.1987 in Karl-Marx-Stadt

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Halle (Saale), den 20.08.2019 (Verteidigungsdatum)

Damaged and degraded habitats, from whatever cause, provide serious challenge. We realise that we can no longer treat the surface of the globe as if it were an unlimited resource. Ever since it has been possible to view the earth from space we have realised the finite limits of the land we inhabit, and of the ecosystems that provide us with the essentials for living. We have, at least, realised that what we damage, we must restore.

Anthony D. Bradshaw (Liverpool, 10th January 1995)
In: K. M. Urbanska and K. Grodzińska (1995): Restoration Ecology in Europe
Geobotanical Institute SFIT Zürich

The figures and tables of the manuscripts were renumbered, and all references were summarised at the end of the thesis. In the case of references that could no longer be precisely assigned, the corresponding references in the chapters have been adapted.

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Danke!

An dieser Stelle möchte ich mich bei all jenen bedanken, die auf ihre Weise zum Entstehen meiner Doktorarbeit beigetragen und mich unterstützt haben.

An erster Stelle gilt mein Dank meinen Betreuern, Prof. Dr. Helge Bruelheide, Prof. Dr. Annett Baasch und Dr. Ute Jandt, die mir jederzeit mit Rat und Tat zur Seite standen.
Liebe Annett, vielen Dank, dass du in mir das Potential gesehen hast, ein Promotionsstudium erfolgreich zu absolvieren und die Möglichkeit dafür im Grünland-Projekt an der Hochschule Anhalt eröffnet hast. Weiterhin danke ich dir für die vielen Stunden gefüllt mit langen Gesprächen zu Ideenentwicklungen, Analyseverfahren und Hinweisen zu den Manuskripten.
Lieber Helge, ich danke dir für die Möglichkeit meine Doktorarbeit am Institut für Geobotanik und Botanischer Garten der Martin-Luther-Universität in deiner Arbeitsgruppe anzufertigen. Du hast jederzeit mit Begeisterungen die Fortschritte der Arbeiten verfolgt und unterstützt. Insbesondere danke ich dir für deine Anregungen zu Analyseverfahren, deine Hilfe bei statistischen Auswertungen, insbesondere in der Anfangszeit, sowie für deine konstruktive Kritik während des Schreibprozesses.
Liebe Ute, vielen Dank für die Unterstützung bei der Selektion der Referenzflächen sowie für deine konstruktiven Gedanken und Anregungen zu den Manuskripten.
Liebe Alex, vielen Dank für deine bereichernden Hinweise und Anregungen zum ersten Manuskript.

Das Grünland-Projekt ist die Grundlage meiner Doktorarbeit. Ohne die fleißigen Mitarbeiterinnen und Mitarbeiter sowie studentischen Hilfskräfte würde es die Langzeitmonitoringdaten zu den Grünlandaufwertungsversuchen nicht geben. Dafür, vielen Dank. Insbesondere danke ich Konstanze und Dorit für die angenehme Arbeitsumgebung, die Anregungen zu den Analysen und letztendlich für Konstanzes Bereitschaft zu Korrekturlesungen.

Ich danke allen Mitarbeitern des Instituts für Geobotanik für die freundliche Atmosphäre und die stete Hilfsbereitschaft. Ebenso gilt mein Dank allen Mitarbeitern der Arbeitsgruppen von Prof. Dr. Annett Baasch und Prof. Dr. Sabine Tischew an der Hochschule Anhalt. Mit den Projekten an der Hochschule Anhalt wird wertvolles Wissen zur Renaturierung von Offenlandlebensräumen generiert, von dem auch ich profitieren durfte.

Ich danke dem Land Sachsen-Anhalt für die finanzielle Unterstützung meines Promotionsvorhabens.

Ein großer Dank gebührt auch Freunden, die mich auch in schwierigen Zeiten immer aufgebaut haben und somit zum Gelingen der Arbeit beitrugen.

Ein herzlicher Dank gilt meinen Eltern, für ihre in jeder Hinsicht bedingungslose Unterstützung, insbesondere seitdem ich nach Bernburg gegangen bin. Ihr habt mir immer die Möglichkeit gegeben, mich in die Richtung zu entwickeln, die für mich richtig war.

Am meisten danke ich Thomas. Danke, für deine kontinuierliche Motivation und für deine Unterstützung in jeder Hinsicht während der Anfertigung meiner Doktorarbeit.

Zusammenfassung

Artenreiche Grünlandbestände sind in Europa stark gefährdete Lebensräume und in den letzten Jahrzehnten wurde eine Vielzahl an Renaturierungsbemühungen unternommen, um dem stetigen Verlust an Fläche, Lebensraumqualität und Artenvielfalt entgegenzuwirken. Die Bewahrung der Vielfalt an Arten und Funktionen ist eine wesentliche Aufgabe der Menschheit im 21. Jahrhundert. Ziel dieser Arbeit ist es, einen Beitrag zum aktuellen Stand der Forschung zur Grünlandrenaturierung zu leisten und so Lücken zwischen theoretischer Ökologie und ökologischer Renaturierung zu schließen. Sie befasst sich mit der Bewertung des Renaturierungserfolgs, indem sowohl die Pflanzenartenzusammensetzung als auch die funktionelle Zusammensetzung von renaturierten Brenndolden-Auenwiesen und Flachland-Mähwiesen analysiert wird und untersucht die Frage, ob die funktionelle Zusammensetzung ein mögliches Instrument für die Beurteilung des Renaturierungserfolgs von Grünland darstellt. Am Beispiel der Renaturierung von Brenndolden-Auenwiesen und Flachland-Mähwiesen mittels Arteinbringung durch Mahdgutübertrag oder Wiesendrusch, beide Methoden auch in Kombination mit Einsaat von regionalen Saatgutmischungen, die im Land Sachsen-Anhalt umgesetzt wurden, wurden verschiedene Ansätze zur Bewertung des Renaturierungserfolgs verglichen.

Dafür wurden traditionelle Kriterien des Renaturierungserfolg, wie Artenreichtum, strukturelle Vielfalt und Artenzusammensetzung, mit funktionellen Kriterien, wie funktioneller Identität, ausgedrückt als gewichtete Merkmalsmittelwerte der Artengemeinschaft (CWM), und funktioneller Diversität (FD), in ihrer Fähigkeit den Renaturierungserfolg von Grünlandbeständen anzuzeigen, verglichen. Der Renaturierungserfolg wurde dabei auf verschiedenen organisatorischen Ebenen und im Vergleich zu unterschiedlich definierten Referenzen untersucht.

Kapitel 2 behandelt die Frage, welche funktionellen Merkmale und Merkmalskombinationen von Pflanzen für die erfolgreiche und nachhaltige Etablierung von Arten in artenarmen Wiesen entscheidend sind. Die Analyse auf Artenebene zeigte, dass die funktionellen Merkmale der Pflanzen eine Schlüsselrolle bei der Wiederherstellung von Grünlandbeständen spielen, während die spezifische Methode wie Samen eingebracht wurden eine untergeordnete Rolle einnimmt. Merkmale im Zusammenhang mit Persistenz (Lebensform und Strategietyp) und Ausbreitung (insbesondere Blühzeitraum) wurden als wichtige Prädiktoren für den Etablierungserfolg identifiziert. Darüber hinaus stellte sich heraus, dass Merkmalskombinationen den Etablierungserfolg am besten erklären und dass der Erklärungswert mit zunehmender Anzahl günstiger Merkmalszustände zunimmt. In den folgenden Kapiteln wird das Potenzial funktioneller Merkmale auf Bestandsebene untersucht.

In Kapitel 3 werden die funktionellen Reaktionen artenarmer Grünlandlebensräume auf Grünland-Renaturierungsmaßnahmen hervorgehoben und der Renaturierungserfolg wird anhand einer lokalen Referenz, unter Nutzung von Vegetationsaufnahmen aus der Umgebung des Renaturierungsstandorts, bewertet. Alle angewendeten Renaturierungsmaßnahmen waren geeignet, um das Renaturierungsziel nicht nur in Bezug auf die Artenzusammensetzung und die Etablierung von Zielarten zu erreichen, sondern auch hinsichtlich der funktionellen Zusammensetzung des Pflanzenbestandes. Fast alle CWM-Werte

zeigten einen Entwicklungsverlauf in Richtung der lokalen Referenz und die FD-Werte nahmen stetig zu.

In Kapitel 4 wird die Zusammensetzung der Arten und Funktionen eines umfassenden Vegetationsdatenpools, der als regionale Referenz dient, analysiert. Es wird die Frage bearbeitet, in welchem Verhältnis die Arten- und funktionelle Zusammensetzung von Brenndolden-Auenwiesen und Flachland-Mähwiesen zu verschiedenen Erhaltungsgraden stehen. Dabei beruht der Erhaltungsgrad der Flächen auf dem lebensraumtypischen Arteninventar und wurde anhand der Anzahl charakteristischer Arten ermittelt. Die Analysen zeigten, dass sich der Erhaltungsgrad einer Wiesengemeinschaft sowohl in der Art- als auch in der funktionellen Zusammensetzung widerspiegelt. Der Erhaltungsgrad der Flachland-Mähwiesen konnte mit akzeptabler Genauigkeit vorhergesagt werden, während die Vorhersage für die Auwiesen eher schlecht war. Nicht eine alleinige Kriteriengruppe spiegelte den unterschiedlichen Erhaltungsgrad der Flachland-Mähwiesen am besten wider, sondern eine Kombination von Variablen aus den gewählten Strukturvariablen, Zeigerwerten und der funktionellen Zusammensetzung. Demnach kann der Erhaltungsgrad eines Grünlandbestandes durch eine Kombination verschiedener Kriterien einschließlich funktioneller Kriterien beschrieben werden.

Durch die Erstellung einer solchen universellen regionalen Referenz eröffnet sich in Kapitel 5 die Gelegenheit, die Möglichkeit der Anwendung allgemein gültiger Kriterien einschließlich funktioneller Kriterien für die Bewertung des Renaturierungserfolgs zu untersuchen. Grünland-Renaturierungsmaßnahmen begünstigen die Entwicklung der funktionellen Zusammensetzung des Bestandes. Sowohl floristische als auch funktionelle Kriterien spiegelten den zuvor anhand lokaler Kriterien bewerteten Renaturierungserfolg wider und zeigten eine positive zeitliche Entwicklung nach Beginn der Renaturierung für alle angewendeten Renaturierungsmethoden und für beide Untersuchungsgebiete. Es hat sich gezeigt, dass diese universellen Kriterien ein starkes Instrument zur Beurteilung des Renaturierungserfolgs darstellen, die von lokalen Kriterien unabhängig sind.

Zusammenfassend wird in dieser Arbeit die Möglichkeit aufgezeigt, verschiedene Kriterien für die Bewertung des Erfolges bei Grünlandrenaturierung anzuwenden. Sowohl lokale als auch regionale Vegetationsaufnahmen können als Referenz dienen, da gezeigt wurde, dass sich die analysierten Kriterien beiden Referenzen annäherten. Darüber hinaus wurde gezeigt, dass funktionelle Kriterien traditionelle Kriterien bestätigen. Die funktionelle Zusammensetzung, die Zusammensetzung der Pflanzenarten und die Analyse der Entwicklung der Zielarten sind der alleinigen Analyse der Artenvielfalt überlegen. Insbesondere die Ergebnisse von Kapitel 5 haben gezeigt, dass floristische und funktionelle Aspekte als gleichermaßen bedeutend zu betrachten sind. Die Beurteilung des Erfolgs der Grünlandrenaturierung sollte sich daher auf so viele zur Verfügung stehende Informationen wie möglich stützen.

