Grassland management with horses: Its role in grassland utilization in Germany and the effects on grassland vegetation

Dissertation

zur Erlangung des Doktorgrades

der Georg-August-Universität Göttingen

vorgelegt von

Anja Schmitz

geboren in Eitorf-Sieg

Göttingen, Dezember 2017

D7

1. Referent: Prof. Dr. Johannes Isselstein

2. Referentin: Prof. Dr. Nicole Wrage-Mönnig

Tag der mündlichen Prüfung: 26. Januar 2018

Meinen Eltern,

den Ponies

und Plackenhohn, meiner geliebten Heimat.

Table of Contents

General Introduction

In agricultural landscapes, grasslands play a crucial role for ecosystem services and biodiversity (Isselstein and Kayser 2014, Kleijn *et al.* 2009, Klimek *et al.* 2014, Plantureux *et al.* 2005). In Germany, 28% of the agricultural area is grassland (Destatis, 2019). Semi-natural grasslands and species diversity in managed grasslands are in decline due to land use intensification as well as abandonment (Allan *et al.* 2015, Klimek *et al.* 2014, Manning *et al.* 2016, Wesche *et al.* 2012). Their decrease is a major challenge for nature conservation in Europe (Manning *et al.* 2016, Wrage *et al.* 2011). To maintain and promote biodiversity and ecosystem services in our agricultural landscapes, effective and innovative management strategies are urgently required. Therefore, better knowledge about the driving forces that enhance biodiversity is needed to develop efficient management strategies for ecological and economic benefits (German Federal Agency of Nature Conservation 2014, Klimek et al., 2007, Wrage et al., 2011).

Generally, grassland management strategies include mowing or grazing. Increased mowing frequencies and nitrogen fertilization decreased species richness in managed grasslands (Blüthgen *et al.* 2012, Wesche *et al.* 2012). Mowing defoliates swards uniformly, and intensive mowing regime and high rates of nitrogen fertilization lead to homogenous swards represented by few competitive species (Socher *et al.* 2012, Tälle *et al.* 2016, Wesche *et al.* 2012). In contrast, grazing by large herbivores can promote species diversity in productive systems at low to intermediate grazing intensity (Diaz *et al.* 2007, Dumont *et al.* 2009, Dumont *et al.* 2012, Klimek *et al.* 2007, Marion *et al.* 2015, Olff and Ritchie 1998, Wrage *et al.* 2011). Grazing establishes small-scaled spatial heterogeneity in sward structure and soil nutrient concentration (de Vries *et al.* 1994), which is due to livestock's grazing behaviour and preferences in diet selection. Adler *et al.* (2001) described this selective grazing behaviour as "patch-grazing", which leads to a stable mosaic of short (grazed) and tall (avoided) sward patches with different growing conditions for plants between those patches. This patchiness enables plants of different strategy types to coexist. Plant species diversity, therefore, increases at the paddock scale (Ludvíková *et al.* 2015, Marion *et al.* 2015, Rook *et al.* 2004, Rossignol *et al.* 2011, Scimone *et al.* 2007). Furthermore, this small-scaled heterogeneity in sward structure provides a cascade of positive effects not only on plant species richness but for fauna as well. In particular, insects and avifauna benefit (Jerrentrup *et al.* 2015, Garrido *et al.* 2019). Therefore, the preservation of large herbivores in landscapes is desirable from a nature conservation point of view.

In Middle and West-Europe, cattle and sheep are the most common grazer species in grasslands. Several studies have targeted their grazing effect and its management for biodiversity benefits (Dumont *et al.* 2012, Jerrentrup *et al.* 2015, Ollf and Ritchie 1998, Rook *et al.* 2004, Wrage *et al.* 2011). However, due to increasing economic pressure in modern agriculture, extensive grazing management with cattle or sheep is challenging to maintain without the financial support of agri-environmental schemes and grazing with common grazer species is in decline (Socher *et al.* 2013, Wesche *et al.* 2012). In addition to reestablishing grazing with traditional grazer species in an agricultural context, established land-use systems that have not been taken into account so far should be analysed to help fulfil the aim of maintaining biodiversity in managed grasslands.

Horse husbandry is such an under-recognised land-use system (Bomans *et al.* 2011, Elgåker *et al.* 2010, Jouven *et al.* 2015). While grazing with horses has the potential to benefit plant diversity in managed grasslands, the ecological value of horse-grazed grassland has not been targeted by systematic research so far. Therefore, the overriding question of this thesis is:

Can horses as a grazer species contribute to the maintenance of plant species richness in managed grasslands?

We first tried to quantify the area of grassland managed for horses in Germany (**Chapter 1**). In an observational study, we compared cattle-grazing with horse grazing under continual or rotational stocking to analyse the effect of these grazing systems on plant species richness and vegetation characteristics in the aboveground vegetation (**Chapter 2**) as well as their long-term effect on plant species richness and characteristics of soil seed banks (**Chapter 3**).

Horses play an increasing role as grazer species in managed grasslands in Germany. The expansion of horse husbandry for leisure purposes is a major land use development, particularly in peri-urban regions and landscapes close to metropolitan areas (Zasada *et al.* 2013). The Federation Equestre Nationale (FN 2017) estimates a population of 1.3 million horses in Germany, which is more than one-tenth of the German cattle population.

This expansion of horse husbandry is under debate, and conflicts are rising (Bomans *et al.* 2011, Elgåker *et al.* 2010, Zasada *et al.* 2013). Spatial accumulation of horse husbandry is suspected of causing considerable environmental impacts due to overstocking and the characteristic grazing behaviour of horses (Elgåker *et al.* 2010, Zasada *et al.* 2013). Horse paddocks are often reported to be in a poor state with patches of bare ground, an increase of undesirable species or shrub encroachment. In this context, Jouven *et al.* (2016) pointed out the limited agricultural knowledge of horse owners, who are driven by their passion for horses and do not consider themselves part of the agricultural sector.

On the other hand, horse husbandry and grassland utilisation with horses can have numerous ecological benefits for the management of extensive grasslands. Intensive ruminant livestock production, and dairy farming, in particular, rely on intensively managed grasslands that provide a high nutritional value (Bruinenberg *et al*. 2006, Dillon *et al.* 2006). Accordingly, grassland use is often limited to productive sites that are also suitable for mechanisation. Horses graze on a wider range of grassland types, as they can utilize herbage of poorer quality than cattle (Menard *et al*. 2002). Intensively managed, ryegrass-dominated swards may even pose a severe health risk as metabolic diseases can occur (Bott *et al.* 2013, Särkijärvi *et al.* 2010, Watts 2010). Therefore, horse farmers do not aim to maximize their yields by intensive fertilization or sward maintenance measures. As horse owners' attitudes on animal welfare changed towards a greater emphasis on pasture and grazing during the last decades (Hölker *et al.* 2016, Ikinger *et al.* 2014), they often took over grasslands formerly managed by dairy production (Bomans *et al.* 2011, Zasada *et al.* 2013). Thus, horse farming offers an opportunity to use grasslands that are at risk of being abandoned from intensive livestock farming. Such continuing management is necessary to maintain these grasslands and their biodiversity, as nature conservation measures, e.g. through grazing with small ruminants, are limited to a very small proportion of grasslands of highest ecological value.

In spite of this increasing importance of grassland use by horses, empirical information on horse husbandry and its spatial distribution remains sparse (Hölker *et al.* 2016). By a rough estimate, horse-grazed grasslands make up as much as 10% of German grasslands, based on the assumption of a population of 1 million horses and 0.5 hectares of grasslands used per horse (Isselstein *et al.* 2015, FN 2017). **Chapter 1** aimed at an improved quantification of the grassland area managed for horses, trying to solve the question: How much grassland is managed though horse husbandry in Germany? We analysed data provided by state authorities and data conducted by an online-survey on 700 horse farms and applied different scenarios. We performed the assessment for Germany and each of its federal states, respectively.

Different grazer species can lead to contrasting plant community composition, diversity and heterogeneity (Marion *et al.* 2010, Ollf and Ritchie 1998, Rook *et al.* 2004). Based on mostly anecdotal knowledge, horses do not have a good reputation among grazer species. In particular, horses are reported as quite "challenging" (Elsäßer 2010), since improper management can lead to degraded grassland swards. Avoided areas may become dominated by nitrophilous weeds, while trampling and overgrazing of preferred areas may lead to bare soil areas and increased abundance of ruderal species. Species richness on horse-grazed paddocks is assumed to be recruited by mostly ruderal weed species (Wellstein *et al.* 2007).

Studies comparing horses and other herbivores are still rare, particularly in agriculturally managed grasslands. Marion *et al.* 2015, Ménard *et al.* 2002, Nolte 2014 and Klink *et al.* 2016 compared horse and cattle grazing for nature conservation purposes. Generally, horses' and cattle's dietary choices overlap (Marion et al. 2015, Ménard et al. 2002), but various vegetation effects can be expected due to some fundamental differences between horses and cattle. Their two pairs of incisors enable horses to graze very selectively and closer to the ground (Archer 1976, Hongo and Akimoto 2003, Bott *et al.* 2013). The patch-grazing effect is stronger than with cattle (Archer 1974, Fleurance *et al.* 2016, Ödberg and Francis-Smith, 1976), leading to a different patch structure (Figure GI-1). Horses avoid to graze near faeces and create distinct latrine areas where they accumulate excreta. In such areas, horses avoid grazing for several years. In other pasture areas, they establish short swards, which they repeatedly graze (Archer 1974). Their impact on plant diversity is expected to result mostly from this grazing-induced patchiness (Loucougaray *et al.* 2004, Marion *et al.* 2015, Menard 2002, Nolte *et al.* 2014, Singer *et al.* 2001). At the same time, distinct heterogeneity in sward structure affects the agronomic value of pastures, since avoided areas hardly provide forage. To manage this grazing effect on swards, farmers apply different grazing systems. In horse husbandry, continuous or rotational grazing regimes are common. Rotational grazing is assumed to regulate the pronounced grazing effect and enforce more uniform grazing (Bott *et al.* 2013, Jerrentrup *et al.* 2015, Kenny 2016, Rook *et al.* 2004,). On the contrary, continuous grazing allows the grazing animals to spatially select and repeatedly graze preferred areas, which leads to more pronounced patchiness.

Pasture vegetation is further considerably affected by stocking rate (Dumont *et al.* 2012, Klink *et al.* 2016). Grazing at lenient and moderate stocking rate promotes biodiversity via increasing habitat diversity. Grazing effects can be expected to increase with stocking density and to differ between grazer species (Klink *et al.* 2016, Nolte *et al.* 2014, 2017). At high stocking rates, cattle graze more homogenously and establish short swards of few grazing-tolerant plant species (Dumont *et al.* 2012). On the contrary, overstocking in equine grazing can lead to sward degradation of heavily grazed short patches and increased ruderal weeds in tall patches (Schmitz and Isselstein 2013). Higher species richness in horse grazed paddocks has been linked to a rise in those ruderal weeds compared to homogenous high-yield grasslands (Wellstein *et al.* 2007).

Most of the studies comparing horse and cattle grazing were based on small-scale experiments, often performed in the context of nature conservation (Ménard *et al.* 2002, Nolte 2014, Klink *et al.* 2016). Their findings lack systematic comparisons in "real-life" farming practice conditions. To the author's knowledge, no study has compared the effect of horses and cattle grazing on vegetation in managed grasslands in real-life farming conditions so far.

Therefore, an observational study was established on farms in the Rhenish uplands (Figure GI-2a) in 2012–2014 to compare vegetation of paddocks grazed by cattle (C) and horses (H). Further, we aimed to analyse effects of the grazing regime in paddocks grazed by horses. In particular, we targeted the effects of continuous (HC) and rotational (HR) grazing with horses. To be able to compare paddocks grazed by cattle or horses directly and clearly distinguish the effects of grazing system and grazing regime from site conditions and management, we applied a stratified triplet-design. In total, we observed the vegetation of a total of 156 paddocks grazed by cattle or horses, arranged in 28 triplets (see Figure GI-2b).

Figure GI-1 Photography and orthographical photography (Orthophoto provided by LandNRW 2015) from paddocks grazed by horses (upper row) and cattle (lower row) grazed at similar stocking rate of about 1.5 LU ha^{-1} a^{-1}.

Chapter 2 analysed the grazing system's (HC, HR, C) effect on plant species richness and vegetation characteristics of 156 paddocks. Vegetation was monitored twice a year, in spring before grazing and in summer during grazing. Sampling was carried out on three subplots (12.6 m^2 each) per paddock and an additional transect of 2 × 50 m (see Figure GI-2c). The analysis focussed on the effects of grazing system and grassland management (grazing intensity and N fertilization) on species diversity and vegetation characteristics (grassland utilization values, Grimes C-S-R strategy types (Grime, 1988) and floristic contrast between patch types). We expected to obtain differences in vegetation characteristics between the grazing systems and in particular differences in floristic contrast between patch types. Further, we expected this floristic contrast to mediate species richness at the paddock-scale.

In the long term, grazing does not only affect vegetation due to reduction of biomass or trampling. Grazing animals affect plant seed production and seed emergence (Jacquemyn *et al.* 2011, Kiss *et al.* 2016). Plant seeds emerge from or accumulate in soil seed banks. Therefore soil seed bank composition can reflect the long-term effects of site management and effect of selective grazing animals (Bekker *et al.* 1997, Wellstein *et al.* 2007) on vegetation. Soil seed banks are widely discussed for their importance in grassland restoration and their contribution to the enrichment of species diversity in swards (Auffret *et al.* 2011, Basto *et al.* 2015 a, Kiss *et al.* 2016, Valkó *et al.* 2014, Vandvik *et al.* 2016, Wellstein *et al.* 2007). In order to analyse the effects of horses as grazer species in agricultural landscapes and to develop strategies for a sustainable grassland management with horses, it is essential to analyse their long term effects on soil seed banks. Given a similar grazing pressure, there are two possible assumptions. Firstly, horse-grazed paddocks may have a history of less intensive melioration measures than cattle grazed paddocks. Secondly, on horse grazed paddocks more species might be able to reproduce and accumulate seeds in the soil. Consequently, to evaluate their potential for grassland biodiversity, species richness and density of vital soil seed banks needs to be analysev and target ruderal weed species and such of a higher ecological value.

In **Chapter 3** we therefore analysed the soil seed bank of a subset of our observational paddocks in the Rhenish Uplands. In 2012, soil seed banks of 30 paddocks grazed with horses or cattle were analysed and differences in seed banks of different patch types were identified.

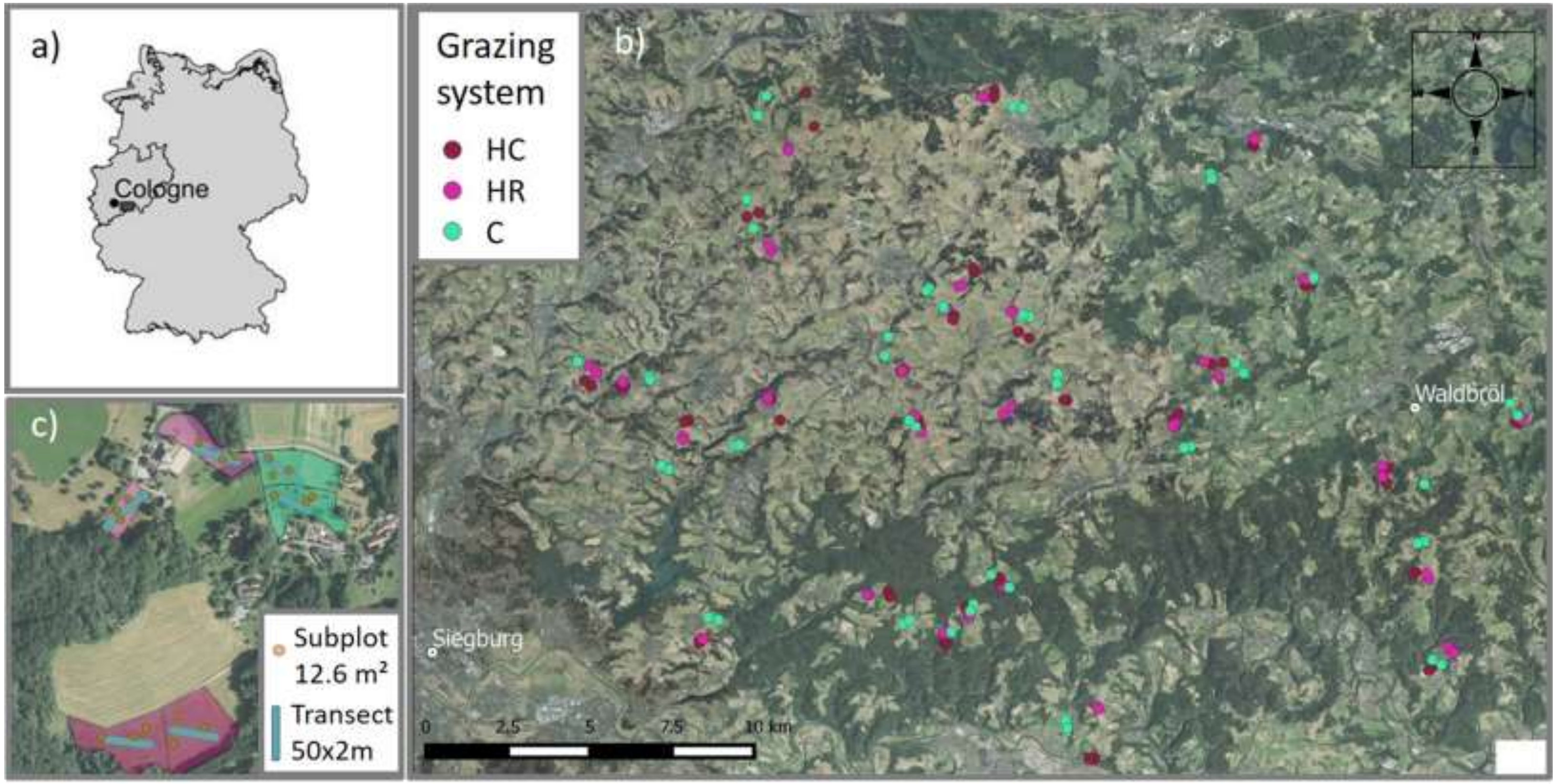

Figure GI-2: Study region in the south east of the Rhenish Uplands (a) and arrangement of the study paddocks (N=156) (b) with paddocks grazed continously with horses (HC in dark pink), rotationally with horses (HR in light pink) and with cattle (C in green). Study design is represented in (c), with two paddocks per grazing system, three subplots and a transect of 50 × 2 meters per paddock. Orthophoto provided by LandNRW2015.

General Introduction - References

Adler, P., Raff, D., Lauenroth, W., 2001. The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128 (4), 465–479. 10.1007/s004420100737.

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., Böhm, S., Grassein, F., Hölzel, N., Klaus, V.H., Kleinebecker, T., Morris, E.K., Oelmann, Y., Prati, D., Renner, S.C., Rillig, M.C., Schaefer, M., Schloter, M., Schmitt, B., Schöning, I., Schrumpf, M., Solly, E., Sorkau, E., Steckel, J., Steffen-Dewenter, I., Stempfhuber, B., Tschapka, M., Weiner, C.N., Weisser, W.W., Werner, M., Westphal, C., Wilcke, W., Fischer, M., 2015. Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecology letters 18 (8), 834–843. 10.1111/ele.12469.

Archer, M., 1973. The species preferences of grazing horses. Grass and Forage Sci 28 (3), 123–128. 10.1111/j.1365-2494.1973.tb00732.x.

Auffret, A.G., Cousins, S.A.O., 2011. Past and present management influences the seed bank and seed rain in a rural landscape mosaic. Journal of Applied Ecology 48 (5), 1278–1285. 10.1111/j.1365-2664.2011.02019.x.

Basto, S., Thompson, K., Phoenix, G., Sloan, V., Leake, J., Rees, M., 2015a. Long-term nitrogen deposition depletes grassland seed banks. Nature communications 6, 6185. 10.1038/ncomms7185.

Bekker, R., Verweij, G., Smith, R., Reine, R., Bakker, J., & Schneider, S., 1997. Soil Seed Banks in European Grasslands: Does Land Use Affect Regeneration Perspectives? Journal of Applied Ecology, 34(5), 1293-1310. 10.2307/2405239

Blüthgen, N., Dormann, C.F., Prati, D., Klaus, V.H., Kleinebecker, T., Hölzel, N., Alt, F., Boch, S., Gockel, S., Hemp, A., Müller, J., Nieschulze, J., Renner, S.C., Schöning, I., Schumacher, U., Socher, S.A., Wells, K., Birkhofer, K., Buscot, F., Oelmann, Y., Rothenwöhrer, C., Scherber, C., Tscharntke, T., Weiner, C.N., Fischer, M., Kalko, E.K.V., Linsenmair, K.E., Schulze, E.-D., Weisser, W.W., 2012. A quantitative index of land-use intensity in grasslands: Integrating mowing, grazing and fertilization. Basic and Applied Ecology 13 (3), 207–220. 10.1016/j.baae.2012.04.001.

Bomans, K., Dewaelheyns, V., Gulinck, H., 2011. Pasture for horses: An underestimated land use class in an urbanized and multifunctional area. Int. J. SDP 6 (2), 195–211. 10.2495/SDP-V6-N2-195-211.

Bott, R.C., Greene, E.A., Koch, K., Martinson, K.L., Siciliano, P.D., Williams, C., Trottier, N.L., Burk, A., Swinker, A., 2013. Production and Environmental Implications of Equine Grazing. Journal of Equine Veterinary Science 33 (12), 1031–1043. 10.1016/j.jevs.2013.05.004.

Bruinenberg, M.H.; Geerts, R.; Struik, P.C.; Valk, H.; Struik, P.C. Dairy cow performance on silage from semi-natural grassland. NJAS Wagening. J. Life Sci. 2006, 54, 95–110, doi:10.1016/S1573-5214(06)80006-0.

Destatis 2019. Landwirtschaftliche Bodennutzung nach ausgewählten Hauptnutzungsarten. URL: https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Feldfruechte-Gruenland/Tabellen/flaechen-hauptnutzungsarten.html;jsessionid=2DB1A251CA77146B211386E0D4302AD9.internet8732#fussnote-A-123242 (assessed 08.01.2021)

Diaz, S., Lavorel, S., McIntyre, S., Falczuk, V., Casanoves, F., Milchunas, D. G., Skarpe, C., Rusch, H, G., Sternberg, M., Noy-Meir, I., Landsberg, J., Zhang, W., Clark, H. and Campbell, B. D., 2007. Plant trait responses to grazing – a global synthesis. Global Change Biology, 13: 313–341. doi:10.1111/j.1365-2486.2006.01288.x

Dillon, P. Achieving high dry-matter intake from pasture with grazing dairy cows. In Fresh Herbage for Dairy Cattle: The Key to a Sustainable Food Chain; Elgersma, A., Dijkstra, J., Tamminga, S., Eds.; Springer: Dordrecht, The Netherlends, 2006; pp. 1–26, ISBN 978-1-4020-5451-8.

Dumont, B., Farruggia, A., Garel, J.-P., Bachelard, P., Boitier, E., Frain, M., 2009. How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? Grass and Forage Science 64 (1), 92–105. 10.1111/j.1365-2494.2008.00674.x.

Dumont, B., Rossignol, N., Loucougaray, G., Carrère, P., Chadoeuf, J., Fleurance, G., Bonis, A., Farruggia, A., Gaucherand, S., Ginane, C., Louault, F., Marion, B., Mesléard, F., Yavercovski, N., 2012. When does grazing generate stable vegetation patterns in temperate pastures? Agriculture, Ecosystems & Environment 153, 50–56. 10.1016/j.agee.2012.03.003.

Elgåker H., Pinzke S., Lindholm G. & Nilsson C., 2010. Horse keeping in Urban and Peri-Urban Areas: New Conditions for Physical Planning in Sweden. Danish Journal of Geography 110 (1), 81–98.

Elsäßer, M. (2010): Typisch Pferdeweide. (K)ein Bild des Jammers. In: Pferdebetrieb.Extra: Pferdeweiden optimal bewirtschaften. 5-9.

Fleurance, G., Farruggia, A., Lanore, L., Dumont, B., 2016. How does stocking rate influence horse behaviour, performances and pasture biodiversity in mesophile grasslands? Agriculture, Ecosystems & Environment 231, 255–263. 10.1016/j.agee.2016.06.044.

FN Deutsche Reiterliche Vereinigung, 2017: Zahlen & Fakten. URL: https://www.pferd-aktuell.de/fn-service/zahlen--fakten/zahlen--fakten (Abruf: 10.09.2017)

German Federal Agency of Nature Conservation, 2014: Grünlandreport. Alles im grünen Bereich? Bonn.

Garrido, P, Mårell, A, Öckinger, E, Skarin, A, Jansson, A, Thulin, C-G. Experimental rewilding enhances grassland functional composition and pollinator habitat use 2019. J Appl Ecol., 56, 946– 955. 10.1111/1365-2664.13338

Grime, J.P., 1988. The C-S-R model of primary plant strategies — origins, implications and tests, in: Gottlieb, L.D., Jain, S.K. (Eds.), Plant Evolutionary Biology. Springer Netherlands, Dordrecht, pp. 371–393.

Hölker, S., Wiegand, K., Spiller, A., Münch, C., 2016. Typologie der deutschen Pferdehaltung - Eine empirische Studie mittels Two-Step-Clusteranalyse. Berichte über Landwirtschaft 94 (3).

Hongo, A., Akimoto, M., 2003. The role of incisors in selective grazing by cattle and horses. J. Agric. Sci. 140 (4), 469–477. 10.1017/S0021859603003083.

Ikinger, C.; Wiegand, K.; Spiller, A., 2014. Reiter und Pferdebesitzer in Deutschland. Göttingen. URL: http://www.uni-goettingen.de/de/document/download/de7465473c18ff587b6b2df1ac03d06a.pdf/AWA%2023-09-2014.pdf, Zugriff am 31.08.2017.

Isselstein, J., Kayser, M., 2014. Functions of grassland and their potential in delivering ecosystem services. Grassland Science in Europe 19, 199-214.

Isselstein J., Michaelis T., Bellof G., Deblitz C., Gerowitt B., Graß R., Greef J.M., Heißenhuber A., Klimek S., Kuka K., Müller J., Pickert J., Pries M., Spiekers H., Spiller A., Taube F., Thünen T., Thumm U., Wachendorf M., Wiggering H., Wrage-Mönnig N., 2015: Grünland innovativ nutzen und Ressourcen schützen. Forschungsstrategie der Deutschen Agrarforschungsallianz. Agrarforschungsallianz, DAFA (Hrsg.), 51 S.

Jacquemyn, H., van Mechelen, C., Brys, R., Honnay, O., 2011. Management effects on the vegetation and soil seed bank of calcareous grasslands: An 11-year experiment. Biological Conservation 144 (1), 416–422. 10.1016/j.biocon.2010.09.020.

Jerrentrup, J.S., Seither, M., Petersen, U., Isselstein, J., 2015. Little grazer species effect on the vegetation in a rotational grazing system. Agriculture, Ecosystems & Environment 202, 243–250. 10.1016/j.agee.2015.01.007.

Jouven, M., Vial, C., Fleurance, G., 2016. Horses and rangelands: Perspectives in Europe based on a French case study. Grass Forage Sci 71 (2), 178–194. 10.1111/gfs.12204.

Kenny, LB., Robson, M., 2016. The effects of rotational and continuous grazing on horses, pasture condition, and soil properties. New Brunswick Electronic Theses and Dissertations.

Kiss R., Valko O., Tothmeresz B. and Török P. 2016: Seed bank research in central European grasslands. – An overview. In: Seed Banks: Types, Roles and Research.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E.D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E.J.P., Tscharntke, T., Verhulst, J., 2009. On the relationship between farmland biodiversity and land-use intensity in Europe. Proceedings. Biological sciences 276 (1658), 903–909. 10.1098/rspb.2008.1509.

Klimek, S., Lohss, G., Gabriel, D., 2014. Modelling the spatial distribution of species-rich farmland to identify priority areas for conservation actions. Biological Conservation 174, 65–74. 10.1016/j.biocon.2014.03.019.

Klimek, S., Richter-Kemmermann, A., Hofmann, M., Isselstein, J., 2007. Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors. Biological Conservation 134 (4), 559–570. 10.1016/j.biocon.2006.09.007.

Klink, R., Nolte, S., Mandema, F.S., Lagendijk, D.D.G., WallisDeVries, M.F., Bakker, J.P., Esselink, P., Smit, C., 2016. Effects of grazing management on biodiversity across trophic levels–The importance of livestock species and stocking density in salt marshes. Agriculture, Ecosystems & Environment 235, 329–339. 10.1016/j.agee.2016.11.001.

LandNRW 2015. Digital Orthophoto (DOP RGBI). Available online: https://www.bezreg-koeln.nrw.de/brk_internet/geobasis/luftbildinformationen/aktuell/digitale_orthophotos/index.html. (Data accessed 2015-08-02).

Loucougaray G, Bonis A, Bouzille JB., 2004. Effects of grazing by horses and/or cattle on the diversity of coastal grasslands in western France. Biological Conservation;116: 59–71

Ludvíková, V., Pavlů, V., Pavlů, L., Gaisler, J., Hejcman, M., 2015. Sward-height patches under intensive and extensive grazing density in an Agrostis capillaris grassland. Folia Geobot 50 (3), 219–228. 10.1007/s12224-015-9215-y.

Manning, P., Gossner, M.M., Bossdorf, O., Allan, E., Zhang, Y.-Y., Prati, D., Blüthgen, N., Boch, S., Böhm, S., Börschig, C., Hölzel, N., Jung, K., Klaus, V.H., Klein, A.M., Kleinebecker, T., Krauss, J., Lange, M., Müller, J., Pašalić, E., Socher, S.A., Tschapka, M., Türke, M., Weiner, C., Werner, M., Gockel, S., Hemp, A., Renner, S.C., Wells, K., Buscot, F., Kalko, E.K.V., Linsenmair, K.E., Weisser, W.W., Fischer, M., 2015. Grassland management intensification weakens the associations among the diversities of multiple plant and animal taxa. Ecology 96 (6), 1492–1501. 10.1890/14-1307.1.

Marion, B., Bonis, A., Bouzillé, J.-B., 2015. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? Écoscience 17 (3), 229–239. 10.2980/17-3-3315.

