Comprehensive Analysis of Case Studies on Ecological Restoration of Degraded Grasslands: Duration, Outcomes, and Methods Postprint

Authors: Shang Zhanhuan, Dong Shikui, Zhou Huakun, Dong Quanmin, Long Ruijun

Date: 2018-01-09T00:00:00+00:00

Abstract

Degradation of grassland ecosystems severely impacts global ecological security, livelihoods of residents in grassland regions, and the development of grassland cultural diversity. Restoration of degraded grasslands relies on drawing upon effective research cases; cases with different study durations serve distinct reference roles for setting objectives in ecological restoration practices and formulating restoration plans, while research cases with guiding value are typically long-term studies. Based on an investigation of 149 ecological restoration cases of degraded grasslands both domestically and internationally, this paper comprehensively analyzes the distribution of study durations, restoration objectives, restoration methods, effectiveness, and methods for acquiring long-term research data for degraded grassland ecological restoration, summarized as follows. (1) Cases with durations less than 10a are relatively numerous and focus more on continuous research; longer-term studies rely more on revisiting previous research cases. (2) Relatively speaking, longer-term study results exhibit higher reliability and their restoration technologies are more persuasive; studies on productivity generally have shorter case durations than those on ecological functions. (3) In the ecological restoration of degraded grasslands, the top three restoration objectives are biodiversity, vegetation coverage, and soil carbon pool. (4) Studies on animal communities are very rare among the investigated research cases. (5) The most frequently applied restoration methods for degraded grasslands are artificial seeding, fencing for restoration, and grazing management. (6) Longer-term research studies mostly adopt the method of case revisiting to obtain data comparable with previous studies. Finally, it is recommended that special attention should be paid to the application of case revisiting methods, and that more field data acquisition should be conducted before comprehensive big data integration, as this is more reliable.

Full Text

Preamble

ACTA ECOLOGICA SINICA (ChinaXiv Partner Journal)
Vol. 37, No. 24, Dec. 2017
DOI: 10.5846/stxb201611212374

Synthesis-Review for Research Cases of Grassland Ecological Restoration: Years, Effect and Method

Shang Z H[1], Dong S K[2], Zhou H K[3], Dong Q M[4], Long R J[1]
[1]School of Life Sciences, Lanzhou University; State Key Laboratory of Grassland Agro-ecosystems
[2]School of Environment, Beijing Normal University
[3]Northwest Institute of Plateau Biology, Chinese Academy of Sciences; Key Laboratory of Restoration Ecology of Cold Area in Qinghai Province
[4]Qinghai Academy of Animal and Veterinary Sciences, Qinghai University

---

Abstract

Degradation of grassland ecosystems severely impacts global ecological security, livelihoods of residents in pastoral areas, and the development of grassland cultural diversity. Restoration of degraded grasslands depends on drawing lessons from effective research cases, which typically involve different study durations that provide varied references for setting restoration goals and formulating restoration schemes. Moreover, obtaining research cases with guiding value usually requires long-term investigations. Based on a survey of 149 international cases of degraded grassland ecological restoration, this paper comprehensively analyzes the distribution of study durations, restoration effects, and methods for acquiring long-term research data. The main conclusions are as follows: (1) Among the 149 cases, most studies lasted less than 10 years and focused on continuous annual experiments, whereas long-term studies (>10 years) relied on field revisiting. (2) Studies with long-term monitoring and surveys produced more reliable results and provided more useful guidelines for restoration techniques. Generally, productivity-focused studies had shorter durations than those targeting ecological functions. (3) The three most common restoration goals were biodiversity, vegetation coverage, and soil carbon pool. (4) Very few cases addressed animal communities. (5) The most frequently applied restoration method was artificial seeding. (6) Studies with longer time spans primarily used field revisiting methods to obtain comparable data from the same sites. In conclusion, we recommend emphasizing the application of field revisiting methods in monitoring and evaluating grassland restoration effects. More on-site field measurements should be conducted before performing big-data synthesis, as this approach yields more reliable results.

Keywords: grassland degradation; ecological restoration; study period (years);

restoration effect; field case revisiting; coordinated distributed experiments-uniformed methods

Introduction

Over the past century, global grassland ecosystems have experienced the most severe threats in human history, leading to extensive and multifaceted grassland degradation. Consequences include biodiversity loss, weakened ecosystem functions, and diminished livelihoods for local residents. As developing countries enter stages of rapid production growth, grassland ecosystems are following the path of industrial-scale destruction. Media reports have consistently claimed that approximately [percentage missing] of grasslands globally are in a degraded state. Since the beginning of this century, global degraded grassland restoration has faced enormous challenges in improving livelihood sustainability and ecological service functions. Restoration ecologists have long focused on degraded grassland ecosystem recovery, dedicating themselves to research and practical work.

The duration of research cases is closely linked to restoration effectiveness and method validity. Successful ecological restoration outcomes are often based on long-term research experience and accumulation. Cases with different study years provide different guidance values for practice. In ecological restoration, accurate assessment of grassland vegetation evolution must be based on long-term monitoring results to enable detailed evaluation of biodiversity and vegetation ecological functions. Long-term grassland restoration ecology research has received early attention and implementation, beginning in Europe and America, where long-term is generally defined as 20–50 years or more. Without long-term restoration experience, management schemes may be counterproductive. Highlighting the long-term characteristics of ecological restoration can better alert policymakers to consider environmental impacts carefully. Understanding research cases with different durations can provide references for China' s current large-scale ecological restoration projects and offer benchmarks for objective evaluation of these efforts. This paper comprehensively analyzes the temporal patterns, restoration goals, and study duration characteristics based on 149 degraded grassland restoration cases surveyed from China and abroad, aiming to provide reference value for current degraded grassland restoration efforts.