Die funktionelle Zusammensetzung der Pflanzenbestände kann als potenzielles Instrument für die Beurteilung des Erfolgs der Grünlandrenaturierung dienen. Es hat sich als zusätzliches Kriterium für die Beurteilung des Renaturierungserfolgs erwiesen, kann jedoch herkömmliche Kriterien nicht ersetzen.

Summary

Species-rich semi-natural grasslands are highly endangered habitats in Central Europe, and in the last decades numerous restoration efforts have been realised to counteract the ongoing losses in spatial extent, habitat quality and species richness of those habitats. Preserving the diversity of species and functions is an essential task of mankind in the 21st century. This thesis aims at contributing to the scientific knowledge about grassland restoration processes, thus bridging some gaps between theoretical ecology and ecological restoration. It addresses the issue of the assessment of restoration success by analysing both the plant species composition and functional composition of restored alluvial and lowland hay meadows and examines the question whether the plant functional composition is a feasible tool for the assessment of grassland restoration success. By taking the restoration of alluvial and lowland hay meadows by species introduction through hay transfer or application of threshing material from a local provenance, both also in combination with addition of regional seed mixtures of target species, that has been implemented in the Federal State of Saxony-Anhalt as a restoration example, different approaches to assess the restoration success were compared.

Therefore, traditional criteria of restoration success, such as species richness, structural diversity and species composition were compared with functional criteria, such as functional identity, expressed as community-weighted mean (CWM) trait values, and functional diversity (FD), in their ability to indicate the restoration success of grasslands. Accordingly, the restoration success is examined on different organisational levels and in comparison to differently defined references.

Chapter 2 addresses the question, which plant functional traits and trait combinations are decisive for the successful and sustainable establishment of species in species-poor grasslands. The analysis at the species level showed that plant functional traits play a key role in grassland restoration, while the specific restoration method of how seeds were transferred played a subordinate role. Traits related to persistence (life form and strategy type) and dispersal (especially flower season) were identified as important predictors for establishment success. Furthermore, trait combinations were identified explaining establishment best and the explanatory power increased with increasing number of favourable trait states. In the following chapters the potential of functional traits at the community level is explored.

In Chapter 3 the functional responses of species-poor grassland habitats to grassland restoration measures are highlighted and the restoration success is assessed against a local reference, using vegetation records of the surrounding of the restoration site. All applied restoration measures were appropriate to achieve the restoration aim not only in terms of species composition and the establishment of target species, but also in terms of plant functional composition. Almost all CWM values showed a trajectory towards the local reference and FD values steadily increased.

In Chapter 4 the species and plant functional composition of a broad vegetation record pool that serve as regional reference is analysed. The question of how the species and functional composition of alluvial and lowland hay meadows is related to different levels of conservation status is addressed. The conservation status of the sites is based on the habitat-specific species inventory and was determined by the number of characteristic plant species. The analyses showed that the conservation status of a meadow's community is reflected in both

species and functional composition. The conservation status of the lowland hay meadows could be predicted with acceptable preciseness, while the predictions for the alluvial meadows were only weak. Not a single group of criteria reflected the different degree of conservation status of the lowland hay meadows best, but a combination of variables out of the chosen structural variables, indicator values, and plant functional composition. Thus, a grassland's conservation status can be described by a combination of different criteria including functional criteria.

By generating such a universal regional reference, in Chapter 5 the opportunity opens to explore the possibility of applying universally valid criteria including functional criteria for the assessment of restoration success. Grassland restoration measures benefit the development of the grasslands plant functional composition. Both floristic and functional criteria reflected the restoration success that has been previously assessed by local criteria, revealing a positive temporal development after restoration started for all applied restoration treatments and across both study sites. It has been shown that these universal criteria provide a powerful tool for the assessment of restoration success, which is independent of local criteria.

In conclusion, this thesis highlights the feasibility of employing various criteria for the evaluation of grassland restoration success. Both local and regional plot records can serve as reference, as it has been demonstrated that the analysed criteria converged towards both. Furthermore, it has been shown that functional criteria corroborate traditional criteria. Plant functional composition, plant species composition and the analysis of the development of target species are superior to the sole analysis of pure species diversity. In particular the results of Chapter 5 revealed that floristic and functional criteria should be considered equally important. Thus, the assessment of grassland restoration success should rely on as much information available as possible. Finally, plant functional composition can serve as a potential tool in the assessment of grassland restoration success. It has proved to be an additional criterion for the assessment of restoration success, however, it cannot replace traditional criteria.

Chapter 1

General Introduction

Biodiversity, plant functional traits and functional composition of plant species communities

In the last decades, the decline of natural and stable ecosystems has become a matter of scientific and public awareness, not least because of the dramatic loss in biodiversity concerning flora and fauna, and ecosystem processes that provide the basis for ecosystem functioning have been widely recognised in research efforts (Cardinale et al. 2012). The functioning of ecosystems is affected by natural drivers, e.g. flooding events, but also by human activities, such as land-use changes, increase in nitrogen deposition and atmospheric CO_2 levels both facilitating climate change, species introduction or removal and the use of modern technologies which have an impact on the whole ecosystem, thereby affecting human well-being (Duraiappah & Naeem et al. 2005).

The diversity of plant species is widely acknowledged as one important determinant of ecosystem functioning (Naeem et al. 1999, Balvanera et al. 2014, Tilman et al. 2014) and the consequences of decreasing species diversity for ecosystem stability became a major concern (Hooper et al. 2005, Cardinale et al. 2012). Ecosystem service hot spots were found to be coincided with a high level in species diversity (Lavorel et al. 2011) and the multifunctionality of ecosystem functioning was found to be positively related with species richness (Cardinale et al. 2012).

Species richness as a surrogate for biodiversity is the most employed measure of biodiversity to monitor biodiversity changes (Hillebrand et al. 2018) and is also often estimated in restoration projects to rate the success of restoration measures (see Ruiz-Jaen & Aide 2005; e.g. Warren et al. 2002, Lindborg & Eriksson 2004, Edwards et al. 2007, Liira et al. 2009, Van Looy 2011, Sengl et al. 2017). However, biodiversity comprises not only species, genetic and ecosystem diversity in a given area (Swingland 2001). In addition, functional diversity defined as the value and range of those species and organismal traits that influence ecosystem functioning (Tilman 2001) was described as an important component of biodiversity (Díaz & Cabido 2001, Petchey & Gaston 2002) and as meaningful determinant of ecosystem processes (Loreau 1998, Chapin III et al. 2000, Tilman 2000, Díaz & Cabido 2001).

Plant functional traits are those morphological, biochemical, physiological, structural, phenological, or behavioural attributes of an individual that are relevant to the species' response to the environment, describing physiological processes, life-history processes, fitness and performance (Violle et al. 2007, Díaz et al. 2013) and were used to understand plant assemblages mechanistically (McGill et al. 2006, Shipley et al. 2006, Mouchet et al. 2010). In addition to abiotic factors affecting functional traits, biotic factors such as competition should be considered (Kraft et al. 2015). Hence, trait-based approaches have been shown to reveal the underlying mechanisms within communities (Zirbel et al. 2017) since the ability of a species establishment and persistence is determined by its traits (McGill et al. 2006, Lavorel et al. 2007). The functional composition of plant species communities can be described by two trait-based metrics: functional identity, expressed as community-weighted mean (CWM) trait values (Garnier et al. 2004), and functional diversity (FD), expressed for example as community-weighted variance (CWV) or related measures. For single traits CWV is identical with Rao's quadratic entropy (Rao 1982), when using a squared Euclidean distance matrix of traits (Champely & Chessel 2002, Bruelheide et al. 2018). Along with the loss of plant species richness, a decline in functional diversity has also been described (Wesche et al. 2012). Because a species establishment success, survival and fitness during restoration is influenced by its traits, many restoration projects covering a multitude of habitats from open landscapes to forest stands, have started to consider plant functional traits in their studies (e.g. Pywell et al. 2003, Lebrija-Trejos et al. 2010, Aerts & Honnay 2011, Woodcock et al. 2011, Clark et al. 2012, D'Astous et al. 2013, Hedberg et al. 2013, Martinez-Garza et al. 2013, Martin & Isaac 2015, Ostertag et al. 2015, Laughlin et al. 2017, Ribeiro et al. 2018). Moreover, species selection for restoration purposes could be guided by the knowledge of those traits associated to ecosystem processes that are relevant during the different stages of restoration (Sandel et al. 2011, Muler et al. 2018). By using these traits or trait combinations that demonstrably require a high degree of diversity (effect traits; Lavorel & Garnier 2002), appropriately assembled seed mixtures could deliberately be used in restoration projects. Thus, by initiating a basic seed matrix, conditions could be created that might promote the further establishment of desired species and functions. While there were numerous studies that considered traits, no study on grassland restoration has yet explored the potential of functional traits as predictor for restoration success.

Species-rich grasslands

Grassland habitats occur worldwide and provide many ecosystem services (Foley et al. 2005, Allan et al. 2015). Depending on the location, climatic influences, form of land use, etc., many different types of grasslands have developed (Gibson 2009). Thereof, semi-natural, temperate grasslands shelter an important part of plant species diversity on a small spatial scale (Wilson et al. 2012, Dengler et al. 2014). Moreover, a multitude of wildlife inhabit and use these grassland habitats (Blakesley & Buckley 2016).

Along river systems floodplain meadows emerged, forming the major grassland types in this habitat. In Europe, remnants of species-rich floodplain meadows were found along large rivers, such as the Elbe (e.g. Hundt 1958, Leyer 2002), Havel (Burkart 1998), Rhine (e.g. Hölzel & Otte 2001, Donath et al. 2003), Oder (Korsch 1999), and Danube (Ružičková et al. 2004). In those landscapes, in addition to flooding events fluctuating groundwater levels led to the development of species-rich plant communities with a characteristic zonation (Leyer 2002). Depending on the small-scale site-specific heterogeneity (relief and substrate) as well as on land use types, floodplain landscapes are characterised by a small-scale changing mosaic of various meadow-grassland communities. In addition to the intrinsic Alluvial meadows (Cnidion dubii), species-rich Lowland hay meadows (Arrhenaterion) occur often in close adjacency in those landscapes.

Over the last centuries, land use changes have led to a continuous decline in spatial extent, habitat quality and species richness of species-rich grasslands in Central Europe (Krause et al. 2011, Wesche et al. 2012, Diekmann et al. 2019), resulting in a persistent deterioration of the conservation status of these habitats (ETC, 2017). In addition, interventions in the river systems, such as river regulation (Tockner et al. 2002) or river drainage (Brunotte et al. 2009) have negative impacts on these meadows. Nowadays, German floodplain meadows are among the most endangered habitats (Finck et al. 2017) and several plant species typical of these grasslands are classified near-threatened and threatened in the red data book Germany (BfN 2018). Thus, the high conservation value of these grasslands was recognised, resulting in the protection by the European Union Directive on the conservation of natural habitats and of wild fauna and flora (92/43/EEC, Council of the European Union 1992) as Natura 2000 habitats 6440 (Alluvial meadows of river valleys of the Cnidion dubii) and 6510 (Lowland hay meadows, hereafter habitat type 6440 and 6510, respectively). In the federal state of Saxony-Anhalt, the habitat type 6440 has one of its main distribution areas along the river Elbe (Fig. 1.1). According to the federal state-specific assessment both habitat types are in an unfavourable-inadequate conservation status (LAU 2013). The habitat type 6440 has been found to a total of about 2700 ha, of which only 21 % were assessed as having a favourable conservation status (conservation status A). Habitat type 6510 has been found of approx. 9000 ha with only 12 % being in a favourable conservation status (LAU 2016). These results indicate the urgent demand of measures to restore species-poor floodplain meadows in order to meet the obligation of restoring a favourable conservation status.