Menard, C., Duncan, P., Fleurance, G., Georges, J.-Y., Lila, M., 2002. Comparative foraging and nutrition of horses and cattle in European wetlands. Journal of Applied Ecology 39 (1), 120–133. 10.1046/j.1365-2664.2002.00693.x.

Nolte, S., Esselink, P., Smit, C., Bakker, J.P., 2014. Herbivore species and density affect vegetation-structure patchiness in salt marshes. Agriculture, Ecosystems & Environment 185, 41–47. 10.1016/j.agee.2013.12.010.

Nolte, S., van der Weyde, C., Esselink, P., Smit, C., van Wieren, S.E., Bakker, J.P., 2017. Behaviour of horses and cattle at two stocking densities in a coastal salt marsh. J Coast Conserv 21 (3), 369–379. 10.1007/s11852-017-0515-7.

Ödberg, F.O., Francis-Smith, K., 1977. Studies on the formation of ungrazed eliminative areas in fields used by horses. Applied Animal Ethology 3 (1), 27–34. 10.1016/0304-3762(77)90068-2.

Olff, H., Ritchie, M.E., 1998. Effects of herbivores on grassland plant diversity. Trends in Ecology & Evolution 13 (7), 261–265. 10.1016/S0169-5347(98)01364-0.

Plantureux, S., Peeters, A. Mc Cracken, D. 2005. Biodiversity in intensive grasslands Evaluation, improvement and challenges. Agronomy Research 3(2), 153-164.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G., Mills, J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biological Conservation 119 (2), 137–150. 10.1016/j.biocon.2003.11.010.

Rossignol, N., Bonis, A., Bouzillé, J.-B., 2011. Impact of selective grazing on plant production and quality through floristic contrasts and current-year defoliation in a wet grassland. Plant Ecol 212 (10), 1589–1600. 10.1007/s11258-011-9932-0.

Särkijärvi S., Niemeläinen O., Sormunen-Cristian R. and Saastamoinen M., 2010. Suitability of grass species on equine pasture: water soluble carbohydrates and grass preferences by horses. Grassland Science in Europe15, 1000-1002.

Schmitz, A.; Isselstein, J. 2013: Effects of management on vegetation structure in horse pastures. In: Grassland Science in Europe, S. 394–396.

Scimone, M., Rook, A.J., Garel, J.P., Sahin, N., 2007. Effects of livestock breed and grazing intensity on grazing systems: 3. Effects on diversity of vegetation. Grass and Forage Sci 62 (2), 172–184. 10.1111/j.1365-2494.2007.00579.x.

Singer, J.W., Bobsin, N., Kluchinski, D., Bamka, W.J., 2001. Equine stocking density effect on soil chemical properties, botanical composition, and species density. Communications in Soil Science and Plant Analysis 32 (15-16), 2549–2559. 10.1081/CSS-120000390.

Socher, S.A., Prati, D., Boch, S., Müller, J., Klaus, V.H., Hölzel, N., Fischer, M., Wilson, S., 2012. Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. J Ecol 100 (6), 1391–1399. 10.1111/j.1365-2745.2012.02020.x.

Socher, S.A.; Prati, D.; Boch, S.; Müller, J.; Baumbach, H.; Gockel, S.; Hemp, A.; Schöning, I.; Wells, K.; Buscot, F.; et al. 2013. Interacting effects of fertilization, mowing and grazing on plant species diversity of 1500 grasslands in Germany differ between regions. Basic Appl. Ecol., 14, 126–136.

Tälle, M., Deák, B., Poschlod, P., Valkó, O., Westerberg, L., Milberg, P., 2016. Grazing vs. mowing: A meta-analysis of biodiversity benefits for grassland management. Agriculture, Ecosystems & Environment 222, 200–212. 10.1016/j.agee.2016.02.008.

Vandvik, V., Klanderud, K., Meineri, E., Måren, I.E., Töpper, J., 2016. Seed banks are biodiversity reservoirs: Species-area relationships above versus below ground. Oikos 125 (2), 218–228. 10.1111/oik.02022.

Vries, M.F.W. de, Daleboudt, C., 1994. Foraging strategy of cattle in patchy grassland. Oecologia 100 (1-2), 98–106. 10.1007/BF00317136.

Watts, K., 2010. Pasture management to minimize the risk of equine laminitis. The Veterinary clinics of North America. Equine practice 26 (2), 361–369. 10.1016/j.cveq.2010.04.007.

Wellstein, C., Otte, A., Waldhardt, R., 2007. Impact of site and management on the diversity of central European mesic grassland. Agriculture, Ecosystems & Environment 122 (2), 203–210. 10.1016/j.agee.2006.12.033.

Wesche, K., Krause, B., Culmsee, H., Leuschner, C., 2012. Fifty years of change in Central European grassland vegetation: Large losses in species richness and animal-pollinated plants. Biological Conservation 150 (1), 76–85. 10.1016/j.biocon.2012.02.015.

Wrage, N., Strodthoff, J., Cuchillo, H.M., Isselstein, J., Kayser, M., 2011. Phytodiversity of temperate permanent grasslands: Ecosystem services for agriculture and livestock management for diversity conservation. Biodivers Conserv 20 (14), 3317–3339. 10.1007/s10531-011-0145-6.

Zasada, I., Berges, R., Hilgendorf, J., Piorr, A., 2013. Horsekeeping and the peri-urban development in the Berlin Metropolitan Region. Journal of Land Use Science 8 (2), 199–214. 10.1080/1747423X.2011.628706.

Chapter I:

Wieviel Grünland wird in Deutschland für Pferde genutzt? Versuch einer Quantifizierung anhand von Bestands- und Praxisdaten

Anja Schmitz und Johannes Isselstein

Veröffentlicht in: Berichte über Landwirtschaft

Schmitz, A., Isselstein, J., 2018: Wieviel Grünland wird in Deutschland für Pferde genutzt? Versuch einer Quantifizierung anhand von Bestands- und Praxisdaten. Berichte über Landwirtschaft 96, 1-31, ISSN 2196-5099, http://dx.doi.org/10.12767/buel.v96i1.186.g379

Zusammenfassung

Das Ziel der Studie ist es, erstmals die Bedeutung der Pferdehaltung für die Grünlandnutzung in Deutschland abzuschätzen. Hierfür werden Primärdaten statistischer Ämter und der Tierseuchenkassen, sowie Daten zur Flächenausstattung von Praxisbetrieben (n = 696) ausgewertet. In einem ersten Schritt wird die von Pferden genutzte Grünlandfläche über den anzunehmenden Futterbedarf des Pferdebestands je Bundesland und die Ertragsleistung des Grünlands quantifiziert. In einem weiteren Schritt wird die Schätzung auf Basis der mittleren Flächenausstattung der befragten Betriebe und ihres jeweiligen Raufutterzukaufs präzisiert. So konnte eine qualifizierte Schätzung der bewirtschafteten Fläche auf Basis verschiedener Datengrundlagen vorgenommen werden.

Als Ergebnis kann in Deutschland insgesamt von einem Anteil von 15-20 % am Grünland ausgegangen werden, das für Pferde bewirtschaftet wird. Zwischen den Bundesländern gibt es jedoch größere Unterschiede. Ausgesprochene Schwerpunkte der Grünlandnutzung für die Pferdehaltung finden sich in Nordrhein-Westfalen (115.000 ha, 30 % des Grünlands) und Niedersachsen (163.000 ha, 23 % des Grünlands). Die Bewirtschaftung des Grünlandes ist mit durchschnittlich 0,8 ha) je Großvieheinheit (GV) vergleichsweise extensiv und die Schläge sind klein. Die Kleinstrukturiertheit der Betriebe (Ø 5,6 ha für Pferde genutztes Grünland je Betrieb) weist besonders darauf hin, dass die Pferdehaltung hinsichtlich des Nutzungserhalts ökologisch wertvollen Grünlands in der Streulage eine große Bedeutung hat. Die Studie verdeutlicht somit die Relevanz von Pferden in unserer Agrarlandschaft und die dringliche Notwendigkeit, die Landnutzung durch Pferdehalter zur analysieren.

1. Einleitung und Problemstellung

1.1 Herausforderungen der Grünlandwirtschaft in Deutschland

Die Optimierung multipler Ökosystemleistungen landwirtschaftlicher Nutzungssysteme ist eine globale Herausforderung hoher Priorität (1, 42). In unserer Agrarlandschaft ist Dauergrünland die entscheidende Ressource vielfältiger Ökosystemleistungen. Sein Erhalt ist daher von wirtschaftlicher, ökologischer und gesellschaftlicher Relevanz (8, 10, 21, 23, 24, 47). Dennoch sind seit Jahrzehnten Rückgang und Wandel der Dauergrünlandfläche festzustellen (20, 23, 45).

Als Ursachen hierfür gelten vorrangig Veränderungen in der Milcherzeugung, denn die Bedeutung des Grünlandes als Futtergrundlage für Milchvieh ist seit Jahren rückläufig. Mit zunehmenden Herdengrößen und steigender Einzeltierleistung verringerte sich der Einsatz grasbetonter Grobfutterkomponenten zugunsten von Maissilage und Kraftfutter (10, 25). Der anhaltende Strukturwandel bedingt somit, dass ein erheblicher Teil des Grünlandes mittelfristig nicht mehr für die Milchproduktion genutzt und freigestellt wird (10, 20, 23, 45).

Artenreiches Grünland ist von den Änderungen in der Milcherzeugung besonders betroffen. Ökonomische Notwendigkeit und technische Möglichkeiten formen zunehmend standortunabhängiges, produktiveres aber auch artenarmes Grünland in immer größeren Schlägen. Aufwüchse des Extensivgrünlands sind aufgrund geringerer Verdaulichkeit für die Ernährung hochproduktiver Milchkühe wenig attraktiv, effiziente Nutzung von Aufwüchsen hoher Energiedichte hingegen angestrebt (25, 32). Daher wurde, wo es die Standortbedingungen zuließen, die Nutzung intensiviert (32, 44, 45). Ferner ist eine Nutzungsverschiebung von der Weidenutzung zur Schnittnutzung zu beobachten (20, 32). Die Stallhaltung gewinnt gegenüber der Weidewirtschaft zunehmend an Bedeutung. Für den Erhalt der Artenvielfalt spielt jedoch besonders die von Weidetieren geformte Heterogenität der Grasnarbe eine Schlüsselrolle (11, 24, 33, 41, 47). Marginale Standorte und Streulagen sind ökologisch besonders interessant (3, 5, 21, 34). Die Bewirtschaftung solcher Flächen ist jedoch in der Milchwirtschaft kaum mehr profitabel zu bewerkstelligen, weshalb ihre Nutzung oftmals aufgegeben wird (8, 9, 21, 45).

Der Erhalt von Grünland ist gesetzlich festgelegt (Dauergrünlanderhaltungsverordnung, 28). Insbesondere der Erhalt artenreichen Grünlands wird aufgrund der ökologischen Relevanz gefordert und gefördert (8, 28). Wie die meisten aus Naturschutzsicht schützenswerten Biotoptypen der Kulturlandschaft ist auch Grünland erst durch landwirtschaftliche Nutzung entstanden, sein Erhalt setzt daher eine bestimmte Art der Nutzung voraus (9, 21, 45). Diese verlangt in der landwirtschaftlichen Praxis jedoch nach einer entsprechenden Wirtschaftlichkeit. Mutterkuh- und auch Schafhaltung spielen für den Erhalt extensiven Grünlands eine sehr wichtige Rolle, können aber das Gesamtproblem *in der Fläche* nicht lösen. Vor diesem Hintergrund werden innovative Verfahren und Nutzungskonzepte des Grünlands in Deutschland benötigt (10) und ergibt sich die Notwendigkeit der Analyse bestehender, bislang wenig beachteter Landnutzungssysteme.

Obschon Pferde als Weidetiere in Landschaftspflegeprojekten vermehrt zum Einsatz kommen (26), so hat die Pferdehaltung als Nutzungssystem im bewirtschafteten Grünland in Deutschland erstaunlicherweise bislang wenig Beachtung gefunden.

1.2 Bedeutung der Pferdehaltung im Grünland

Pferdesport hat sich in den letzten Jahrzehnten zum Breitensport entwickelt und der deutsche Pferdebestand ist entsprechend gewachsen (7, 16, 17, 18, 46). Mittlerweile wird die Anzahl in Deutschland gehaltener Pferde und Ponies auf 1,3 Millionen (Deutsche Reiterliche Vereinigung, FN) geschätzt. Damit übertrifft die Pferdehaltung sogar den Bestand von Mutterkühen (knapp 700 Tsd. Großvieheinheiten, destatis 2016) und Schafen (knapp 160 Tsd. Großvieheinheiten, destatis 2016). Markant ist diese Entwicklung vor allem im peri-urbanen Raum und in Ballungsraumnähe (2, 4, 37, 49) Regional kann hier eine „Horsification" (4, 49) ganzer Landstriche beobachtet werden.

Pferde dienen vorrangig Freizeit- und Sportzwecken, ihre Haltung ist daher nicht per se als Landwirtschaft zu qualifizieren. Landwirtschaftlichen Status erlangt Pferdehaltung erst, wenn der überwiegende Anteil des benötigten Futters auf eigenen Flächen produziert werden kann (§ 35 Abs. 1 Nr. 1, § 201 BauGesetzBuch).

Grünland ist die Basis der Pferdeernährung. Grundsätzlich ist daher jegliche Pferdehaltung, auch solche ohne landwirtschaftlichen Status, an die Bewirtschaftung von Grünland gebunden. Doch Pferde brauchen und verwerten in der Praxis anderes Grünland als Milchkühe (15, 27, 36). Die Art und Weise der Grünlandnutzung zur Futterproduktion für Pferde ist eine andere als die der Milchviehhaltung. Hierin begründet sich das Potential von Pferdehaltern zum Erhalt extensiven Grünlands:

Pferde eigenen sich hervorragend als Verwerter von Aufwüchsen extensiven Grünlands. Hochwertiges Grünlandfutter, wie es in der Milchviehfütterung benötigt wird, kann bei Pferden gefürchtete Stoffwechselerkrankungen hervorrufen, die zur Einschränkung der Nutzbarkeit und in schweren Fällen zum Tode führen können (27, 35, 43). Für den Erhalt extensiven Dauergrünlands hat die Pferdehaltung somit eine potentiell große Bedeutung: Einerseits können die Aufwüchse extensiven Grünlands gut verwertet werden, andererseits besteht (zumindest theoretisch) kaum ein Anreiz, die Bewirtschaftungsintensität wie in der Milchviehhaltung üblich zu erhöhen, um Futter mit einer hohen Energiedichte produzieren zu können.

Weidegang hat in der Pferdehaltung einen ausgesprochen hohen Stellenwert. Seit wenigen Jahrzehnten wird einer an den Bedürfnissen des Flucht- und Lauftieres Pferd ausgerichteten Haltung mehr Bedeutung zugemessen (16, 17, 29, 37, 46). Täglicher Weidegang ist für viele Pferdebesitzer das ausschlaggebende Kriterium für die Wahl eines Pensionsstalles (16, 17, 29). Regional resultiert dies bereits in der Ablösung traditioneller Weidetiere in der Landschaft durch das Pferd (4, 49). Auch in Ackerbauregionen, in denen ein wirtschaftlicher Erhalt von Grünland kaum mehr möglich ist, spielen weidende Pferde zunehmend eine Rolle im Landschaftsbild (4).

Obwohl Pferde aufgrund ihres markanten Weideeffekts umstritten sind (13, 30, 31, 33) konnten jüngere Studien auf Pferdeweiden im direkten Vergleich zu Rinderweiden höhere Artenzahlen, besonders der High-Nature-Value Kennarten verzeichnen (38, 39) und dies eben auf den spezifischen Weideeffekt zurückführen.

Betriebs- und Schlaggrößen in der Pferdehaltung sind abhängig vom Professionalisierungsgrad der Betriebe aber im Vergleich zur Milchviehhaltung klein (16). Eine besondere Stellung nimmt die Haltung von Pferden aus Liebhaberei ein. Diese unterliegt keinen betriebswirtschaftlichen Zwängen oder der Notwendigkeit intensiver Grünlandnutzung (16, 17). Nicht selten erhalten solche Hobbyhalter daher Kleinstbetriebe und ökologisch wertvolle Flächen in Nutzung, die aufgrund ihrer Lage, Kleinstrukturiertheit oder mangelnden Fruchtbarkeit im Zuge des Strukturwandels aus der Landwirtschaft freigestellt wurden (37).

1.3 Problem: Intransparente Datenlage

Trotz wiederholter Betonung der wirtschaftlichen und ökologischen Bedeutung der Pferdehaltung (7, 16, 17, 18, 38, 46), ist die Datenlage zum Pferdebestand und seiner landwirtschaftlichen Relevanz nach wie vor ausgesprochen unbefriedigend. Bereits die Angaben zur Anzahl der in Deutschland gehaltenen Pferde variieren stark. Über Agrarstrukturerhebungen (AStE) wurden 2016 etwa 420.000 Pferde erfasst, bei den Tierseuchenkassen (TSK) sind im selben Jahr 950000 Equiden (einschließlich Eseln und Maulesel) gemeldet.

Es ist bislang nicht beziffert, wie viel Grünland von und für Pferdehaltung bewirtschaftet wird. Angenommen wird, dass etwa 500.000 ha, also 10% des deutschen Grünlands für Pferde genutzt werden (10). Spätestens vor dem Hintergrund der verstärkten Einforderung des Erhalts extensiven Grünlands ist eine genauere Quantifizierung und Analyse des Nutzungssystems „*Pferdegrünland*“ überfällig.

Ziel der vorliegenden Studie ist daher eine Präzisierung der Schätzung des durch und für Pferdehaltung in Deutschland genutzten Grünlands.

Die generelle Vorgehensweise bei der Schätzung bedient sich der Primärdaten der statistischen Ämter zum Grünland, der Tierseuchenkassen zum Pferdebestand und verschneidet diese mit Orientierungswerten der Pferdeernährung und Umfragedaten zur Flächenausstattung aus der Praxis.

2. Material und Methoden

In dieser Studie werden verschiedene Datengrundlagen und einfache Schätzverfahren genutzt, um das für Pferde genutzte Grünland schrittweise zu quantifizieren.

Ein erster Ansatz schätzt den Futterbedarf des Pferdebestands je Bundesland und schließt anhand der Ertragsleistung des Grünlands im Bundesland auf die notwendigerweise zur Deckung des Futterbedarfs bewirtschaftete Fläche.

Dieser theoretische Schätzer wird in einem darauffolgenden Schritt durch Praxisdaten optimiert. Unter Pferdehaltern wurde der Flächenbesatz erhoben und auf den Pferdebestand der Bundesländer umgelegt. Ergänzt wird dieser Schätzer um die Berechnung der durch Raufutterzukauf entstandenen Grundfutter Schattenfläche der Betriebe.

Die Güte der ermittelten Schätzwerte hängt wesentlich von der Genauigkeit der Inputdaten und der getroffenen Annahmen ab. Daher wird in anschließenden Sensitivitätsanalysen die Inputgröße der mittleren Ertragsleistungen variiert.

2.1 Datengrundlage

2.1.1 Primärdaten der Tierseuchenkassen und statistischen Ämter

Pferdebestand:

Als Datengrundlage zum Pferdebestand zieht die vorliegende Studie zwei Quellen heran:

Die einzige auf *Bundeslandebene* vorliegende Datengrundlage zum Pferdebestand sind die Meldedaten der Tierseuchenkassen. Halter von Equiden sind nach EU Verordnung Nr. 504/2008 und der Viehverkehrsverordnung (ViehVerkV) in der Fassung vom 3. März 2010 verpflichtet, ihren Bestand bei der der Tierseuchenkassen zu melden. Der Equidenbestand umfasst neben Pferden auch Esel, Maultiere und Zebras, eine Differenzierung der Daten nach Spezies ist nicht möglich. Im Folgenden werden diese Angaben dennoch vereinfacht als *Pferdebestand* angeführt. Da Aufgabe der Tierseuchenkassen nicht die statistische Erfassung der Pferdezahlen ist, erheben ihre Daten keinen Anspruch auf Genauigkeit. Trotz Meldepflicht ist eine der Unkenntnis einiger Halter geschuldete Ungenauigkeit zu erwarten (16, persönliche Mitteilungen Tierseuchenkassen). Die Daten für 2016 wurden den Jahresberichten der jeweiligen Tierseuchenkassen der Bundesländer entnommen oder gezielt bei den Tierseuchenkassen erfragt. Die Pferdebestandsdaten summieren sich 2016 bundesweit auf über 950.000 Equiden.

Als bundesweite Annahme zum Pferdebestand wird zudem die Schätzung der deutschen Reiterlichen Vereinigung (FN) von 1,3 Millionen Pferden und Ponies angenommen. Ihre Hochrechnungen beruhen auf verschiedenen Studien (17, 18).

Datengrundlage Grünland

Die aktuelle Dauergrünlandfläche der Bundesländer wurde dem Bericht zur Agrarstrukturerhebung (AStE) 2016 entnommen.

Der mittlere Ertrag vom Grünland wurde je Bundesland aus den Daten der Ernte- und Betriebsberichterstattung (EBE) als 3-Jahres Mittel (2014, 2015, 2016) des Ertrags von Wiesen und Weiden berechnet. Diese Leistungserfassung basiert auf repräsentativen Biomasseschätzungen, kann jedoch in Abhängigkeit vom Witterungsverlauf sowie dem Auftreten von Krankheiten fehlerhaft sein (Statistisches Bundesamt Wiesbaden, 2015). Einer mit den naturräumlichen Voraussetzungen und dem Flächenmanagement einhergehenden Variabilität der Ertragsleistung des Grünlands kann hier nur begrenzt Rechnung getragen werden. Pferde werden in der Praxis mit Aufwüchsen von Grünland einer mittleren oder minderen Produktivität gefüttert. Daher wurden in anschließenden einfachen Sensitivitätsanalysen die Berechnungen auch für die Szenarien des mittleren Ertrags ‚minus 5dt' bzw. ‚minus 10dt durchgeführt. Tabelle I-1 gibt einen Überblick über die in der Studie zusammengestellten Primärdaten der Bundesländer.

Tabelle I-1: Übersicht der zur Analyse verwendeten Primärdaten

[1]BL	[2] Pferdebestand in tausend	[3]Grünland in tausend ha	[4]Ø Ertrag in dt je ha
D	952,1	4694,5	67,5
SH	77,1	327,8	87,7
HH	3,3	6,8	-
NI	209,9	690,9	89,9
HB	-	-	-
NW	147,5	392,0	59,4
HE	68,2	294,2	60,5
RP	43,1	227,8	57,5
BW	112,3	545,3	55,3
BY	140,0	1063,3	72,2
SL	9,7	40,8	55,8
BE	1	-	-
BB	34,0	296,2	54,6
MV	23,0	268,4	53,3
SN	30,9	191,0	69,9
ST	28,3	175,8	49,9
TH	23,7	167,1	61,1

[1]Bundesländer(BL): Baden-Württemberg (BW), Bayern (BY), Berlin (BE), Brandenburg (BB), Bremen (HB), Hamburg (HH), Hessen (HE), Mecklenburg-Vorpommern (MV), Niedersachsen (NI), Nordrhein-Westfalen (NW), Rheinland-Pfalz (RP), Saarland (SL), Sachsen (SN), Sachsen-Anhalt (ST), Schleswig-Holstein (SH), Thüringen (TH). [2]gemeldeter Pferdebestand der Tierseuchenkassen (2016). [3]über Agrarstrukturerhebung erfasstes Grünland (2016). [4]3-Jahres Mittel des Ertrags vom Grünland der EBE (2014, 2015, 2016)

2.1.2 Orientierungswerte zum Futterbedarf

Zur Schätzung des Futterbedarfs werden im Folgenden Orientierungswerte der Pferdeernährung herangezogen.

Die Futteraufnahme von Pferden variiert in Abhängigkeit von der geforderten Leistung und der Größe der Tiere (27). Für Pferde in Erhaltung, Wachstum und Trächtigkeit gibt die Gesellschaft für Ernährungsphysiologie (15) als Orientierungswerte zur täglichen Trockenmasseaufnahme 23 g Trockensubstanz je kg Lebendmasse an, in Arbeit 29 g, in Laktation 30 g. Dies entspricht bei einer Großvieheinheit von 500 kg (GV) einer täglichen Aufnahme von 11,5 – 15 kg Trockensubstanz. Für die ausschließliche Aufnahme von Grünfuttermitteln auf der Weide werden von der Gesellschaft für Ernährungsphysiologie Maximalwerte von bis zu 5 % der Lebendmasse angegeben. Da der Bedarf in der Pferdefutterration zumeist nicht ausschließlich über Grasprodukte gedeckt wird, wird im

Weiteren einen Schätzer von täglich 10 kg Trockensubstanz je Großvieheinheit aus Grasprodukten angenommen, um den Jahresbedarf des Pferdebestandes der Bundesländer zu berechnen.

2.1.3 Praxisdaten der Online-Befragung

Datenerhebung

In einer Online-Befragung wurden vom 8.1.2017 – 31.7.2017 deutschlandweit Betriebsstrukturdaten von Pferdehaltern erhoben. Die Umfrage richtete sich grundsätzlich an alle pferdehaltenden Betriebe, Vereine und privaten Pferdehalter in Deutschland. Abgefragt wurden Betriebsorganisation (Haupterwerb, Nebenerwerb, Hobbyhalter), Betriebsausrichtung (Pensionspferdehaltung, Pferdezucht, Training/Ausbildung, Reitverein, Hobbyhaltung), Daten zum Pferdebestand (Anzahl der Ponies, Kleinpferde und Großpferde), zur vorrangigen Nutzung der Pferde (Sport, Zucht, reine Freizeitnutzung), der Flächenausstattung (ausschließlich für den Pferdebestand genutztes Grünland in ha) sowie der prozentuale Anteil zugekauften Raufutters. Der Pferdebestand wurde erfasst als die Anzahl von Ponies (bis 350 kg), von Kleinpferden (bis 500 kg) und Großpferden (über 500 kg). Aus diesen Angaben wurden die Großvieheinheiten je Betrieb berechnet, angelehnt an die Gewichtseinheiten für Ponies 0,75 Großvieheinheit, für Kleinpferde 1 Großvieheinheit, für Großpferde 1,2 Großvieheinheit. Ferner wurde gefragt, wie lange der Großteil der Flächen bereits für Pferde genutzt wird und so bekannt, wie das Grünland vorher genutzt wurde.

Zur Erstellung und Durchführung der Umfrage wurde die Software Lime-Survey verwendet. Die Verbreitung der Umfrage erfolgte über Reitsportverbände, Pferdefachzeitschriften, email-Verteiler, Internetforen und Social Media.

Beschreibung der in der Umfrage erfassten Betriebe und Daten

Insgesamt haben 702 Pferdehalter die Umfrage vollständig beantwortet. Nach Ausschluss von nicht in der Bundesrepublik Deutschland ansässigen Teilnehmern wurden Daten von 696 Betrieben analysiert. Tabelle I-2 gibt eine deskriptive Analyse der erhobenen Pferdehaltungen.

Insgesamt zeichnet sich die für die weiteren Analysen herangezogene Variable der Flächenausstattung (Grünland in ha je Großvieheinheit) durch eine ausgesprochene Variabilität aus (Tabelle I-2). Die Verteilung ist deutlich rechtschief mit einigen Ausreißern hoher Flächenausstattung. Daher wird der Median anstelle des arithmetischen Mittelwerts auf Bundesebene verwendet.

Tabelle I-2: Deskriptive Analyse der in der Umfrage erfassten Betriebsdaten

je Betrieb (N=696)	Mittelwert		Sd	Median	Min	Max
Anzahl Pferde	8,3	±	13,6	4	1	200
GV (500kg)	8,7	±	15,2	4,4	0,75	240
Für Pferde genutztes GL[1] in ha	5,6	±	9,4	3	0	100
GV je ha GL	2,0	±	1,6	1,6	0,2	15,05
GL in ha je GV	0,8	±	0,7	0,6	0	5
Raufutterzukauf (%)	54,5		44,1	70	0	100

[1] GL Grünland

Der überwiegende Anteil der Teilnehmer hält Pferde als Hobby ohne jeden Erwerbszweck (70,2 %). Da erwerbsorientierte und Hobbypferdehaltungen nicht signifikant im Flächenbesatz (ha je Großvieheinheit) voneinander abweichen (Test: lm mit post-hoc Tukey-Test im lsmeans package, Statistiksoftware R), wurde im Weiteren nicht mehr nach Erwerbsform unterschieden. Die erfassten Betriebsausrichtungen sind zu über 80 % die reine Hobbynutzung, 24 % gaben an Pensionspferdehaltung zu betreiben, 18 % halten Pferde zur Zucht, 12 % sind dem Bereich Training/Ausbildung zuzuordnen und etwa 9 % der Teilnehmer sind Reitvereine. 28 % der Teilnehmer unterhält weitere landwirtschaftliche Betriebszweige neben der Pferdehaltung. Die Nutzung der Pferde der erfassten Betriebe wurde überwiegend als Nutzung zum reinen Freizeitvergnügen (90 %) angegeben, 30 % werden auch im Sport genutzt und 26 % zur Zucht.

Der überwiegende Teil (55 %) der befragten Betriebe bewirtschaftete den Großteil des Grünlands bereits seit mehr als 10 Jahren, 23 % bereits über 20 Jahre. Die vorherige Nutzung wurde von 40 % als Nutzung für Rinder angegeben. Bei 26 % wurde Acker zu Grünland für Pferdehaltung umgewandelt.

In Tabelle I-3 ist die Verteilung der anhand der Umfrage erfassten Betriebe sowie die Grünlandfläche und Tierzahl je Bundesland dargestellt.

Insgesamt liegen Daten zum Management von fast 4000 ha Grünland und 5754 Pferden vor, was einem Anteil von 0,1 % des Dauergrünlands und 0,6 % des bei den Tierseuchenkassen gemeldeten Pferdebestands entspricht. In Tabelle I-3 ist der Anteil am gemeldeten Bestand je Bundesland aufgeführt. Der in Abbildung I-1 gezeigte, mit Ausnahme von Bayern relativ enge lineare Zusammenhang von Primärdaten und Online-Befragung kann als Indiz dafür herangezogen werden, dass die Online-Stichprobe die Strukturdaten der Grundgesamtheit der Pferdehalter in Deutschland recht gut widerspiegelt.