1. Temporal Scope

Contemporary ecological research has broken through traditional boundaries, as evident from its broad temporal span. Jackson (2001) identified three time scales in ecological research: the first is general ecological research time (real-time), ranging from years to decades; the second is Q-time (quaternary); and the third exceeds 100 years (deep-time), belonging to paleontology and geographical change research. According to this classification, grassland restoration ecology generally falls under real-time, as degraded grasslands recover relatively quickly, making most grassland ecology research time spans relatively short. Long-term ecological research is typically defined as 20–50 years.

Time-related degraded grassland restoration research cases mainly focus on monitoring after restoration technique implementation, using results to evaluate restoration effectiveness. Among 149 randomly surveyed grassland restoration cases, most time scales were less than 10 years, with the next most common being 10–20 years. This indicates that most cases assess degraded grassland restoration based on relatively short-term results. Long-term research methods in restoration ecology mainly include: (1) long-term continuous monitoring of the same plots, (2) chronosequence studies, and (3) revisiting of intermittently studied plots. Among these 149 cases, many long-term studies rely on revisiting previous research sites based on literature or documented records to obtain evaluable data.

[Figure 1: see original paper] The number of 149 grassland restoration study cases across different time periods
[Figure 2: see original paper] Evaluation of restoration effects for 149 grassland restoration cases

2. Restoration Effects

In the comprehensive comparison of 149 grassland restoration cases, restoration outcomes represent the degree of negative and positive effects after restoration technique implementation. Artificial scoring was conducted based on restoration goals and final achieved effects. Statistical results show no relationship between restoration outcomes and duration—both short-term and long-term restoration results can be good or bad, demonstrating the importance of matching appropriate restoration techniques with restoration time. However, longer durations generally lead grassland restoration toward positive succession, often achieving good results, with result significance depending on duration length. For restoration techniques, degraded grassland recovery should preferably use disturbance-exclusion methods. Currently, various degraded grassland restoration techniques implemented in China are difficult to evaluate in the short term, requiring long-term tracking to gain deeper understanding of ecological restoration effects.

Different grassland types and observation objects yield substantially different results. Cases with negative outcomes mainly concentrate on target species and community structure restoration, soil function or nitrogen level restoration. Soil system restoration over longer periods is generally difficult to achieve targets. Cases with reduced vegetation coverage are related to climate variability. In grassland ecosystems, measures that exclude disturbance generally deviate from expected goals to some extent. Appropriate restoration techniques can usually achieve positive effects on biodiversity and vegetation coverage. Grazing, burning, fertilization, and tillage can all demonstrate positive restoration effects after implementation. However, for meadows with high nutrient heterogeneity and high species richness, results are more uncertain.

3. Global Distribution and Temporal Patterns of Research Cases

The duration of long-term degraded grassland restoration cases is closely related to regional research capacity. Europe has strong research infrastructure and numerous long-term research stations, with many reported cases across different durations that become longer-term cases over time. American research is mainly concentrated in the United States, with long-term studies increasing in recent years, particularly through the U.S. Long-Term Ecological Research program. Asian grassland restoration research is primarily distributed in China, mixing long-term station research with multiple revisiting cases. With increased Chinese scientific investment in recent years, research has gradually been enriched and improved. Australia and Africa have relatively few cases, but Africa' s long-term degraded grassland restoration work is well-maintained and worthy of reference.

[Figure 3: see original paper] Distribution of all 149 study cases across different continents (Australia, Africa, America, Europe, and Asia) and periods (years)

4. Restoration Goals

Degraded grassland restoration goals are similar to those of other ecosystem restorations but have detailed distinctions in specific cases. Among randomly surveyed cases, goals concentrated on two functions: ecological function and productivity. The three most common restoration goals were biodiversity (24.28%), vegetation coverage (29.48%), and soil carbon pool (13.87%). Other goals like soil microorganisms, plant community structure, soil seed banks, and forage grasses were relatively rare. Many studies actually had multiple restoration targets, such as vegetation coverage and productivity, or biodiversity and productivity. Restoration goals are more or less related to the ecological and biological characteristics of research objects and researchers' expertise.

Biodiversity restoration research appears more frequently in long-term ecological studies. For example, in Australia, biodiversity recovery in abandoned cultivated grasslands reached [duration missing], while North American steppe grassland monitoring reached [duration missing]. In European controlled experiments, the effect of management factors on herbaceous plant diversity recovery can be monitored for [duration missing]. Productivity restoration research cases generally have shorter durations, indicating that ecological function is primary in long-term ecological research, while productivity function is more influenced by human demand and has temporary characteristics. Soil systems are always considered key in grassland restoration, appearing across all study durations. Soil microorganisms have received increasing attention with technological development in recent years, but the microbial system is complex with difficult-to-define restoration targets, generally considered together with soil nutrients.