Restoration ecology and the assessment of restoration success

In the human-influenced changing environment on earth, conservation, and especially, ecological restoration become more and more important to maintain the basis for existence of all living being (Young 2000, Young et al. 2005, Brudvig 2011, Wiens & Hobbs 2015). "Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER International Science and Policy Writing Group, 2004), which has varied motivations, thus requiring well-articulated goals (Hallett et al. 2013, Perring et al. 2015, Wiens & Hobbs 2015, Martin 2017, Rohr et al. 2018) and in the context of applied ecology it is one of the most intrinsic challenges (Suding 2011). The fundamental goal of restoration is to establish a self-sustaining ecosystem resilient to perturbation (Ruiz-Jaen & Aide 2005, Perring et al. 2015). Furthermore, the provision of ecosystem services can be increased by ecological restoration (Dodds et al. 2008, Benayas et al. 2009, De Groot et al. 2013). Because of the plurality of initial conditions, expected timeframes and spatial scales, there is a variety of different strategies for ecosystem restoration and management (Perring et al. 2015). In restoration projects, goals can be set at different organisational levels, from the species level up to the ecosystem level (Rohr et al. 2018) based on different metrics targeting the structure, function and diversity of the restored site (Ruiz-Jaen & Aide 2005, Benayas et al. 2009). Importantly, it must be underpinned by a standard or reference by which the outcoming can be evaluated (Aronson et al. 1995). An often determined

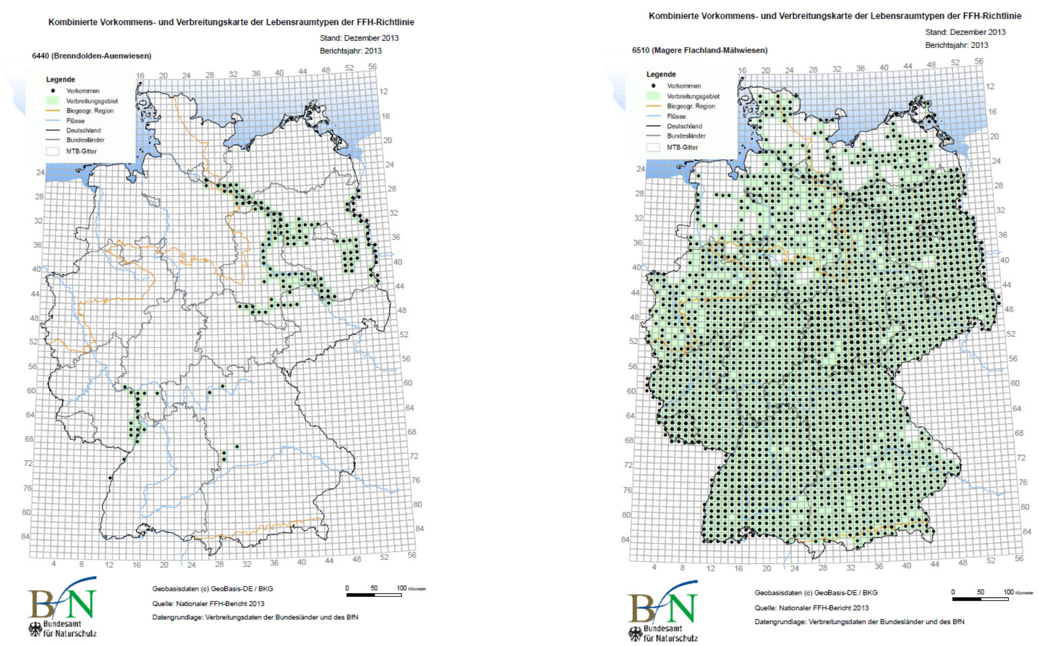

Fig. 1.1: Distribution of habitat types 6440 (left) and 6510 (right) in Germany (BfN 2013).

restoration goal is the recovering of a particular set of species or formerly existing species community focusing on taxonomic composition with a certain community structure that is used as a reference ecosystem (Brudvig 2011, Hallett et al. 2013, Waldén & Lindborg 2016, Török & Helm 2017). However, this strategy focuses exclusively on species identities and abundances without revealing the functional mechanisms affecting restoration results. Since traits became an important topic describing community assembly, the functional perspective was incorporated into restoration practice by analysing the functions in question affecting community assembly during restoration (e.g. Hedberg et al. 2014, Zirbel et al. 2017), which also resulted in the definition of functional restoration goals (Laughlin 2014 & 2017). It must be clearly defined, which functions should or can be achieved, even in a given time frame (Laughlin 2014). Therefore, the knowledge of benchmark states is essential, since without, reference setting and thus the definition of restoration goals would be impossible. With respect to German floodplain meadows, no attempt has been made yet to close this gap.

The restoration ecology is at the turning point from assessing restoration success by evaluating progress and goals based on specific goals with respect to species and habitats towards the restoration of more dynamic processes (Perring et al. 2015, Ockendon et al. 2018, Rohr et al. 2018). Hence, it is imperatively necessary to take the step in-between by gaining knowledge of the plant functional composition of a specific predefined species community acting as goal community. This presupposes, however, that the species composition is regarded as an indicator of restoration outcomes (Reid 2015).

In practice, there are two possibilities to achieve these benchmark states. One the one hand, a site-specific way is to analyse the functional composition either of an existing intact reference site in the surrounding of restoration sites or of historic data when the habitats were destroyed, and then take these as the benchmark ("*local reference*"; Hallett et al. 2013). On the other hand, this approach can be more generalised by defining the benchmark states based on vegetation data with respect to a specific predefined species community of a broader spatial and temporal scale ("*regional reference*"; Ruiz-Jaen & Aide 2005). Hence, restoration outcomes become assessable and more predictable (Benayas et al. 2009).

The process of ecological restoration is consistent of three major phases: planning, implementation and the assessment of restoration outcomes, also called monitoring (Tischew et al. 2010, Nilsson et al. 2016; Fig. 1.2). By the consideration of different evaluation criteria indicating restoration success in the monitoring phase, new projects can benefit from these results (Nilsson et al. 2016).

Rohr et al. (2018) emphasises a list of essential restoration variables for the restoration of degraded and disturbed ecosystems, which range from individual fitness to community structure and composition to species traits and ecosystem functions. Thus, depending on the restoration goal, different evaluation criteria are used for the assessment of restoration success. Species and structural diversity as well as the plant species composition are among the traditional criteria that are often used to assess restoration success. However, studies comparing traditional criteria with functional criteria are rare. It remains unclear how functional criteria can contribute to the assessment of restoration success, and whether functional criteria may be superior to traditional criteria or even not.

Török & Helm (2017) identified four main questions that every restoration ecologist shall ask. One of them addresses the factors determining the successful establishment of species. Beside site-condition, climatic and

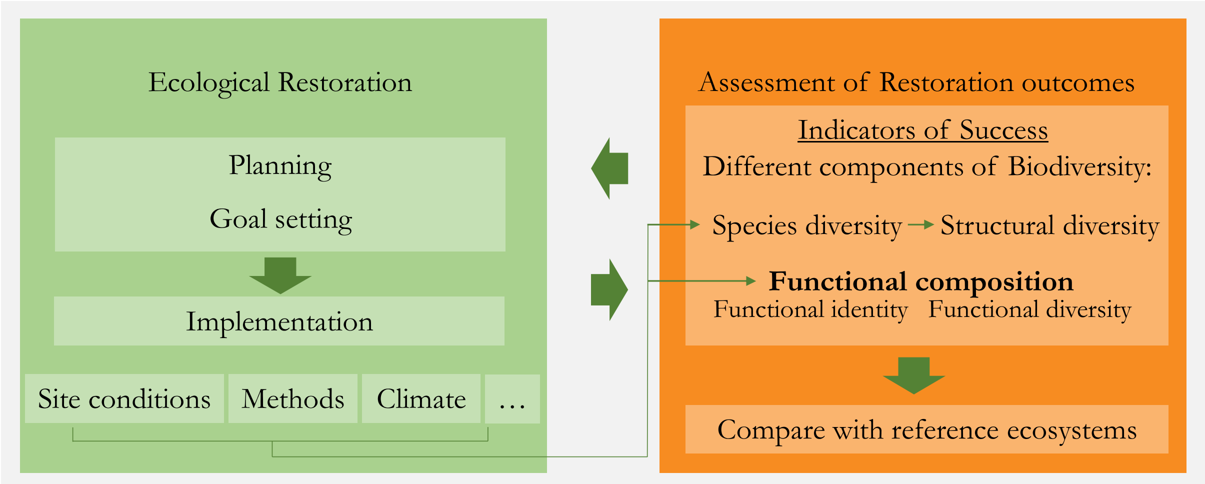

Fig. 1.2: The assessment of the restoration outcome strongly depends on the defined goals, i.e. which indicators have to be evaluated and what is the reference to be reached, which feeds back to future restoration efforts.

measurement effects, the successful establishment of introduced species might require different functional traits. Traits related to germination, dispersal, and reproduction affect the different stages of a species' life cycle in the different restoration phases. Thus, a major concern is the identifying of responsible key traits (Muler et al. 2018).

Restoration of species-poor grasslands

Biodiversity experiments have demonstrated that highly diverse grasslands compared to low diversity grasslands are more productive, exhibit a higher resilience against perturbation, e.g. flooding events, and provide higher and more stable levels of ecosystem functioning (Hector et al. 1999, Roscher et al. 2005, Proulx et al. 2010, Isbell et al. 2015, Weisser et al. 2017, Wright et al. 2017). Accordingly, the need for ecological restoration of species-poor grasslands is evident.

Furthermore, the European Directive on the conservation of natural habitats and of wild fauna and flora (92/43/EEC, Council of the European Union 1992) obliges all member states to take actions to maintain or restore a favourable conservation status of natural habitats and species of wild fauna and flora of Community interest. It thus serves the commitments undertaken by the EU Member States in 1992 to protect biodiversity (Convention on Biological Diversity). To meet the requirements given by the Habitats Directive, there is the urgent demand for both, to establish new species-rich meadows, e.g. on ex-arable fields, and to restore species-poor grasslands exhibiting an unfavourable conservation status. In the context of the Habitats Directive, the main goal is to maintain or restore a favourable conservation state. Specifically, this means restoring the species community that is characteristic of the specific habitat. In addition to this straight-lined path, trait-approaches provide frameworks to restore desired functions.

The (re-)establishment of a specific species community requires a definition of restoration targets taking into account the knowledge of existing possibilities. There are three key considerations that need to be pointed out: site-specific conditions, the restoration method to be applied and in the case of grasslands the initiation of an appropriate land use subsequently to the restoration measures (Török & Helm 2017).

Since the decline of the grasslands diversity is usually either a result of intensification through fertilisation to increase the productivity and the cutting frequency or insufficient land use through the abandonment of mowing or grazing (Gerstner et al. 2014, Joyce 2014, Krause et al. 2011, Wesche et al. 2012), a first step towards successful restoration might be the adjustment of site or management conditions, e.g. by stopping the fertilisation, reducing or increasing the intensity of use. Particularly stenoecious, mostly very small and less competitive species are affected by the changes in site conditions and land use (Lepš 1999, Venterink et al 2001, Hölzel 2003, Rosenthal & Hölzel 2004). However, often, the desired species communities do not, or only incompletely, develop after the initiation of adequate size-conditions or land use (Bakker 1989, Berendse et al. 1992, Hutchings & Booth 1996, Pegtel et al. 1996). The same applies to alluvial meadows on ex-arable land that were developed exclusively through self-colonisation, which consisted of comparatively few and frequent grassland species even after 10 to 15 years even though the nutrient status of the soils was successfully restored (Donath et al. 2003, Bissels et al. 2004, Rosenthal & Hölzel 2004). This is caused by a lack of availability of seeds (Tilman et al 1997, Stampfli & Zeiter 1999, Turnbull et al 2000, Pywell et al 2002, Smith et al. 2002), especially if the corresponding habitat types are absent in the surrounding as well as by the very low dispersal rates of many grassland species (Bischoff 2002, Hölzel et al. 2006, Bischoff et al. 2009).