Tabelle I-3: Übersicht der mittels Umfrage erfassten Daten in den Bundesländern

BL	[1]Betriebe	[2]GL in ha	[3]Anzahl Pferde	GV (500kg)	[4]% Pferdebestand des BL
D	696	3939	5754	6042	0,6
SH	46	347	643	691	0,8
HH	2	23	7	5	0,2
NI	154	712	1174	1232	0,6
NW	120	659	1034	1102	0,7
HE	77	594	778	807	1,1
RP	56	292	331	344	0,8
BW	79	504	800	828	0,7
BY	62	249	401	418	0,3
SL	7	31	25	26	0,3
BB	30	267	279	289	0,8
MV	13	62	46	47	0,2
SN	25	129	143	154	0,5
ST	10	26	44	47	0,2
TH	15	44	49	53	0,2

[1]Anzahl der in der Umfrage erfassten Betriebe, [2]je Bundesland erfasste ha Grünland, [3]Anzahl der je Bundesland erfassten Pferde, [4]Anteil der erfassten Pferde am Pferdebestand (Tierseuchenkassen) des Bundeslands. Keine Teilnahme aus Bremen und Berlin.

2.2 Methoden zur Quantifizierung der Grünlandnutzung durch Pferdehalter

2.2.1 Schätzung der benötigten Fläche zur Deckung des Futterbedarfs anhand von Primärdaten der statistischen Ämter und Tierseuchenkassen

In einem ersten Schritt wird der jährliche theoretische Futterbedarf des Tierseuchenkassen gemeldeten Pferdebestands der Bundesländer berechnet. Hierfür wird der Orientierungswert einer täglichen TM Aufnahme von 10 kg angenommen. Die Kenntnis des mittleren Grünlandertrags der Bundesländer ermöglicht die Ableitung der zur Deckung des Bedarfs benötigten Fläche. Dieser wird auf Bundesebene aufsummiert und ergibt die Fläche die in Deutschland theoretisch zur Deckung des Bedarfs von Pferden genutzt werden müsste (D1).

$$D1 = \sum \frac{Jahresbedarf\ TM\ je\ GV * Pferdebestand\ je\ BL}{mittlerer\ Grünlandertrag\ je\ BL}$$

Die Ableitung der benötigten Fläche wird ebenfalls für die Schätzung der FN von 1,3 Millionen Pferden und Ponies in Deutschland angewendet.

$$D1\_FN = \frac{Jahresbedarf\ TM\ je\ GV * Pferdebestand\ FN}{mittlerer\ Grünlandertrag\ D}$$

2.2.2 Schätzung der direkt mit Pferden genutzten Fläche über Umfragedaten

Um den theoretischen Schätzer D1 zu prüfen und auf Basis von Praxisdaten zu verbessern, wurden Daten zur Flächenausstattung von Pferdebetrieben verwendet (Tabelle I-2 und I-3). Anhand dieser Umfragedaten wird der mittlere Flächenbesatz aller erfassten Betriebe berechnet, da die Anwendung eines mittleren Flächenbesatzes je Bundesland aufgrund der unterschiedlichen Anzahl statistisch nicht zulässig ist. Wegen der Schiefe der Flächenbesatzdaten wird zusätzlich zum arithmetischen Mittelwert der Median angewendet.

Die Verschneidung des mittleren Flächenbesatzes mit dem Pferdebestand je Bundesland ermöglicht die Schätzung des durch Pferdehalter direkt genutzten Grünlands (D2).

$$D2 = \sum \emptyset\ ha\ je\ GV\ in\ D * Pferdebestand\ je\ BL$$

Die Ableitung der genutzten Fläche wird ebenfalls für die Schätzung der FN von 1,3 Millionen Pferden und Ponies in Deutschland angewendet.

$$D2_{FN} = \emptyset\ ha\ je\ GV\ in\ D * Pferdebestand\ FN$$

2.2.3 Schätzung der insgesamt für Pferde genutzten Fläche über Umfragedaten unter Berücksichtigung des Futterzukaufs

Pferdehalter produzieren nicht grundsätzlich selbst Raufutter. So kaufen 70% der Umfrageteilnehmer Futter zu. Durch den Futterzukauf nutzt der Betrieb „Schattenfläche“, die außerhalb der der Pferdehaltung zugehörigen Flächen, aber indirekt für die Pferde des Betriebs bewirtschaftet wird. Der oben verwendete Bezug ha Grünland je Großvieheinheit ist daher hinsichtlich der gesamten Flächennutzung je Großvieheinheit nicht korrekt und unterschätzt die tatsächlich genutzte Fläche.

Die Schätzung der Schattenfläche erfolgt anhand des prozentualen Anteils zugekauften Raufutters, des Futterbedarfs des Pferdebestands und Ertragsleistung des Grünlands. Angenommen wird, dass die Pferde an 180 Tagen ihren Bedarf auf der Weide decken und an 180 Tagen durch konserviertes Raufutter (Heu, Heulage) ernährt werden. Dieser vereinfachte Schätzer unterstellt eine klare Trennung von Sommer- und Winterfütterung. Mögliche Managementvarianten wie Winterweidehaltung, tägliche Zufütterung zum Weidegang bleiben unberücksichtigt. Aus den erhobenen Daten ist nicht abzuleiten, woher das Futter bezogen wird. Die folgenden Berechnungen werden daher durchgeführt unter der Annahme, dass das Futter im Bundesland produziert wird in dem der Betrieb verortet ist.

$$Schattenfläche\ je\ GV\ Betrieb = \frac{Anteil\ Raufutterzukauf * (180 * Bedarf\ TM\ je\ GV)}{Ertragsleistung\ GL\ des\ BL}$$

Die Gesamtfläche je Großvieheinheit im Betrieb ergibt sich aus der Summe von ha Grünland je Großvieheinheit und der Schattenfläche je Großvieheinheit Betrieb. Dieser um die Schattenfläche korrigierte Schätzer kann nun für eine genauere Abschätzung der Gesamtfläche genutzt werden.

$$D3 = \sum \text{Ø}\, Gesamtfläche\ ha\ \ je\ GV\ * Pferdebestand\ BL$$

Dies wird ebenfalls auf die Schätzung der FN von 1,3 Millionen Pferden und Ponies in Deutschland angewendet.

$$D3_{FN} = \text{Ø}\, Gesamtfläche\ ha\ \ je\ GV\ * Pferdebestand\ FN$$

2.2.4 Sensitivitätsanalysen

Die Güte der ermittelten Schätzwerte hängt wesentlich von der Genauigkeit der Inputdaten und der getroffenen Annahmen ab.

Pferde werden in der Praxis mit Aufwüchsen von Standorten mittlerer oder schlechterer Produktivität gefüttert (27, 35, 36). Daher wird in Sensitivitätsanalysen die Inputgröße der mittleren Ertragsleistungen variiert und Berechnungen auch für die Szenarien des mittleren Ertrags – 5dt bzw -10dt durchgeführt.

3. Ergebnisse

3.1 Schätzung der benötigten Fläche zur Deckung des Futterbedarfs anhand von Primärdaten der statistischen Ämter und Tierseuchenkassen

Im ersten Schritt wurde der theoretische Futterbedarf des gemeldeten Pferdebestands je Bundesland berechnet und daraus die zu seiner Deckung notwendigerweise benötigte Fläche abgeleitet (Tabelle I-4).

Tabelle I-4: Benötigte Fläche zur Deckung des Futterbedarfs anhand von Primärdaten der statistischen Ämter und Tierseuchenkassen

		Mittlerer Ertrag			Mittlerer Ertrag – 5dt		Mittlerer Ertrag – 10dt	
Bundesländer								
[1]BL	[2]Futterbedarf je BL in Tsd. t	ha^{-1}GV^{-1}	[3] Tsd. ha	[4]% GL in BL	Tsd. ha	% GL in BL	Tsd. ha	% GL in BL
SH	281,4	0,42	32,1	9,8	34,0	10,4	36,2	11,1
NI	766,1	0,41	85,3	12,3	90,3	13,1	95,9	13,9
NW	538,5	0,61	90,7	23,1	99,1	25,3	109,1	27,8
HE	249,1	0,60	41,1	14,0	44,9	15,3	49,3	16,8
RP	157,4	0,63	27,7	12,0	29,9	13,2	33,1	14,5
BW	409,9	0,66	74,2	13,6	81,6	15,0	90,6	16,6
BY	511,1	0,51	70,8	6,7	76,1	7,2	82,2	7,7
SL	35,4	0,65	6,4	15,6	6,9	17,1	7,7	19,0
BB	124,1	0,67	22,8	7,7	25,0	8,5	27,9	9,4
MV	84,0	0,68	15,8	5,9	17,4	6,5	19,4	7,2
SN	112,7	0,52	16,1	8,5	17,4	9,1	18,8	9,9
ST	103,4	0,73	20,7	11,8	23,0	13,1	25,9	14,7
TH	86,5	0,60	14,2	8,5	15,4	9,2	16,9	10,1
Deutschland								
Formel	Futterbedarf in Tsd t	ha^{-1}GV^{-1}	Tsd. ha	% GL	Tsd. ha	% GL	Tsd. ha	% GL
D 1	3475,3	0,54	517,37	11,02	560,99	11,95	613,00	13,06
D1_FN	4745	0,54	702,85	14,97	759,08	16.17	825,08	17,58

[1]Bundesländer ohne Stadtstaaten, [2]jährlicher Futterbedarf des Pferdebestands je Bundesland in Tonnen, bei 10kgTS GV^{-1} Tag^{-1}, [3]Flächenbedarf zur Deckung des Futterbedarfs je BL bei mittlerem Ertrag je BL; [4]Anteil am Grünland je Bundesland

[1]Bundesländer(BL): Baden-Württemberg (BW), Bayern (BY), Berlin (BE), Brandenburg (BB), Bremen (HB), Hamburg (HH), Hessen (HE), Mecklenburg-Vorpommern (MV), Niedersachsen (NI), Nordrhein-Westfalen (NW), Rheinland-Pfalz (RP), Saarland (SL), Sachsen (SN), Sachsen-Anhalt (ST), Schleswig-Holstein (SH), Thüringen (TH). [2]gemeldeter Pferdebestand der Tierseuchenkassen (2016). [3]über Agrarstrukturerhebung erfasstes Grünland (2016).

3.2 Schätzung der direkt mit Pferden genutzten Fläche anhand von Umfragedaten

In einem zweiten Ansatz wurden die in der Praxis erhobenen Daten als Schätzer für die Flächennutzung der pferdehaltenden Praxis auf den im Bundesland gemeldeten Pferdebestand bezogen. Erwerbsorientierte Betrieb und Hobbyhaltungen unterschieden sich zwar hinsichtlich ihrer Gesamtfläche, jedoch nicht in der je Großvieheinheit zur Verfügung stehenden Fläche, weshalb hier nicht weiter unterschieden wurde. Die durchschnittliche Flächenausstattung der befragten Betriebe umfasst 0,8 ha (± 0,7 ha sd) Grünland je Großvieheinheit. Aufgrund der Schiefe der Praxisdaten wurde die Analyse auch unter Verwendung des Medians (0,6 ha) der Flächenausstattung durchgeführt. Tabelle I-5 stellt die Ergebnisse der Schätzung auf Bundeslandebene und für die gesamte Bundesrepublik Deutschland zusammen.

Tabelle I-5: Schätzung der direkt mit Pferden genutzten Fläche anhand von Umfragedaten (N=696 Betriebe) und der berechneten mittleren genutzten Fläche je GV (bzw. des Medians der genutzten Fläche je GV). Dargestellt sind die geschätzte Fläche in Tsd. ha sowie der Anteil dieser Fläche am Grünland (GL) im jeweiligen Bundesland.

	Ø: 0,8 ha/GV		**Median:** 0,6 ha/GV	
In Bundesländern BL [1]	in Tsd, ha	% GL je BL	in Tsd, ha	% GL je BL
SH	61,6	18,8	45,7	13,9
NI	167,7	24,3	124,4	18,0
NW	117,9	30,1	87,4	22,3
HE	54,5	18,5	40,4	13,7
RP	34,5	15,1	25,6	11,2
BW	89,8	16,5	66,6	12,2
BY	111,9	10,5	83,0	7,8
SL	7,8	19,0	5,7	14,1
BB	27,2	9,2	20,2	6,8
MV	18,4	6,9	13,6	5,1
SN	24,7	12,9	18,3	9,6
ST	22,6	12,9	16,8	9,5
TH	18,9	11,3	14,0	8,4
In Deutschland				
	in Tsd, ha	% GL	in Tsd, ha	% GL
D2	760,9	16,2	564,2	12,0
D2_FN	1038,9	22,1	770,4	16,4

[1] Bundesländer ohne Stadtstaaten. [1] Bundesländer(BL): Baden-Württemberg (BW), Bayern (BY), Berlin (BE), Brandenburg (BB), Bremen (HB), Hamburg (HH), Hessen (HE), Mecklenburg-Vorpommern (MV), Niedersachsen (NI), Nordrhein-Westfalen (NW), Rheinland-Pfalz (RP), Saarland (SL), Sachsen (SN), Sachsen-Anhalt (ST), Schleswig-Holstein (SH), Thüringen (TH). [2] gemeldeter Pferdebestand der Tierseuchenkassen (2016). [3] über Agrarstrukturerhebung erfasstes Grünland (2016).

3.3 Schätzung der für Pferde genutzten Fläche über Umfragedaten unter Berücksichtigung des Futterzukaufs

Raufutterzukauf ist in der Pferdehaltung gängig. 70 % der befragten Betriebe kaufen Raufutter hinzu. Als Gründe gaben 67 % eine zu knappe Flächenausstattung an, bei 54 % mangelt es an einer ausreichenden Maschinenausstattung, für 46 % ist der Arbeitsaufwand zu hoch, für 33 % wäre die Eigenproduktion teurer als der Zukauf und 11 % erwarten eine bessere Qualität bei zugekauftem Futter.

Durch die Berechnung der aus Raufutter Zukauf entstehenden Schattenfläche kann die tatsächlich je Großvieheinheit genutzte Fläche präzisiert werden. Bei einem mittleren Ertrag erhöht sich so das arithmetisches Mittel auf 0,95 ha je Großvieheinheit (± 0,7 ha sd) bzw. einen Median von 0,78 ha je Großvieheinheit.

Tabelle I-6 zeigt die Schätzung der insgesamt für Pferde genutzten Fläche unter Einbezug der Schattenfläche, berechnet für die Szenarien der mittleren Ertragsleistung, -5 dt, -10 dt Ertragsleistung je Bundesland und auf Bundesebene aufsummiert.

Tabelle I-6: Schätzung der mit Pferden genutzten Fläche anhand von Umfragedaten (N=696 Betriebe)anhand der im Betrieb genutzten Fläche und Berücksichtigung des Raufutterzukaufs in verschiedenen Ertragsszenarien. Dargestellt sind die geschätzte Fläche in Tsd. ha sowie der Anteil dieser Fläche am Grünland (GL) im jeweiligen Bundesland. Schätzung der für Pferde genutzten Fläche über Umfragedaten

	Fläche bei mittlerem Ertrag				Fläche bei mittlerem Ertrag – 5 dt				Fläche bei mittlerem Ertrag – 10 dt			
N=696	[2]**Ø:** 0,95		[3]**Median:** 0,78		**Ø:** 0,96		**Median:** 0,79		**Ø:** 0,97		**Median:** 0,82	
Bundesländer												
[1]BL	in Tsd ha	% GL	in Tsd ha	% GL	in Tsd ha	% GL	in Tsd ha	% GL	in Tsd ha	% GL	in Tsd ha	% GL
SH	73,0	22,3	59,8	18,3	74,0	22,6	61,0	18,6	75,2	22,9	62,9	19,2
HH	3,1	45,4	2,5	37,2	3,1	46,0	2,6	37,9	3,2	46,7	2,7	39,1
NI	198,8	28,8	162,9	23,6	201,5	29,2	166,0	24,0	204,6	29,6	171,3	24,8
NW	139,8	35,7	114,5	29,2	141,6	36,1	116,7	29,8	143,8	36,7	120,4	30,7
HE	64,6	22,0	53,0	18,0	65,5	22,3	54,0	18,3	66,5	22,6	55,7	18,9
RP	40,8	17,9	33,5	14,7	41,4	18,2	34,1	15,0	42,0	18,5	35,2	15,5
BW	106,4	19,5	87,2	16,0	107,8	19,8	88,8	16,3	109,5	20,1	91,7	16,8
BY	132,6	12,5	108,7	10,2	134,4	12,6	110,7	10,4	136,5	12,8	114,3	10,7
SL	9,2	22,5	7,5	18,5	9,3	22,8	7,7	18,8	9,5	23,2	7,9	19,4
BE	0,9	118,7	0,8	97,3	1,0	120,3	0,8	99,1	1,0	122,2	0,8	102,3
BB	32,2	10,9	26,4	8,9	32,6	11,0	26,9	9,1	33,2	11,2	27,8	9,4
MV	21,8	8,1	17,9	6,7	22,1	8,2	18,2	6,8	22,4	8,4	18,8	7,0
SN	29,3	15,3	24,0	12,6	29,6	15,5	24,4	12,8	30,1	15,8	25,2	13,2
ST	26,8	15,3	22,0	12,5	27,2	15,5	22,4	12,7	27,6	15,7	23,1	13,2
TH	22,5	13,4	18,4	11,0	22,8	13,6	18,8	11,2	23,1	13,8	19,4	11,6
Deutschland												
D3	901,9	19,2	739,0	15,7	914,0	19,5	753,1	16,0	928,3	19,8	777,2	16,6
D3_FN	1231,5	26,2	1009,1	21,5	1247,9	26,5	1028,2	21,9	1267,5	27,0	1061,2	22,6

[1]Bundesländer ohne Hansestadt Bremen, [2]arithmetisches Mittel der Fläche in ha je GV , [3]Median der Fläche in ha je GV

4. Diskussion

4.1 Methodendiskussion und Limitationen der Studie

Die Zuverlässigkeit der dargestellten Schätzungen hängt grundlegend von der Qualität der verwendeten Inputgrößen und deren Limitationen ab. Daher soll im Folgenden die Qualität der verschiedenen in dieser Arbeit verwendeten Datenkategorien diskutiert werden.

4.1.1 Pferdebestandsdaten

Bereits die Angaben zur Anzahl der in Deutschland gehaltenen Pferde verdeutlichen das in der Pferdebranche vorliegende Datenstrukturproblem. Die derzeit zuverlässigsten Bestandsdaten sind die Meldungen der Tierseuchenkassen. Trotz gesetzlicher Meldepflicht wird bei diesen Daten jedoch von einer gewissen Ungenauigkeit ausgegangen, die vor allem auf die unzureichende Meldebereitschaft der Pferdehalter zurückgeführt wird (16, persönliche Mitteilungen Tierseuchenkassen). Es ist zu erwarten, dass sich die Datenqualität zum Pferdebestand durch die Einführung von Equidenpässen und die Einbindung der Pferdebestandsmeldungen in die HIT Datenbanken (seit 2011) in den kommenden Jahren deutlich verbessern wird.
Die vorliegenden Analysen wurden auf Bundeslandebene durchgeführt. Eine Bereitstellung von Pferdebestandsdaten auf Landkreisebene wird nicht in allen Bundesländern gewährt. Eine wünschenswerte Analyse regionaler Zusammenhänge höherer räumlicher Auflösung ist aus diesem Grund bislang nicht möglich.

4.1.2 Daten der Grünlandnutzung

Die Angaben zur Grünlandfläche der Bundesländer beziehen sich auf die Daten der Agrarstrukturerhebung. Die Erhebungen greifen erst ab einer Betriebsgröße von 5 ha, und können somit die tatsächliche Grünlandfläche in Deutschland unterschätzen. Als Schätzer für die Leistungsfähigkeit des Grünlands zur Quantifizierung der benötigten Fläche wurden Daten der Ernte und Betriebsberichterstattung der Bundesländer verwendet. Hier ist nicht nur ein auf regionale Standortunterschiede, sondern auch auf Schätzfehler der Melder zurückzuführender Fehler zu erwarten (destatis).

4.1.3 Annahmen zum Futterbedarf

Die Schätzmethoden treffen des Weiteren Annahmen, die die Variabilität reeller Bedingungen vereinfachen. Zur Berechnung des Futterbedarfs wurden Orientierungswerte der Pferdefütterung zur Trockensubstanzaufnahme herangezogen. Diese kann bereits beim selben Tier zwischen Raufutter (23g je kg Lebendmasse) und Aufnahme auf der Weide (bis zu 5% Lebendmasse) variieren. Die hinzukommende betriebs-, nutzungs- und tierindividuelle Variabilität der Rationsgestaltung bleibt unberücksichtigt. Zur Berechnung der Schattenfläche je Betrieb mussten die vereinfachenden Annahmen getroffen werden, dass das Raufutter im selben Bundesland produziert wird und nur in der Winterperiode (180 Tage) eingesetzt wird.

4.1.4 Limitationen der Umfragedaten

Mit der Online Erhebung zur Pferdehaltung im Zusammenhang mit der Grünlandwirtschaft ist es erstmals für Deutschland gelungen, einen mit über 700 Pferdehaltungen sehr umfangreichen und konsistenten Praxisdatensatz auf Betriebsebene zur Analyse zur Verfügung zu haben. Trotz der hohen Teilnehmerzahl kann der Datensatz keine vollständige Repräsentativität der Pferdehaltung in Deutschland für sich beanspruchen. Dennoch haben die eigenen Analysen gezeigt (vgl. Abbildung 1), dass die Daten in wichtigen Merkmalen die prinzipiellen Verhältnisse in den Bundesländern gut widerspiegeln und somit in der hier dargestellten Analyse aussagekräftig sind. Gleichwohl unterliegen solche Praxisdaten grundsätzlich gewissen Begrenzungen, die in der Art der

Ansprache der Betriebe begründet sind. Die Befragung erfolgte online, ebenso wie ihre Verbreitung, was möglicherweise in einer Unterschätzung von weniger internetaffinen Pferdehaltern resultiert. Eine weitere Limitation ist eine Selbstselektion aufgrund interessenabhängiger Teilnahme (Self-Selection-Bias), was als Einschränkung jedweder freiwilliger Studien gilt (48).

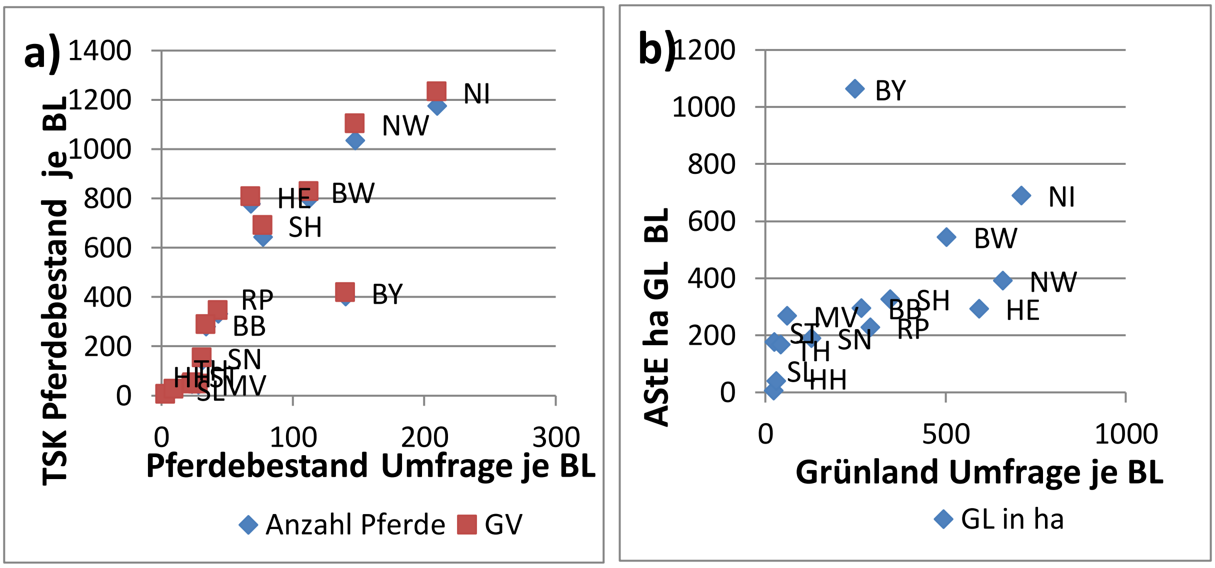

Abbildung I-1: (a) Zusammenhang zwischen dem 2016 bei den deutschen Tierseuchenkassen gemeldeten Pferdebestand (in Tausend) und der für die jeweiligen Bundesländer akkumulierten Anzahl Pferde bzw. GV der Umfrageteilnehmer, bzw. (b) dem über die Agrarstrukturer

4.2 Tragfähigkeit der Studie

Präzision und Tragfähigkeit einer Schätzung auf Basis vager Datengrundlage des Pferdebestands und der Grünlandnutzung bleiben sicherlich zu diskutieren. In diesen Unsicherheiten mag begründet liegen, dass eine solche Quantifizierung bislang nicht gewagt wurde und wenig wissenschaftlich fundierte Erkenntnisse vorliegen. Die hier vorgelegte methodische Studie zeigt jedoch erstmals Möglichkeiten auf, die für Pferde genutzte Grünlandfläche auf verschiedenen Datengrundlagen und anhand verschiedener Methoden zu präziser als bisher zu schätzen. Insbesondere die Einbindung der Praxisdaten liegt in dieser Form für Grünlandnutzung in der Pferdehaltung noch nicht vor.

Die Studie vermag eine bislang nicht erreichte Qualität der Quantifizierung zu leisten und dient damit als ein erster Schritt einer weiterhin zu präzisierenden Analyse der Flächennutzung durch Pferdehalter in Deutschland.

Generell ist davon auszugehen, dass die Unsicherheiten bzw. die offensichtliche Unterschätzung des Pferdebestands bisher zu einer systematischen Unterschätzung der tatsächlich für Pferde genutzten Fläche geführt haben. Auf der anderen Seite deutet unsere Studie eine Unterschätzung der in der Agrarstrukturerhebung erfassten Grünlandfläche an sich an, da (Pferde-)Betriebe unter 5 ha landwirtschaftlicher Nutzfläche nicht erfasst werden. Die Anpassung der Erfassungsgrenze speziell für Pferdebetriebe würde hier wesentlich zur Optimierung der statistischen Erfassung der Landnutzung beitragen. Darüber hinaus werden weiter zu entwickelnde Verfahren der Fernerkundung (z.B. Satellitenbildanalysen) in nicht allzu ferner Zukunft dazu beitragen, konkretere Zahlen zur

Landnutzung, auch der durch Pferdehaltung vorzulegen. Die hier vorliegende Studie kann vorab die Relevanz aufzeigen, die unter theoretischen Annahmen zu erwarten ist.

4.3 Ergebnisdiskussion

Die Ergebnisse der vorliegenden Studie können keinen Anspruch auf eine abschließende Quantifizierung des tatsächlich für die Pferdehaltung genutzten Grünlands erheben. Dennoch zeigen sie, dass die bisherige vereinfachte Annahme anhand der Faustzahl von etwa 0,5 ha je Großvieheinheit und der daraus abgeleiteten 500.000 ha oder 10 % des Grünlands in Deutschland (10) zu kurz greift. Die Flächenrelevanz des für Pferde genutzten Grünlands wurde bislang erheblich unterschätzt. Tabelle I-7 gibt einen Überblick über die Spanne der Quantifizierung anhand verschiedener Schätzverfahren.

Tabelle I-7: Synthese der über verschiedene Methoden ermittelten Schätzer des für Pferde genutzten Anteils am Grünland in Deutschland.

					Sensitivitätsanalyse			
Methode[1]	Ø[2]	Median[3]	Mittlerer Ertrag GL		Mittlerer Ertrag GL		Mittlerer Ertrag GL	
D1			11,0		12,0		13,1	
D1_FN			15,0		16,2		17,6	
D2	16,2	12,0						
D2_FN	22,1	16,4						
			Ø	Median	Ø	Median	Ø	Median
D3			19,2	15,7	19,5	16,0	19,8	16,6
D3_FN			26,2	21,5	26,5	21,9	27,0	22,6

[1] Verwendete Schätzmethode: D1 Schätzung auf Basis des Futterbedarfs des Pferdebestandes und der mittleren Ertragsleistung vom Grünland, D2 Schätzung auf Basis der Flächenausstattung je Betrieb aus Umfragedaten, D3 Schätzung auf Basis der Flächenausstattung und des Raufutterzukaufs je Betrieb Pferdebestandes und der mittleren Ertragsleistung vom Grünland; D_FN zeigt die entsprechende Schätzung unter Verwendung des von der FN angenommenen Pferdebestands. [2] arithmetisches Mittel der Flächenausstattung je GV aus Umfragedaten; [3] Median der Flächenausstattung je GV aus Umfragedaten.

4.3.1 Flächenquantifizierung Schätzung auf Basis des Futterbedarfs

Da keine hinreichenden Daten zur in der Praxis für Pferde genutzten Fläche vorliegen, ist ein naheliegender erster Schritt die Schätzung des Flächenbedarfs zur Ernährung einer Großvieheinheit. Somit kann die notwendigerweise zur Ernährung des Pferdebestandes mindestens zu bewirtschaftende Fläche abgeleitet werden.

Eine gängige Faustzahl der Beratungspraxis zum Flächenbedarf in der Pferdehaltung beläuft sich auf etwa 0,5 ha je Großvieheinheit zur Deckung des Futterbedarfs (26). Wird eine Trockenmasseaufnahme von 10 kg je Großvieheinheit und Tag sowie eine mittlere Ertragsleistung vom Grünland unterstellt, dann bedarf es einer Fläche von 0,54 ha je Großvieheinheit. Dass dieser Schätzer jedoch ausgesprochen standortabhängig ist, wird bei der bundeslandspezifischen Schätzung deutlich. Während nach dieser Rechnung in Niedersachen und Schleswig-Holstein weniger als 0,5 ha je Großvieheinheit benötigt werden, so sind es in NRW bereits 0,61 ha und in Sachsen-Anhalt sogar 0,73 ha. Für die

Beratungspraxis der Bundesländer bedeutet dies, dass die Faustzahl von 0,5 ha je Pferde-Großvieheinheit bei räumlich differenzierter Betrachtung keinesfalls korrekt sein kann bzw. je nach Bundesland und auch Produktivität des Standortes modifiziert werden sollte. Nicht einkalkuliert ist der aufgrund des Weideeffektes des Pferdes zu erwartende Weiderest. Dieser ist in Abhängigkeit vom Weidesystem sehr variabel, die Nichtberücksichtigung bedingt eine systematische Unterschätzung des Grünlands.