Animal community research is very rare in the surveyed cases. Only two studies addressed ants and butterflies in grassland restoration. These reports represent typical cases considering animals, particularly insects, in grassland restoration. One 3-year study examined ant communities in savanna grassland under enclosure restoration, showing longer restoration was more beneficial for ant community recovery. A butterfly report studied the effects of shrub clearing and other methods on butterflies in abandoned grasslands over 5–15 years, showing artificial seeding after abandonment had good restoration effects. Another insect community study with a 40-year interval reported insect community recovery in eastern German dry grasslands under woody plant control, with good results.

[Figure 4: see original paper] Percentage of different restoration goals among 149 degraded grassland restoration cases

5. Restoration Measures

Ecological restoration techniques have always been an important research direction for restoration ecologists, yet universally applicable techniques remain elusive. For degraded ecosystems, the most general approach is disturbance elimination, though the lengthy recovery time sometimes necessitates faster restoration techniques for landscape and ecological functions. For degraded grassland ecosystems, restoration techniques concentrate on artificial reseeding or sowing, fencing (grazing exclusion), grazing utilization, fertilization, and burning. Other techniques like shrub clearing, topsoil transplantation, woody plant control, hay covering, and water addition have strong regional characteristics.

Among these grassland restoration techniques, artificial seeding deserves special attention. This technique is generally used in Europe and America for relatively rapid restoration of grassland ecological functions, typically using local native plant seeds with mixed sowing. A crucial issue is that reported artificial seeding in European and American grassland restoration generally involves mixed sowing of many species, not the 2–3 species commonly used in China. Researchers in Nebraska, USA, considered 5-species mixes as low-diversity and 15–20 species as high-diversity mixes for analyzing artificial community stability and recovery capacity. In China, very few grass species are used in mixed sowing for degraded grassland restoration, sometimes only one species, which should be prohibited as it leads to extremely unstable artificial grasslands, wasting substantial human and material resources and causing rapid re-degradation—an important reason for failed restoration efforts.

Burning measures in surveyed cases had relatively long durations, with many long-term studies. For example, U.S. woodland-grassland burning restoration research lasted [duration missing], southern Australian grassland burning restoration lasted [duration missing], and Swedish dry grassland burning restoration lasted [duration missing]. Many grassland restoration techniques focus on clearing expanding or invasive shrubs from grasslands, often combined with grazing or artificial seeding.

[Figure 5: see original paper] Percentage of different restoration techniques among 149 grassland restoration cases

6. Continuous Monitoring Methods

Among the 149 surveyed cases, 56 involved continuous monitoring methods. Continuous monitoring is crucial for long-term ecological research, enhancing study credibility and understanding of ecosystem changes, but requires substantial material resources. For degraded grassland restoration, continuous monitoring helps demonstrate detailed restoration processes and propose more effective management strategies. The greatest challenge is securing long-term funding and sustainable research teams, which is difficult globally.

With automation development, continuous monitoring has become increasingly feasible. Many short-term studies achieve continuous monitoring through annual or monthly observations. Automated equipment and meteorological monitoring are increasingly applied. However, complete continuous monitoring is mainly concentrated in short-term studies, relying on stable research teams and funding, as well as national monitoring programs. For example, one study in Inner Mongolia, China, lasted [duration missing].

Continuous monitoring or surveys also appear in periodic revisiting studies, where research continues with at least annual intervals. In our survey, such strictly periodic revisiting cases were few, indicating limited application of this method, which indeed requires long-term planning and sustained human resources.

7. Aperiodic Revisiting Methods

Most long-term grassland restoration research relies on aperiodic revisiting methods. In our surveyed cases, aside from annual continuous monitoring and periodic revisiting cases, all others involved aperiodic revisiting. This method better fits current ecological restoration research characteristics and resource availability, providing relatively large information volumes. It is widely applied not only in developed countries but also increasingly promoted in developing countries with social stability.

Aperiodic revisiting is concentrated in studies exceeding 10 years, while mixed continuous-aperiodic revisiting appears more in cases over 20 years. This method is highly recommended for grassland restoration research in terms of feasibility and comparability. Continuous monitoring is sometimes unnecessary, especially during stable vegetation stages where natural succession changes slowly. For longer-term research, sustainable results can only be obtained through aperiodic revisiting, as sustained support across generations is limited. Examples include studies in New Mexico desert grasslands with [duration missing] intervals, Texas grasslands with [duration missing] intervals, and Czech research with [duration missing] intervals. These long-span studies yielded meaningful results with good reference value for regional vegetation management.

A crucial consideration for long-term aperiodic revisiting research is the availability of previous study materials—original sites must be accurately located using documented records with detailed information. This is more easily achieved in areas with established experimental stations.

8. Establishment and Analysis of Big Data Time Series

Under current information technology conditions, big data analysis reliability depends on statistical trend analysis of large datasets. In grassland restoration ecology, big data time series analysis includes: (1) meta-analysis of aggregated statistics, and (2) statistical analysis of field measurement data. These are often based on integrating various experimental surveys, especially meta-analyses of similar methods, involving case mining and dimensionless comparison of results.

In ecology, meta-analysis has faced substantial criticism, leading to a divide between data miners and experimentalists. We recommend field-based approaches where researchers personally conduct unified-method surveys before comprehensive comparison. The coordinated distributed experiments approach proposed by Professor Fraser from Thompson Rivers University, Canada, represents an emerging tool for testing global hypotheses in ecology and environmental science, characterized by methodological uniformity and cross-regional applicability. Long-term time series establishment or big data comprehensive analysis actually relies more on aperiodic field revisiting.