Therefore, the restoration ecology strongly recommends near-natural methods for the introduction of target plant species, e.g. by sowing of regional seed mixtures (Bullock et al. 2007, Kirmer et al. 2012a, Prach et al. 2013), transfer of seeds from species-rich donor sites through freshly cut hay (Donath et al. 2007, Klimkowska et al. 2007, Baasch et al. 2012, Albert et al. 2019), transfer of seeds extracted from fresh hay by onsite threshing (see Scotton et al. 2012) or transfer of vacuum or brush harvested seed mixtures (Czerwiński et al. 2018, Edwards et al. 2007, Scotton et al. 2009). A multitude of studies refer to the good outcomes of this restoration strategy showing progress towards the desired target (see Kiehl et al. 2010, Török et al. 2011). However, the functional consequences of introducing plant target species remains unclear.

Finally, the establishment of an adequate land use subsequently to the restoration measures is of great importance. By the removal of the competitive pressure, the successful establishment of introduced species is facilitated (Hofmann & Isselstein 2004, Jones & Hayes 1999). Furthermore, a community-specific management adopted to the existing plant species can promote the long-term occurrence of the target plant species.

Required data sets: Long-term Grassland Restoration projects

By conducting biodiversity experiments, valuable insights concerning community assembly were obtained, in particular because factors such as location, land use and natural diversity can be controlled. However, these are artificially formed communities, which are also usually artificially maintained by weeding. It is unclear whether these results are transferable to natural systems. Therefore, long-term studies in restored and real-world managed grassland systems are essential to investigate the role of the plant functional composition within the monitoring of vegetation development of implemented restoration measures.

The studies of this thesis were carried out in the framework of the research project 'Grassland restoration in Natura 2000 areas using different methods of species introduction', which was conducted in Saxony-Anhalt, Germany. The core objective was to restore species-poor grasslands by different methods introducing target species. In this thesis, data of two study sites were used: "Untere Schwarze Elster" and "Küchenholzgraben" (Fig. 1.3). At "Untere Schwarze Elster" the aim was to restore an

Fig. 1.3: Study sites of this thesis eight years after restoration implementation in 2017 (left: Küchenholzgraben, right: Untere Schwarze Elster).

alluvial meadow, whereas at "Küchenholzgraben" a lowland hay meadow was defined as target community. At both sites, the implementation of restoration measures took place in 2009 applying the same strip-design. In a randomised block-design two crossed treatments, transfer of seed-containing plant material and sowing of regional seed mixtures (four variants) were used. Transfer of seed-containing plant material was applied by freshly cut hay and seeds extracted from fresh hay by on-site threshing. These two types of seed addition methods were combined either with or without additional sowing of regional seed mixtures. For a more detailed description, see Chapters 2 and 3.

There are two possibilities to set the reference to compare the restoration site's plots with. On the one hand, the donor sites, from which the transferred plant material was obtained, can serve as *local reference*. On the other hand, a compilation of vegetation records of a broader scale can serve as *regional reference*.

Objectives

The general objective of this thesis is to contribute for bridging gaps between theoretical ecology and ecological restoration, as prompted by Török & Helm (2017). Moreover, Brudvig et al. (2017) called for including additional aspects in the assessment of restoration projects to interpret variability and judge success during restoration. The central theme is the evaluation of restoration success employing different criteria. As there are no comprehensive studies yet on using plant functional traits and their composition for floodplain meadows in evaluating the success of restoring species-poor meadows with methods of species introduction, this thesis aims to close some of the gaps.

By the use of long-term grassland restoration data sets, it is possible to analyse plant functional traits at different organisational levels, thus, exploring the potential of functional traits both at the species level and at the community level. In addition, this allows comparisons between traditional criteria, such as species diversity, and functional criteria. Furthermore, since the restoration outcome has to satisfy the comparison with benchmark states, the question arises which levels of both species and functional diversity can be restored or expected.

In the following four chapters, it is intended (1) to analyse the establishment success of grassland species depending on their plant functional traits, (2) to evaluate grassland restoration success using both plant functional composition and traditional evaluation criteria in the *local context*, (3) to analyse the species and plant functional composition of a *regional reference* consisting of plot records of alluvial and lowland hay meadows differing in conservation status, and (4) to assess grassland restoration outcome with respect to its conservation status based on the plant species and functional composition in the *regional context*.

Therefore, the following research questions are addressed:

- Which plant functional traits and trait combinations are decisive for the successful and sustainable establishment of re-introduced species in species-poor grasslands?
- What are the functional responses of species-poor grassland habitats to grassland restoration measures? Is the restoration success also reflected in the plant functional composition of the established community?
- How is species and functional composition of alluvial and lowland hay meadows related to different levels of conservation status?
- Can functional identity (CWM) and functional diversity (FD) be used to assess the restoration success? Which criteria best reflect restoration success? Which general functional criteria can be identified for the assessment of grassland restoration success?

In **Chapter 2** the question which traits affect the establishment of re-introduced species is addressed. Therefore, data of both study sites, "Küchenholzgraben" and "Untere Schwarze Elster" were analysed at species level (Fig. 1.4). To make sure, that only re-introduced species were analysed, the study included only target species that could have been potentially introduced by the applied restoration methods and that were not present at the receptor sites before the restoration took place. The effects of the applied restoration method, time after implementation, traits related to germination, dispersal, and reproduction, and combinations of these traits on the establishment success were analysed (Fig. 1.4).

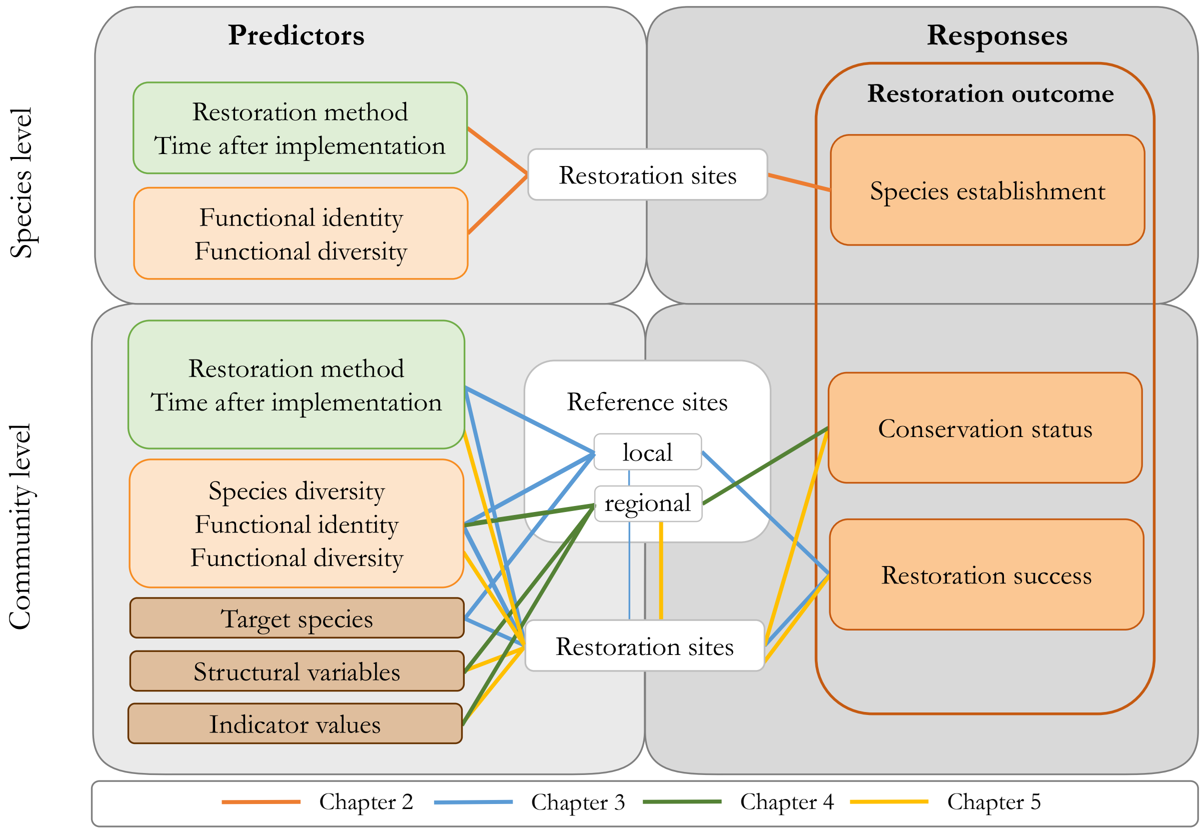

Fig. 1.4: Overview of predictors and responses used to assess the restoration outcome with respect to different organisational levels.

Chapter 3 makes use of the study site "Untere Schwarze Elster" and evaluates the different restoration measures that had been carried out with respect to functional identity and diversity. In addition, floristic composition, species diversity and number and cover of target species were assessed and used as traditional restoration criteria for a comparison with functional criteria (Fig. 1.4).

Chapter 4 describes both the species composition and functional composition of alluvial and lowland hay meadows with respect to its conservation status in the regional context (Fig. 1.4). The quality of those meadows was related to either one or a combination of criterion groups, which comprise structural variables, Ellenberg indicator values, functional identity and functional diversity.

Based on the analyses in Chapter 4, it was now possible to evaluate a grasslands restoration outcome with respect to its conservation status concerning the plant species composition and functional composition (**Chapter 5**). Applying the most predictive discriminant functions, for the restoration sites plots the conservation status with respect to its functional composition has been predicted (Fig. 1.4).

Finally, a synthesis is presented in **Chapter 6** that summarises the key findings, highlights the links between the different chapters and discusses the potential contributions of functional approaches for grassland restoration as well as implications for further research.

Chapter 2

Predicting the establishment success of introduced target species in grassland restoration by functional traits

Karina Engst, Annett Baasch, Helge Bruelheide

Ecology and Evolution, 7, 7442–7453

Abstract

Species-rich semi-natural grasslands are highly endangered habitats in Central Europe and numerous restoration efforts have been made to compensate for the losses in the last decades. However, some plant species could become more easily established than others. The establishment success of 37 species was analyzed over 6 years at two study sites of a restoration project in Germany where hay transfer and sowing of threshing material in combination with additional sowing were applied. The effects of the restoration method applied, time since the restoration took place, traits related to germination, dispersal, and reproduction, and combinations of these traits on the establishment were analyzed. While the specific restoration method of how seeds were transferred played a subordinate role, the establishment success depended in particular on traits such as flower season or the lifeform. Species flowering in autumn, such as *Pastinaca sativa* and *Serratula tinctoria*, became established better than species flowering in other seasons, probably because they could complete their life cycle, resulting in increasingly stronger seed pressure with time. Geophytes, like *Allium angulosum* and *Galium boreale*, became established very poorly, but showed an increase with study duration. For various traits, we found significant trait by method and trait by year interactions, indicating that different traits promoted establishment under different conditions. Using a multi-model approach, we tested whether traits acted in combination. For the first years and the last year, we found that models with three traits explained establishment success better than models with a single trait or two traits. While traits had only an additive effect on the establishment success in the first years, trait interactions became important thereafter. The most important trait was the season of flowering, which occurred in all best models from the third year onwards. Overall, our approach revealed the potential of functional trait analysis to predict success in restoration projects.