Entsprechend der jeweiligen Ertragsleistung des Grünlands und des Pferdebestandes variieren die Schätzungen der notwendigerweise zu bewirtschaftenden Fläche bzw. des jeweiligen Grünlandanteils für die Bundesländer erheblich. Auffällig ist ein West-Ostgefälle, das sich anhand von Unterschieden in der Einwohnerdichte und der Etablierung traditioneller Pferderegionen erklären lässt. So wird in Mecklenburg Vorpommern theoretisch bloß knapp 6 % des Grünlands für die Pferdeernährung beansprucht, in Nordrhein-Westfalen sind aber über 23 % notwendig.

Deutschlandweit kann auf Basis der für die Bundesländer berechneten Fläche zur Deckung des Futterbedarfs davon ausgegangen werden, dass ***mindestens*** **11 % des deutschen Grünlands** notwendigerweise zur Deckung des Futterbedarfs beansprucht werden. Unterstellt man den Pferdebestandszahlen eine der Meldemoral geschuldete Ungenauigkeit und zieht die Angaben der FN von 1,3 Millionen Pferden bundesweit heran, dann ist davon auszugehen, dass sogar **15 % des deutschen Grünlands** für die Futterbereitstellung für Pferde benötigt werden. In der Praxis ist eine Fütterung von Aufwüchsen geringerer Qualität und von Standorten unterdurchschnittlicher Ertragsleistung anzunehmen, weshalb der Anteil Grünlands sogar noch höher zu veranschlagen sein könnte (bei den Tierseuchenkassen gemeldeter Bestand: 13 %, FN Bestand: 17,6 %).

4.3.2 Flächenquantifizierung auf Basis von Daten der Online-Befragung

Die Quantifizierung der Fläche über den Futterbedarf ist eine theoretische Größe. Es stellte sich die Frage, inwiefern diese den reellen Bedingungen der Praxis entspricht, denn eine ausgeprägte Spannbreite an Betriebsstrukturen und damit einhergehender Flächennutzung charakterisiert die Pferdewirtschaft (16, 17). Darüber hinaus beeinflussen Faktoren wie natürliche Standortvoraussetzungen, Siedlungsstrukturen und Flächenpreise die tatsächliche Flächenausstattung der Betriebe in der Praxis (16). Ein konsequenter zweiter Schritt war daher der Einbezug von Praxisdaten, um zu prüfen, wieviel Fläche Pferdehalter tatsächlich durchschnittlich je Großvieheinheit nutzen und ob die in der Beratung verwendete Faustzahl von 0,5 ha je Großvieheinheit so in der Praxis Anwendung findet. Eine sich hieraus ableitende insgesamt in Deutschland für Pferde genutzte Fläche lässt eine praxisorientierte Optimierung der theoretischen Schätzung erwarten.

Die mittels online-Befragung erfassten Daten zur Flächenausstattung von fast 700 Betrieben bestätigen die erwartete Variabilität in der Pferdehaltung. Die durchschnittliche Flächenausstattung der befragten Betriebe beträgt 0,8 ha (± 0,7 ha sd, Median 0,6 ha) je Großvieheinheit die im Betrieb *direkt* für Pferde genutzt werden. Somit liegt die mittlere Flächenausstattung deutlich über der Faustzahl. Erwerbsorientierung oder Hobbyhaltung hatten keinen Einfluss auf die Fläche je Großvieheinheit.

Zur Fläche die in den Betrieben *direkt* genutzt wird kommt jedoch noch die Schattenfläche die *indirekt* durch den Zukauf von Raufutter genutzt wird. Der Zukauf von Raufutter spielt eine entscheidende Rolle in der Pferdewirtschaft, erst der Einbezug der *indirekt* bewirtschafteten Schattenfläche vervollständigt somit eine praxisorientierte Quantifizierung. Bei mittlerer Ertragsleistung des Grünlands werden 0,95 ha je Großvieheinheit (bzw. 0,78 ha je Großvieheinheit (Median)) bewirtschaftet. Die tatsächliche Flächennutzung in der Praxis muss also erheblich höher eingeschätzt werden als es der in der Beratung gängigen Faustzahl entspricht.

Bezogen auf die Angaben zum Pferdebestand ergeben sich auf Basis der erhobenen Praxisdaten der Flächenausstattung je Großvieheinheit verschiedene Szenarien der gesamten Flächennutzung durch Pferdehalter **zwischen 11 % und 27 % des Grünlands in Deutschland** (Tabelle I-6). Auch hier sind wieder deutliche Unterschiede in den Bundesländern zu erkennen. Diese Spannen verdeutlichen einerseits die Dringlichkeit besserer Datenerfassungen in Bezug auf die Pferdehaltung. Darüber hinaus wird aber die Relevanz der Pferdehalter *in der Fläche* bestätigt. Auf Basis der vorliegenden Szenarien liegt eine Schätzung von **etwa 15-20 % für Pferde genutzten Grünlands** nahe. Dies ist weit mehr als bislang angenommen.

4.3.3 Relevanz für den Nutzungserhalt von Extensivgrünland in der Fläche

Über die tatsächliche Flächennutzung von Pferdehaltern, insbesondere der Hobbypferdehalter lagen bislang keine Erkenntnisse vor. Die Studie gewährt einen aufschlussreichen Einblick in die ausgesprochene Variabilität der Flächenausstattung. Im Vergleich zur Milchviehwirtschaft sind die Betriebsgrößen in der Pferdehaltung sehr klein. Selbst erwerbsorientierte „große" Pferdebetriebe bewirtschaften selten mehr als 100 ha landwirtschaftlicher Nutzfläche Die mittlere für Pferde genutzte Grünlandfläche der befragten Betriebe beträgt sogar weniger als 6 ha (± 9,8 ha sd). Bereits über die geringe Gesamtfläche der erfassten Pferdehaltungen kann auf die Bewirtschaftung vergleichsweise kleiner Schlaggrößen geschlossen werden. Besonders die Hobbyhalter gilt es an dieser Stelle hervorzuheben. 70 % der befragten Hobbypferdehalter nutzen insgesamt weniger als 5 ha landwirtschaftlicher Nutzfläche. Damit gehen zwei ganz wesentliche und zu betonende Aspekte einher. Zum einen wird diese Gruppe von Pferdehaltern aufgrund der zu geringen jeweils bewirtschafteten Fläche nicht über Agrarstrukturerhebungen erfasst und damit insgesamt in Agrarstatistiken systematisch unterschätzt. Zum anderen sind in Zeiten zunehmender Betriebs- und Herdengrößen in der Milchviehhaltung von diesen Kleinstbetrieben bedeutsame Potentiale zum Erhalt kleinparzellierten Grünlands zu erwarten. Immerhin 40 % der befragten Pferdehalter gaben an, dass ihr Grünland vorab für Rinder bewirtschaftet wurde. Im Zuge des Strukturwandels wurde und wird kleinparzelliertes Extensivgrünland insbesondere in isolierten Streulagen für die Milchviehwirtschaft weitgehend unattraktiv und freigestellt. Die Übernahme und Nutzung dieser Flächen durch Pferdehalter ist vor allem im ballungsraumnahen ländlichen Raum gängige Praxis (4, 12, 49). Kleine Betriebs- und Herdengrößen sowie im Falle der Hobbyhalter die fehlende Gewinnerzielungsabsicht, ermöglichen eine Offenhaltung von Flächen, die aufgrund ihrer vielfältigen Flora und Fauna von erheblicher ökologischer Relevanz in der Agrarlandschaft sind (3, 34).

Ferner deutet die durchschnittlich zur Verfügung stehende Fläche je Großvieheinheit der erfassten Pferdebetriebe im Vergleich mit intensiver Haltung anderer Nutztiere wie Milchkühen, ein eher extensives Flächenmanagement an. Darüber hinaus sind die Ansprüche der Pferdehalter an den Energiegehalt des Futters deutlich geringer (27, 35, 36, 43). Eine auf die Steigerung der Ertragsleistung und Energiedichte abzielende intensive

Bewirtschaftung dieser Flächen ist für die Pferdehaltung weder erforderlich noch erwünscht.

Trotz der beschriebenen Potentiale gehen mit der Grünlandnutzung für Pferde nicht zu unterschätzende Herausforderungen einher. Insbesondere im ballungsraumnahen Ländlichen Raum kommt es nicht selten zu Landnutzungskonflikten (4, 12, 49) und einer kontroversen Diskussion um Pferdehaltung. Die Bewirtschaftung von Extensivgrünland erfordert eine gute Kenntnis der komplexen ökologischen Zusammenhänge und der standortspezifischen Wirkung von Maßnahmen des Managements und spezifischer Weidetiere (5, 24, 31, 33). Gleichwohl gründet der geringere Teil der befragten Betriebe der vorliegenden Studie das Flächenmanagement auf eine landwirtschaftliche (19 %), pferdebezogene (25 %) oder ökologische Ausbildung (<9 %). Ähnliches wurde bereits von JOUVEN (2016) in Frankreich beobachtet. Insbesondere im fehlenden landwirtschaftlichen Hintergrund, in der mangelnden Ausbildung und Kenntnis vieler Pferdehalter wird die Herausforderung für einen nachhaltige Grünlandbewirtschaftung gesehen (22).

Ihr spezifischer Weideeffekt (2, 30, 38, 39) erhebt die Weidewirtschaft mit Pferden zur „Königsdisziplin" im beweideten Grünland, Pferde werden mitunter als „schwierige" Weidetiere (13) beschrieben. Ihr ausgeprägter Weideeffekt erfordert besondere Kenntnisse und Aufmerksamkeit im Weidemanagement. In der Tat weiden Pferde im Vergleich zu Rindern und Schafen ausgesprochen selektiv (2, 14). Aufgrund ihrer zwei Paar Schneidezähne sind sie in der Lage, sehr gezielt auf einzelne, wohlschmeckende Pflanzen zu selektieren. Ihre dentale Anatomie erlaubt es ihnen zudem, die präferierten Arten tief, mitunter bis zum Boden zu verbeißen. Dies kann den Wiederaustrieb der Pflanzen beeinträchtigen. Damit nehmen Pferde als Weidetiere direkten Einfluss auf die Wuchs- und Konkurrenzverhältnisse im Pflanzenbestand und letztlich auf die Artenzusammensetzung der Grasnarbe. Über die dentale Anatomie hinaus zeichnet Pferde auch ein spezifisches Weideverhalten aus. Pferde zeigen ein sogenanntes Latrinenverhalten, sie legen Fraß- und Toilettenbereiche an. Fraßbereiche werden wiederholt befressen und bei knappem Futterangebot tief verbissen, während die Toilettenbereiche (Geilstellen) langfristig vom Fraß ausgespart werden. Auf der Weide führt dieses Verhalten in Abhängigkeit vom Weidedruck und der Intensität der aufgewendeten Grünlandpflegemaßnahmen zu einer Umverteilung der Nährstoffe und nachhaltigen Beeinflussung des Pflanzenbestandes (2). In beanspruchten Fraßbereichen finden sich typischerweise vermehrt Magerkeits- und Störungszeiger, in den Geilstellen stickstoffliebende Arten (38, 39). Bei einem *zu hohen*, nicht an die Leistungsfähigkeit des Standortes angepassten Tierbesatz in Kombination mit unangepasstem Flächenmanagement kann dieser Weideeffekt Grasnarben rasch degradieren (6, 14, 38, 39, 40). Bei den in Ballungsraumnähe zu beobachtenden hohen/höheren Besatzstärken auf begrenzter Fläche provoziert dies in der Praxis regelmäßig Konflikte (4, 49). Der typische Weideeffekt muss jedoch keineswegs in degradierten Grasnarben resultieren. Heterogene Weidebereiche wie sie Pferde anlegen, werden als ein Schlüssel für den Erhalt von Artenvielfalt im beweideten Grünland angesehen (31, 47). Die Weidewirkung von Pferden in der landwirtschaftlichen Praxis ist jedoch noch wenig untersucht.

Jüngere Observationsstudien konnten unter Praxisbedingungen positive Effekte relativ extensiver Beweidung mit Pferden für die pflanzliche Artenvielfalt und Indikatorarten artenreichen Grünlands aufzeigen (38, 39). In einer bundesweiten Studie wurde auf 70 Betrieben unter verschiedenen Standortvoraussetzungen die Vegetation von insgesamt fast

300 für Pferde genutzten Flächen untersucht. Basierend auf dem gefundenen Arteninventar konnten über 40 Prozent der dort untersuchten Flächen als High-Nature-Value (HNV) - Grünland, also Grünland von besonderem Naturwert klassiert werden. Maßgeblich für die Ausprägung der Artenvielfalt und HNV-Arten war in dieser Studie die Beweidungsintensität (39). Auch im direkten Vergleich zu Rinderweiden konnte auf Pferdeweiden eine größere Artenvielfalt einschließlich von HNV-Arten beobachtet werden. Unabhängig von der Beweidungsintensität wurden auf den untersuchten Pferdeweiden höhere Artenzahlen als auf Rinderweiden beobachtet. (38). Diese Studien heben die ökologische Relevanz von Pferdegrünland hervor und betonen, dass unter landwirtschaftlichen Praxisbedingungen wertvolles Grünland durch eine Beweidung mit Pferden bewirtschaftet und erhalten werden kann.

Die Wirkungszusammenhänge zwischen der Grünlandbewirtschaftung mit Pferden und den Ökosystemleistungen des Grünlands sind insgesamt jedoch noch unzureichend bekannt.. Das bestehende Wissen zur Weidehaltung basiert neben einzelnen Studien weitgehend auf Erkenntnissen zu anderen Nutztieren.

Die Deutsche Agrarforschungsallianz fordert im 2015 vorgelegten Forschungsstrategiepapier die Entwicklung von zukunftsorientierten Produktionssystemen und betont vehement die Notwendigkeit der Analyse der Wirkungszusammenhänge zwischen den Produktionssystemen und Ökosystemleistungen als Grundlage für eine Bewertung der Leistung dieser Systeme und einer Kommunikation der Inwertsetzung von Grünland (10). Vor dem Hintergrund der in der vorliegenden Studie aufgezeigten Flächenrelevanz sollte dies ebenso für Pferdehaltung im Grünland gelten. Um das Landnutzungssystem Pferdehaltung und die hier erbrachten Leistung bewerten und die damit einhergehenden Potentiale optimal nutzen zu können, bedarf es weiterer umfassender Analysen. Das bestehende Wissen zur Weidehaltung anderer Nutztiere lässt sich keineswegs uneingeschränkt auf das Pferd als Verwerter von Grünlandaufwüchsen und Weidetier anwenden. Es gilt daher nicht nur die spezifische Weidewirkung von Pferden und ihrer Abhängigkeit von Standort und Flächenmanagement zu analysieren, sondern auch die Ansprüche des Pferdes an das Grünland. Zum anderen verlangt die ausgesprochene Vielfalt der Pferdebetriebe und ihrer Betriebsziele, sowie ihre Effekte in der Agrarlandschaft nach einer umfassenden Analyse.

5. Schlussfolgerung und Aussicht

Zentrales Anliegen der Studie war die Quantifizierung des für Pferde genutzten Grünlands. Dabei wurde das generelle Datenstrukturproblem der Pferdebranche offenkundig. Dennoch ist es nun erstmals auf Basis verschiedener Datengrundlagen gelungen, die bisherige Schätzung zu präzisieren.

Die Relevanz der Pferdehaltung als Landnutzungssystem in Deutschland muss auf Basis der vorgelegten Schätzungen überdacht werden. Die Fläche, die Pferdehaltung im Grünland beansprucht, wurde bislang deutlich unterschätzt. Es kann ein Anteil von 15-20 % am Grünland angenommen werden der mit oder für Pferde bewirtschaftet wird. Zwischen den Bundesländern sind jedoch erhebliche Unterschiede zu verzeichnen. Doch Potentiale ergeben sich nicht nur in der Fläche. Der sich in der modernen Landwirtschaft immer schwieriger gestaltende Erhalt extensiv genutzten, kleinparzellierten und relativ artenreichen Grünlands ist gängige Praxis in der Pferdehaltung. Insbesondere die Hobbypferdehalter lassen ein ausgesprochenes Potential für den Erhalt von kleinflächigem

Grünland in Streulage erwarten. Obschon sie nicht selten in rechtlichen Grauzonen agieren, betreiben Pferdehalter durch die Nutzung solcher Flächen bereits aktiven Kulturlandschaftsschutz, ohne dass hierfür umfassende Ausgleichszahlungen aufgebracht werden müssten. Die Studie hat ferner verdeutlicht, dass relativ wenig über das Wirtschaften und den Kenntnisstand der Pferdehalter in der Praxis bekannt ist. Um die Potentiale der Pferdehalter für die Nutzung und den Erhalt extensiven Grünlands optimal auszuschöpfen, gilt es daher zunächst die Grundlagen ihres Wirtschaftens sowie die Effekte von Pferden als Weidetiere im Grünland besser zu analysieren. Daraus hervorgehend gilt es spezielle, auf Pferde und Pferdehalter zugeschnittene Beratungsstrategien zu entwickeln und in der Praxis zielführend umzusetzen.

Quellen- und Literaturverzeichnis

Datenquellen:

Flächennutzungs- und Ertragsdaten:

Statistisches Bundesamt Wiesbaden (2015): Ernte- und Betriebsberichterstattung (EBE): Feldfrüchte und Grünland. URL: https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/ErnteFeldfruechte/FeldfruechteJahr2030321147164.pdf?__blob=publicationFile (Abruf 13.08.2017)

Statistisches Bundesamt Wiesbaden (2016): Ernte- und Betriebsberichterstattung (EBE): Feldfrüchte und Grünland. URL: https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/ErnteFeldfruechte/FeldfruechteJahr2030321167164.pdf?__blob=publicationFile (Abruf 13.08.2017)

Statistisches Bundesamt Wiesbaden (2017): Bodennutzung der Betriebe (Landwirtschaftlich genutzte Flächen). URL: https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/Bodennutzung/LandwirtschaftlicheNutzflaeche.html (Abruf 13.08.2017)

Tierbestandsdaten:

FN Deutsche Reiterliche Vereinigung, 2017: Zahlen & Fakten. URL: https://www.pferd-aktuell.de/fn-service/zahlen--fakten/zahlen--fakten (Abruf: 10.09.2017)

Tierseuchenkasse Baden-Württemberg, 2017: Pferdebestand Baden-Württemberg 2016. Auskunft per email 9. März 2017.

Tierseuchenkasse des Saarlandes, 2017: Pferdebestand Saarland 2016. Auskunft per email 9. März 2017.

Tierseuchenkasse Thüringen, 2017: Pferdebestand Thüringen 2016. Auskunft per email 10. März 2017.

Tierseuchenkasse Sachsen-Anhalt, 2017: Pferdebestand Sachsen-Anhalt 2016. Auskunft per email 13. März 2017.

Tierseuchenkasse Hessen, 2017: Pferdebestand Hessen 2016. Auskunft per email 21. März 2017.

Tierseuchenkasse Nordrhein-Westfalen, 2017: Pferdebestand NRW 2016. Auskunft 23. März 2017.

Tierseuchenkasse Bayern, 2017: Pferdebestand Bayern 2016. Auskunft per email 4. April 2017.

Tierseuchenkasse Schleswig-Holstein, 2017: Pferdebestand Schleswig-Holstein 2016. Auskunft per email 19. April 2017.

Tierseuchenkasse Mecklenburg-Vorpommern, 2017: Pferdebestand Mecklenburg-Vorpommern 2016. Auskunft per email 28. April 2017.

Tierseuchenkasse Berlin, 2017: Pferdebestand Berlin 2016. Telefonische Auskunft August 2017.

Tierseuchenkasse Niedersachsen, 2017: Pferdebestand Niedersachsen 2016. URL: https://www.ndstsk.de/index.php?bereich=1&topic_id=781&akk=1 (Abruf:10.08.2017)

Tierseuchenkasse Brandenburg, 2017: Pferdebestand Brandenburg 2016. http://www.tsk-bb.de/pdf/aktuelles/Auszug%20aus%20dem%20Jahresbericht%202016.pdf (Abruf:10.08.2017)

Tierseuchenkasse Sachsen, 2017: Pferdebestand Sachsen 2016. Auskunft per email 20. April 2017.

Tierseuchenkasse Hamburg, 2017: Pferdebestand Hamburg 2016. Auskunft per email 6. April 2017.

Tierseuchenkasse Rheinland-Pfalz, 2017: Pferdebestand Rheinland-Pfalz 2016. Auskunft per emai. 4. April 2017.

Statistisches Bundesamt Wiesbaden, 2017: Fachserie 3 Reihe 4.1 Land- und Forstwirtschaft, Fischerei. Viehbestand. URL: https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/TiereundtierischeErzeugung/TiereundtierischeErzeugung.html (Abruf:10.09.2017)

Literatur:

1. Allan, E.; Manning, P.; Alt, F.; Binkenstein, J.; Blaser, S.; Blüthgen, N.; Böhm, S.; Grassein, F.; Hölzel, N.; Klaus, V. H.; Kleinebecker, T.; Morris, E. K.; Oelmann, Y.; Prati, D.; Renner, S. C.; Rillig, M. C.; Schaefer, M.; Schloter, M.; Schmitt, B.; Schöning, I.; Schrumpf, M.; Solly, E.; Sorkau, E.; Steckel, J.; Steffen-Dewenter, I.; Stempfhuber, B.; Tschapka, M.; Weiner, C. N.; Weisser, W. W.; Werner, M.; Westphal, C.; Wilcke, W.; Fischer, M., 2015: Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. In: Ecology letters, Jg. 18, H. 8, S. 834–843.
2. Archer, M., 1973: The species preferences of grazing horses. In: Journal of british grassland society, H. 28, S. 123–128.
3. Bennett, A. F.; Radford, J. Q.; Haslem, A., 2006: Properties of land mosaics. Implications for nature conservation in agricultural environments. In: Biological Conservation, Jg. 133, H. 2, S. 250–264.
4. Bomans, K.; Dewaelheyns, V.; Gulinck, H., 2011: Pasture for horses. An underestimated land use class in an urbanized and multifunctional area. In: International Journal of Sustainable Development and Planning, Jg. 6, H. 2, S. 195–211.
5. Bonari, G.; Fajmon, K.; Malenovský, I.; Zelený, D.; Holuša, J.; Jongepierová, I.; Kočárek, P.; Konvička, O.; Uřičář, J.; Chytrý, M., 2017: Management of semi-natural grasslands benefiting both plant and insect diversity. The importance of heterogeneity and tradition. In: Agriculture, Ecosystems & Environment, Jg. 246, S. 243–252.
6. Bott, R. C.; Greene, E. A.; Koch, K.; Martinson, K. L.; Siciliano, P. D.; Williams, C.; Trottier, N. L.; Burk, A.; Swinker, A., 2013: Production and Environmental Implications of Equine Grazing. In: Journal of Equine Veterinary Science, Jg. 33, H. 12, S. 1031–1043.
7. Brade, W., 2013: Die deutsche Reitpferdezucht - aktueller Stand und wirtschaftliche Bedeutung. In: Berichte über Landwirtschaft, 91(1).
8. Bundesamt für Naturschutz, 2014: Grünlandreport 2014. Alles im grünen Bereich? Bonn. https://www.bfn.de/fileadmin/BfN/landwirtschaft/Dokumente/PK_Gruenlandpapier_30.06.2014_final_layout_barrierefrei.pdf., Zugriff am 26.10.2017.
9. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2017: Biologische Vielfalt in Deutschland: Fortschritte sichern - Herausforderungen annehmen! Rechenschaftsbericht 2017 der Bundesregierung zur Umsetzung der Nationalen Strategie zur biologischen Vielfalt. http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Naturschutz/nationale_strategie_rechenschaftsbericht_2017_bf.pdf., Zugriff am 26.10.2017.
10. Deutsche Agrarforschungsallianz, 2015: Fachforum Grünland. Grünland innovativ nutzen und Ressourcen schützen. Forschungsstrategie der Deutschen Agrarforschungsallianz. http://www.dafa.de/fileadmin/dam_uploads/images/Fachforen/FF_Gruenland/ff_gruenland-strategie-de_2015.pdf, Zugriff am 26.10.2017.

11. Dumont, B.; Farruggia, A.; Garel, J.-P.; Bachelard, P.; Boitier, E.; Frain, M., 2009: How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? In: Grass and Forage Science, Jg. 64, H. 1, S. 92–105.
12. Elgåker, H.; Pinzke, S.; Lindholm, G.; Nilsson, C., 2010: Horse keeping in Urban and Peri-Urban Areas:New Conditions for Physical Planning in Sweden. In: Danish Journal of Geography, 110(1).
13. Elsäßer, M., 2010: Typisch Pferdeweide. (K)ein Bild des Jammers., Pferdebetrieb Extra: Pferdeweiden optimal bewirtschaften.
14. Fleurance, G.; Farruggia, A.; Lanore, L.; Dumont, B., 2016: How does stocking rate influence horse behaviour, performances and pasture biodiversity in mesophile grasslands? In: Agriculture, Ecosystems & Environment, Jg. 231, S. 255–263.
15. Gesellschaft für Ernährungsphysiologie, 2014: Empfehlungen zur Energie- und Nährstoffversorgung von Pferden.
16. Hölker, S.; Wiegand, K.; Spiller, A.; Münch, C., 2016: Typologie der deutschen Pferdehaltung. Eine empirische Studie mittels Two-Step-Clusteranalyse. In: Berichte über Landwirtschaft, 94(3).
17. Ikinger, C.; Wiegand, K.; Spiller, A., 2014: Reiter und Pferdebesitzer in Deutschland. Göttingen. URL: http://www.uni-goettingen.de/de/document/download/de7465473c18ff587b6b2df1ac03d06a.pdf/AWA%2023-09-2014.pdf, Zugriff am 31.08.2017.
18. IPSOS, 2001: Faszination Zukunft. Neue Perspektiven im Pferdesport. Die FN Marktanalyse "Pferdesportler in Deutschland 2001" kompakt und kommentiert.
19. Isbell, F.; Craven, D.; Connolly, J.; Loreau, M.; Schmid, B.; Beierkuhnlein, C.; Bezemer, T. M.; Bonin, C.; Bruelheide, H.; Luca, E. de; Ebeling, A.; Griffin, J. N.; Guo, Q.; Hautier, Y.; Hector, A.; Jentsch, A.; Kreyling, J.; Lanta, V.; Manning, P.; Meyer, S. T.; Mori, A. S.; Naeem, S.; Niklaus, P. A.; Polley, H. W.; Reich, P. B.; Roscher, C.; Seabloom, E. W.; Smith, M. D.; Thakur, M. P.; Tilman, D.; Tracy, B. F.; van der Putten, Wim H; van Ruijven, J.; Weigelt, A.; Weisser, W. W.; Wilsey, B.; Eisenhauer, N., 2015: Biodiversity increases the resistance of ecosystem productivity to climate extremes. In: Nature, Jg. 526, H. 7574, S. 574–577.
20. Isselstein, J.; Jeangros, B.; Pavlu, V., 2005: Agronomic aspects of extensive grassland farming and biodiversity management. In: Grassland Science in Europe, H. 10.
21. Isselstein, J.; Kayser, M., 2014: Functions of grassland and their potential in delivering ecosystem services. In: Grassland Science in Europe, H. 19, S. 199–214.
22. Jouven, M.; Vial, C.; Fleurance, G., 2016: Horses and rangelands. Perspectives in Europe based on a French case study. In: Grass and Forage Science, Jg. 71, H. 2, S. 178–194.
23. Klimek, S.; Lohss, G.; Gabriel, D., 2014: Modelling the spatial distribution of species-rich farmland to identify priority areas for conservation actions. In: Biological Conservation, Jg. 174, S. 65–74.
24. Klimek, S.; Richter, A.; Hoffmann, M.; Isselstein, J., 2007: Plant species richness and composition in managed grasslands. The relative importance of field management and environmental factors. In: Biological Conservation, Jg. 134, H. 4, S. 559–570.
25. Köhler, B.; Spiekers, H.; Kluß, C.; Taube, F., 2017: Leistungen vom Grünland im Futterbaubetrieb. – Analyse auf Betriebsebene unter bayerischen Standortbedingungen. In: Berichte über Landwirtschaft, 95(1).
26. Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg, 2006: Dokumentation und Handreichung zur Biotoppflege mit Pferden. https://www4.lubw.baden-wuerttemberg.de/servlet/is/31415/pferdebeweidung_in_der_biotoppflege.pdf?command=downloadContent&filename=pferdebeweidung_in_der_biotoppflege.pdf, Zugriff am 31.08.2017.
27. Meyer, H.; Coenen, M., 2014: Pferdefütterung. Stuttgart: Enke Verlag.
28. Ministerium des Innern des Landes Nordrhein-Westfalen, 2011: Verordnung zur Erhaltung von Dauergrünland.
29. Näther, M.; Theuvsen, L., 2012: Risikomanagement im Pferdebetrieb. Leitfaden für Pferdebetriebe: So behalten Sie die Risisken im Griff. Göttingen: Cuvillier.
30. Ödberg, F. O.; Francis-Smith, K., 1977: Studies on the Formation of ungrazed eliminative areas in fields used by horses. In: Applied Animal Ethology, H. 3, S. 27–34.
31. Olff, H.; Ritchie, M. E., 1998: Effects of herbivores on grassland plant diversity. In: Trends in Ecology & Evolution, Jg. 13, H. 7, S. 261–265.