9. Summary and Outlook

Through analysis of 149 reported research cases, we confirm that long-term degraded grassland restoration research indeed holds important value for scientific research and restoration practice. However, it is limited by human and material support and depends on multiple factors. Obtaining comparable long-term data through case revisiting methods is crucial, and the long-term chronosequence database approach in ecological restoration deserves promotion and strengthening.

No necessary relationship exists between restoration methods and duration—effectiveness depends more on method suitability. China’ s degraded grassland restoration using plant seeding should emphasize mixed planting with more species rather than current methods using only 2–3 species. China has already implemented large-scale ecological restoration research and established various research bases, but particularly needs sustainable research design and funding systems. Short-term field studies should implement continuous observation as much as possible to provide more data references for future long-term research.

From a disciplinary perspective, restoration ecology requires new paradigms to guide theoretical and technical development.

References

[1] Squires V R, Lu X S, Lu Q, Wang T, Yang Y L. *Rangeland Degradation and Recovery in China' s Pastoral Lands*. London: CAB International, 2009.
[2] Squires V R, Hua L M, Zhang D G, Li G L. *Towards Sustainable Use of Rangelands in North-West China*. Heidelberg, Germany: Springer, 2010.
[3] Xu J T, Yin R S, Li Z, Liu C. China' s ecological rehabilitation: unprecedented efforts, dramatic impacts, and requisite policies. *Ecological Economics*, 2006, 57(4): 595-607.
[4] Han J G, Zhang Y J, Wang C J, Bai W M, Wang Y R, Han G D, Li L H. Rangeland degradation and restoration management in China. *The Rangeland Journal*, 2008, 30(2): 233-239.
[5] van Andel J, Aronson J. *Restoration Ecology: The New Frontier*. Malden, MA, Oxford: Blackwell Publishing, 2006.
[6] Monaco T A, Jones T A, Thurrow T L. Identifying rangeland restoration targets: an appraisal of challenges and opportunities. *Rangeland Ecology & Management*, 2012, 65(6): 599-605.
[7] Dong S K, Kassam K A S, Tourrand J F, Boone R B. *Building Resilience of Human-Natural Systems of Pastoralism in the Developing World: Interdisciplinary Perspectives*. Switzerland: Springer, 2016.
[8] Hegedüšová K, Senko D. Successional changes of dry grasslands in southwestern Slovakia after 46 years of abandonment. *Plant Biosystems*, 2011, 145(3): 666-687.
[9] Weaver J E, Bruner W E. A seven-year quantitative study of succession in grassland. *Ecological Monographs*, 1945, 15(3): 297-319.
[10] White J W, Holben F J, Richer A C. Maintenance level of nitrogen and organic matter in grassland and cultivated soils over periods of 54 and 72 years. *Journal of the American Society of Agronomy*, 1945, 37: 21-33.
[11] Gardner J L. Effects of thirty years of protection from grazing in desert grassland. *Ecology*, 1950, 31(1): 44-50.
[12] Williams O B. Studies in the ecology of the riverine plain. V. Plant density response of species in a Danthonia caespitosa grassland to 16 years of grazing by merino sheep. *Australian Journal of Botany*, 1969, 17(2): 255-268.
[13] Willis K J, Araujo M B, Bennett K D, Figueroa-Rangel B, Froyd C A, Myers N. How can a knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long-term ecological studies. *Philosophical Transactions of the Royal Society B*, 2007, 362(1478): 175-186.
[14] Rull V, Vegas-Vilarrúbia T. What is long-term in ecology? *Trends in Ecology & Evolution*, 2011, 26(1): 3-4.
[15] Jackson S T. Integrating ecological dynamics across timescales: real-time, Q-time, and deep-time. *PALAIOS*, 2001, 16(1): 1-2.
[16] Li Y H, Wang W, Liu Z L, Jiang S. Grazing gradient versus restoration succession of Leymus chinensis grassland in Inner Mongolia. *Restoration*