Keywords

functional traits, Germany, grassland restoration, hay transfer, on-site threshing, seeding, seedling establishment, species introduction

Chapter 3

Functional community ecology meets restoration ecology: Assessing the restoration success of alluvial floodplain meadows with functional traits

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Konstanze May, Ralf Schmiede, Helge Bruelheide

Journal of Applied Ecology, 53, 751–764

Summary

1. Species-rich grasslands are highly endangered habitats in Central Europe. To halt their ongoing loss, many sites have become subjects of restoration efforts. Traditionally, restoration success is measured using target species or by comparing similarity in species composition. Here, we suggest to additionally use functional community composition to assess restoration success as functional traits might offer mechanistic insights into restoration processes.

2. In a 5-year restoration experiment, we annually evaluated the responses of (i) floristic composition and species diversity, (ii) number and cover of target species, (iii) functional identity and (iv) functional diversity to four different methods of assisted recolonization through species introduction: hay transfer and application of threshing material from a local provenance, combined with and without addition of regional seed mixtures of target species, as well as to a control treatment.

3. Across all treatments, floristic composition, species diversity, and number and cover of target species approached the values of reference sites. In the last observation year, Shannon diversity was still lower in all treatment plots than in the reference plots, while the number of target forb species had reached or exceeded the reference levels. We demonstrated that the community was also restored functionally in many aspects, but not in all studied traits. Calculated community-weighted means (CWMs), specific leaf area (SLA) and leaf dry matter content (LDMC) in experimental plots did not differ significantly from the reference plots, thereby indicating that productivity of restored sites had reached target values. In contrast, CWMs of strategy types and pollination modes revealed significant differences, showing that biotic interactions among plant species and with other trophic levels have not yet been fully restored. However, almost all CWMs showed a trajectory towards the reference, thus giving a positive prospect for the future development. With respect to functional diversity (FD), we found steadily increasing FD values for almost all traits analysed.

4. Synthesis and applications. We demonstrated that all applied restoration measures were appropriate to achieve the restoration aim in terms of species composition of a given community and the establishment of target species. With respect to many functional traits, the restored meadows were already as functional as communities from the reference sites. Hence, including functional criteria did not only corroborate traditional criteria of restoration success but also allowed identifying those floodplain meadow's functions that can be quickly and less quickly restored.

Key-words: ecological restoration, functional diversity, grasslands, hay transfer, plant functional traits, seed transfer from hay threshing, species diversity, species introduction

Chapter 4

How well is the conservation status of alluvial and lowland hay meadows reflected in their plant functional composition?

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Journal of Vegetation Science, submitted

Abstract

Aims

While the conservation status of Natura 2000 habitat types is usually assessed in the field, we here explore the potential to base this assessment on vegetation plot records. Using a large set of vegetation records of two grassland habitat types (Natura 2000 codes 6440 and 6510), we assessed the conservation status based on the number and identity of characteristic species of that habitat. We then asked whether the conservation status was reflected in either one or a combination of criterion groups: i) structural variables, ii) indicator values, iii) functional identity and iv) functional diversity.

Location

River floodplains in Saxony-Anhalt, Germany

Methods

We compiled grassland vegetation records and assigned each record exclusively to either habitat type 6440 or 6510. Afterwards, we assigned each record to a level of conservation status with respect to species inventory. We employed linear models to relate species richness measures, structural variables and indicator values to the conservation status. Linear discriminant analysis was employed to differentiate the levels of conservation status.

Results

We found that sites with a favourable conservation status were species-rich, harboured a high number and cover of endangered species and showed a low Ellenberg indicator value for nutrient supply. Applying linear discriminant analyses, the conservation status of only the lowland hay meadows (6510) could be predicted with acceptable preciseness. Beside the confirmation of species richness as main criterion by which conservation status could be defined, there was not a single group of criteria that performed best, but a combination of criteria including functional traits in addition to structural variables and the Ellenberg indicator value for nutrient supply resulted in the best separation of the different levels of conservation status.

Conclusions

Semi-natural grasslands of the same habitat type do not only differ in plant species diversity, but also in plant functional composition. The finding that a habitat's conservation status can be described by a combination of functional criteria increases our understanding of which conditions are favourable and allows assessing its restoration potential.

Keywords

Conservation status, Ellenberg indicator values, Floodplain meadows, Functional diversity, Habitats Directive, Species diversity, River Elbe

Chapter 5

Using multi-criteria discriminant functions to assess grassland restoration success

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Paper in preparation for Restoration Ecology

Abstract

Restoration of species-poor grasslands is a widely used approach to halt the ongoing loss of biodiversity. While there is consensus on the most successful restoration measures, there are several ways to assess the restoration success. Traditionally, different types of indicators were considered separately and compared to a predefined reference for which often serves the donor site. Here, we introduce two global approaches for the assessment of restoration success employing analyses of plot's conservation status with respect to i) floristic criteria (CS_S) and ii) species inventory based on a criteria combination including functional criteria (CS_F) and compared those with the local assessment that was based on the number of target species that were present at the donor sites and occurred after restoration implementation. CS_S was determined by the calculation of the number of characteristic species of the respective habitat type that occurred in a plot. CS_F was based on a combination of criteria including structural characteristics, indicator values, functional identity and functional diversity. We made use of discriminant functions that allow identifying the conservation status of different types of Natura 2000 grassland habitats, which were derived from a large vegetation plot database of the Federal State of Saxony-Anhalt, Germany.

We applied these functions to two study sites which had been restored by an assisted recolonization through species introduction: hay transfer and application of threshing material from a local provenance, combined with and without addition of regional seed mixtures of target species.

Floristic criteria and discriminant functions reflected the local assessment, especially for the lowland hay meadows, indicating consistent trajectories with respect to restoration success. For the alluvial meadow, the local criterion of number of target species was a more conservative assessment tool, indicating that the full re-creation of the donor site's full composition of target species may be a too ambitious goal. However, in particular those treatments with an addition sowing revealed a good restoration outcome concerning CS_S and CS_F. Furthermore, at both study sites, both the CS_S and CS_F assessment revealed an increasing restoration success with time. However, while employing discriminant functions to assess grasslands restoration success, methodological constrains need to be considered. Overall, we demonstrated that universal discriminant functions based on database criteria provide powerful tools for the assessment of restoration success, which is independent of idiosyncratic local criteria.

Key words

conservation status, discriminant function, floodplain meadows, functional diversity, Habitats Directive, hay transfer, Natura 2000 habitats, restoration success, seed transfer from hay threshing, species introduction

Implications for Practice

- Restoration success can be assessed with universally applicable discriminant functions.
- We recommend to derive reference states based on a large pool of sites with favourable conservation status to evaluate the restoration success.
- Models of discriminant analysis should be further developed. Special attention must be paid to the selection of suitable variables.

Chapter 6

Synthesis

Key findings

This thesis focused on the link between Restoration Ecology and Functional Ecology. Including a comprehensive number of evaluation criteria and grassland restoration experiments of different habitat types, this thesis demonstrated how restoration efforts can be evaluated using traditional criteria, based on species composition and functional criteria, based on plant functional traits.

The key findings of each chapter are briefly summarised.

1) Plant functional traits play a key role in grassland restoration:

1.1) The establishment success of introduced species depended in particular on plant species traits.

1.2) The specific restoration method of how seeds were transferred was less important.

1.3) Trait combinations explained the establishment success better than models with a single trait or two traits.

2) Restoration success is reflected in the plant functional composition compared to a local reference:

2.1) All applied restoration measures were appropriate to achieve the restoration aim in terms of species composition of a given community in the surrounding of the restoration site and the establishment of target species.

2.2) Almost all community-weighted mean values showed a trajectory towards the local reference.

2.3) Functional diversity values steadily increased.

2.4) Functional criteria corroborated traditional criteria and after six years the restored study site was already as functional as the donor sites that were used as local reference.

3) The conservation status of a meadow's community is reflected in both species and functional composition:

3.1) Species richness was confirmed as main criterion by which the conservation status of grassland habitats could be defined.

3.2) The conservation status of the lowland hay meadows could be predicted with acceptable preciseness, while the results for the alluvial meadows were only weak.

3.3) Not a single group of criteria reflected the different degree of conservation status of the lowland hay meadows best, but a combination of variables consisting of structural variables, indicator values, and plant functional composition.

3.4) A habitat's conservation status can be described by a combination of different criteria including functional criteria.

4) Restoration success can be evaluated using a universal regional reference:

4.1) Restoration success can be assessed with universally applicable discriminant functions. Both plant species and functional composition can be restored by active grassland restoration measures with an increasing positive temporal development.

4.2) Treatments with an additional sowing reached the goal more quickly.

4.3) Methodological constraints need to be considered when applying the employed approach.

General discussion

Despite a large body of research on plant sociology, vegetation and functional ecology as well as on the restoration of species-poor grasslands, several aspects have not been fully addressed so far. Especially, the success of grassland restoration was less assessed from a functional perspective. Thus, the main theme of this thesis was the analysis of the plant functional composition of alluvial and lowland hay meadows in the context of grassland restoration considering both data of a long-term grassland restoration project and data of permanent grasslands. With this thesis, it has been demonstrated that it is possible to counteract the constant loss of species-rich grasslands by restoration and that the success of different restoration measures can be evaluated by criteria based both on species and functional traits.

Species diversity and functional diversity are not independent of each other, as the loss of plant species in grassland habitats is accompanied by a decline of functional diversity (Wesche et al., 2012), and otherwise, losses in functional diversity result in a loss of species diversity in the long term (Mayfield et al. 2010). With this thesis, it has been demonstrated that near-natural grassland restoration methods are appropriate to restore not only a certain species community but also a desired functional composition (**Chapter 3** and **5**). One might argue that restoring the desired functional composition is a direct consequence of reestablishing target species. However, this is not necessarily the case. On the one hand, species may become established without impact on the community's functional composition. This may happen, if the species only have low cover, and thus, do not have much impact on functional identity and diversity. In this case, a functional composition that lags behind species establishment may indicate unfavourable growing conditions for the target species in the long run. On the other hand, the functional composition may have been restored while the target species have not yet become established. In this case, functional composition indicates favourable conservation prospects with high chances of the target species to become established in the future. However, this can only be detected by carrying out the corresponding analyses focussing on the plant functional composition.

The goal of restoration projects needs to be well-articulated (Perring et al. 2015, Rohr et al. 2018), and also has to be realistic (Choi 2004, Hobbs 2007, Miller & Hobbs 2007). Usually these goals, which have to be measurable (Waldén & Lindborg 2016), specify which evaluation criteria are applied. Since the *ultimate goal* of all restoration projects is to establish a self-sustaining ecosystem resilient to perturbation reaching a species composition and community functioning similar to a reference community (Ruiz-Jaen & Aide 2005, Van Andel & Aronson 2012, Helm et al. 2015, Perring et al. 2015, Rohr et al. 2018), both levels of biodiversity the plant species composition and the plant functional composition need to be considered by monitoring procedures in restoration projects. For the applied data sets, the initial goal was to introduce species into species-poor grasslands by active restoration measures in order to increase the plant species diversity, to restore a characteristic species composition and thus, to restore those grasslands at a favourable conservation status with respect to the European Habitats Directive in the long term.

In order to achieve the *ultimate goal*, it is necessary to analyse functional criteria and to assess whether a desired diverse plant functional composition can be achieved through restoration measures. Here, it is necessary to extend the pool of criteria to be considered by the component of functional identity (CWM) and functional diversity (FD).