32. Plantureux, S.; Peeters, A.; McCracken, D., 2005: Biodiversity in intensive grasslands : Evaluation, improvement and challenges. In: Agronomy Research, 3(2), S. 153–164.
33. Rook, A. J.; Dumont, B.; Isselstein, J.; Osoro, K.; WallisDeVries, M. F.; Parente, G.; Mills, J., 2004: Matching type of livestock to desired biodiversity outcomes in pastures – a review. In: Biological Conservation, Jg. 119, H. 2, S. 137–150.
34. Rösch, V.; Tscharntke, T.; Scherber, C.; Batáry, P., 2015: Biodiversity conservation across taxa and landscapes requires many small as well as single large habitat fragments. In: Oecologia, Jg. 179, H. 1, S. 209–222.
35. Särkijärvi, S.; Niemeläinen, O.; Sormunen-Cristian, R.; Saastamoinen, M., 2010: Suitability of grass species on equine pasture: water soluble carbohydrates and grass preferences by horses. In: Grassland Science in Europe, H. 15, S. 1000–1002.
36. Schmitz, A.; Hüppe, C.; Recktenwald, C.; Dingfeld, J.; Brinsa, C.; Florek, J.; Maulhardt, J.; Isselstein, J.: „50 shades of green". -Qualität und floristische Diversität von Heu der pferdehaltenden Praxis. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau, S. 227–229. http://www.zalf.de/de/aktuelles/Seiten/LSE/aktuelles_2017AUG_aggftagung.aspx, Zugriff am 20.10.2017.
37. Schmitz, A.; Hüppe, C.; Recktenwald, C.; Dingfeld, J.; Brinsa, C.; Florek, J.; Maulhardt, J.; Isselstein, J.: „Die neue Kuh?!". - zur Bedeutung und Charakteristika der Grünlandbewirtschaftung durch Pferdehalter. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau, S. 223–226. http://www.zalf.de/de/aktuelles/Seiten/LSE/aktuelles_2017AUG_aggftagung.aspx, Zugriff am 20.10.2017.
38. Schmitz, A.; Isselstein, J.: Besser als ihr Ruf? Artenvielfalt und Vegetationskomposition von Pferdewedein im direkten Vergleich zu Rinderweiden der Praxis. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau, S. 208–211.
39. Schmitz, A.; Isselstein, J.: Effects of management on vegetation structure in horse pastures. In: Grassland Science in Europe, S. 394–396.
40. Singer, J. W.; Bobsin, N.; Kluchinski, D.; Bamka, W. J., 2001: Equine stocking density effect on soil chemical properties, botanical composition, and species density. In: Communications in Soil Science and Plant Analysis, Jg. 32, 15-16, S. 2549–2559.
41. Tallowin, J. R. B.; Rook, A. J.; Rutter, S. M., 2005: Impact of grazing management on biodiversity of grasslands. In: Animal Science, Jg. 81, H. 02, S. 419.
42. Tsiafouli, M. A.; Drakou, E. G.; Orgiazzi, A.; Hedlund, K.; Ritz, K., 2017: Editorial. Optimizing the Delivery of Multiple Ecosystem Goods and Services in Agricultural Systems. In: Frontiers in Ecology and Evolution, Jg. 5, S. 14296.
43. Watts, K., 2010: Pasture management to minimize the risk of equine laminitis. In: The Veterinary clinics of North America. Equine practice, Jg. 26, H. 2, S. 361–369.
44. Wellstein, C.; Otte, A.; Waldhardt, R., 2007: Impact of site and management on the diversity of central European mesic grassland. In: Agriculture, Ecosystems & Environment, Jg. 122, H. 2, S. 203–210.
45. Wesche, K.; Krause, B.; Culmsee, H.; Leuschner, C., 2012: Fifty years of change in Central European grassland vegetation. Large losses in species richness and animal-pollinated plants. In: Biological Conservation, Jg. 150, H. 1, S. 76–85.
46. Wiegand, K.; Fischer, T.; Spiller, A., 2016: Die Einstellung zur Pferdesteuer in der deutschen Bevölkerung. In: Berichte über Landwirtschaft, 94 (1).
47. Wrage, N.; Strodthoff, J.; Cuchillo, H. M.; ISSELSTEIN, J.; Kayser, M., 2011: Phytodiversity of temperate permanent grasslands. Ecosystem services for agriculture and livestock management for diversity conservation. In: Biodiversity and Conservation, Jg. 20, H. 14, S. 3317–3339.
48. Wright, K.B. 2005: Researching Internet-Based Populations: Advantages and Disadvantages of Online Survey Research, Online Questionnaire Authoring Software Packages, and Web Survey Services. In: Journal of Computer-Mediated Communiation. Jg.10, H 3. URL: http://onlinelibrary.wiley.com/doi/10.1111/j.1083-6101.2005.tb00259.x/full. Zugriff am 01.11.2017.
49. Zasada, I.; Berges, R.; Hilgendorf, J.; Piorr, A., 2013: Horsekeeping and the peri-urban development in the Berlin Metropolitan Region. In: Journal of Land Use Science, Jg. 8, H. 2, S. 199–214.

Danksagung

Die Datenerhebung dieser Studie erfolgte im Rahmen eines vom Bundesministerium für Bildung und Forschung geförderten Projektes zur forschungsorientierten Lehre (FoLL), unter Mitwirkung der Studierenden Celine Brinsa, Joyce Dingfeld, Julia Florek, Cecilia Hüppe, Julius Maulhardt und Claus Recktenwald. Ihnen sei herzlich für Ihre Mitarbeit bei der Datenerhebung gedankt.

Chapter II:

Effect of Grazing System on Grassland Plant Species Richness and Vegetation Characteristics: Comparing Horse and Cattle Grazing

Anja Schmitz and Johannes Isselstein

Published in Sustainability:

Schmitz, A., Isselstein, J., 2020. Effect of grazing system on grassland plant species richness and vegetation characteristics: Comparing horse and cattle grazing. Sustainability 12, 3300, 1-17.

https://doi.org/10.3390/su12083300

Abstract:

Horses are of increasing relevance in agriculturally managed grasslands across Europe. There is concern to what extent grazing with horses is a sustainable grassland management practice. The effect of longer-term horse grazing on the vegetation characteristics of grasslands has received little attention, especially in comparison to grazing cattle. Our study analyses the relative importance of grazing system (grazer species and regime) and grassland management for vegetation characteristics in grasslands as indicator for sustainable management. We monitored grassland vegetation in western central Germany and compared paddocks grazed by horses under two different regimes, continuous (HC) vs. rotational (HR), to paddocks grazed by cattle (C) under similar trophic site conditions. We observed more plant species and more High Nature Value indicator species on HC compared to C. The vegetation of C was more grazing tolerant and had higher forage value than HC. Regardless of the grazing regime, the competitive component was lower, the stress-tolerant component higher and the floristic contrast between patch types stronger on HC and HR paddocks compared to C. Species richness was strongly influenced by the extent of the floristic contrast. Our results emphasize the potential of horse grazing for biodiversity in agriculturally managed grasslands.

Keywords: agriculturally managed grasslands; equine grazing; pasture management; grazer species; biodiversity

1. Introduction

Grazing livestock is seen as a promising option for maintaining and promoting grassland biodiversity [1–4]. Due to the preferences of grazing animals in forage selection, their disturbance of the sward and patchy nutrient return [3,5], they increase and maintain the spatial heterogeneity of the sward structure and vegetation composition [1,6,7]. Adler et al. [5] termed this effect “patch grazing”. This heterogeneity means that plants of different strategy types and demands can coexist in close proximity, increasing plant species turnover within the paddock, i.e. β-diversity [3,7–9]. Differences in grazing regimes and thus vegetation between paddocks can also contribute to the landscape-scale biodiversity [10]. Hautier et al. [11] recently emphasized the importance of diverse grasslands with both species-rich local communities (α-diversity) and large compositional differences between sites (β-diversity) for the multifunctionality of ecosystems on a global scale.

Different grazer species lead to different effects on grassland vegetation due to their specific nutritional demands, jaw anatomy and grazing behaviour [2]. In Europe, cattle are the most common grazing animals in agriculturally managed grasslands. Several studies have analysed their grazing effects and management strategies for biodiversity benefits [1–3,6,12]. For several decades, horses have played an increasing role in grasslands and across Europe, at least six million hectares of grasslands are estimated to be managed for horses [13]. Horse keeping and grazing is widespread nowadays and has a considerable effect on the shape of agricultural landscapes [14], particularly in peri-urban regions [15–17]. Horse keepers often rely on grassland that had been released from intensive dairy production [14,15,18]. Compared to grasslands managed with cattle or sheep, those grazed with horses have received little scientific attention in Europe with regard to a targeted grassland utilization.

Several characteristics make horse husbandry suitable for the management of extensive grasslands. The usual basic nutrition of horses is grass. As hindgut fermenters, horses are able to utilise herbage from nutrient-poor grasslands, but herbage from intensively managed ryegrass-dominated swards pose a health risk [19–21]. This is why horse keepers prefer to manage nutrient-poor grasslands to protect their horses from metabolic disorders [14].

There is concern to what extent grazing with horses is a sustainable grassland management practice. Their two pairs of incisors enable them to graze more selectively and closer to the ground [19,22,23]. As selective grass feeders [24] horses increase the proportion of forbs in the swards [25,26]. Since horses actively avoid grazing where they defecate, they create distinct ungrazed tall grass latrine areas where excreta and nutrients accumulate. Repeatedly grazed short patches, on the other hand, experience nutrient export, which result in a nutrient transfer and a corresponding vegetation shift between patch types [22,26,27]. Especially phosphorous is accumulated via horse dung in latrine areas, which is known to promote competitive species and reduce species richness [28,29]. Therefore, the patch grazing effect of horses is expected to be stronger than that of cattle [8,22,25,30]. In addition, the movement behaviour of the horses can put a strain on the sward, especially when the grazing area or grazing duration are restricted. Running and trampling lead to areas with bare and compressed soil [19,24].

In temperate grasslands, the grazing regime, i.e. continuous or rotational grazing, can modify the grazer's effect on the pasture vegetation [3,12,19,25]. Under continuous grazing, grazers have unrestricted access to a paddock during prolonged periods of the grazing season, which promotes the development of distinct short and tall grass patches [24]. In contrast, under rotational grazing the access of the grazing area is limited in time and space which leads to a more uniform grazing [19,21,31].

Apart from the grazing regime, the grazing intensity affects the pasture vegetation and its patch structure [6,8,32–34]. Generally, grazing effects on the vegetation increase with stocking density. Differences between livestock species are also becoming clearer [26,33]. While cattle tend to defoliate the grass sward more evenly with increasing stocking density, thereby creating a homogenous sward of grazing tolerant plants [6,7,35], horses continue to graze heterogeneously, avoid foraging on latrine areas and defoliate strongly in other areas [30].

Only few studies have been carried out in the last century that looked more closely at the grazing preferences of horses [22,30]. More recently, research has focused on free-ranging horses grazing in nature reserves to study the effects of horse grazing on grassland vegetation and sward structure [8,26,36–39], some demonstrating benefits for nature conservation [40,41]. However, these results are not directly transferrable to agricultural grassland with domesticated horses. Thus, there is currently a considerable lack of scientific knowledge on the effects of grazing by domesticated horses on vegetation in a normal agricultural context. This has consequences for the practice of horse grazing, which is often inappropriate and causes land use conflicts in peri-urban and rural landscapes [17].

Given this background, our study aimed to investigate the effect of horse compared to cattle grazing on vegetation characteristics in agricultural grassland. In addition, we investigated the effect of the grazing regime (continuous vs. rotational grazing) by horses. Target variables were the vascular plant species richness, the High-Nature-Value (HNV) plant indicator species richness, the proportion of Grime's C-S-R-strategy types [42], the grassland utilisation indicator values [43] and the β-diversity between patch types.

We performed an observational on-farm study in the Rhenish Uplands in Germany. The methodology of the observational study has become well established in recent years to assess the medium to long-term effects of different agricultural management methods. Examples of this are the examination of the effectiveness of agri-environmental measures [44], the effectiveness of weed control in wheat cultivation [45] or the grazing effects of different cattle breeds [46]. The performance of field experiments would require many years of research. At the same time, the identification of interactions with the site conditions would require complex, multi-site field experiments. A stratified design allowed us to compare paddocks grazed by cattle or horses and to distinguish between effects of the grazing system (grazer species and grazing regime) from those of site conditions and management. More precisely we addressed the following hypotheses:

H1. Grazing system affects species richness, HNV-species richness and vegetation characteristics (proportion of C-S-R-strategy components, utilisation indicator values);

H2. There is a relationship between vegetation characteristics (proportion of C-S-R-strategy types, utilisation indicator values), which are affected by grazing system, and observed species richness;

H3. Grazing system affects floristic contrast between patch types, which mediates species richness at paddock scale;

H4. Beyond grazing system, grassland management (stocking density and fertilisation) affects species richness.

2. Materials and Methods

2.1 Study Region

The research area is located in the Rhenish uplands in North Rhine-Westphalia, Germany (50.87′N, 7.48′E, Figure II-1) and covers a total area of approximately 400 km².

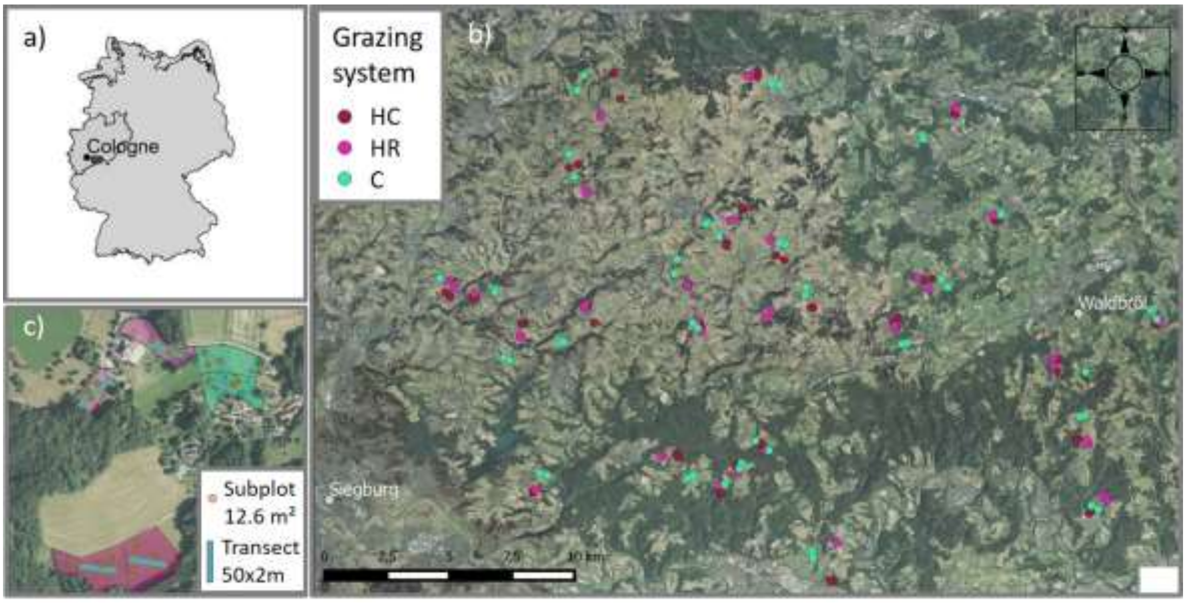

Figure II-1. Study location in the Rhenish Uplands in North Rhine-Westphalia in Germany (a). Distribution of study paddocks (N = 156) in the study region (b). Triplet design with six paddocks at one site grazed by cattle (C) or horses (HC, HR), three subplots and one transect per paddock (c) Orthophotographs provided by LandNRW[47].

The study region has a naturally low agricultural production potential. A humid climate and shallow, loamy, acidic cambisols led to grasslands being the predominant land-use system (65% to 90% of the utilised agricultural area) after forests [48]. Grasslands in the study region are mainly used for dairy production, but horses play a considerable role too. According to the local livestock numbers (Animal Health Fund, oral communication), at least 10% of grasslands in the study region are managed with horses. The grassland vegetation of the study paddocks belongs to the Molinio-Arrhenatheretea class.

2.2 Sampling Design

A total of 156 paddocks were included in the study. The paddocks were arranged in 26 triplets that covered a gradient of different site conditions and land-use intensities (Figure II-1). Within each triplet six paddocks were studied, representing three grazing systems. Four paddocks were grazed with horses, two in a continuous (HC, n = 52) and two in a rotational grazing regime (HR, n = 52). The other two paddocks were grazed by cattle (C, n = 52). As we were particularly interested in the grazing effect of horses, cattle-grazed paddocks serve as a "control", as they represent the predominant regional grazing management. The study design did not distinguish the grazing regime in cattle paddocks, which included rotational and continuous stocking. The paddocks within a triplet were located at a linear distance of no more than 2 km and were selected as having similar site factors (i.e. soil type, slope, altitude). On each paddock, three circular subplots of 12.6 m^2 (radius of 2 m) were established for the assessment of vascular plant species richness, composition and soil properties (Figure II-1 c). Subplots were selected according to a stratified random approach. One subplot each was placed on a short, on a tall or an intermediate vegetation height patch (patch type). For this, we measured the compressed sward height within each paddock using a rising plate meter (30 cm diameter, 200 g [49]) at 50 randomly chosen points. Short patches were defined as heavily grazed areas with a mean sward height below the paddock's average. In contrast, tall patches were mainly avoided areas with a mean sward height above the paddock's average and intermediate patches lay in between. Subplots for the vegetation analysis were established at the end of the grazing season of the preceding year when the heterogeneity of the sward height was most pronounced. Within the patch types, subplots were placed randomly within areas of similar local conditions in altitude and inclination and within a minimum distance of 5 meters from the field boundary to avoid boundary effects. Additionally, a diagonal transects (2 m × 50 m) was established on each paddock. The geographic position of each subplot was recorded (Figure II-1 c).

2.3 Site Conditions

In general, the study sites were chosen so that the paddocks within each triplet offer the most uniform topographic site conditions possible. Paddock borders were mapped on an orthophotograph [47] and paddock size (ha) calculated using Quantum GIS [50]. A digital elevation model (DEM 50, [51]) was used to calculate altitude (meters above sea level, m.a.s.l.) and slope (%) per paddock as topography-related environmental variables.

Soil was sampled on each subplot in autumn at the end of the grazing season in order to determine the pH and the extractable soil nutrients (available plant nutrients P2O5, K2O in mg per 100g dry matter (DM), calcium-acetate-lactate analysis). On each of the three subplots 500 ml of soil of the top layer (0–10 cm) was taken. In the statistical analysis we used the average soil nutrient concentration of three subplots (Table II-1).

2.4. Grassland Management

As part of the study, data on current grassland management were collected from personal interviews with farmers using a standardised questionnaire. Only paddocks with a consistent management regime over at least the last five years were included. Most paddocks had a much longer history of grazing by the same grazer species. For cattle-grazed paddocks, the average grazing history was 53 years (SD 22 years, n = 46), for horse-grazed paddocks 23 years (SD 11.7 years, n = 52) for HC and 22 years (SD 11.8 years, n = 52) for HR. Farmers were asked whether their grasslands had been ploughed and reseeded. For 45 paddocks such information was not available, 78 paddocks had not been disturbed for at least 60 years (C: n = 22; HC: n = 30; HR: n = 26). On average, the age of the grass swards was 52 years (SD 18.4, n=111) with little variation among the grazing systems (C: 48.6 years, SD 18.7, n = 34; HC: 55.4 years, SD 15.5, n = 40; HR: 50.3 years, SD 20.6, n = 37).

For the present analysis, management data that covered a period of the preceding five years were collected. The variables were: average number of livestock per paddock, mean weight of livestock, mean grazing duration per day, mean number of rotations, and mean grazing duration per year. Live weights were converted to standard livestock units (500 kg live weight) per hectare and year to calculate stocking rate (ha-1 year-1). Stocking rate was used as a proxy for grazing intensity. Some paddocks were not only grazed but also mown for hay or haylage (C: n = 16; HC: n = 12, HR: n = 7). Mowing was included as binary variable in the analysis. The amount and type of fertilizer that was applied on the grasslands was recorded for mineral N, farmyard manure and slurry separately. The total amount of nitrogen supply (N kg ha-1 year-1) was deduced from this information (see Table II-1).

Table II-1. Descriptive statistics of site factors, grassland management and soil chemical parameters. Variables were tested for differences between grazer species (lm, Tukey). Cattle-grazed paddocks (C, n = 52) were used as a baseline. In case of significant different estimates (est.), contrasts to C are given for both horse continuously grazing (HC, n = 52) and rotationally grazing (HR, n = 52).

	TOTAL (N=156)				C	HC		HR	
Variable	**Mean**	**sd**	**Min**	**Max**	**est.**	**Contrast**	**p**	**Contrast**	**p**
Paddock size (ha)	2.06	2.7	0.20	14	3.2	−1.2	*	−2.0	***
Altitude (m.a.s.l.)	239.2	44.4	118.7	335	238.6	−0.2		−2.0	
Slope (%)	9.0	4.9	1	26.3	9.5	−0.8		−0.5	
Fertiliser N kg ha^{-1} $year^{-1}$	38	44	0	265	50.2	−31.8	***	−6.2	
Stocking rate ha^{-1} $year^{-1}$	1.28	1	0.04	7.2	1.3	0.0		−0.06	
Soil pH	5.2	0.5	4.3	6.8	5.3	−0.2	*	−0.2	
P_2O_5 mg 100g DM^{-1}	12.8	6.4	3.2	33.4	12.9	−0.5		−0.2	
K_2O mg 100g DM^{-1}	26.5	13.4	5.9	76.7	27.0	0.6		−2.3	

Significant contrasts of grazing systems are indicated by their levels of significance as * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

2.5 Species Data

Vegetation surveys were carried out in 2013 and 2014 with 13 triplets per year. In order to obtain a full record of species, every paddock was visited twice, in spring before grazing started and in summer during the grazing season. In both surveys, the total number of vascular plant species in the three subplots per paddock were identified to species level and their individual share of biomass was visually estimated. Additionally, all species within the transects were identified. In order to analyse species diversity at the paddock scale, species richness (SR) refers to the cumulative number of plant species that were observed in 138 m^2 per paddock (the three subplots and the transect) in the spring and summer surveys. In addition to plant species richness, we assessed the number of High-Nature-Value (HNV) plant indicator species according to the German Federal Agency for Nature Conservation [52]. We applied the regional list of HNV indicator species for the mid-west/north-west of Germany

[53]. The number of single HNV indicator species per paddock (HNV-SR) was used as a proxy for the nature conservation value of the respective grassland. For this, we used the classification system of the HNV farmland monitoring [52]: Paddocks with 4 to 5 indicator species were classified as HNV-III grassland of "moderately high-nature-value", paddocks with 6 to 7 indicator species as HNV-II grassland of "very high-nature-value" and paddocks with 8 and more indicator species as HNV-I with "exceptionally high-nature-value".

As described by Hunt et al. [54], plant species' strategy types were converted to a numeric C-S-R signature (C – competitive strategy, S – stress-tolerant strategy, R – ruderal strategy). Based on the estimated proportion of biomass per species, we calculated the C-S-R signature for each of the three subplots per paddock. We then calculated an average value for each strategy type per paddock. In the same way, we assessed utilization indicator values [43], i.e. grazing tolerance, trampling tolerance and forage value.

As a measure of floristic contrast between short and tall patches within paddocks we calculated the Sørensen index [55]: Sørensen=2 c / (a + b + 2 c) for short and tall patch types, with "a" representing the number of species exclusively present in short patches, "b" exclusively in tall patches and "c" present in both.

2.6 Data Analysis

We performed linear mixed-effects models in combination with model averaging to disentangle the important drivers of vegetation for horse- and cattle-grazed pastures.

In a first step, mixed effects models with a Gaussian distribution were set up for each species response variable. Vegetation variables, i.e. SR, HNV-SR, Grime's strategy types, utilization indicator values and Sørensen index were modelled as a function of grazing system, stocking rate, nitrogen fertilisation, mowing, trophic site conditions and soil-chemical variables. All global models were checked for multicollinearity between explanatory variables (fixed effects) using variance inflation factors (VIF). Since VIFs were below 3 in most cases [56,57] and well below 10 in all cases, all explanatory variables were considered for the statistical analyses. All global models were checked visually for normal distribution and homoscedasticity of residuals. In case of heterogeneity of variance, weights structures were applied following the protocol of Zuur et al. [57]. All explanatory variables were centralised to zero means and scaled to 0.5 standard deviations [58] before analysis, which allows a direct comparison of effects of all fixed factors. Model averaging was performed on each global model to assess parameter and error estimates that derive from weighted averages of these values across multiple models [59]. For each global model, second-order Akaike information criterion AICc [60] was calculated on every possible combination of variables. These were ranked using the 'dredge' function of the package 'MuMIn'. Weighted parameter estimates were averaged over the set of models whose cumulative Akaike weight was ≤0.95, which is the 95% confidence set to the best approximating model [59,60]. Relative importance was estimated as the sum of Akaike weights over all models including the explanatory variable in the 95% confidence set. Significance of predictors was calculated from the supported models using z-statistics. Based on the model averaging, a minimum adequate model (MaM) was identified and the variable grazing system was tested for differences among the grazing systems via post hoc pairwise Tukey test.

In a second step, further linear mixed effects models were set up to analyse the relationship between vegetation characteristics (propotion of Grime's strategy types, utilisation indicator values and floristic contrast) and SR. For this, SR was modelled as a function of grazing system and each vegetation variable, as well as their interaction. In a third step, linear mixed effects models were set up to analyse effects of grazing system and the interaction with grazing intensity as well as N-fertilisation on SR and HNV-SR.

In all models, triplet was included as random term, to account for the nesting structure of the study design, which generates a more powerful analysis by ensuring that variance due to block is taken into account and not just included in the error term.

Statistical analyses were carried out in R (3.5.1, R Development Core Team, 2018) using the MuMin-package [59,61], nlme package [62] and the emmeans package [63]).

3. Results

On 156 paddocks, we found 179 plant species in total. The average species number (SR) per paddock (referring to the sampled area of 138 m^2, each) was 57 (min 24, max 129). Forty - three single species were classified as HNV-indicator species. 80% of HC, 75% of HR and 55% of C paddocks could be allocated to HNV grasslands with four or more HNV indicator species. Of these, 55% of HC and 26% of C were assigned as HNV-I grasslands of exceptionally high-nature-value with more than eight HNV indicator species.

3.1. Effect of Grazing System on Species Richness and Vegetation Characteristics (H1)

According to the model averaging results, a high relative importance of the variable grazing system was obtained for the majority of the target variables. These effects were significant in the full models for SR, HNV-SR, forage indicator value and the floristic contrast between patch types (Table II-2). Post-hoc testing of the minimum adequate models (MaM) confirmed significant differences among grazing systems for each vegetation variable, except for the component of ruderal strategy type, and in tendency to trampling tolerance (Table II-3).

SR differed significantly between C and HC: In terms of the total number of species, on average eleven more species and three more HNV species were found on HC than on C (Figure II-2). However, no significant differences in SR or HNV-SR were present between HR and C.

Considering Grime's strategy types, a higher proportion of the competitive and stress-tolerant strategy component occurred on C than on HC and HR, but no difference was observed for the proportion of ruderal strategy component.

Cattle-grazed paddocks (C) revealed a higher forage value than HC as well as a slightly higher grazing tolerance than HR. The forage value indicator did not differ significantly between HR and C. In regard to grazing tolerance, HC was not significantly different from C or HR (Table II-3).

Comparing grazing regimes in horse-grazed paddocks, almost seven more species and two more HNV species were found in HC than HR. The utilisation value for grazing was higher on HR than on HC (Table II-3, Figure II-2). Post-hoc testing identified no further significant differences between HC and HR.

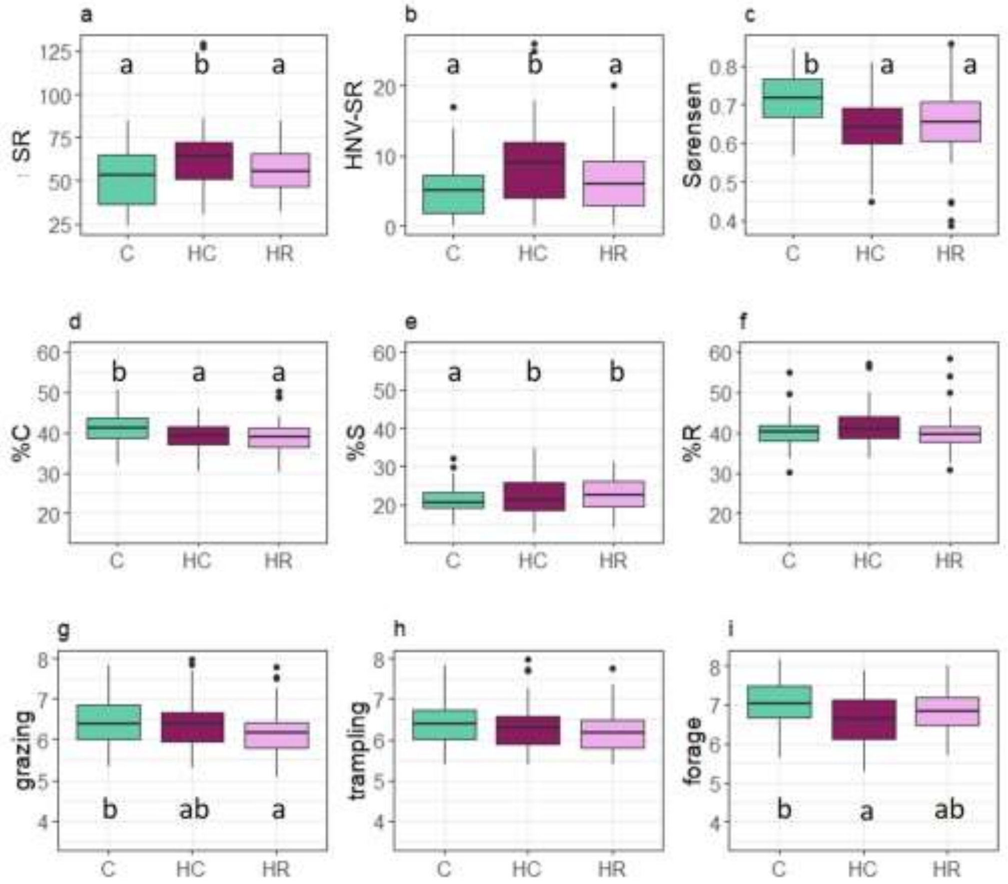

Figure II-2. The effect of the grazing system (cattle, C, or horses, HC and HR) on the target variables: a) species richness (SR), b) number of HNV species (HNV-SR), c) floristic contrast (Sørensen), d–f) proportion of Grime's strategy type components (%C, %S, %R) and g)-i) utilisation indicator values (grazing, trampling, forage). Boxplots present median, 1st and 3rd quartile and outliers of target variables. Lower case letter indicates significant differences between grazing systems obtained within the minimum adequate models (see Table II-3 for remaining variables and effect sizes) at significance level $p < 0.05$.

Table II-2. Results of the multimodel inference for the effects of grazing regime, grassland management and site factors on vegetation target variables. As target variables species richness (SR), the number of observed HNV species (HNV-SR), proportion of competitive strategy component (%C) and ruderal strategy component (%R), utilisation values and floristic contrast (Sørensen) were tested. The second column gives the intercept representing cattle grazing (C), HC gives results for continuously and HR rotationally grazed horse paddocks. Grassland management is represented by average stocking rate, nitrogen (N) fertilization and mowing, abiotic site conditions by size (ha), slope, soil pH and phosphorus concentration. Model averaged coefficients (coef) of explanatory variables remaining in the 95% confidence set of submodels are shown in the remaining columns along with relative importance values (I) and significance levels (P) obtained by z-statistics shown as * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001. Variables with a relative importance of >0.6 are shown in bold.