Ecology, 2008, 16(4): 572–583.
[17] Galvanek D, Lepš J. Changes of species richness pattern in mountain grasslands: abandonment versus restoration. *Biodiversity and Conservation*, 2008, 17(13): 3241–3253.
[18] Fritch R A, Sheridan H, Finn J A, Kirwan L, hUallacháin D Ó. Methods of enhancing botanical diversity within field margins of intensively managed grassland: a 7-year field experiment. *Journal of Applied Ecology*, 2011, 48(3): 551–560.
[19] Seymour C L, Milton S J, Joseph G S, Dean W R J, Ditlhobolo T S, Cumming G S. Twenty years of rest returns grazing potential, but not palatable plant diversity, to Karoo rangeland, South Africa. *Journal of Applied Ecology*, 2010, 47(4): 859–867.
[20] Pecháčková S, Hadincová V, Münzbergová Z, Herben T, Krahuolec F. Restoration of species-rich, nutrient-limited mountain grassland by mowing and fertilization. *Restoration Ecology*, 2010, 18(S1): 166–174.
[21] Duprè C, Stevens C J, Ränke T, Bleeker A, Pepper-Lisbach C, Gowing D J G, Dise N B, Dorland E, Bobbink R, Diekmann M. Changes in species richness and composition in European acidic grasslands over the past 70 years: the contribution of cumulative atmospheric nitrogen deposition. *Global Change Biology*, 2010, 16(1): 344–357.
[22] Dormaar J F, Willms W D. Effect of forty-four years of grazing on fescue grassland soils. *Journal of Range Management*, 1998, 51(1): 122–126.
[23] Liu W G, Wei J, Cheng J M, Li W J. Profile distribution of soil inorganic carbon along a grassland restoration chronosequence on a 22-year scale in the Chinese Loess plateau. *Catena*, 2014, 121: 321–329.
[24] Matějková I, van Diggelen R, Prach K. An attempt to restore a central European species-rich mountain grassland through grazing. *Applied Vegetation Science*, 2003, 6(2): 161–168.
[25] Lunt I D, Morgan J W. Vegetation changes after 10 years of grazing exclusion and intermittent burning in a Themeda triandra grassland reserve in southeastern Australia. *Australian Journal of Botany*, 1999, 47(4): 537–552.
[26] Wilson S D. Competition, resources, and vegetation during 10 years in native grassland. *Ecology*, 2007, 88(12): 2951–2958.
[27] Dzwonko Z, Loster S. A functional analysis of vegetation dynamics in abandoned and restored limestone grasslands. *Journal of Vegetation Science*, 2007, 18(2): 203–212.
[28] He N P, Wu L, Wang Y S, Han X G. Changes in carbon and nitrogen in soil particle-size fractions along a grassland restoration chronosequence in northern China. *Geoderma*, 2009, 150(3/4): 302–308.
[29] Brady W W, Stromberg M R, Aldon E F, Bonham C D, Henry S H. Response of a semidesert grassland to 16 years of rest from grazing. *Journal of Range Management*, 1989, 42(4): 284–288.
[30] Barbaro L, Dutoit T, Cozic P. A six-year experimental restoration of biodiversity by shrub-clearing and grazing in calcareous grasslands of the French Prealps. *Biodiversity & Conservation*, 2001, 10(1): 119–135.
[31] Hejcman M, Klaudisová M, Schellberg J, Honsová D. The Rengen grassland

experiment: plant species composition after 64 years of fertilizer application. *Agriculture, Ecosystems & Environment*, 2007, 122(2): 259-266.
[32] Smith R S, Shiel R S, Bardgett R D, Millward D, Corkhill P, Evans P, Quirk H, Hobbs P J, Komete S T. Long-term change in vegetation and soil microbial communities during phased restoration of traditional meadow grassland. *Journal of Applied Ecology*, 2008, 45(2): 670-679.
[33] Baoyin T, Li F Y. Can shallow plowing and harrowing facilitate restoration of Leymus chinensis grassland? Results from a 24-year monitoring program. *Rangeland Ecology & Management*, 2009, 62(4): 314-320.
[34] Ruprecht E, Enyedi M Z, Szabó A, Fenesi A. Biomass removal by clipping and raking vs burning for the restoration of abandoned Stipa-dominated European steppe-like grassland. *Applied Vegetation Science*, 2016, 19(1): 78-88.
[35] Hansson M, Fogelfors H. Management of a seminatural grassland; results from a 15-year-old experiment in southern Sweden. *Journal of Vegetation Science*, 2000, 11: 31-38.
[36] Maccherini S, Santi E. Long-term experimental restoration in a calcareous grassland: identifying the most effective restoration strategies. *Biological Conservation*, 2012, 146(1): 123-135.
[37] Yuan J Y, Ouyang Z Y, Zheng H, Xu W H. Effects of different grassland restoration approaches on soil properties in the southeastern Horqin sandy land, northern China. *Applied Soil Ecology*, 2012, 61: 34-39.
[38] Schnoor T, Bruun H H, Olsson P A. Soil disturbance as a grassland restoration measure—effects on plant species composition and plant functional traits. *PLoS One*, 2015, 10(4): e0123698.
[39] Menke S B, Gaulke E, Hamel A, Vachter N. The effects of restoration age and prescribed burns on grassland ant community structure. *Environmental Entomology*, 2015, 44(5): 1336-1347.
[40] Wang S K, Zuo X A, Zhao X Y, Li Y Q, Zhou X, Lv P, Luo Y Q, Yun J Y. Responses of soil fungal community to sandy grassland restoration in Horqin sandy land, northern China. *Environmental Monitoring and Assessment*, 2016, 188(1): 21.
[41] Billeter R, Peintinger M, Diemer M. Restoration of montane fen meadows by mowing remains possible after 4-35 years of abandonment. *Botanica Helvetica*, 2007, 117(1): 1-13.
[42] Sammul M, Kauer K, Köster T. Biomass accumulation during reed encroachment reduces efficiency of restoration of Baltic coastal grasslands. *Applied Vegetation Science*, 2012, 15(2): 219-230.
[43] Berg M, Joyce C, Burnside N. Differential responses of abandoned wet grassland plant communities to reinstated cutting management. *Hydrobiologia*, 2012, 692(1): 83-97.
[44] Gilhaus K, Vogt V, Hölzel N. Restoration of sand grasslands by topsoil removal and self-greening. *Applied Vegetation Science*, 2015, 18(4): 661-[page missing].
[45] Török P, Miglécz T, Valkó O, Kelemen A, Tóth K, Lengyel S, Tóthmérész B. Fast restoration of grassland vegetation by combination of seed mixture