However, before the restoration success is assessed at the community level, it is much more important to clarify the question of whether and which of the introduced species could become established and **which plant functional traits and trait combinations are decisive for the successful and sustainable establishment of those species in species-poor grasslands**. The potential of functional trait analysis to predict the species establishment success in restoration projects at the species level has been demonstrated in **Chapter 2**. The establishment success of introduced species strongly depended on plant functional traits as numerous models in **Chapter 2** each containing a single trait outperformed the model without traits, while the specific restoration method of how seeds were transferred played a subordinate role. Only the design-specific variable 'presence in the seed mixture' ranked higher than any trait, which was not surprisingly and highlighted the outstanding importance of additionally sowing in restoration projects. In both the single-trait and the multi-trait approach traits related to persistence (life form and strategy type) and dispersal (especially flower season) were identified as important predictors. In their study on grassland restoration Albert et al. (2019) found seed mass and lateral spread as significant predictors with successfully transferred species having a high seed mass and a low capacity for lateral spread. In grassland restoration projects without any active species introduction, species traits related to establishment (Dzwonko & Loster 2007) as well as dispersal both in space and time (Poschlod et al. 1998, Helsen et al. 2013, see Török et al. 2018) were detected as major drivers of the species successful establishment. Though, Mudrák et al. (2018) found species frequently colonising with a high capacity for clonal growth, which promotes only short distance dispersal. Compared to restoration through spontaneous colonisation of target species, which requires a common occurrence in the surrounding landscape (Helsen et al. 2013, Mudrák et al. 2018), it has been expected that other traits might be important when applying active species introduction. Traits related to dispersal should be less important since dispersal barriers were overcome through the restoration techniques. This expectation was confirmed, since models including clonal growth organs and seed mass ranked lower than the no-trait model. In addition, the study by Albert et al. (2019) also confirms this expectation, as transferred and established species out of the harvested seed mixtures were those possessing a low capacity for lateral spread.

The most predictive traits in **Chapter 2** were those related to flowering and not those that were related to dispersal and germination. Species flowering in autumn performed better than those flowering earlier, which might be due to the completion of their life cycle, resulting in increasingly stronger seed pressure on the one hand or on the other hand it might be an artefact of the restoration measures since mowing of the donor site was performed in autumn, resulting in a higher representation of species exhibiting this trait state. Analysing 35 grasslands restored by sowing of a regional seed mixture, Mudrák et al. (2018) found a successful establishment of spontaneous colonisers that also possess a high capacity for a late phenology. They explained their results by concluding that the seed production of species that flower late in the vegetation period are not inhibited by the mowing regime, and thus those species are able to complete their life cycle. Further research is needed to analyse the phenology of spontaneous colonisers at the study sites that were involved in this thesis.

Finally, not only one trait was important for the successful establishment, but trait combinations were identified explaining establishment best and the explanatory power increased with increasing number of favourable trait states. In the first year after restoration measures have been carried out the highest establishment success was predicted for those species with a diaspore type different from "fruit segment", that were no "geophytes" and did not belong to the "CSR-strategy" type. A strategy different than CSR had not much effects on establishment success as a single trait. However, when combining this trait state with the other two traits the establishment success has been increased considerably, resulting in a predicted establishment probability of species characterised by all three favourable trait states to 52%. For the other years, the same pattern has been found. From a large grassland transplant experiment, Breitschwerdt et al. (2019) reported also trait combinations and trait interactions predicting plant performance characterised by relative growth rates and survival.

Using the multi-trait model approach to analyse the combined effect of several species' traits, also the importance of flower phenology was pointed out, since the most important trait was season of flowering 'spring', which occurred in all best models from the third year onwards. However, this is not contradictory to the statement that species with a late phenology performed better, since those species flowering in spring performed predominantly worse (Fig. 2.3). To conclude, the cutting dates to gain the plant material that should be transferred needs to be more closely adapted to the flower phenology of key target species. In addition, such species may be more easily transferred with more than one time of hay making. Furthermore, including species with a particular phenology, such as those flowering in spring, in additional seed mixtures might significantly increases the chance of establishing these species. Mudrák et al. (2018) have postulated that the key for a successful restoration is an appropriate composition of the seed mixture with a focus on those species that regenerate only by seeds as most successful species in restored grasslands were found to have a high capacity for clonal growth. Hence, in particular nonclonal species should be facilitated by sowing. The authors also suggest to omit species that possess a late phenology since they might colonise the restoration site on their own. However, the latter one should only be considered if sufficient seed sources are in the surrounding. Furthermore, seed mixtures applied in restoration projects should comprise species having no or less overlapping niches based on different traits, thus, reducing interspecific competition and fostering better establishment of those species (Rinella & James 2017, Torrez et al. 2017). Thus, containing seeds of both phenology types flowering in spring, e.g. *Cardamine pratensis* and flowering in autumn, e.g. *Selinum dubium* fulfil this condition. Finally, the restoration outcome also depends on the seed mixture diversity and the density of seeded species, and was found to be more successful with more diverse seed mixtures (Kirmer et al. 2012a, Lepš et al. 2007) sown at higher densities (Carter & Blair 2012, Nemec et al. 2013, Barr et al. 2017). A further factor that might influence the successful establishment of target species is the mowing regime in the years after the restoration measures have been carried out. By using mosaic and phased mowing (i.e. mowing at different times on different areas at the study site), target species might fulfil their life cycle and ripe seeds might shed across the whole restoration site.

Further research is required concerning other species' traits that might affect the species successful establishment. Traits related to specific germination requirements such as light or chilling affect species-specific germination rates. Thus, a more detailed analysis of the species dormancy behaviour or the genetic fitness of the donor sites species pool might provide new insights. In the case of alluvial meadows, traits related to flooding resistance might probably explain establishment success even better. Finally, the ecological functions of habitats depend on the interaction between biotic and abiotic components. Since abiotic filters can modify species assembly (Kraft et al. 2015, Török et al. 2018), soil properties as well as climatic factors are of great importance. Though, these site factors were not explicitly included in this thesis. However, soil characteristics especially in terms of the nutrient status are crucial for a successful establishment (Fry et al. 2017), which has been outlined in **Chapters 4** and **5**.

Considering the restoration success at the community level, the results which are presented in **Chapter 3** and **Chapter 5** are in line with other studies restoring grasslands which have shown that by using near-natural restoration techniques such as transfer of freshly cut hay or transfer of seeds extracted from fresh hay by onsite threshing, the desired plant communities can be restored successfully (see Kiehl et al. 2010; Török et al. 2011). The active introduction of target species has been found to increase the species diversity, which is accompanied by a change in species composition towards the reference community. In the case of alluvial and lowland hay meadows, which are characterised by a high level of species, structural and functional diversity (**Chapter 4**), both the establishment of target species and the associated increase of plant species diversity are suitable indicators of restoration success (**Chapter 3**).

Traditionally, plant species diversity, expressed as species number or Shannon diversity, are used to assess whether the aim of restoring species-poor grassland has been achieved (e.g. Martin et al. 2005, Baasch et al. 2012, D'Astous et al. 2013, Sengl et al. 2017, Resch et al. 2019). In **Chapter 4** it has been shown that species diversity of grasslands in river floodplains in Saxony-Anhalt and closely adjacent areas is related to their conservation status. Schmiede et al. (2012) found increasing species number with time in a species-poor grassland after the transfer of plant material. Similarly, in a long-term restoration project in Sweden restoring abandoned grasslands by tree clearing and the re-introduction of a grazing regime, Waldén & Lindborg (2016) described a significantly increasing number of species with time after restoration measures were carried out. These studies demonstrate that the active introduction of desired species via diaspore-rich plant material both generalist species and grassland specialists can become established. Although the number of species was an important criterion in **Chapters 3**, **4** and **5**, it has been shown that species richness is not sufficient as a sole criterion for restoration success, as species richness provides no information on nontarget species or species with undesired functions. Hence, further criteria need to be considered to evaluate restoration success. One simple way to obtain an overview of the floristic composition related to the restoration methods applied as well as to the time elapsed since restoration started is to employ ordination approaches (**Chapter 3**) which incorporates additional information since the relative abundances of all occurring species are considered. Using such an approach, an approaching species community towards the reference was detected. Albert et al. (2019) found the same result using RDA analysis of species composition after restoration by the transfer of green hay. In addition, those treatments with an additional sowing were more successful than the treatments without additional sowing. However, this analysis alone does not reveal the underlying mechanisms that indicate what makes species successful at a certain restoration treatment. Another criterion applied in this thesis was the analyses of the number and cover of target species typical of the desired plant species community (**Chapter 3**). The evaluation of pre-defined target species is already considered a meaningful measure of restoration success (e.g. Bakker et al. 2000, Hölzel & Otte 2003, Rosenthal 2003, Donath et al. 2007, Kiehl et al. 2010, Baasch et al. 2012, Hertog & Turnhout 2018, Albert et al. 2019). For the study site "Untere Schwarze Elster" it has been shown that the applied restoration measures led to an increase in number and cover of target species. Baasch et al. (2016) found a similar trajectory for the second study site "Küchenholzgraben". By the use of this criterion, the restoration practitioners are able to examine the successful establishment of target species and to monitor the further development of those species to get information of the required management. An approach that is comparable to the determination of target and non-target species for assessing restoration success has been introduced by Helm et al. (2015) by their concept of characteristic diversity, consistent of a habitat-specific species pool that is historically developed and currently present in a particular habitat and derived diversity, consistent of species that do not belong to the habitat-specific species pool. In **Chapter 3**, target and non-target species groups were defined based on several criteria. The development of those groups was analysed in comparison to a reference. Helm et al. (2015) extended this idea and suggest to use the "Index of Favourable Conservation Status" which is defined as log ratio of characteristic:derived diversity. However, there is no link between the "Index of Favourable Conservation Status" and the term "Favourable Conservation Status" in the context of the European Directive on the conservation of natural habitats and of wild fauna and flora. Helm et al. (2015) also highlighted the possibility of misinterpretations when assessing only the total number of observed species. The conservation status of a habitat depends in particular on which species occurred at the respective site. Thus, the proportion of derived diversity can provide information about the phase in which the restored site currently is and whether guiding intervention is necessary, as it also does the assessment of non-target species. However, a solely species-based assessment is insufficient as ecological differences between species are not considered.

By exploring the potential of functional traits as predictor for restoration success, it has been demonstrated that **the success of grassland restoration is also reflected in the plant functional composition**, as **functional identity and functional diversity** of experimental plots **responded to the restoration measures**. Other studies also showed positive shifts of plant functional composition after implementation of restoration measures (e.g. D'Astous et al. 2013, Pywell et al. 2011). Furthermore, both criteria approached the reference with time (**Chapter 3** and **5**) and restoration success was almost always reflected in an increase in FD values with higher FD values of the restoration treatments compared to the untreated control plots. For instance, the treatments plots representing grassland restoration by transfer of seed-rich plant material showed a higher trait variation compared to the control plots, as it was also demonstrated by Hedberg et al. (2014) during a fen restoration. In grassland restoration, where seeds of target species are introduced by different methods, an increase in FD was expected. Several studies have shown that an increase in species number leads to an increase in functional diversity and in community stability (Roscher et al. 2004, Cadotte et al. 2011, Isbell et al. 2015, Weisser et al. 2017). However, maximising FD is not automatically the best goal for ecological restoration. First, the FD to be reached depends on the habitat (Hedberg et al. 2013). Second, FD cannot be maximised for traits that have extreme CWMs (Dias et al. 2013). However, applying functional criteria allows a more differentiated assessment of restoration success, as key traits related to germination, dispersal, and reproduction affect the different stages of a species' life cycle in the different restoration phases. Hence, valuable information for the understanding of community assembly during grassland restoration can be obtained by the assessment of those traits (Zirbel et al. 2017, Torrez et al. 2017).

A major topic of this thesis was also the **analysis concerning the species and plant functional composition of a broad set of plot records of alluvial and lowland hay meadows** exhibiting different levels of conservation status with respect to species inventory. In **Chapter 4**, **general functional criteria for the assessment of grassland restoration success** should be **identified.** This required a classification of grassland plot records, which was done by the assignment to a conservation status on a three-level scale, where (A) corresponds to an excellent, (B) a good and (C) a medium to bad conservation status with respect to species inventory according to the rules of the field manual for Natura 2000 Habitat Mapping (LAU 2010). Additionally, a fourth category called 'N' („no conservation status assignable“) was defined for such pre-selected records of a particular habitat type that did not hold the minimum number of characteristic species and thus could not be assigned to a conservation status of the respective habitat type. This approach allowed to categorise plot records with respect to their floristic conservation status.