		Grazing System					**Grassland Management**									**Abiotic Site Conditions**											
		HC			**HR**		**Stocking rate**			**N fertilisation**			**Mowing**			**Ha**			**Slope**			**pH**			**P$_2$O$_5$**		
Species variable	Inter-cept	coef	I	P	coef	P	coef	I	P	coef	I	P	coef	I	P	coef	I	P	coef	I	P	coef	I	P	coef	I	P
SR	52.08	12.04	**1**	***	4.60	*	0.14	0.26		−0.39	0.29		−1.78	0.52		0.28	0.27		11.59	**1**	***	−2.55	0.57		−7.48	**0.98**	**
HNV-SR	5.48	3.34	**1**	***	1.14		0.07	0.27		−0.23	0.35		−0.34	0.39		0.04	0.25		2.81	**0.99**	***	−1.81	**0.87**	.	−1.77	**0.90**	*
%C	0.41	−0.02	**0.83**	.	0.01		−0.01	**0.72**		0.00	0.26		0.002	0.35		0.003	0.38		−0.002	0.34		0.001	0.31		0.003	0.39	
%S	0.21	0.01	**0.68**		0.01		−0.01	**0.79**		−0.00	0.25		−0.001	0.29		−0.002	0.33		0.025	**1**	***	−0.01	0.49		−0.03	**1**	***
%R	0.40	0.00	0.34		0.00		0.002	**1**	***	−0.00	0.28		0.00	0.25		−0.00	0.25		−0.001	**0.83**		−0.001	0.25		0.02	**0.98**	**
Grazing	6.39	−0.06	**0.66**		−0.146		0.28	**0.99**	***	−0.07	0.48		0.10	0.55		0.00	0.26		−0.28	**0.96**	**	−0.01	0.26		0.35	**1**	***
Trampling	6.33	−0.11	0.50		−0.091		0.23	**0.97**	**	−0.02	0.32		0.13	**0.69**		0.01	0.29		−0.30	**0.99**	***	0.02	0.33		0.36	**1**	***
Forage	6.90	−0.27	**0.87**	*	−0.114		−0.08	**0.657**		0.11	0.56	**	0.22	**0.83**		0.05	0.42		−0.13	**0.75**	**	0.04	0.37	*	0.3	**0.97**	**
Sørensen	0.71	−0.063	**1**	***	−0.058	***	−0.006	0.39		0.00	0.27		0.014	0.54		0.00	0.25		0.04	**0.96**	**	0.01	0.50		0.00	0.26	

Table II-3. Effects of all explanatory variables remaining in minimum adequate mixed effects models on species variables. Rm²: marginal coefficient of determination.

	Grassland Management								Abiotic Site Conditions								
	Grazing System		Stocking rate		N Fertilisation		Mowing		Ha		Slope		pH		P2O5		
Species variable	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	**Rm²**
SR	17.6	<0.001					3.5	0.06			26.9	<0.001			14.9	<0.001	0.31
HNV-SR	14.9	<0.001									20.7	<0.001	5.4	0.02	13.9	<0.001	0.31
%C	4.7	0.01	5.8	0.02													0.08
%S	3.5	0.03	4.0	0.047							21.1	<0.001			33.2	<0.001	0.31
%R			16.2	<0.001							7.6	0.007			10.28	0.002	0.19
Grazing	3.1	0.04	13.8	<0.001							11.9	<0.001			15.4	<0.001	0.24
Trampling	2.7	0.07	11.7	<0.001			1.1	0.29			17.7	<0.001			22.6	<0.001	0.30
Forage	8.8	<0.001	6.5	0.01	11.2	0.001					6.7	0.01			11.2	0.001	0.24
Sørensen	9.4	<0.001					4.1	0.04			9.8	0.002	2.2	0.14			0.18

3.2. Relationship between Vegetation Characteristics and Species Richness (H2)

SR was modelled as a function of each vegetation characteristic or grazing system and their interaction. In this approach, SR was strongly correlated with most of the vegetation variables (Figure II-3). A higher proportion of the competitive component was associated with an overall decrease in SR (p<0.001, lme) and similar, but less pronounced, a higher proportion of the ruderal component was linked with a decreasing SR (p = 0.02, lme). In contrast, species richness increased (p < 0.001, lme) with the proportion of the stress-tolerant component (Figure II-3). SR was negatively correlated with all utilisation indicator values (p < 0.001 in all cases, lme), with slightly lower values for continuously grazed horse paddocks. No significant interactions of strategy type and grazing system or utilization value and grazing system were found.

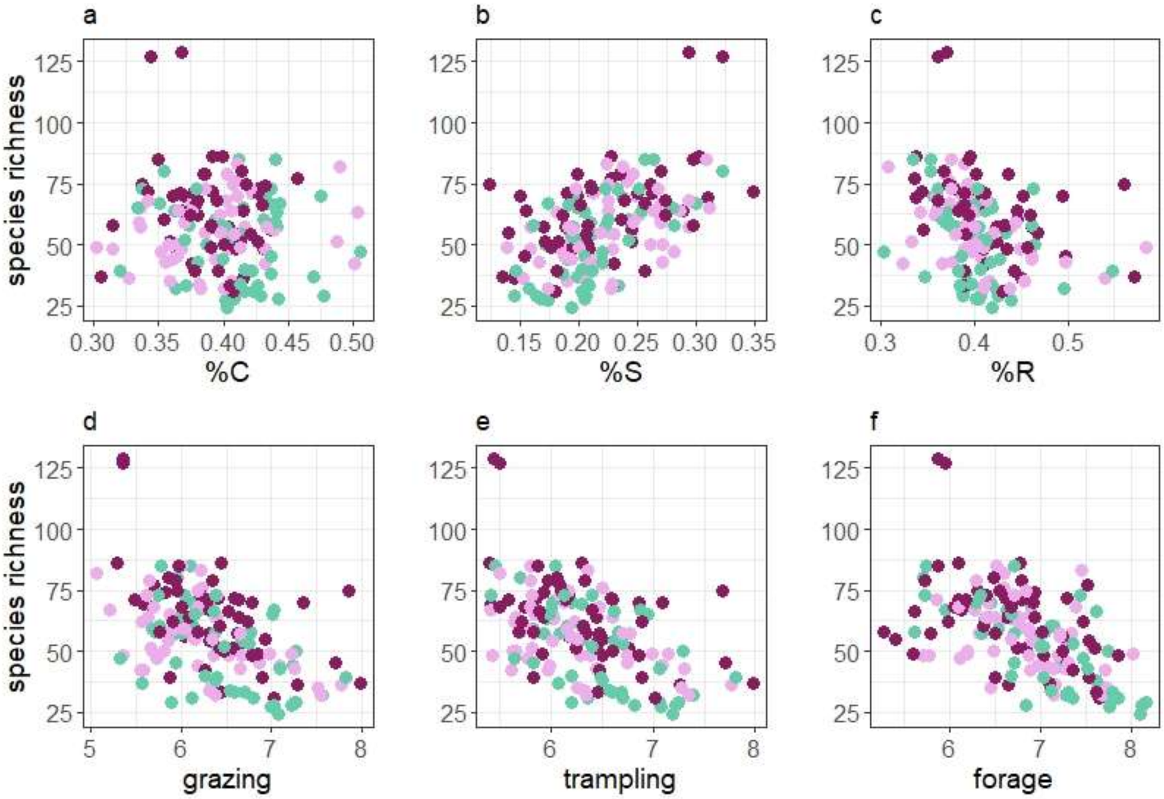

Figure II-3. Relationship of species richness and vegetation characteristics: a) competitive strategy component (%C) and b) stress-tolerant strategy component (S%) and c) ruderal strategy component (%R), d) grazing tolerance value, e) trampling tolerance value, f) forage value). Green dots represent paddocks grazed by cattle C, purple dots continuously grazed horse paddocks HC and pink dots rotationally grazed horse paddocks HR.

3.3. Effect of Grazing System on Floristic Contrast (H3)

Sørensen index was used as a measure of the floristic contrast between patches. Sørensen differed between paddocks grazed by cattle or horses. Both HC and HR showed a stronger floristic contrast between short and tall patches than C (Table II-3, Figure II-2).

The floristic contrast significantly affected SR as well as HNV-SR on paddock scale. More species and more HNV species were observed when swards were less homogenous (Figure II-4). Interactions of Sørensen and grazing system were not significant in both models.

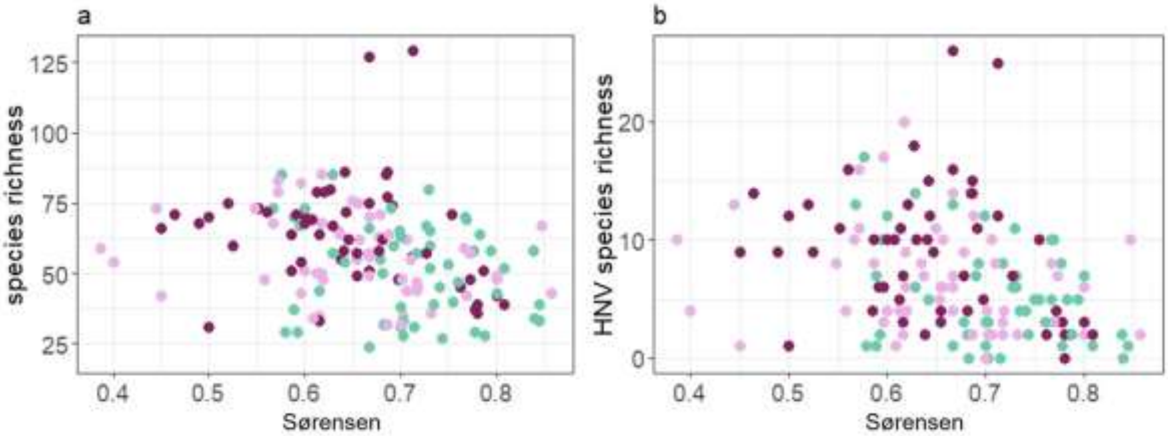

Figure II-4. Relationship of (a) species richness (SR) and (b) HNV species richness (HNV-SR) with Sørensen index as a measure for floristic contrast. Green dots represent paddocks grazed by cattle C, purple dots continuously grazed horse paddocks HC and pink dots rotationally grazed horse paddocks HR.

3.4. Effect of Grassland Management on Species Richness (H4)

Both within the model averaging approach and in the MaMs, neither stocking rate nor N fertilisation was a significant predictor of SR or HNV-SR when applied equally weighted to the same model as the variable grazing system and site conditions (Table II-2). However, the MaM showed a trend of decreasing SR with additional mowing for forage conservation (Table II-3).

Stocking rate affected strategy types as well as utilisation indicator values. A higher stocking rate led to a lower proportion of the competitive and stress-tolerant strategy component but increased the ruderal strategy component. Higher grazing and trampling tolerance were found on paddocks with higher stocking rate. Forage value was higher on paddocks with higher N fertiliser application (Table II-2, Table II-3).

SR and HNV-SR were further modelled as a function of grazing system and its interaction with stocking rate or N fertilisation in order to check for interaction effects. As indicated by model averaging, the effect of grazing system remained significant. However, no significant relationship of the grazing system with stocking rate or N fertilisation was found.

4. Discussion

To our knowledge, this is the first study systematically examining the vegetation characteristics of horse-grazed paddocks in managed temperate grasslands. Compared to experimental studies, observational studies are more challenging in data analysis as effects of land use (e.g. type of livestock, grazing regime, grazing intensity and fertilisation) are confounded with those of the site conditions [64,65]. However, this situation of variable conditions [64,66] is also of particular interest as it reflects "real-life" conditions. In this study we confirmed that the site conditions have an effect on the vegetation and that they interact with land use variables [4,65,67–69]. In order to cope with this situation, we employed a rigid study design with a rather large number of replications and applied a statistical approach of multi-model-inference. Thereby we could disentangle the effects of the design variables and the other variables.

Since cattle are the most frequent grazer species of in European grasslands and recommended for biodiversity-oriented management of semi-natural grassland [70-72] we used cattle-grazed paddocks (C) as a baseline in our study. At similar site conditions we directly compared their vegetation characteristics to those of paddocks grazed by horses. As we were particularly interested in how the grazing regime regulates the grazing effect of horses, our variable grazing system combines grazer species effects (cattle vs. horse), and effects of grazing regime (continuous (HC) vs. rotational grazing (HR)) within the horse-grazed paddocks.

4.1. Effect of Grazing System

We hypothesized that the grazing system affects species richness (SR) and further vegetation characteristics (H1). We found grazing system to be of a high relative importance for almost every measured vegetation variable when applied to the same model as variables of site conditions and grassland management. These effects were mainly driven by differences between HC and other paddocks, whereas differences between HR and C were comparatively small. Hence, an important finding of this study is that SR and botanical composition in horse-grazed paddocks is affected by the grazing regime, i.e. continuous or rotational grazing. Comparing the three grazing systems in our study, we found significantly higher SR on HC compared to C. Moreover, we found significantly higher high-nature-value species richness (HNV-SR) on HC than on C, indicating a higher nature value of horse-grazed paddocks. Using the regional classification key [53], we identified 55% of HC compared to 26% of C as high-nature-value grassland with more than eight HNV indicator species per paddock. Even considering that our monitoring transects (2 m x 50 m) are longer than those used for regular HNV-monitoring (2 m x 30 m), this is an important finding, since less than 14% of grasslands in Germany have recently been evaluated as being of high-nature-value 52]. It is well established that grazer species differ in their effect on the grassland botanical composition, i.e. community composition, diversity and heterogeneity [3,4,871]. While horses select for grasses, cattle prefer forbs (dicotyledonous species), which is assumed to be due to their different digestive systems [8,71]. This could explain the higher number of HNV species, most of which are forbs, on horse pastures compared to cattle pastures. Higher SR under horse grazing had been found before, but was attributed to an increase of ruderal species [69] rather than species of high nature value.

4.2. Relationship of Vegetation Characteristics and Species Richness

We assumed a relationship between vegetation characteristics (proportions of C-S-R-strategy components, utilisation indicator values) and SR, and that this relationship is mediated by the grazing system (H2). The proportion of the ruderal strategy component was high (>40%) in all treatments, but it was neither related to SR, nor were there differences between horse- and cattle-grazed paddocks. The proportion of the competitive strategy component was lower on HC and HR than on C. HNV species are mainly stress-tolerators with a low competitive strength. In contrast, highly productive grass species are competitors [42,73,74]. They benefit from nitrogen fertilisation and are related to reduced species richness [66]. Farmers often sow them to increase the productivity and forage quality. Differences in utilization values between grazing regimes in horse-grazed paddocks were not significant. Nevertheless, a tendency for higher forage quality in HR compared to HC indicates that the grazing regime might have an effect on the agronomical value of such grasslands as has also been shown in experimental approaches [19,31]. Further research is needed in the future where herbage is sampled and analysed for its nutritive value under different grazing regimes in the farming practice.

4.3. Relationship of Floristic Contrast and Species Richness

We hypothesised that the grazing system affects the floristic contrast between patch types and this contrast mediates SR on the paddock scale (H3). Our results strongly support this assumption. As expected, horse grazing led to a stronger floristic contrast between the patch types than cattle grazing. This finding confirms the presumed clear diversification effect of the sward in horse grazing. In a study on wetlands managed for nature conservation, variation in the vegetation composition between patch types was found [8]. This variation depended on the grazer species, with horses creating a larger heterogeneity than cattle. Similarly, we found more species and more HNV species on paddocks with a higher floristic contrast. A greater sward heterogeneity means that there is a greater variety of varying environmental conditions (niches) at a small spatial scale which allows a higher plant species richness on the paddock scale [3,5,8,9]. This phenomenon is generally known and has been suggested as a key driver for biodiversity in grasslands at the local and the landscape scale [1,10,11,74]. It is noteworthy that the horse paddocks showed a larger sward heterogeneity than the cattle pastures irrespective of the grazing regime (HC or HR). Usually, farmers prefer rotational over continuous grazing because rotational grazing ensures a more uniform herbage utilisation, reduces the formation of patches of different sward height, prevents overgrazing and provide herbage of a higher quality [18,19,24]. Our results on floristic contrasts, however, indicate that this approach may be less effective than assumed under horse grazing. The stronger patch-grazing effect under horse compared to cattle grazing indicates that maintaining homogenous swards with horses is much more challenging. Nevertheless, horse keepers do often not aim at maximising grassland yields and are thus able to tolerate a heterogeneous sward structure to some extent. This provides an opportunity for biodiversity in grazed grasslands.

4.4. Effects of Grassland Management on Species Richness

Beyond the effects of the grazing system, it was assumed that the intensity of grassland management (stocking density and fertilisation) influences SR (H4). This assumption was not confirmed. Neither fertilisation nor stocking rate significantly affected SR or HNV-SR. This was true for horse- and cattle-grazed paddocks. With an average nitrogen fertilisation of about 40 kg ha-1 year-1 and an average stocking rate of 1.5 ha-1 year-1 the grasslands in the present study were managed quite extensively. Although no direct effect of fertilisation on species richness was found, two indirect effects might be relevant. First, significantly higher amounts of N were applied on cattle-grazed paddocks, which had higher grassland utilisation values and lower species richness. However, when included in the same global model as grazing system and other variables on management and site condition, fertilisation was of low relative importance for most vegetation characteristics. Despite of this, forage value was significantly increased by N fertilization. Paddocks with additional mowing for forage conservation showed a slightly lower floristic contrast between patch types, which could also be linked to a trend of lower SR.

It has been shown recently that grazing creates stable structures of short and tall grass patches, whose relationship is controlled by the grazing pressure [7]. The grazing induced patchiness, particularly the proportion of short patches was found to be the main driver of plant diversity in low-input pastures, not grazing intensity [35]. For SR, the positive effect of grazing is considered to be strongest in productive grasslands [66]. In this study, we did not find evidence for effects of grazing intensity on floristic contrast and subsequently on SR. In a grazing experiment with horses in an upland region in France, Fleurance et al. [25] compared paddocks of two different stocking rates (“high” 1.8 LU ha-1 year-1 vs. “moderate” 1.1 LU ha-

1 year-1) and likewise found no effects on species richness. On the other hand, van Klink et al. 2016 [33] found higher plant species richness under higher stocking rates in a grazed salt marsh system, although the stocking rate in their "intensive" grazing regime was quite low (1.1 LU ha-1 year-1) compared the range of stocking rates observed in horse husbandry [14]. We therefore conclude that horses create a patchy structure of the sward and a distinct floristic contrast irrespective of the grazing intensity.

4.5 Study Limitations

Our analyses are based on plant species data, since their presence and frequencies provide essential information on the growing conditions [43,73, 74]. Beyond vegetation data, other ecosystem characteristics need to be included to provide a complete assessment of the sustainability of grassland management with horses. In spite of a relatively high average SR, some of the studied paddocks had little diversity and showed larger areas of bare soil, grazed areas with only a few species and rather high numbers of ruderal or stress-tolerant species, which is obviously a result of overgrazing. Our study was performed in a regional context of an upland region typical for Central Europe. Studies by Socher et al. (2013) [66] and Kleijn et al. (2009) [75] have demonstrated that regional conditions should be taken into consideration to address conservation issues. The results presented here should therefore be handled with care if conclusions for an appropriate conservation management in a wider spatial context are to be drawn. While grazing intensities in our study varied strongly among horse-grazed paddocks, we are aware that in the farming practice far higher stocking rates of horses, up to 10 LU ha^{-1} $year^{-1}$, occur, especially in peri-urban regions [15,17]. Thus, our results should not be considered as valid for such conditions.

It might be argued that the horse-grazed paddocks in our study had been established on sites of initially higher species diversity and that the observed grazer species effect is therefore due to site conditions or grassland management apart from grazing. While we do not have information about the vegetation before the present grazing system was established, all studied paddocks were managed in the same way for at least five years. Most of the studied paddocks had been grazed by the same grazer species and not been renovated for decades and the vegetation can therefore be assumed to be in a state of equilibrium with the current management regime. Our study therefore demonstrates that it is possible to manage and maintain grasslands of a relatively high diversity through horse grazing, compared to grasslands managed in the context of dairy production. In direct comparison with cattle-grazed paddocks, horse paddocks did at least not perform worse regarding the nature value of those grasslands. In Germany, 15–20% of the total grassland area is managed by horse keepers, in some regions it is up to 30% [14]. These data underpin the potential role of horse husbandry for the maintenance of species-rich grasslands.

5. Conclusions

Due to their patch-grazing behaviour, horses are generally considered as a more difficult grazer species than cattle. Several authors stress that horse grazing is associated with environmental risks. Our study did not confirm increasing risks, at least not in relation to the nature value of the horse-grazed grasslands. In particular, continuous grazing with horses led to a pronounced floristic contrast within paddocks, and species richness at paddock scale was strongly related to this heterogeneity. Our study demonstrated the potential of horse grazing to maintain species richness of temperate grasslands. However, more in-depth research is required to better understand interactions of horse grazing, grazing regime and the landscape context. This will then provide a basis for a more targeted grazing management with horses for the benefit of species rich grasslands in temperate climate.

Supplementary Materials: Data analysed in this paper are provided S1 Data (Schmitz_Isselstein_data.xlxs); S2 Metadata (Schmitz_Isselstein_meta.docx)

Funding: Anja Schmitz' work has been funded by the German Federal Environmental Foundation (DBU) as part of the PhD-Fellowship Programme (AZ 20012/175).

Acknowledgments: We gratefully thank the German Federal Environmental Foundation (DBU) for funding within the PhD-Fellowship Programme. We thank all farmers that participated in our studies and provided access to their land. We thank M. Komischke, A. Cymmer and C. Wißmann for their help during fieldwork, B. Tonn for her help on the manuscript and L. Sutcliffe for English language editing.

References

1. Wrage, N.; Strodthoff, J.; Cuchillo, H.M.; Isselstein, J.; Kayser, M. Phytodiversity of temperate permanent grasslands: Ecosystem services for agriculture and livestock management for diversity conservation. *Biodivers. Conserv.* **2011**, *20*, 3317–3339.
2. Olff, H.; Ritchie, M.E. Effects of herbivores on grassland plant diversity. *Trends Ecol. Evol.* **1998**, *13*, 261–265.
3. Rook, A.J.; Dumont, B.; Isselstein, J.; Osoro, K.; WallisDeVries, M.F.; Parente, G.; Mills, J. Matching type of livestock to desired biodiversity outcomes in pastures – a review. *Biol. Conserv.* **2004**, *119*, 137–150.
4. Tälle, M.; Deák, B.; Poschlod, P.; Valkó, O.; Westerberg, L.; Milberg, P. Grazing vs. mowing: A meta-analysis of biodiversity benefits for grassland management. *Agric. Ecosyst. Environ.* **2016**, *222*, 200–212.
5. Adler, P.; Raff, D.; Lauenroth, W. The effect of grazing on the spatial heterogeneity of vegetation. *Oecologia* **2001**, *128*, 465–479.
6. Dumont, B.; Rossignol, N.; Loucougaray, G.; Carrère, P.; Chadoeuf, J.; Fleurance, G.; Bonis, A.; Farruggia, A.; Gaucherand, S.; Ginane, C.; et al. When does grazing generate stable vegetation patterns in temperate pastures? *Agric. Ecosyst. Environ.* **2012**, *153*, 50–56.
7. Tonn, B.; Raab, C.; Isselstein, J. Sward patterns created by patch grazing are stable over more than a decade. *Grass Forage Sci.* **2019**, *74*, 104–114.
8. Marion, B.; Bonis, A.; Bouzillé, J.-B. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? *Écoscience* **2010**, *17*, 229–239.
9. Scimone, M.; Rook, A.J.; Garel, J.P.; Sahin, N. Effects of livestock breed and grazing intensity on grazing systems: 3. Effects on diversity of vegetation. *Grass Forage Sci.* **2007**, *62*, 172–184.
10. Klimek, S.; Marini, L.; Hofmann, M.; Isselstein, J. Additive partitioning of plant diversity with respect to grassland management regime, fertilisation and abiotic factors. *Basic Appl. Ecol.* **2008**, *9*, 626–634.
11. Hautier, Y.; Isbell, F.; Borer, E.T.; Seabloom, E.W.; Harpole, W.S.; Lind, E.M.; MacDougall, A.S.; Stevens, C.J.; Adler, P.B.; Alberti, J.; et al. Local loss and spatial homogenization of plant diversity reduce ecosystem multifunctionality. *Nat. Ecol. Evol.* **2018**, *2*, 50–56.
12. Jerrentrup, J.S.; Seither, M.; Petersen, U.; Isselstein, J. Little grazer species effect on the vegetation in a rotational grazing system. *Agric. Ecosyst. Environ.* **2015**, *202*, 243–250.
13. European Horse Network—Environmental and Rural Impact. Available online: http://www.europeanhorsenetwork.eu/horse-industry/environmental-and-rural-impact/ (accessed on 30 December 2019).
14. Schmitz, A.; Isselstein, J. Wieviel Grünland wird in Deutschland für Pferde genutzt? *Berichte Über Landwirtsch. Z. Für Agrarpolit. Landwirtsch.* **2018**, *96*, 1– 32.
15. Bomans, K.; Dewaelheyns, V.; Gulinck, H. Pasture for horses: An underestimated land use class in an urbanized and multifunctional area. *Int. J. Sustain. Dev. Plan.* **2011**, *6*, 195–211.
16. Elgåker, H.; Pinzke, S.; Lindholm, G.; Nilsson, C. Horse keeping in Urban and Peri-Urban Areas: New Conditions for Physical Planning in Sweden. *Geogr. Tidsskr.-Dan. J. Geogr.* **2010**, *110*, 81–98.
17. Zasada, I.; Berges, R.; Hilgendorf, J.; Piorr, A. Horsekeeping and the peri-urban development in the Berlin Metropolitan Region. *J. Land Use Sci.* **2013**, *8*, 199–214.
18. Jouven, M.; Vial, C.; Fleurance, G. Horses and rangelands: Perspectives in Europe based on a French case study. *Grass Forage Sci.* **2016**, *71*, 178–194.

19. Bott, R.C.; Greene, E.A.; Koch, K.; Martinson, K.L.; Siciliano, P.D.; Williams, C.; Trottier, N.L.; Burk, A.; Swinker, A. Production and Environmental Implications of Equine Grazing. *J. Equine Vet. Sci.* **2013**, *33*, 1031–1043.
20. Watts, K. Pasture Management to Minimize the Risk of Equine Laminitis. *Vet. Clin. North Am. Equine Pract.* **2010**, *26*, 361–369.
21. Williams, C.A.; Kenny, L.B.; Burk, A.O. Effects of grazing system and season on glucose and insulin dynamics of the grazing horse. *J. Equine Vet. Sci.* **2017**, *52*, 87.
22. Archer, M. The species preferences of grazing. *Grass Forage Sci.* **1973**, *28*, 123–128.
23. Hongo, A.; Akimoto, M. The role of incisors in selective grazing by cattle and horses. *J. Agric. Sci.* **2003**, *140*, 469–477.
24. Singer, J.W.; Bobsin, N.; Kluchinski, D.; Bamka, W.J. Equine stocking density effect on soil chemical properties, botanical composition, and species density. *Commun. Soil Sci. Plant Anal.* **2001**, *32*, 2549–2559.
25. Fleurance, G.; Farruggia, A.; Lanore, L.; Dumont, B. How does stocking rate influence horse behaviour, performances and pasture biodiversity in mesophile grasslands? *Agric. Ecosyst. Environ.* **2016**, *231*, 255–263.
26. Nolte, S.; Esselink, P.; Smit, C.; Bakker, J.P. Herbivore species and density affect vegetation-structure patchiness in salt marshes. *Agric. Ecosyst. Environ.* **2014**, *185*, 41–47.
27. Schmitz, A.; Isselstein, J. Effects of management on vegetation structure in horse pastures. In Helgadóttir, Á.; Hopkins, A. *Proceedings of the 17th Symposium of the European Grassland Federation. The Role of Grasslands in a Green Future: Threats and Perspectives in Less Favoured Areas*; Borgarnes, Iceland, **2013**; pp. 394–396.
28. Ceulemans, T.; Merckx, R.; Hens, M.; Honnay, O. A trait-based analysis of the role of phosphorus vs. nitrogen enrichment in plant species loss across North-west European grasslands: Trait-based analysis of the role of P vs. N enrichment. *J. Appl. Ecol.* **2011**, *48*, 1155–1163.
29. Critchley, C.N.R.; Chambers, B.J.; Fowbert, J.A.; Sanderson, R.A.; Bhogal, A.; Rose, S.C. Association between lowland grassland plant communities and soil properties. *Biol. Conserv.* **2002**, *105*, 199–215.
30. Ödberg, F.O.; Francis-Smith, K. Studies on the formation of ungrazed eliminative areas in fields used by horses. *Appl. Anim. Ethol.* **1977**, *3*, 27–34.
31. Kenny, L.B. The Effects of Rotational and Continuous Grazing on Horses, Pasture Condition, and Soil Properties. M.Sc. Thesis, Rutgers University, New Brunswick, New Jersey, USA, 2016. doi:10.7282/T38P62MN.
32. Herrero-Jáuregui, C.; Oesterheld, M. Effects of grazing intensity on plant richness and diversity: A meta-analysis. *Oikos* **2018**, *127*, 757–766.
33. van Klink, R.; Nolte, S.; Mandema, F.S.; Lagendijk, D.D.G.; WallisDeVries, M.F.; Bakker, J.P.; Esselink, P.; Smit, C. Effects of grazing management on biodiversity across trophic levels–The importance of livestock species and stocking density in salt marshes. *Agric. Ecosyst. Environ.* **2016**, *235*, 329–339.
34. Milchunas, D.G.; Varnamkhasti, A.S.; Lauenroth, W.K.; Goetz, H. Forage quality in relation to long-term grazing history, current-year defoliation, and water resource. *Oecologia* **1995**, *101*, 366–374.
35. Tonn, B.; Densing, E.M.; Gabler, J.; Isselstein, J. Grazing-induced patchiness, not grazing intensity, drives plant diversity in European low-input pastures. J. Appl. Ecol. 2019, 56, 1624–1636, doi:10.1111/1365-2664.13416.
36. Hennig, J.D.; Beck, J.L.; Scasta, D.J. Spatial Ecology Observations from Feral Horses Equipped With Global Positioning System Transmitters. *Hum. Wildl. Interact.* **2018**, *12*, 10.
37. Henning, K.; Lorenz, A.; von Oheimb, G.; Härdtle, W.; Tischew, S. Year-round cattle and horse grazing supports the restoration of abandoned, dry sandy grassland and heathland communities by supressing Calamagrostis epigejos and enhancing species richness. *J. Nat. Conserv.* **2017**, *40*, 120–130.
38. Lamoot, I.; Callebaut, J.; Degezelle, T.; Demeulenaere, E.; Laquière, J.; Vandenberghe, C.; Hoffmann, M. Eliminative behaviour of free-ranging horses: Do they show latrine behaviour or do they defecate where they graze? *Appl. Anim. Behav. Sci.* **2004**, *86*, 105–121.
39. Rupprecht, D.; Gilhaus, K.; Hölzel, N. Effects of year-round grazing on the vegetation of nutrient-poor grass- and heathlands—Evidence from a large-scale survey. *Agric. Ecosyst. Environ.* **2016**, *234*, 16–22.
40. Köhler, M.; Hiller, G.; Tischew, S. Year-round horse grazing supports typical vascular plant species, orchids and rare bird communities in a dry calcareous grassland. *Agric. Ecosyst. Environ.* **2016**, *234*, 48–57.
41. Saastamoinen, M.; Herzon, I.; Särkijärvi, S.; Schreurs, C.; Myllymäki, M. Horse Welfare and Natural Values on Semi-Natural and Extensive Pastures in Finland: Synergies and Trade-Offs. *Land* **2017**, *6*, 69.
42. Grime, J.P. Evidence for the Existence of Three Primary Strategies in Plants and Its Relevance to Ecological and Evolutionary Theory. *Am. Nat.* **1977**, *111*, 1169–1194.