sowing and low-diversity hay transfer. *Ecological Engineering*, 2012, 44: 133–138.
[46] Török P, Vida E, Deák B, Lengyel S, Tóthmérész B. Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs. *Biodiversity and Conservation*, 2011, 20(11): 2311–2332.
[47] Carter D L, Blair J M. High richness and dense seeding enhance grassland restoration establishment but have little effect on drought response. *Ecological Applications*, 2012, 22(4): 1308–1319.
[48] Zhang T, Sun Y, Shi Z Y, Feng G. Arbuscular mycorrhizal fungi can accelerate the restoration of degraded spring grassland in central Asia. *Rangeland Ecology & Management*, 2012, 65(4): 426–432.
[49] Pickett S T A, Kolasa J, Jones C G. *Ecological Understanding: The Nature of Theory and the Theory of Nature*. 2nd ed. Amsterdam: Elsevier, 2007.
[50] Kollmann J, Meyer S T, Bateman R, Conradi T, Gossner M M, de Souza Mendonça M Jr, Fernandes G W, Hermann J M, Koch C, Müller S C, Oki Y, Overbeck G E, Paternó G B, Rosenfield M F, Toma T S P, Weisser W W. Integrating ecosystem functions into restoration ecology—recent advances and future directions. *Restoration Ecology*, 2016, 24(6): 722–730.
[51] Lengyel S, Varga K, Kosztyi B, Lontay L, Déri E, Török P, Tóthmérész B. Grassland restoration to conserve landscape-level biodiversity: a synthesis of early results from a large-scale project. *Applied Vegetation Science*, 2012, 15(2): 264–276.
[52] James J J, CarricK P J. Toward quantitative dryland restoration models. *Restoration Ecology*, 2016, 24(S2): S85–S90.
[53] Fensham R J, Butler D W, Fairfax R J, Quintin A R, Dwyer J M. Passive restoration of subtropical grassland after abandonment of cultivation. *Journal of Applied Ecology*, 2016, 53(1): 274–283.
[54] Coffin D P, Lauenroth W K, Burke I C. Recovery of vegetation in a semiarid grassland 53 years after disturbance. *Ecological Applications*, 1996, 6(2): 538–555.
[55] Wilsey B J, Martin L M. Top-down control of rare species abundances by native ungulates in a grassland restoration. *Restoration Ecology*, 2015, 23(4): 465–472.
[56] Ballantine K, Schneider R. Fifty-five years of soil development in restored freshwater depressional wetlands. *Ecological Applications*, 2009, 19(6): 1467–1480.
[57] Pywell R F, Meek W R, Webb N R, Putwain P D, Bullock J M. Long-term heathland restoration on former grassland: the results of a 17-year experiment. *Biological Conservation*, 2011, 144(5): 1602–1609.
[58] Bach E M, Baer S G, Meyer C K, Six J. Soil texture affects soil microbial and structural recovery during grassland restoration. *Soil Biology & Biochemistry*, 2010, 42(12): 2182–2191.
[59] Baer S G, Bach E M, Meyer C K, Du Preez C C, Six J. Belowground ecosystem recovery during grassland restoration: South African highveld compared to US tallgrass prairie. *Ecosystems*, 2015, 18(3): 390–403.
[60] Rosenzweig S T, Carson M A, Baer S G, Blair J M. Changes in soil proper-

ties, microbial biomass, and fluxes of C and N in soil following post-agricultural grassland restoration. *Applied Soil Ecology*, 2016, 100: 186-194.
[61] Woodcock B A, Bullock J M, Mortimer S R, Brereton T, Redhead J W, Thomas J A, Pywell R F. Identifying time lags in the restoration of grassland butterfly communities: a multi-site assessment. *Biological Conservation*, 2012, 155: 50-58.
[62] Schuch S, Bock J, Leuschner C, Schaefer M, Wesche K. Minor changes in orthopteran assemblages of central European protected dry grasslands during the last 40 years. *Journal of Insect Conservation*, 2011, 15(6): 811-822.
[63] Dong S K, Wen L, Li Y Y, Wang X X, Zhu L, Li X Y. Soil-quality effects of grassland degradation and restoration on the Qinghai-Tibetan plateau. *Soil Science Society of America Journal*, 2012, 76(6): 2256-2264.
[64] Oakley C A, Knox J S. Plant species richness increases resistance to invasion by non-resident plant species during grassland restoration. *Applied Vegetation Science*, 2013, 16(1): 21-28.
[65] Dong S K, Wang X X, Liu S L, Li Y Y, Su X K, Wen L, Zhu L. Reproductive responses of alpine plants to grassland degradation and artificial restoration on the Qinghai-Tibetan plateau. *Grass and Forage Science*, 2014, 70(2): 229-238.
[66] Murphy C A, Foster B L. Soil properties and spatial processes influence bacterial metacommunities within a grassland restoration experiment. *Restoration Ecology*, 2014, 22(5): 685-691.
[67] Prach K, Jongepierová I, Řehounková K, Fajmon K. Restoration of grasslands on ex-arable land using regional and commercial seed mixtures and spontaneous succession: successional trajectories and changes in species richness. *Agriculture, Ecosystems & Environment*, 2014, 182: 131-136.
[68] Wilson S D. Managing contingency in semiarid grassland restoration through repeated planting. *Restoration Ecology*, 2015, 23(4): 385-392.
[69] Auestad I, Austad I, Rydgren K. Nature will have its way: local vegetation trumps restoration treatments in seminatural grassland. *Applied Vegetation Science*, 2015, 18(2): 190-196.
[70] Klimkowska A, van Diggelen R, Grootjans A P, Kotowski W. Prospects for fen meadow restoration on severely degraded fens. *Perspectives in Plant Ecology, Evolution and Systematics*, 2010, 12(3): 245-255.
[71] Wu X, Li Z S, Fu B J, Zhou W M, Liu H F, Liu G H. Restoration of ecosystem carbon and nitrogen storage and microbial biomass after grazing exclusion in semiarid grasslands of Inner Mongolia. *Ecological Engineering*, 2014, 73: 395-403.
[72] Hald A B, Vinther E. Restoration of a species-rich fen-meadow after abandonment: response of 64 plant species to management. *Applied Vegetation Science*, 2000, 3(1): 15-24.
[73] Pykälä J. Cattle grazing increases plant species richness of most species trait groups in mesic seminatural grasslands. *Plant Ecology*, 2005, 175(2): 217-226.
[74] Pykälä J, Luoto M, Heikkinen R K, Kontula T. Plant species richness and persistence of rare plants in abandoned seminatural grasslands in northern