For this chapter another criterion related to abiotic site characteristics which can be used for the assessment of restoration success has been introduced: Ellenberg indicator values (EIVs; (Ellenberg et al. 1991, 2001).

There was a correlation between the level of conservation status and species number, number and cover of endangered species and the Ellenberg indicator value for nutrient supply, indicating a higher level of conservation status of the studied grasslands with increasing species number as well as with increasing number and cover of endangered species and decreasing indicator value for nutrient supply. In particular, the indicator value for nutrient supply turned out to be important since a better conservation status was associated with low Ellenberg nitrogen indicator values. Thus, grasslands exhibiting a large number of target species are characterised by low mean Ellenberg nitrogen indicator values. By the detection of high Ellenberg nitrogen indicator values, this could be an indication that target species either will not or did not become established at all or only in low coverages. In addition, one cause for a failed restoration can be obtained by the analyses of the Ellenberg indicator value for nutrient supply. However, also Ellenberg indicator values cannot be used as a sole criterion for restoration success, since they are a measure that allow for conclusions on abiotic site characteristics (Diekmann, 2003), but neither on the identity of actual established plant species nor on the restored functions.

For both habitat types, the conservation status of the grassland habitat types (6440 and 6510) was reflected not only in the number and identity of characteristic species but also in criteria with respect to structures and functions. Moreover, a **combination of criteria** including functional traits resulted in the best separation of the different levels of conservation status for the lowland hay meadows. Similar to the result presented in **Chapter 3**, FD values increased with increasing level of conservation status (**Chapter 4**). Hence, a favourable conservation status of a grassland habitat reflects both a certain community composition and structure typical for this community related to a specific species richness and a high functional diversity. Thus, the **success of restoration measures** needs to be **assessed based on several variables** out of different **criterion groups**, as it has been demonstrated in **Chapter 5**. However, the models of the discriminant analysis without including species number as predictor should be further developed since for both analysed habitat types kappa values reached only values up to 0.64. First, the selection of key traits that are included in the selection procedure are important. By including traits that reflect a species' resistance against flooding or drought (Winkel et al. 2016, Wright et al. 2017) or germination traits such as germination rates or germination requirements (Pywell et al. 2003, Hölzel & Otte 2004) kappa values would probably be increased. Second, special attention must be paid to the selection of reference sites included in the analysis. In this thesis, all criteria were considered against a reference that was defined either locally (**Chapter 3**) or regionally (**Chapter 4** and **5**). It has been shown that the **plant functional composition** approached the reference and that this trajectory is consistent between local and regional references (**Chapter 5**), which provided quantitative evidence that it could be a **potential tool** in the monitoring of grassland communities (Ansquer et al. 2009, Piqueray et al. 2015), and furthermore, in the **assessment of restoration success**. However, the question of site validity either locally or regionally arose and should be shortly discussed. Choosing a local reference to compare the restoration outcome with, it is rather likely that abiotic site conditions are similar and a respective species and functional composition can be restored. Nevertheless, the conditions of the chosen local reference site cannot be completely equal to the receptor site. Furthermore, choosing only one local reference is a very site-specific proceeding which can severely limit the restoration goal. In addition, different local references can lead to a very different assessment of restoration success. However, the choice of reference also depends on the chosen restoration method. In particular when transfer of green hay is applied, the comparison with the donor site is of extraordinary importance, since introduction or transfer rates (**Chapter 2**) are also a good indicator of restoration success (Kiehl et al. 2010). In contrast, a reference of a broader spatial and temporal scale is independent of idiosyncratic local criteria and can level those disadvantages. In **Chapter 4**, plot records within the Federal State of Saxony-Anhalt and close adjusted areas were analysed. Considering the selection of a regional reference pool, it might be useful to focus on clearly defined regions. A national reference is not recommended in this context, as the river systems, e.g. Elbe and Rhine with their associated grasslands are too different with respect to both abiotic and biotic characteristics.

An important result of this thesis is, that both species and plant functional composition approached the reference sites, which was also found by Albert et al. (2019). However, when assessing the restoration outcome against a local or a regional reference, there are differences that remained between the restored and the reference sites concerning both levels of biodiversity, suggesting that the complete restoration of diversity, structure, and function remains difficult. For example, pollination was not fully restored (**Chapter 3**), that reflects the difficulty also to restore biotic interactions between plants and other trophic levels. As Perring et al. (2015) postulated interdisciplinary approaches, e.g. combined surveys of plant species and other taxa such as invertebrates (Winsa et al. 2017) or birds (Fletcher & Koford 2002), combined analyses of above- and belowground responses (Fry et al. 2017, Herz et al. 2017a, 2017b) or the assessment of the seed bank dynamics in the post-restoration phase (Rayburn et al. 2016, Wagner et al. 2018), which can significantly widen our understanding of grassland restoration. Other studies reported functional differences between restored and reference sites that remained after several years for restored dry grasslands (Albert et al. 2019), calcareous grasslands from forest stands (Piqueray et al. 2011 & 2015) or abandoned pastures (Winsa et al. 2017). Thus, restoring a grasslands' full functionality might be not achievable. Both soil conditions and the currently adopted land use regime might give some indications why those differences still exist. Therefore, further monitoring and close cooperation with land-owners is essential. In addition, there is still a need for long-term restoration monitoring (Choi 2004, Herrick et al. 2006, Montoya et al. 2012), since habitats develop continually driven by ecological processes as well as abiotic conditions. Although differences between restored and reference sites remained, **both functional identity and functional diversity** revealed a positive trajectory towards the local as well as the regional reference with the final conclusion that they **can be used to assess restoration success.**

With this thesis, general benchmark states for each conservation status and each variable included have been defined. Such benchmark states are important, in particular for grassland managers to quickly assess their grasslands and to ascertain a need for improvement. One possible, however, simple way to obtain the threshold values is to determine mean values of each level of conservation status for each variable based on the regional reference pool, as it is shown in Fig. 6.1. Subsequently, the obtained values of each restoration method applied of the restoration sites can be compared with these threshold values. However, using mean values might not be the optimal solution. Equal mean values can be based on different frequency distributions of a variable. Thus, particular attention must be payed to the selection of reference plot records. Furthermore, a pre-defined reference range, e.g. ±1 standard deviation (SD) as it was applied in **Chapter 3** can be employed to define the thresholds. However, using mean values and ranges bear the problem of overlapping ranges of the different levels of conservation status, reducing the applicability of the defined ranges. This problem can be solved by the employment of generalized linear models (glms), using a logit link function with binomial error distribution as it was applied in **Chapter 4**. Hence, threshold values (CS_{50}) for all variables used in the analysis above which the next more favourable conservation status is reached were defined. However, the obtained CS_{50} thresholds are less applicable, since they have some limitations. First, since the values were obtained from several generalized linear models (glms) for which only the significant ones were taken, a lot of gaps are present. Second, based on the glms, values below 0 and above 1 for CWM and above 100 for structural variables were obtained indicating an over- or underrepresentation of this trait or variable state, respectively. Therefore, further research with respect to statistical modelling of those CS_{50}-threshold values is needed. In contrast to the approach of defining benchmark states by glms, which is an univariate one, the approach applying discriminant functions is a multivariate approach. Hence, by the glm-approach it was possible to define a CS_{50}-threshold value for each single variable. Employing the discriminant functions only statements about

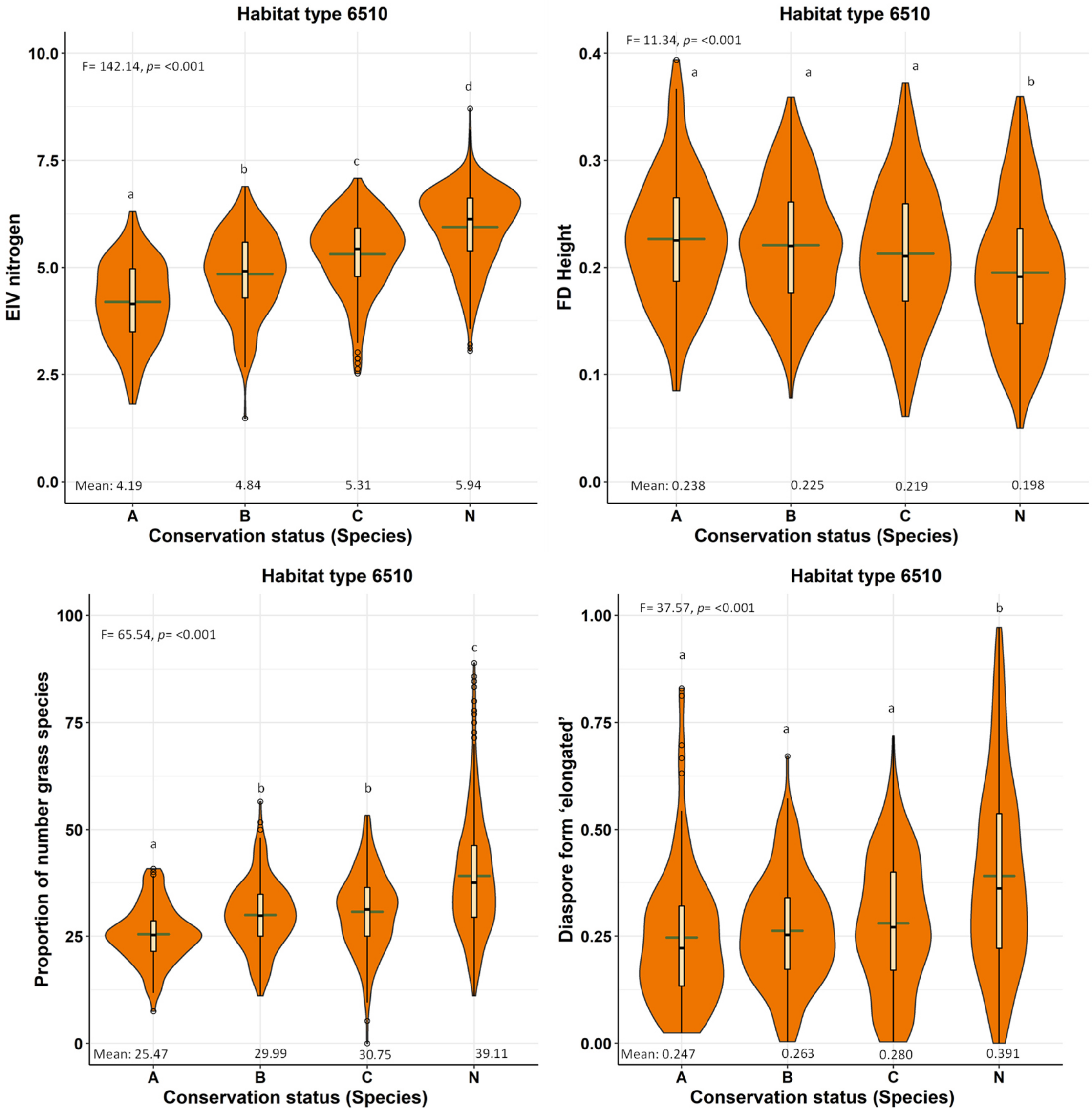

Fig. 6.1: Simple way to obtain threshold values by determining the mean value (green line). Significance of the predictor was tested with type I ANOVA, and in case of significant effects, Tukey–Kramer multiple comparison tests were calculated for the detection of significant differences between different levels of conservation status.

benchmark states for the six selected variables were given. However, it is not meaningful to perform discriminant functions with all variables, otherwise an overprediction takes place. Furthermore, using the glm-approach a threshold for each level of conservation status was obtained. Although the discriminant analyses separating all four levels of conservation status were performed, it has been found that the separation could not be explained well, because only low kappa values were determined.