43. Briemle, G.; Nitsche, S.; Nitsche, L. Nutzungswertzahlen für Gefäßpflanzen des Grünlandes. *Schriftenreihe Für Veg.* **2002**, *38*, 203–225.
44. Kleijn, D.; Berendse, F.; Smit, R.; Gilissen, N. Agri-environment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. *Nature* **2001**, *413*, 723–725.
45. Ulber, L.; Steinmann, H.-H.; Klimek, S.; Isselstein, J. An on-farm approach to investigate the impact of diversified crop rotations on weed species richness and composition in winter wheat. *Weed Res.* **2009**, *49*, 534–543.
46. Pauler, C.M.; Isselstein, J.; Braunbeck, T.; Schneider, M.K. Influence of Highland and production-oriented cattle breeds on pasture vegetation: A pairwise assessment across broad environmental gradients. *Agric. Ecosyst. Environ.* **2019**, *284*, 106585.
47. LandNRW. Digital Orthophoto (DOP RGBI). Available online: https://www.bezreg-koeln.nrw.de/brk_internet/geobasis/luftbildinformationen/aktuell/digitale_orthophotos/index.html. (Data accessed 2015-12-22). .
48. Landesdatenbank Nordrhein-Westfalen Bodennutzungshaupterhebung. Available online: https://www.landesdatenbank.nrw.de/ldbnrw/online/data;sid=120F53FEBB1ECAD3E7473A272AFD6B20.ldb1?operation=statistikAbruftabellen&levelindex=0&levelid=1577708904302&index=3 (accessed on 2019-12-30).
49. Castle, M.E. A simple disc instrument for estimating herbage yield. *Grass Forage Sci.* **1976**, *31*, 37–40.
50. QGIS Entwicklungsteam QGIS Geographisches Informationssystem. *Open Source Geospatial Foundation Projekt*; Version 2.6; Brighton, UK, 2014.
51. LandNRW. Digital elevation model (DEM50). Available online: https://www.bezreg-koeln.nrw.de/brk_internet/geobasis/hoehenmodelle/gelaendemodell/index.html, (Data accessed 2015-12-22).
52. Hünig, C. und Benzler, A. *Das Monitoring der Landwirtschaftsflächen mit hohem Naturwert in Deutschland*. BfN Skripten 476, Bonn, **2017**. Available online: https://www.bfn.de/fileadmin/BfN/service/Dokumente/skripten/Skript476.pdf (accessed on 2019-12-30) (accessed on 2019-12-30)
53. Bundesamt für Naturschutz (BfN) *Kenntaxa für die regional differenzierte Bewertung von Grünlandflächen im Rahmen des HNV-Farmland-Indikators für Deutschland*. Bonn, **2014**. Available online: https://www.bfn.de/fileadmin/BfN/monitoring/Dokumente/14_02_26_Kennartenliste_HNV_barrfrei.pdf (accessed on 2019-12-30)
54. Hunt, R.; Hodgson, J.G.; Thompson, K.; Bungener, P.; Dunnett, Np.; Askew, Ap. A new practical tool for deriving a functional signature for herbaceous vegetation. *Appl. Veg. Sci.* **2004**, *7*, 163–170.
55. Magurran, A.E. *Measuring Biological Diversity*; John Wiley & Sons: New York, NY, USA, 2013.
56. Dormann, C.F.; Elith, J.; Bacher, S.; Buchmann, C.; Carl, G.; Carré, G.; Marquéz, J.R.G.; Gruber, B.; Lafourcade, B.; Leitão, P.J.; et al. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography* **2013**, *36*, 27–46.
57. Zuur, A.F., Ed. *Mixed Effects Models and Extensions in Ecology with R*; Statistics for biology and health; Springer Science & Business Media: New York, NY, USA, **2009**.
58. Grueber, C.E.; Nakagawa, S.; Laws, R.J.; Jamieson, I.G. Multimodel inference in ecology and evolution: Challenges and solutions: Multimodel inference. *J. Evol. Biol.* **2011**, *24*, 699–711.
59. Burnham, K.P.; Anderson, D.R. Multimodel Inference: Understanding AIC and BIC in Model Selection. *Sociol. Methods Res.* **2004**, *33*, 261–304.
60. Symonds, M.R.E.; Moussalli, A. A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. *Behav. Ecol. Sociobiol.* **2011**, *65*, 13–21.
61. Bartoń, K. *MuMIn: Multi-Model Inference*; R package version 1.43.15**,** 2019. Available online: https://CRAN.R-project.org/package=MuMIn (accessed on 2020-01-20).
62. Pinheiro, J.; Bates, D.; DebRoy, S.; Sarkar, D.; R Core Team. *nlme: Linear and Nonlinear Mixed Effects Models*; R package version 3.1-137, 2018. Available online: https://CRAN.R-project.org/package=nlme> (accessed on 2018-09-01).
63. Lenth, R.; Singmann, H.; Love, J.; Buerkner, P.; Herve, M. *emmeans. Estimated Marginal Means, aka Least-Squares Means*; R package version 1.4.3.01, 2019. Available online: https://CRAN.R-project.org/package=emmeans (accessed on 2020-01-20).
64. Socher, S.A.; Prati, D.; Boch, S.; Müller, J.; Klaus, V.H.; Hölzel, N.; Fischer, M. Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. *J. Ecol.* **2012**, *100*, 1391–1399.

65. Klimek, S.; Richter gen. Kemmermann, A.; Hofmann, M.; Isselstein, J. Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors. *Biol. Conserv.* **2007**, *134*, 559–570.
66. Socher, S.A.; Prati, D.; Boch, S.; Müller, J.; Baumbach, H.; Gockel, S.; Hemp, A.; Schöning, I.; Wells, K.; Buscot, F.; et al. Interacting effects of fertilization, mowing and grazing on plant species diversity of 1500 grasslands in Germany differ between regions. *Basic Appl. Ecol.* **2013**, *14*, 126–136.
67. Basto, S.; Thompson, K.; Phoenix, G.; Sloan, V.; Leake, J.; Rees, M. Long-term nitrogen deposition depletes grassland seed banks. *Nat. Commun.* **2015**, *6*, 6185.
68. Valkó, O.; Tóthmérész, B.; Kelemen, A.; Simon, E.; Miglécz, T.; Lukács, B.A.; Török, P. Environmental factors driving seed bank diversity in alkali grasslands. *Agric. Ecosyst. Environ.* **2014**, *182*, 80–87.
69. Wellstein, C.; Otte, A.; Waldhardt, R. Impact of site and management on the diversity of central European mesic grassland. *Agric. Ecosyst. Environ.* **2007**, *122*, 203–210.
70. Pykälä, J. Plant species responses to cattle grazing in mesic semi-natural grassland. *Agric. Ecosyst. Environ.* **2005**, *108*, 109–117.
71. Menard, C.; Duncan, P.; Fleurance, G.; Georges, J.-Y.; Lila, M. Comparative foraging and nutrition of horses and cattle in European wetlands. *J. Appl. Ecol.* **2002**, *39*, 120–133.
72. Bonari, G.; Fajmon, K.; Malenovský, I.; Zelený, D.; Holuša, J.; Jongepierová, I.; Kočárek, P.; Konvička, O.; Uřičář, J.; Chytrý, M. Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition. *Agric. Ecosyst. Environ.* **2017**, *246*, 243–252.
73. Ellenberg, H.; Weber, H.E.; Düll, R.; Wirth, V.; Werner, W. *Zeigerwerte von Pflanzen in Mitteleuropa*, 3rd ed.; Verlag Eric Goltze, Göttingen, Germany, 1992.
74. Kleyer, M.; Bekker, R.M.; Knevel, I.C.; Bakker, J.P.; Thompson, K.; Sonnenschein, M.; Poschlod, P.; van Groenendael, J.M.; Klimeš, L.; Klimešová, J.; et al. The LEDA Traitbase: A database of life-history traits of the Northwest European flora. *J. Ecol.* **2008**, *96*, 1266–1274.
75. Kleijn, D.; Kohler, F.; Báldi, A.; Batáry, P.; Concepción, E.D.; Clough, Y.; Díaz, M.; Gabriel, D.; Holzschuh, A.; Knop, E.; et al. On the relationship between farmland biodiversity and land-use intensity in Europe. *Proc. R. Soc. B Biol. Sci.* **2009**, *276*, 903–909.

Chapter III:

How horses affect soil seed banks compared to cattle grazing in temperate managed grasslands

Anja Schmitz and Johannes Isselstein

Abstract:

Horses play an important role in agriculturally managed grasslands across Europe. There is concern to what extent grazing with horses is a sustainable grassland management practice. The long-term effects of horse grazing on grassland vegetation has not been targeted by research so far, especially in comparison to grazing cattle. Soil seed banks reflect the long-term effects of grassland management since they can store seeds for decades. They also play a fundamental role for restoring grassland biodiversity.

Since grazer species may have a different effect on species richness, density, composition and ecological value of seed banks, our study targeted the relative importance of grazing system (grazer species and regime) and grassland management for soil seed bank characteristics in grasslands as indicator for sustainable management.

We analysed soil seed banks in western central Germany and compared paddocks grazed by horses (H) under two different regimes, continuous (HC) vs. rotational (HR), to paddocks grazed by cattle (C) under similar trophic site conditions.

We found significant differences in soil seed banks of horse- compared to cattle-grazed paddocks. A higher overall species richness and density of HNV species occurred in horse-grazed paddocks. Density of weed species seeds was not different in horse- and cattle grazed paddocks. Among horse-grazed paddocks, no differences in seed bank characteristics were obtained between grazing regimes (continuous vs rotational), despite slightly higher species richness in continuously grazed paddocks. The floristic contrast between short and tall patches did not differ between grazer species and grazing regimes. None of the seed bank target variables was significantly affected by patch type.

We conclude that in the long term, grazing with horses may potentially preserve species-rich seed banks and does not necessarily lead to an accumulation of grazing-related ruderal weed species in seed banks.

Keywords: agriculturally managed grasslands; diaspor; seeds; equine grazing; pasture management; grazer species; biodiversity

1. Introduction

Permanent grasslands play an essential role as a source of ecosystem services and biodiversity in agricultural landscapes (Isselstein and Kayser 2014, Wrage *et al.* 2011). In recent decades, land-use intensification and abandonment have become major threats to grassland biodiversity (Klimek *et al*. 2014, Valkó *et al.* 2014, Wesche *et al.* 2012). Hence there is an urgent need for management strategies that maintain or, at best, increase grassland biodiversity (Borer *et al.* 2014, Wrage *et al.* 2011).

Soil seed banks play an important role in grassland vegetation dynamics (Kiss *et al.* 2016, Vandvik *et al.* 2016). They are widely discussed for their potential to contribute to grassland restoration and diversity (Bakker *et al.* 1996, Bekker *et al.* 1997, Fenner and Thompson 2005, Kiss *et al.* 2016). They consist of seeds provided from the reproduction of recent and historical swards. Depending on their longevity, soil seed banks can store buried seeds from species that are already lost in the aboveground vegetation (Valkó *et al.* 2014, Wellstein *et al.* 2007 (b)). In grasslands, many plant species' long-term persistence depends on their ability to maintain seed banks through long-term survival of seeds or regular replenishment (Kiss *et al.* 2016). Moreover, a functionally diverse species pool available for germination (Kalamees and Zobel 1998, Vandvik *et al.* 2016) contributes to community resilience in the context of climate change (Kiss *et al.* 2018).

Grassland management is considered a major factor determining the vegetation composition of swards (Tälle *et al.* 2016, Socher *et al.* 2012). It controls growth, reproduction and competition among the different plant species. In particular, livestock grazing is known as one of the most important mechanisms affecting grassland diversity (Nolte *et al.* 2014, Rook *et al.* 2004, Wrage *et al.* 2011). Grazing is related to the formation of gaps in the sward, the spatial heterogeneity of the sward structure, and the soil nutrient concentration. This is due to the grazing animals' behaviour, particularly the preferences in diet selection (Adler *et al.* 2001, Dumont *et al.* 2012). Palatable plants of high nutritional value are preferred, while mature vegetation and plants growing close to a dung patch are avoided. This behaviour has been described as "patch grazing" (Adler *et al.* 2001). It leads to a stable mosaic of short (grazed) and tall (avoided) sward patches providing very different growing conditions for plants. At the paddock scale, heterogeneity increases plant species diversity, as plants of varying strategy types and growth forms can exist in close proximity (Marion *et al.* 2015, Rook *et al.* 2004, Scimone *et al.* 2007).

This pattern might be reflected in the soil seed bank. In tall patches, where plants are not (or less) grazed, they can set seed which can be transfered to the soil seed bank. In contrast, frequent defoliation limits plant reproduction in short patches. Plants might be grazed before flowering or setting seeds. Moreover, grazers induce gaps in swards or even patches of bare soil due to trampling. These gaps provide light and conditions that favour germination of viable seeds. Where those seeds can establish, grow and contribute to swards, this process can help to recruit species from seed banks that were already lost in the aboveground vegetation. However, where swards are defoliated repeatedly before plants can reproduce, this process can deplete the seed bank in the long term (Burke and Grime 1996).

Jacquemyn *et al.* (2011) confirmed a positive effect of grazing on species richness and density of soil seed banks compared to mowing or abandonment. Beyond that, the impact of grazing management on the soil seed bank in temperate managed grasslands has received little attention so far. To our knowledge, no research has addressed the grazing species or the patch grazing effect on characteristics of soil seed banks in managed grasslands.

Horses play an important role in grassland management in Europe. At least 6 million horses live in Europe, estimated to use at least 6 million ha of grassland (European Horse Network 2019, Jouven *et al.* 2016). However, there is some concern to what extent grazing with horses is a sustainable grassland management practice regarding sward botanical composition and biodiversity. Comparing horses and cattle as grazer species, various effects on vegetation and consequently seed banks can be expected. Horses are known to cause more significant disturbance to the sward than cattle: Due to their two pairs of incisors, they can graze more selectively and closer to the ground (Archer 1973, Bott *et al.* 2013, Hongo and Akimoto 2003,). As selective grass feeders (Singer *et al.*, 2001), horses increase the share of forbs in the swards (Fleurance *et al.* 2016, Nolte *et al.* 2014). Moreover, their patch grazing effect is more substantial than that of cattle (Archer 1973, Fleurance *et al.* 2016, Ödberg and Francis-Smith 1977) since they avoid grazing where they defecate. They create latrine areas where they accumulate excreta and large areas where they repeatedly graze. This behaviour leads to a distinct nutrient transfer and a corresponding vegetation shift between patch types (Archer 1973). Further, their locomotion behaviour can stress swards. Running and trampling can result in bare soil patterns, which is more likely to occur when the grazing area and time are restricted (Bott *et al.* 2013, Singer *et al.* 2001). Bare soil enables buried seeds to emerge from seed banks. Especially seeds from ruderal weed species are quite sensitive to sparse vegetation cover, which is known as the ability of gap detection (Silvertown 1981). As a result, in frequently defoliated short patches and damaged swards, weeds like *Plantago major*, *Ranuculus repens* and *Rumex obtusifolius* may spread (Bott *et al.* 2013, Singer *et al.* 2001).

In addition to the grazer species, the grazing regime can also regulate pasture vegetation (Bott *et al.* 2013, Rook *et al.* 2004). Commonly, horse farms practice continuous or rotational grazing. In continuous grazing, horses are provided unrestricted access to a paddock during extended grazing season periods. This promotes the development of distinct short and tall patches (Singer *et al.* 2001). In rotational grazing, paddocks are smaller and are provided for short periods, which forces horses to graze more uniformly (Bott *et al.* 2013, Singer *et al.* 2001). However, the effects of grazing systems on seed banks, particularly with horses as the grazer species, have not been addressed by systematic research so far.

Therefore, our study aimed to investigate the effect of horse compared to cattle grazing and the effect of the grazing regime (continuous vs. rotational) in horse grazed paddocks on the soil seed bank of managed grasslands. Hence, we aimed at clarifying the context of patch grazing and soil seed bank characteristics. We established an observational study in managed grasslands on horse and cattle farms in the Rhenish Uplands in Germany. We used a stratified sampling design to compare soil seed banks of grasslands grazed by cattle or horses and to distinguish grazer species effects from those of site conditions and management. As seed bank characteristics, we considered species richness, seed density, β-diversity between patch types, seed bank longevity, and share of C-S-R-strategy types (Grime 1988).

We addressed the following hypotheses:

H1 Soil seed bank composition and characteristics differ between paddocks grazed by cattle or horses.

H2 Grazing regime (continuous grazing vs rotational grazing) in horse-grazed paddocks and grassland management (stocking density, mowing regime and fertilisation) affect soil seed bank characteristics.

H3 Grazer species effects on soil seed banks at the paddock scale are mediated by patch type.

2. Material and Methods

2.2 Study region

The study region is located in the Rhenish uplands in North Rhine-Westphalia, Germany (50.87'N, 7.48'E, Figure III-1) and covers a total area of approximately 400 km^2.

A humid temperate climate and shallow, loamy acidic cambisols result in a naturally low agricultural production potential. Grasslands make up a share of 65% up to 90% of the total agricultural area (Landesdatenbank NRW 2019). The altitude above sea level ranges from 118 to 335 m.

The grassland vegetation of the study sites belongs to the Molinio-Arrhenatheretea class. Most grasslands in the study region are managed for dairy production, but horses play a considerable role, too. According to the local livestock numbers (Animal Health Fund, oral communication), at least 10% of grasslands in the study region are estimated to be managed with horses.

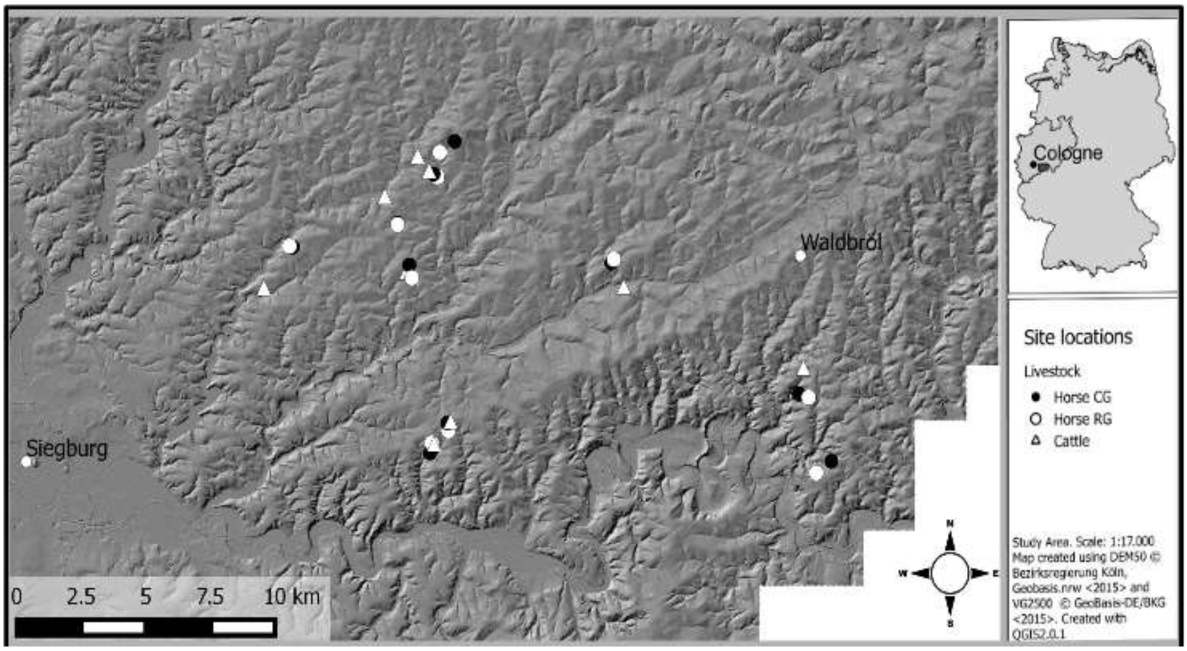

Figure III-1: Arrangement of study paddocks (N=30) in the south east of the Rhenish Uplands

2.3 Sampling design

We included a total of 30 paddocks of grasslands under regular agricultural management in the study. We arranged paddocks in 10 triplets that covered a gradient of different site conditions and land-use intensities. Within each triplet, we chose three paddocks, each representing a grazing system. Two paddocks were grazed by horses (H), one in a continuous (HC, n=10), the other in a rotational grazing system (HR, n=10). The third paddock was grazed by cattle (C, n=10, five grazed rotationally and five grazed continually). The three paddocks within each triplet are located in linear distance of max 1.5 km.

On each paddock, we chose two circular subplots of 12.6 m^2 (radius 2 m) in a stratified random approach. One subplot was in a short, the other in a tall vegetation patch. Sampling took place at the end of the grazing season when heterogeneity of the sward height was pronounced and it was easy to identify different patch types. We obtained mean sward height per paddock as an average of 50 compressed sward height (CSH) measurements using a rising plate meter (30 cm diameter, 200 g, Castle, 1976). We defined short patches as heavily grazed areas with a mean sward height below the paddock's average. Tall patches, in contrast, were mostly avoided areas with mean sward height above the paddock's average. Within patch types, we chose subplots randomly but with similar altitude and slope.

2.4 Site conditions

For all paddocks, we calculated size and topography-related environmental variables using Quantum GIS 9 and geodata provided by geobasis.nrw (2015). Paddock borders were mapped on an orthophotograph and paddock size (ha) calculated using Quantum GIS. A digital elevation model (DEM 50) was used to calculate average altitude (m.a.s.l.) and slope (%) per paddock as topography-related environmental variables.

The soil was sampled at each subplot in autumn at the end of the grazing season to determine the pH and the extractable soil phosphorus (P_2O_5 mg^{-1} 100 g^{-1} DM, extraction by calcium-acetate-lactate (CAL)). On each subplot, we took a 500 ml sample of the soil top layer (0-10 cm).

Generally, observational sites were selected so that paddocks within each triplet were as uniform in topographic site factors as possible. To check for paddocks' similarity within triplets, we compared standard deviation (sd) of averages among triplets to the average of sd within each triplet for all measured site conditions (Table III-1).

2.5 Grassland management

Before the study, we obtained data on current grassland management from personal interviews with farmers using a standardised questionnaire. Farmers provided information on land-use history, i.e. the year the current livestock grazing management was established. We included paddocks with a constant management regime of at least five years.

We obtained data on the number of livestock, mean weight per livestock, mean grazing duration per day, the number of rotations, mean number of grazing days per year and converted them to standard livestock unit (500 kg live weight) grazing days per hectare and year (LUgd ha^{-1} a^{-1}). We used LUgd as an indicator of grazing intensity in the analysis.

Additional to grazing, some of the observed paddocks were mown for fodder production. We recorded mowing as a binary variable (at least one cut per year vs exclusively grazing). Fertilisation with organic or mineral nitrogen fertiliser was recorded as binary data (fertilised, not fertilised).

Table III-1. Abiotic site conditions and management parameters of three grazing systems (Cattle (C), Horse continuous grazing (HC), Horse rotational grazing (HR)). Descriptive statistics (mean ± standard deviation) of untransformed environment variables used in the analyses and additional variables that have not been included in models. Significant differences of environmental variables between grazing systems or patch types were obtained by linear models and are given as * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

				C n=10			**HC n=10**			**HR n=10**				
Variables used in models		sd among triplets n=10	sd within triplets n=3	mean		sd	mean		sd	mean		sd	sig. Differences grazing system	patch type
Mean slope angle °	slope	3.2	2.5	10.8	±	5.2	7.5	±	3.6	6.7	±	2.8	***	
Soil pH site average	pH mean	0.4	0.3	5.4	±	0.5	5.5	±	0.6	5.4	±	0.4		
Phosphorus mg 100g^{-1} soil DM	P_2O_5 mean	5.9	5.6	13.6	±	7.5	19.5	±	9.7	15.8	±	7.2	*	
	short			12.0	±	9.2	12.8	±	6.6	11.4	±	5.4		***
	tall			15.1	±	6.9	25.9	±	17.0	19.7	±	11.4		
LU-days ha^{-1} year^{-1}	LUgd	261.5	156.2	389.9	±	244.2	514.6	±	390.8	485.4	±	282.9		
				count			count			count				
Fertilization (yes/no)	Nfert (yes)			7			7			6				
Forage conservation (yes/no)	cut (yes)			4			2			2				
Additional variables not included in models														
Paddock size	ha	0.7	0.5	1.5	±	0.9	1.3	±	0.8	0.8	±	0.7	***	
Altitude above sea level	masl	26.0	12.4	240.4	±	32.7	240.8	±	27.9	240.1	±	22.7		
Compressed sward height	CSH_mean	3.2	1.5	6.3	±	1.7	7.2	±	5.1	6.3	±	3.8		
LU ha^{-1} grassland per farm	LU ha^{-1}	0.8	0.8	1.5	±	1.1	2.0	±	1.7	1.7	±	0.7		
Land-use history	age	8.1	15.8	48.3	±	17.5	21.2	±	7.8	16.3	±	6.7	***	

2.6 *Seed bank sampling*

We collected 42 soil cores along the circular border of each subplot using a half-open soil auger (2 cm × 1.5 cm × 10 cm depth). The soil samples represent 1260 cm^3 soil per 12.6 m^2 subplot, which is in concordance with minimum requirements for seed bank studies in grasslands (Oomes and Ham 1983). We removed the litter layer and manually divided each soil core into 0 - 5 cm and 5 - 10 cm segments to account for possible differences in seed bank composition between upper and lower soil layer. Thus, the data represent the soil seed bank without litter and seeds deposited during the vegetation period. Within each subplot, we pooled all core segments per soil layer.

2.7 *Seedling emergence*

Sampling of seed banks was carried out in autumn. Therefore, samples lacked natural stratification. We mimicked winter stratification by storing samples in a climate chamber at 3 °C for six weeks. We used the method of Ter Heerdt *et al.* (1996) to concentrate samples and achieve faster germination success: Vegetative organs and stones were removed by washing over a coarse sieve of 3mm and fine soil components were washed out using a 0.121 mm fine mesh. We spread the remaining subtrate evenly in a 4 mm thick layer on a tray filled with 4 cm sterilised potting soil and a fine layer of sterile sand.

Trays were randomly distributed in a greenhouse (DNPW, University of Goettingen), exposed to warm and standardised conditions (day temperature 18 - 22° C, night temperature 15° C) and watered twice a day. During the experiment, sample–free control trays were placed randomly between the trays to monitor background seed contamination.

Immediately after the cotyledons appeared, we counted the seedlings, identified species and removed them from trays. Seedlings that were unidentifiable at that time were transplanted and grown in separate pots until identification. Consistent with Ter Heerdt *et al.* (1996), germination ended after six weeks. After seven weeks, we stopped watering for one week to introduce drought stress. We crumbled the dried sample layers and turned them to bring buried seeds to the surface. To stimulate further germination, we watered trays again. After ten weeks, we terminated the experiment as no significant further germination was observed. Since no germination occurred in control trays, contamination of experimental trays can be neglected.

2.8 *Data processing and analysis*

2.8.1 Species response variables

In accordance with other studies (Bossuyt *et al.* 2006), we found more seedlings and more species in the upper soil layer compared to the lower soil layer. As this vertical distribution did not significantly differ between patch types nor grazer species, we pooled species data of both segments for statistical analysis.

Seed bank density (SBD) refers to the total number of germinated individuals per subplot. SBD includes seedlings not identified to species level. Species richness (SR) refers to the total number of identified species. As a further measure of diversity, we calculated Shannon evenness following Magurran (2004) as $E = -[\sum p_i \ln(p_i)] / SR$, with p_i being the proportion of individuals belonging to species i.

We used a regional list of High-Nature-Value (HNV)-Indicator species for middle-west/north-west of Germany (German Federal Agency of Nature Conservation, 2016) to evaluate the nature conservation value of the viable seed bank. The number of HNV species per sample did not vary much. However, the seed density of HNV species did. Therefore we targeted density of HNV species (HNV SBD) rather than their species richness.

As a measure of floristic contrast between the two subplots placed in short and tall patches within each paddock, we calculated the *Sørensen* index Sø: $Sø = 2c \ / \ (a + b + 2c)$, with a representing the number of species exclusively present in one subplot, b the number of species found exclusively in the other subplot and c the number of species present in both. Further, we calculated the Bray-Curtis-Index (BC) as an abundance-based index as: $BC = 2c / a + b$, with c representing the sum of seedlings of species shared by both subplots per paddock and $a + b$ representing the number of all seedlings that germinated per paddock. Both indices were calculated following Magurran (2011).