Europe. *Basic and Applied Ecology*, 2005, 6(1): 25–33.
[75] Straskrabová J, Prach K. Five years of restoration of alluvial meadows: a case study from central Europe. In: Joyce C, Wade P, eds. *European Wet Grasslands: Biodiversity, Management and Restoration*. Chichester: John Wiley & Sons, 1998: 295–303.
[76] Kahmen S, Poschlod P, Schreiber K F. Conservation management of calcareous grasslands. Changes in plant species composition and response of functional traits during 25 years. *Biological Conservation*, 2002, 104(3): 319–328.
[77] Oelmann Y, Broll G, Hölzel N, Kleinebecker T, Vogel A, Schwarze P. Nutrient impoverishment and limitation of productivity after 20 years of conservation management in wet grasslands of north-western Germany. *Biological Conservation*, 2009, 142(12): 2941–2948.
[78] Galvanek D, Lepš J. How do management and restoration needs of mountain grasslands depend on moisture regime? Experimental study from north-western Slovakia (Western Carpathians). *Applied Vegetation Science*, 2009, 12(3): 273–282.
[79] Schrautzer J, Fichtner A, Huckauf A, Rasran L, Jensen K. Long-term population dynamics of Dactylorhiza incarnata after abandonment and re-introduction of mowing. *Flora*, 2011, 206(7): 622–630.
[80] Pavlů V, Schellberg J, Hejcman M. Cutting frequency vs. N application: effect of a 20-year management in Lolio-Cynosuretum grassland. *Grass and Forage Science*, 2011, 66(4): 501–515.
[81] Niklaus P A, Wohlfender M, Siegwolf R, Körner C. Effects of six years atmospheric CO_2 enrichment on plant, soil, and soil microbial C of a calcareous grassland. *Plant and Soil*, 2001, 233(2): 189–202.
[82] Sindhøj E, Hansson A C, Andrén O, Kätterer T, Marissink M, Pettersson R. Root dynamics in a seminatural grassland exposed to elevated atmospheric CO_2 for five years. *Acta Agriculturae Scandinavica*, 2004, 54(2): 50–59.
[83] Hejcman M, Klaudisová M, Štursa J, Pavlů V, Schellberg J, Hejcmanová P, Hakl J, Rauch O, Vacek S. Revisiting a 37-year abandoned fertilizer experiment on Nardus grassland in the Czech Republic. *Agriculture, Ecosystems & Environment*, 2007, 118(1/4): 231–236.
[84] Maccherini S, Santi E, Marignani M. Detection of the effects of restoration on community composition in a calcareous grassland: does scale matter? *Grassland Science*, 2014, 60(1): 31–35.
[85] Metsola J A, Neuenkamp L, Pihu S, Vellak K, Kalwij J M, Zobel M. Restoration of flooded meadows in Estonia—vegetation changes and management indicators. *Applied Vegetation Science*, 2012, 15(2): 231–244.
[86] Sindhøj E, Andrén O, Kätterer T, Marissink M, Pettersson R. Root biomass dynamics in a seminatural grassland exposed to elevated atmospheric CO_2. *Acta Agriculturae Scandinavica*, 2004, 54(2): 50–59.
[87] Halpern C B, Haug R D, Antos J A, Kaas S S, Kilanowski A L. Grassland restoration with and without fire: evidence from a tree-removal experiment. *Ecological Applications*, 2012, 22(2): 425–441.
[88] Hall S L, McCulley R L, Barney R J. Restoration of native warm season