For the restoration of species-rich meadows different techniques and approaches have been proposed (e.g. Baasch et al. 2016, Bischoff et al. 2018, Sengl et al. 2017) and the successful application have been confirmed in this thesis. In such projects, traits are less frequently used to define the restoration goals. For future restoration projects, the definition of targets should focus not only on traditional criteria, but also on including the functions of the habitats to be restored (Laughlin 2014, Laughlin et al. 2018). A key question of this thesis was **which criteria best reflect restoration success**. It has been demonstrated that by using the criteria of the plant functional composition the restoration success can be evaluated in addition to other criteria. However, it cannot replace traditional criteria. Although Clark et al. (2012) reported that plant trait models explained almost as much as species taxonomic identity, models characterising responses to restoration measures, thus highlighting the feasibility of using plant traits instead of species taxonomic identity, the assessment of restoration success should rely on **as much information available as possible**. Plant species composition, plant functional composition and the consideration of the development of occurring target species are superior to the sole analysis of pure species number or Shannon diversity as discussed above. In contrast, applying only single criteria result is an insufficient assessment of restoration success. In fact, it is a combination of multiple criteria that should be considered when assessing the restoration outcome insofar as time and financial resources allow for. Each restoration project has to trace back to the goal, which was defined before restoration started, hence, the choice of evaluation criterion should therefore be based on this goal. On ex-arable land and in restored semi-natural grasslands, respectively, Fukami et al. (2005) and Helsen et al. (2012), respectively found trait convergence while species more or less diverged through time. Hence, the sole consideration of functional criteria is insufficient since the dissimilarity of the functional community composition between plot records is not described by these criteria. In any case, when assessing restoration success a major focus should be on the analysis of the development of the species composition, since only then the monitoring of the successful establishment of desired target species is possible and calibration steps might be adopted in case of failure establishment of those target species. Functional criteria are an additional criterion for the assessment of restoration success, however, they cannot replace those criteria that allow to evaluate the development of a certain community towards a desired plant community.

The big challenge to overcome is the question of how the functional perspective can be incorporated into grassland restoration. Solutions need to be developed on how land users can achieve both traditional and functional targets in order to preserve and restore biodiversity and ecosystem services. McDonald et al. (2016) proposed a progress evaluation ‘recovery wheel’, measuring progress toward a restored state capturing different attributes from physical conditions via species composition and community structure through ecosystem function. However, they note that users need to develop indicators and metrics specific to their system and ecosystem type. Therefore, further research and a close cooperation with land users from an early state is needed (Ockendon et al. 2018). Hence, these solutions should combine traditional and functional components, that provides pathways to preserve the multifunctionality of landscapes considering trade-offs between different services (Foley et al. 2005, Lavorel et al. 2011, Martin et al. 2014, Allan et al. 2015).

With this thesis, a new avenue of research has been opened. The approach presented in **Chapter 4** and **5** has to be adopted to further grassland restoration sites demonstrating the transferability to other sites. Furthermore, in order to assess the approach applied it should be adopted to further plant species communities testing for universality. Evaluation of both species composition and functional composition should definitely be continued, as the sustainable establishment of desired target species and the appearance of desired functions might be attained only after a long time, thus requiring long-time monitoring.

Future scientific grassland restoration projects should combine both the restoration of a specific plant community associated with their respective characteristic plant species and the restoration of predefined functions. Hence, the next step is to conduct a grassland restoration project that manipulates functional diversity while controlling plant species diversity in natural systems. However, this approach can only be conducted by sowing defined seed mixtures with different levels of functional diversity. Uyttenbroeck et al. (2015) already tested such an approach while creating perennial flower strips to foster the plant-pollinator network. By creating a gradient of functional diversity, it is possible to examine whether, on the one hand, the expected increasing FD values of the different treatments that represents different levels of functional diversity were realised. On the other hand, responses of species diversity and composition at those different levels of functional diversity can be analysed. Another approach deriving species assemblages presented by Laughlin et al. (2018) that can simultaneously optimise functional identity and functional diversity could be adopted to further grassland restoration projects. For example, using the function proposed by the authors a species pool could be assembled that maximises the diversity of flowering times as an indicator for a high-quality pollinator habitat while CWM of the flooding tolerance of the assembled species is high. Thus, seed mixtures for floodplain meadows can be assembled, which promotes both species and functional diversity.

The main result of this thesis is, that **plant functional composition can serve as a potential tool in the assessment of grassland restoration success.** However, the results presented should be adopted to further grass-land communities, such as dry grasslands or wet Molinia meadows. Furthermore, as discussed above further plant functional traits should be incorporated. Since soil properties as well as climatic factors were not explicitly included in this thesis, further analyses should include those factors. Especially variables such as precipita-tion, water availability in the soils or the nutrient status might provide further reaching results. In addition, further statistical analysis methods could be adopted to gain more explanation. For example, at the species level species establish-ment success dependent on plant functional traits could be analysed by performing a regression tree analysis as it has been performed by Mudrák et al. (2018).

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Appendix

Curriculum vitae

Persönliches

Name:	Karina Engst (geb. Hofmann)
Geburtsdatum:	25.08.1987
Geburtsort:	Karl-Marx-Stadt
Nationalität:	deutsch

Ausbildung

1998-2004 Blaise-Pascal-Mittelschule Chemnitz
Abschluss: Mittlere Reife

2004-2007 F+U Berufliches Gymnasium Chemnitz
Abschluss: Allgemeine Hochschulreife

2008-2011 Hochschule Anhalt, Bernburg
Studiengang: Naturschutz und Landschaftsplanung
Abschluss: Bachelor of Science (Note 1,3)
Titel der Arbeit: Natürliche Dynamik und anthropogene Veränderungen von besonders geschützten Biotopen – Ein Vergleich nach elf Jahren (Note 1,0)

2011-2013 Hochschule Anhalt, Bernburg
Studiengang: Naturschutz und Landschaftsplanung
Abschluss: Master of Science (Note 1,2)
Titel der Arbeit: Untersuchungen zur Vegetationsentwicklung sowie zu wertgebenden Arten am Beispiel der Tonhalde und des Sandtrockenrasens Petersroda in der Bergbaufolgelandschaft „Goitzsche" (Note 1,0)

Deutschlandstipendium der Hochschule Anhalt

ab Dez. 2013 Martin-Luther-Universität Halle-Wittenberg, Hochschule Anhalt, Bernburg
Promotionsstudium
angestrebter Abschluss: Dr. rer. nat.
Forschungsthema: Funktionelle Pflanzenmerkmale, -typen und Diversität in Auengrünland im Land Sachsen-Anhalt - Grundlagen für die Renaturierung nach der FFH-Richtlinie und die Wiederherstellung von Ökosystemfunktionen

gefördert durch die Graduiertenförderung des Landes Sachsen-Anhalt: 01.12.2013-30.11.2014, 01.12.2014-30.11.2015, 01.12.2015-31.05.2016, 01.06.2016-30.11.2016)

Berufliche Tätigkeit

2007-2008 Freiwilliges Ökologisches Jahr
Sächsische Landesstiftung Natur und Umwelt, Außenstelle Lichtenwalde

2009-2016 Co-Teaming (Seminarbegleitung) - Freiwilliges Ökologisches Jahr
Sächsische Landesstiftung Natur und Umwelt

2010-2013	Studentische Hilfskraft an der Hochschule Anhalt, Bernburg im Projekt „Grünlandaufwertung in FFH-Gebieten mittels neuer Methoden zur Etablierung von Zielarten“
2012, 2014, 2016	Biotop- und Vegetationskartierungen
2014, 2015	BFD-Seminar „Knospenbestimmung von Gehölzen“ für Sächsische Landesstiftung Natur und Umwelt
2015-2016	Lehrauftrag an der Hochschule Anhalt, Bernburg Seminare Gehölzkunde für die Studiengänge Bachelor Naturschutz und Landschaftsplanung und Bachelor Landschaftsarchitektur und Umweltplanung
ab 2016	wissenschaftliche Mitarbeiterin an der Hochschule Anhalt, Bernburg assoziiert zur Professur Landschaftspflege und Gehölzkunde (Prof. Dr. A. Baasch) ▪ Seminare Gehölzkunde für die Studiengänge Bachelor Naturschutz und Landschaftsplanung und Bachelor Landschaftsarchitektur und Umweltplanung ▪ Übung: Bestandsaufnahme Arten und Biotope im Studiengang Naturschutz und Landschaftsplanung ▪ Betreuung von studentischen Projekten, Bachelor- und Masterarbeiten
ab 2017	wissenschaftliche Mitarbeiterin an der Hochschule Anhalt, Bernburg im Projekt „Erhöhung der floristischen Diversität von artenarmen Grünland in FFH-Gebieten“

<u>Publikationsliste</u>

Engst, K. Bruelheide, H., Dullau, S., Jandt, U. & Baasch, A. (in Vorbereitung). Using multi-criteria discriminant functions to assess grassland restoration success. Restoration Ecology.

Engst, K., Bruelheide, H., Jandt, U. & Baasch, A. (eingereicht). How well is the conservation status of alluvial and lowland hay meadows reflected in their plant functional composition? Journal of Vegetation Science.

Baasch, A., **Engst, K.,** May, K., Runge, K., Schuboth, C., Rast, G. (2018) Entwicklung von Grünlandlebensräumen in Auen: Praxisbeispiele aus Sachsen-Anhalt. In: Vischer-Leopold, M., Ellwanger, G., Balzer, S., Ssymank, A., Brandt, K. & Meyer-Rath, A. (Hrsg.) Natura 2000 und Artenschutz in der Agrarlandschaft. Naturschutz und Biologische Vielfalt 164, 205–232.

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Engst, K., Baasch, A., Tischew, S. & Bruelheide, H. (2016) Restoration ecology meets Functional community ecology: Assessment of restoration success of semi-natural grasslands. - Jahrestagung der GfÖ (Marburg, 05. September – 09. September 2016).

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Hofmann, K., Bruelheide, H., Erfmeier, A., Jandt, U. & Baasch, A. (2014) Functional traits and diversity of floodplain meadows in Saxony-Anhalt. - Auenökologischer Workshop 2014 (Brambach, 03. – 04. April 2014).

Hofmann, K., Bruelheide, H., Erfmeier, A., Jandt, U. & Baasch, A. (2014) Functional traits and diversity of floodplain meadows in Saxony-Anhalt. Conceptual framework of a comparative trait-based investigation using data from restoration projects and the German Vegetation Reference Database (GVRD). - Vegetationsdatenbanken Tagung „Vegetation Databases and Ecological Restoration“ (Koblenz, 24. - 26. Februar 2014).

Ort, Datum

Karina Engst

Eigenständigkeitserklärung

Hiermit erkläre ich an Eides statt, dass die Arbeit mit dem Titel „Plant functional composition as a tool for the assessment of grassland restoration success“ bisher weder bei der Naturwissenschaftlichen Fakultät I Biowissenschaften der Martin-Luther-Universität Halle-Wittenberg noch einer anderen wissenschaftlichen Einrichtung zum Zweck der Promotion vorgelegt wurde.

Darüber hinaus erkläre ich, dass ich die vorliegende Arbeit eigenständig und ohne fremde Hilfe verfasst sowie keine anderen als die im Text angegebenen Quellen und Hilfsmittel verwendet habe. Textstellen, welche aus verwendeten Werken wörtlich oder inhaltlich übernommen wurden, wurden von mir als solche kenntlich gemacht.

Ich erkläre weiterhin, dass ich mich bisher noch nie um einen Doktorgrad beworben habe.

Ort, Datum

Karina Engst