grassland species in a tall fescue pasture using prescribed fire and herbicides. *Restoration Ecology*, 2012, 20(2): 194–201.
[89] Halpern C B, Antos J A, Beckman L M. Vegetation recovery in slash-pile scars following conifer removal in a grassland-restoration experiment. *Restoration Ecology*, 2014, 22(6): 731–740.
[90] Munson S M, Lauenroth W K. Plant community recovery following restoration in semiarid grasslands. *Restoration Ecology*, 2012, 20(5): 656–663.
[91] [Chinese reference on artificial grassland production in the Qinghai-Tibet Plateau]
[92] [Chinese reference on underground processes in the Sanjiangyuan region]
[93] Rychnovská M, Blažková D, Hrabé F. Conservation and development of floristically diverse grasslands in central Europe. In: ' t Mannetje L, Frame J, eds. *Grassland and Society*. Wageningen: Wageningen Pers, 1994: 266–277.
[94] Malmström C M, Butterfield H S, Barber C, Dieter B, Harrison R, Qi J Q, Riaño D, Schrötenboeer A, Stone S, Stoner C J, Wirka J. Using remote sensing to evaluate the influence of grassland restoration activities on ecosystem forage provisioning services. *Restoration Ecology*, 2009, 17(4): 526–538.
[95] Foster B L, Kindscher K, Houseman G R, Murphy C A. Effects of hay management and native species sowing on grassland community structure, biomass, and restoration. *Ecological Applications*, 2009, 19(7): 1884–1896.
[96] Hájková P, Hájek M, Kintrová K. How can we effectively restore species richness and natural composition of a Molinia-invaded fen? *Journal of Applied Ecology*, 2009, 46(2): 417–425.
[97] Kinucan R J, Smeins F E. Soil seed bank of a semiarid Texas grassland under three long-term (36-year) grazing regimes. *The American Midland Naturalist*, 1992, 128(1): 11–21.
[98] Xie Z B, Cadisch G, Edwards G, Baggs E M, Blum H. Carbon dynamics in a temperate grassland soil after 9 years exposure to elevated CO_2 (Swiss FACE). *Soil Biology & Biochemistry*, 2005, 37(7): 1387–1398.
[99] Breuer L, Huisman J A, Keller T, Frede H G. Impact of a conversion from cropland to grassland on C and N storage and related soil properties: analysis of a 60-year chronosequence. *Geoderma*, 2006, 133(1/2): 6–18.
[100] Feng Y, Lu Q, Tokola T, Liu H, Wang X. Assessment of grassland degradation in Guinan county, Qinghai Province, China, in the past 30 years. *Land Degradation & Development*, 2009, 20(1): 55–68.
[101] Carilla J, Grau H R. 150 years of tree establishment, land use and climate change in Montane grasslands, Northwest Argentina. *Biotropica*, 2010, 42(1): 49–58.
[102] Kinyua D, McGeoch L E, Georgiadis N, Young T P. Short-term and long-term effects of soil ripping, seeding, and fertilization on the restoration of a Tropical rangeland. *Restoration Ecology*, 2010, 18(S1): 226–233.
[103] De Deyn G B, Shiel R S, Ostle N J, McNamara N P, Oakley S, Young I, Freeman C, Fenner N, Quirk H, Bardgett R D. Additional carbon sequestration benefits of grassland diversity restoration. *Journal of Applied Ecology*, 2011, 48(3): 600–608.
[104] Andrade B O, Overbeck G E, Pilger G E, Hermann J M, Conradi T,

Boldrini I I, Kollmann J. Intraspecific trait variation and allocation strategies of calcareous grassland species: results from a restoration experiment. *Basic and Applied Ecology*, 2014, 15(7): 590–598.
[105] Miao R H, Jiang D M, Musa A, Zhou Q L, Guo M X, Wang Y C. Effectiveness of shrub planting and grazing exclusion on degraded sandy grassland restoration in Horqin sandy land in Inner Mongolia. *Ecological Engineering*, 2015, 74: 164–173.
[106] Jacquemyn H, van Mechelen C, Brys R, Honnay O. Management effects on the vegetation and soil seed bank of calcareous grasslands: an 11-year experiment. *Biological Conservation*, 2011, 144(1): 416–422.
[107] Sykora K V, Stuiver H J, de Ronde I, de Nijs L J. Fourteen years of restoration and extensive year-round grazing with free foraging horses and cattle and its effect particularly on dry species-rich riverine grasslands. *Phytocoenologia*, 2009, 39(3): 265–286.
[108] Bakker J D, Wilson S D, Christian J M, Li X D, Ambrose L G, Waddington J. Contingency of grassland restoration on year, site, and competition from introduced grasses. *Ecological Applications*, 2003, 13(1): 137–153.
[109] [Chinese reference on abandoned land succession and restoration ecology]
[110] Watson C J, Matthews D I. A 10-year study of phosphorus balances and the impact of grazed grassland on total P redistribution within the soil profile. *European Journal of Soil Science*, 2008, 59(6): 1171–1180.
[111] Van Eekeren N, Bommelé L, Bloem J, Schouten T, Rutgers M, de Goede R, Reheul D, Brussaard L. Soil biological quality after 36 years of ley-arable cropping, permanent grassland and permanent arable cropping. *Applied Soil Ecology*, 2008, 40(3): 432–446.
[112] Kueffer C, Niinemets Ü, Drenovsky R E, Kattge J, Milberg P, Poorter H, Reich P B, Werner C, Westoby M, Wright I J. Fame, glory and neglect in meta-analyses. *Trends in Ecology & Evolution*, 2011, 26(10): 493–494.
[113] Koricheva J, Gurevitch J. Uses and misuses of meta-analysis in plant ecology. *Journal of Ecology*, 2014, 102(4): 828–844.
[114] Fraser L H, Henry H A, Carlyle C N, White S R, Beierkuhnlein C, Cahill J F Jr, Casper B B, Cleland E, Collins S L, Dukes J S, Knapp A K, Lind E, Long R J, Luo Y Q, Reich P B, Smith M D, Sternberg M, Turkington R. Coordinated distributed experiments: an emerging tool for testing global hypotheses in ecology and environmental science. *Frontiers in Ecology and the Environment*, 2013, 11(3): 147–155.
[115] Choi Y D. Restoration ecology to the future: a call for new paradigm. *Restoration Ecology*, 2007, 15(2): 351–353.
[116] [Chinese reference on ecosystem service evolution in ecological restoration]

Note: Figure translations are in progress. See original paper for figures.