As a measure of the persistence of the seed bank we calculated the longevity index LI as: $LI = (SP + LP) / (T + SP + LP)$, where T, SP and LP represent the total number of transient, short-term and long-term persistent records, respectively (Bekker *et al.* 1998). Transient seeds (T) are supposed to be viable up to one year, short-term persistent seeds (SP) viable for one to five years and long-term persistent seeds (LP) live for at least five years or more (LEDA-Traitbase, Kleyer *et al.* 2008). LI ranges from 0, being strictly transient, to 1, being strictly persistent.

As described by Hunt *et al.* (2004), we converted plant species' strategy types to a numeric C-S-R signature (C strategy – competitive strategy component, S strategy – stress tolerant strategy component, R strategy – ruderal strategy component). Based on the species and number of seedlings found in the seed bank, a weighted average value was calculated for each strategy component per subplot.

2.8.2 Statistical analysis

Seed bank characteristics

All statistical analyses on seed bank characteristics were performed using the software R (R Core Team 2014). We used linear mixed-effects models in combination with model averaging (MuMin-package (Barton 2011, Burnham and Anderson 2004, Grueber *et al.* 2011) to dissect the important drivers of soil seed bank characteristics for horse- and cattle-grazed pastures.

Linear mixed effects models (function 'lme', 'nlme' package (Pinheiro J. *et al.* 2014)) were set up for each seed bank characteristics variable (SR, SBD, HNV SBD, share of C-, S- and R-strategy component, LI, Sø and BC) as well as for seed density of single weed species of interest (*Plantago major*, *Ranunculus repens*, *Rumex obtusifolius*). In these global models, each seed bank response variable was modelled as a function of grazing system (cattle (C), horse continuous grazing (HC), horse rotational grazing (HR)), patch type (short, tall), LUgd, cutting, fertilisation, soil pH, soil P_2O_5 and slope. To account for the nested study design, we used PaddockID nested in TripletID as random term.

All global models were checked for multicollinearity of fixed factors using variance inflation factors (VIF). Since VIF's were below 3 in most cases and well below 10 (Dormann *et al.* 2013, Zuur *et al.* 2009) in all cases, we considered all explanatory variables for the statistical analyses.

Before analysis, we centralised all explanatory variables to zero mean and scaled to 0.5 standard deviation (Grueber *et al.* 2011), which allows comparing effects of all fixed effects directly.

We visually checked all global models for normal distribution and homoscedasticity of residuals. As Symonds and Moussalli (2010) suggest, we checked goodness of fit (R^2) for each global model prior to model reduction. (Pseudo-)R^2 was assessed following Nakagawa *et al.* (2013). We then performed model averaging (MA) on each global model to evaluate weighted averages of parameter and error estimates across multiple models (Burnham and Anderson 2016) as follows. For each global model, we calculated second order Akaike information criterion (AICc accounting for small sample size (Burnham and Anderson 2004) on every possible combination of variables. These were ranked using the 'dredge' function in the 'MuMIn' package (Barton 2016). We averaged the weighted parameter estimates over the set of models with cumulative Akaike weight ≤0.95. This set of models can be interpreted as 95% confidence set to the best approximating model (Burnham and Anderson 2004, Symonds and Moussalli 2011)). We estimated relative importance (I) of each parameter as the sum of Akaike weights over all models including the explanatory variable in the 95% confidence set. I range from 0% (parameter not given in any model in the confidence set) to 100% (parameter appears in all confidence set models). We used *Z*-statistics to calculate the significance of predictors from the supported models.

In case of a significant grazing system, we conducted Tukey post-hoc tests (lsmeans package, Lenth 2016) for pairwise comparisons between HC and HR.

Seed bank composition

To obtain relationships between seed bank composition, grassland management parameters and site conditions, we performed Redundancy Analysis (RDA) in CANOCO 4.5 (ter Braak and Smilauer, 2002). We used the full species dataset, including all species, and a subset including only HNV-species in a separate analysis.

In order to assess the appropriateness of RDA, we first subjected the species datasets to a Detrended Correspondence Analysis (DCA). We applied square-root transformation and downweighting of rare species implemented in CANOCO before analysis. As the first DCA axis's Eigenvalues were below 3 in both datasets, we chose linear RDA over unimodal ordination for further analysis. We tested statistical significance of RDAs using a Monte Carlo unrestricted permutation test under full model with 999 permutations (Leps and Smilauer 2003). The hierarchical design was considered by defining TripletID as block and patch within siteID as split-plot. To account for samples' spatial autocorrelation, geographical coordinates (longitude and latitude) were used as covariates in each analysis.

3. Results

Out of 120 samples, a total of 14.362 seedlings emerged from the soil samples, which could be assigned to 77 species. Of these, 12 species and in total 404 seedlings were classified as HNV-species. Converted to seeds per m^2, the average SBD on subplots ranged from 15.895 seeds per m^2 to 29.045 seeds per m^2.

3.1 Grazer species effect on seed bank characteristics at the paddock scale (H1)

Table III-3 shows the model-averaged coefficients of each explanatory variable of mixed effects models that remained in the 95% confidence set. Their relative importance for the target variables of seed bank response is given in column I. As it sums up the weights w_i of each model where the variable appears, relative importance indicates how likely an explanatory variable is to be included in the best-performing model of all models in the confidence set (Symonds and Moussalli 2011). It varies from 0 (not included in any model) to 1 (included in every model).

Models confirm a significant grazer species effect on SR as well as on HNV SBD. In both cases, grazing system was included in 99 % of the models (Table III-3). Significantly more species emerged from soil samples of horse grazed paddocks (MA: HC $p = 0.002$, $z = 3.107$, HR $p = 0.01$, $z = 2.506$) than from cattle-grazed paddocks. Further, samples from horse-grazed paddocks had a higher HNV SBD (MA: HC $p < 0.001$, $z = 4.265$, HR $p < 0.001$, $z = 4.442$) than samples from cattle-grazed paddocks (Table III-2, Figure III-2). Models did not confirm significant grazing system effects on SBD, LI or shares of CSR-strategy types, nor single weed species.

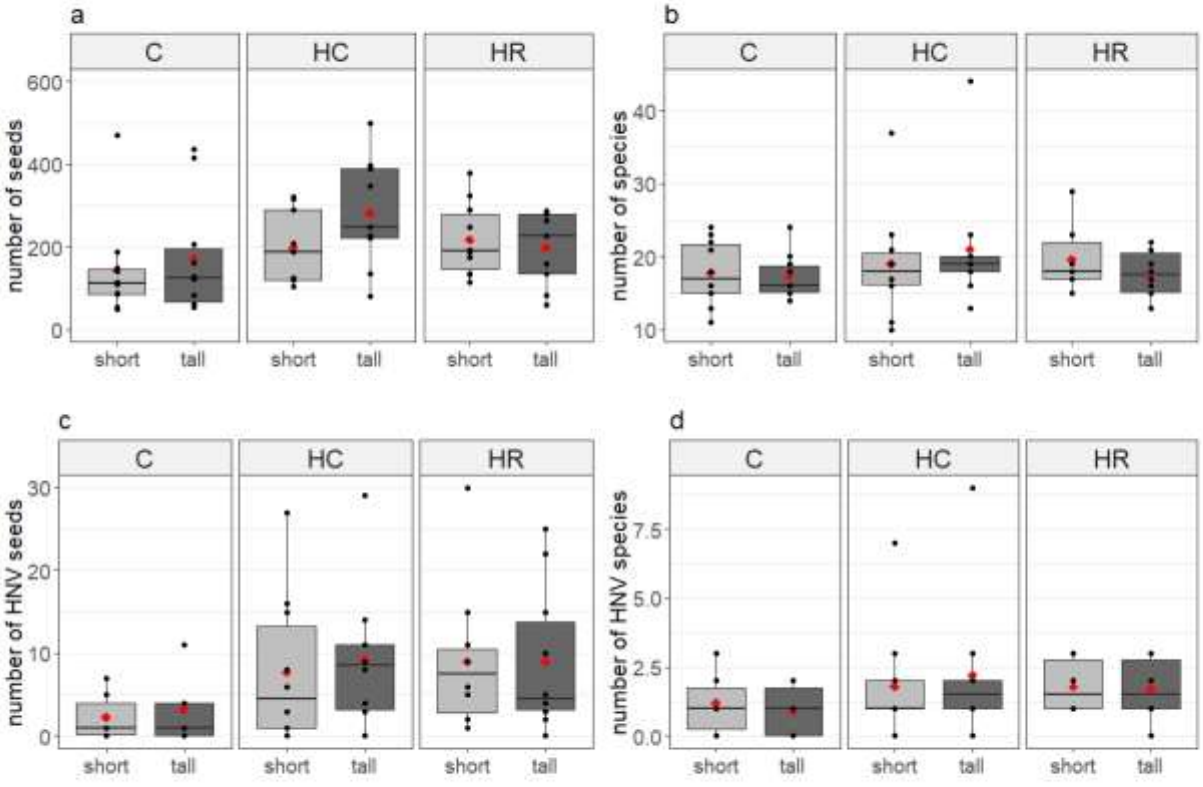

Figure III-2 Variation of (a) number of germinated seeds (SBD), (b) number of germinated species (SR), (c) number of germinated seeds of HNV species (HNV SBD) and number of germinated HNV species (HNV SR) in paddocks grazed by cattle (C) or horses (HC, HR) and patch tpes (short vs tall). Boxplots present median, 1st and 3rd quartile and outliers of untransformed target variables

3.2 Effect of grazing system and paddock management (H2)

The effect of continuous vs. rotational grazing was studied for paddocks grazed by horses. More species were found on horse-grazed paddocks under continuous than under rotational grazing (Tukey: $p = 0.046$, $F = 3.332$). No other target variable differed significantly between continuous and rotational grazing with horses.

Mowing and N fertilization showed no effect on SR, density or HNV SBD. However, N fertilization was likely to be included in models for shares of CSR-strategy components.

Testing single species, *Plantago major* significantly increased (MA $p < 0.001$, $z = 3.893$) with increasing LUgd.

3.3 Effects of patch type (H3)

Patch type had no significant effect on any of the target variables and was not likely to be included into models (Table III-2). Floristic contrast between short and tall patches did not differ between grazer species and grazing regimes, neither measured presence-absence based as *Sø* nor frequency-based as *BC*.

3.4 Site factors

Aside from the effect of grazer species, slope was the most important explanatory variable for SR (I = 1, $P < 0.001$, $z = 4.327$) and HNV species density (I = 0.99, $p = 0.0133$, $z = 2.477$). Higher SR and HNV SBD were observed on paddocks with a steeper slope. Further, slope was important for share of S- and R-strategy components.

3.5 Seed bank composition

The results of the RDA analysis are shown in Figure III-3 and Table III-3. All explanatory variables combined explained 25.1 % and 23.7 % of the variation in the full species dataset and in the HNV-species subset, respectively.

Within the ordination analyses, grazer species and grazing system were not distinguished. Here, grazing system is represented by a dummy scaled variable containing C, HC and HR. Grazing system did not significantly explain variation in composition of the full dataset (Figure III-3 a, Table III-3). However, in the HNV-species subset, it alone explained 8% of the total variation (RDA: $p = 0.012$, $F = 5.33$). Species linked to extensive grassland management, such as *Leucanthemum vulgare, Centaurea jacea* and *Stellaria graminea* were more likely to germinate from samples representing horse-grazed paddocks than cattle-grazed paddocks (Figure III-3 b).

In contrast to univariate analysis, patch type did affect species composition in the full species dataset (RDA: $p = 0.006$, F = 0.97). However, it explained only 4% of total variation and was thus less important than the grazing system effect. HNV-species composition was also affected by patch type (RDA: $p = 0.001$, F = 1.11), which explained 8.4 % of the total variation.

LUgd explained 16% of variation in species composition (RDA: $p = 0.013$, F = 3.22). Ordination biplots (Figure III-3) visualize positive correlation of LUgd with *Sagina procumbens, Poa annua, Capsella bursa pastoris* and *Plantago major*. In ordination on the HNV-species subset, grazing intensity was negatively correlated with ecologically valuable species like *Leucanthemum vulgare* or *Centaurea jacea.*

Phosphorous significantly affected the composition of the full data set and was associated with tall patches.

Further, there was no significant effect of site or management parameters on species composition. Neither slope nor mowing or N fertilization significantly explained variance in the species or HNV-species datasets.

Table III-3 Results of the multimodel inference for the effects of grazer species and regime, grassland management and site factors on soil seed bank characteristics parameters on patch scale. The patch × grazing system interaction was included in all models, but did not remain in most confidence sets thus is not included in this table. No significant effect was obtained for the variable cut, therefore results have not been reported in this table. The first column shows the global models R^2GLMM (variance explained by fixed and random effects), the second column gives the averaged intercept representing cattle grazing. Model averaged effect sizes of explanatory variables remaining in the 95% confidence set of submodels (est) are given in the remaining columns along with relative importance values (I) and significance levels obtained by z-statistics shown as * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$. Variables with a relative importance of > 0.5 are shown bold.

Seed bank characteristics patch-scale	**R^2**	Est.	HC			HR			Patch tall			LUgd			Nfert			P_2O_5			pH			slope		
			est	**I**	**p**	**est**	**I**	**p**	**est**	**I**	**p**	**est**	**I**	**p**	**est**	**I**	**p**	**est**	**I**	**p**	**est**	**I**	**p**	**est**	**I**	**p**
Species richness	0.48	16.03	**4.86**	**0.99**	**	**3.94**	**0.99**	*	-0.01	0.22		-0.37	0.3		-0.15	0.22		0.37	0.29		**-1.81**	**0.63**		**6.53**	**1**	***
Shannon E	0.45	0.74	**-0.06**	**0.57**		**-0.06**	**0.57**		**-0.04**	**0.54**		**-0.14**	**0.99**	**	0.01	0.23		0.01	0.23		-0.01	0.26		0.01	0.29	
Seed density	0.39	208.93	35.88	0.3		30.11	0.3		31.78	0.43		**63.36**	**0.62**		-3.43	0.21		11.75	0.26		-9.52	0.24		-4.77	0.22	
HNV species density	0.58	1.36	**8.13**	**1**	***	**8.95**	**1**	***	0.47	0.32		-0.39	0.28		-0.69	0.33		**-3.94**	**0.81**		0.47	0.28		**5.90**	**0.97**	*
LI	0.47	0.59	0.00	0.17		0.01	0.17		0.00	0.23		0.01	0.36		0.01	0.36		0.00	0.22		0.00	0.26		-0.01	0.31	
C Strategy	0.3	27.37	-1.43	0.26		-0.79	0.26		1.28	0.39		-1.26	0.4		**-3.01**	**0.6**		**-3.01**	**0.55**		**-2.68**	**0.54**				
S Strategy	0.4	16.81	-0.06	0.33		0.62	0.33		0.03	0.2		-0.12	0.23		**-2.41**	**0.83**		0.02	0.23		**-1.60**	**0.72**		**2.34**	**0.9**	
R Strategy	0.45	54.18	2.80	0.44		0.80	0.44		-0.94	0.34		1.57	0.43		**6.07**	**0.85**		1.15	0.32		**5.40**	**0.78**		**-3.31**	**0.61**	

Figure III-3 RDA biplots of species data (arrows) and observed explanatory variables (grazer species (HC, HR, C), patch type (short, tall), grazing intensity (LUgd), nitrogen fertilization (Nfert), mowing management (cut), soil pH (pH), extractable soil phosphorus (P) and slope. Biplots visualize RDA on a) full species dataset (0-10 cm, n = 60 samples, 25 best fitting species) and b) HNV species (0-10 cm, n = 60 samples). Biplots are presented in interspecies distance scaling, species scores divided by species standard deviation, so the length of each species arrow expresses how well the ordination diagram approximates that species' values.

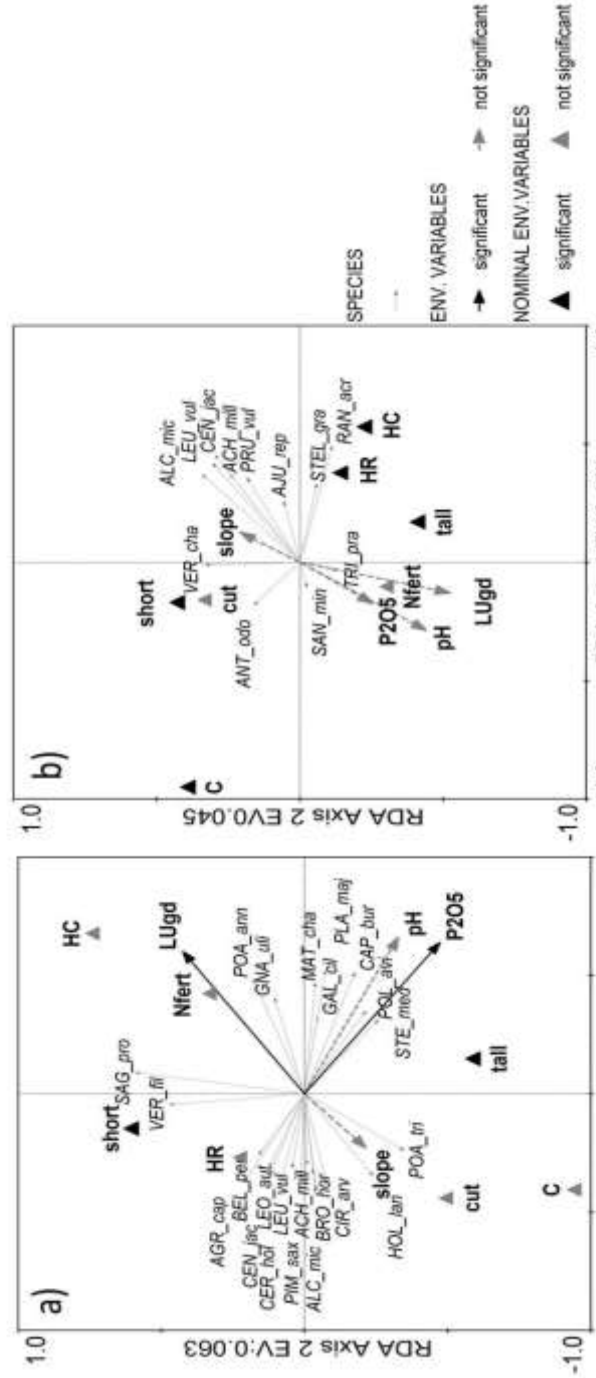

Table III-4 Results of RDA analyses performed on species composition (counts per species) for all species and HNV species exclusively germinated from soil samples (0-10 cm depht). The same set of explanatory variables as in mixed-effects models was used. % = sum of all canonical eigenvalues (i.e. percentage of variance explained), for each explanatory variable LambdaA is given as a value of variance explained due to that variable conditional to the other variables in the model in the specific species dataset, for grazing system as dummy-scaled variable only one value is provided, p= corresponding probability value obtained by Monte-Carlo-permutation test (999 permutations) displayed as * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001 and p ≤ 0.1. Significant variables are shown bold.

	All species		HNV-species	
%	0.251		0.237	
Variable	*LambdaA*	*p*	*LambdaA*	*p*
grazing system	0.03		**0.08**	*
patch type	**0.01**	**	**0.02**	**
LUgd	**0.04**	*	0.02	
Nfert	0.02		0.01	
cut	0.01		0.01	
P2O5	**0.06**	*	0.01	
pH	0.03	.	0.04	
slope	0.03		0.04	

4. Discussion

Compared to other studies in managed grasslands presented in a recent review paper (Kìss *et al.* 2016), seed banks in our study showed a moderate species richness and similar seed density.

4.1 Grazer species

Our study showed significant differences in soil seed banks of horse- compared to cattle-grazed paddocks, with higher overall species richness and density of species indicating a higher ecological value (HNV species) in horse-grazed paddocks. We could confirm this beyond the well-known general effects of topography and soil-related as well as management variables (Auffret *et al.* 2011, Basto *et al.* 2015 a, Basto *et al.* 2015 b, Bischoff *et al.* 2000, Valkó *et al.* 2014, Wellstein *et al.* 2007). Including topographic variables and grassland management parameters as equally weighted variables in the same model enabled us to compare their relative importance for our target variables and clearly highlight the effect of grazer species on paddocks.

Grazing is a well-accepted grassland management tool to enhance aboveground vegetation diversity (Socher *et al.* 2012, Tälle *et al.* 2016, Wrage *et al.* 2011) and to promote the species richness of soil seed banks (Jacquemyn *et al.* 2011). This effect has not yet been linked to horses as a grazer species in managed grasslands. As horses are observed to expose swards to more substantial disturbances due to their selectivity, latrine and locomotion behaviour (Archer 1973, Singer *et al.* 2001) we expected them to differ from cattle in their effect on seed bank density, functional traits, longevity and composition. However, in the present study no such effect was found. Even though there was a remarkable variability between and within seed bank density of horse- and cattle-grazed pastures (Figure III-2), effects were not significant. Furthermore, we obtained no significant difference in share of C-S-R-strategy types. Generally, we found an average share of ruderals over 50% per paddock, for both cattle and horses. This is consistent with findings of Wellstein *et al.* (2007), who observed higher amounts of ruderal species due to grazing and linked that to a higher degree of disturbance. Ruderal species are known for their rapid growth and generative reproduction that enable them to colonize damaged swards (Bekker *et al.* 1997, Thompson *et al.* 1998). Since the grazing impact of horses is more pronounced and degradation of swards is one of the most discussed aspects of horse-grazed paddocks (Bott *et al.* 2013, Kenny *et al.* 2016, Singer *et al.* 2001), more ruderals were expected to emerge from their seed banks. Testing single weed species (*Plantago major, Ranunculus repens, Rumex obtusifolius*), there were no significant differences between horse- or cattle-grazed paddocks either. Therefore, we cannot confirm that seed banks under horse-grazed pastures generally recruit their composition mostly from ruderal weed species per se. The same holds for the longevity of seedbanks. Seed banks in our study did not differ in their persistence between horse- or cattle-grazed pastures. Indeed, supporting these findings, seed bank composition of the full-species dataset was not significantly affected by grazer species (Figure III-3, Table III-3). However, grazer species did affect HNV-species composition. Here, most HNV species were observed under horse-grazed paddocks and negatively correlated with cattle grazed paddocks. Again, this emphasizes the ecological value of those paddocks and horses as grazer species.

4.2 Grazing system and grazing intensity

In horse-grazed paddocks, we found no significant difference between grazing systems, despite slightly higher species richness in continuously grazed paddocks. Grazing system is known to be able to manipulate the grazing impact of horses in aboveground vegetation, because they are forced into different spatial behaviour and more homogenous utilization of swards while grazing (Kenny *et al.* 2016). Therefore, we expected it to be reflected in seed banks as well. However, this effect could not be shown for the soil seed bank in our study.

In our study, neither LUgd nor any of the recorded land-use intensity parameters included in the models significantly affected seed bank characteristics. Generally, grazing intensity is known as one of the important drivers of vegetation characteristics in grazing management (Dumont *et al.* 2012, Socher *et al.* 2012). Former seed bank studies in managed grasslands linked intensification of management, i.e. increased frequency of defoliation, to a decrease of species number in the soil seed banks (Zeiter *et al.* 2013), while abundance of ruderal pioneer species increased (Bekker *et al.* 1997, Wellstein *et al.* 2007). Because of their distinct grazing impact, in grasslands grazed by horses, overgrazing is not rare (Jouven *et al.* 2016, Singer *et al.* 2001). It is noteworthy that in contrast to cattle grazing, horse grazing often involves unusually high grazing intensities. In such cases, paddocks are not primarily used to provide forage but for exercise (Bott *et al.* 2013, Singer *et al.* 2001). In our study, average grazing intensity did not differ between grazing systems, but the variation in stocking rate among horse grazed paddocks was remarkable, ranging from 80 to > 1000 LUgd ha^{-1} a^{-1}. Paddocks exposed to such high stocking rates are mainly used for horses' locomotion behaviour and swards are stressed.

Even though our data per se cannot confirm an effect of land use intensity on species richness, the highest species richness per paddock was observed in paddocks with the lowest grazing and fertilization intensity. Furthermore, species composition was significantly affected by grazing intensity. *Plantago major* and *Poa annua* as species known for their ability to germinate in gaps were positively correlated with LUgd.

4.3 Patch type

Patch types significantly differed in nutrient concentration and compressed sward height (Table III-1) and therefore represented small-scale heterogeneity. However, the seed bank did not reflect this heterogeneity. None of the seed bank target variables was significantly affected by patch type. The floristic contrast between short and tall patches measured as Bray-Curtis-Distance at the paddock scale did not differ between grazer species and grazing regimes. We expected patch type to determine seed bank response. Thus, this finding is quite surprising. Small-scale heterogeneity in conditions of light availability and nutrient concentration, as well as states of reproduction, are known to determine the species composition of aboveground vegetation (Hautier *et al.* 2017, Socher *et al.* 2012). Comparing pastures and meadows, Wellstein *et al.* (2007) found that contrasting habitats at the small scale in pastures favour the establishment in gaps compared to more stable meadow systems and therefore influence seed bank composition and traits.

Our results can be explained in the light of previous observations (Bekker *et al.* 1997) that aboveground vegetation and soil seed banks do not necessarily have to be very similar. Contrary processes might weaken strong quantitative patch effects on soil seed banks. In short patches, seeds might germinate immediately and might not be available to build up seed banks. On the contrary, in tall patches, litter accumulation could work as a seed trap and suppress burying of seeds.

4.4 Relative importance of grazer species in relation to environmental variables

Environmental variables that gained comparable importance for seed bank response in our models were slope and soil pH. Several studies have found seed bank characteristics to be influenced by topographic factors like slope, elevation and soil chemical parameters (Kiss *et al.* 2016). These factors are indirectly linked to land use intensities and (historical) management (Auffret *et al.* 2011, Kampmann *et al.* 2008, Wellstein *et al.* 2007), as topographic and soil-related site characteristics influence the spatial distribution of the management practices within landscapes (Klimek *et al.* 2007, 2008). Even though we set up our study following the quantitative requirements of seed bank studies and designed the sampling scheme to control for different local site conditions, our data still show considerable variation. We attribute this random noise to variabilities in land-use history and site factors that cannot completely be controlled in an observational study.

5. Conclusion

Our study is the first comparison of soil seed banks in grasslands grazed by cattle and horses. Characteristics of soil seed banks reflect the long-term effects of grassland management since they can store seeds for decades and are therefore essential in evaluating sustainable grassland management. We found more species and vital seeds of species indicating a high nature value (HNV species) in horse-grazed paddocks. At the same time, seed banks of cattle grazed paddocks stored similar levels of grazing-related ruderal weed species as those of horse grazed paddocks, regardless of the grazing regime in the latter (continuous vs rotational). The patch grazing effect was not reflected in seed banks, as no differences in seed bank characteristics occurred between patch types. This indicates that higher species richness in soil seed banks of horse-grazed paddocks might be linked to land-use history rather than horses' grazing behaviour. Future studies should target this issue and address the relationship of aboveground vegetation and soil seed banks in different grazing systems. However, based on our results, we can conclude that grazing with horses might indeed play an important role to preserve such species-rich soil seed banks and does not necessarily lead to an accumulation of grazing-related ruderal weed species as suspected. In order to develop sustainable land-use systems promoting plant species richness in managed grasslands, this finding is crucial in the evaluation of horses as grazer species.

6. References

Adler, P., Raff, D., Lauenroth, W., 2001. The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128 (4), 465–479. 10.1007/s004420100737.

Archer, M., 1973. The species preferences of grazing horses. Grass and Forage Sci 28 (3), 123–128. 10.1111/j.1365-2494.1973.tb00732.x.

Auffret, A.G., Cousins, S.A.O., 2011. Past and present management influences the seed bank and seed rain in a rural landscape mosaic. Journal of Applied Ecology 48 (5), 1278–1285. 10.1111/j.1365-2664.2011.02019.x.

Bakker, J.P., Poschlod, P., Strykstra, R.J., Bekker, R.M. & Thompson, K., 1996. Seed banks and seed dispersal: important topics in restoration ecology. Acta botanica neerlandica, 45(4), 461–490.

Bartoń, K. MuMIn: Multi-Model Inference; R package version 1.43.15, 2019. Available online: https://CRAN.R-project.org/package=MuMIn (accessed on 2020-01-20).

Basto, S., Thompson, K., Phoenix, G., Sloan, V., Leake, J., Rees, M., 2015a. Long-term nitrogen deposition depletes grassland seed banks. Nature communications 6, 6185. 10.1038/ncomms7185.

Basto, S., Thompson, K., Rees, M., 2015b. The effect of soil pH on persistence of seeds of grassland species in soil. Plant Ecol 216 (8), 1163–1175. 10.1007/s11258-015-0499-z.

Bekker, R., Verweij, G., Smith, R., Reine, R., Bakker, J., & Schneider, S., 1997. Soil Seed Banks in European Grasslands: Does Land Use Affect Regeneration Perspectives? Journal of Applied Ecology, 34(5), 1293-1310. doi:10.2307/

Bekker, R.M., Bakker, J.P., Grandin, U., Kalamees, R., Milberg, P., Poschlod, P., Thompson, K. and Willems, J.H., 1998, Seed size, shape and vertical distribution in the soil: indicators of seed longevity. Functional Ecology, 12: 834-842. 10.1046/j.1365-2435.1998.00252.x

Bischoff, A., Mahn, E.-G., 2000. The effects of nitrogen and diaspore availability on the regeneration of weed communities following extensification. Agriculture, Ecosystems & Environment 77 (3), 237–246. 10.1016/S0167-8809(99)00104-8.

Borer, E.T., Seabloom, E.W., Gruner, D.S., Harpole, W.S., Hillebrand, H., Lind, E.M., Adler, P.B., Alberti, J., Anderson, T.M., Bakker, J.D., Biederman, L., Blumenthal, D., Brown, C.S., Brudvig, L.A., Buckley, Y.M., Cadotte, M., Chu, C., Cleland, E.E., Crawley, M.J., Daleo, P., Damschen, E.I., Davies, K.F., DeCrappeo, N.M., Du, G., Firn, J., Hautier, Y., Heckman, R.W., Hector, A., HilleRisLambers, J., Iribarne, O., Klein, J.A., Knops, J.M.H., La Pierre, K.J., Leakey, A.D.B., Li, W., MacDougall, A.S., McCulley, R.L., Melbourne, B.A., Mitchell, C.E., Moore, J.L., Mortensen, B., O'Halloran, L.R., Orrock, J.L., Pascual, J., Prober, S.M., Pyke, D.A., Risch, A.C., Schuetz, M., Smith, M.D., Stevens, C.J., Sullivan, L.L., Williams, R.J., Wragg, P.D., Wright, J.P., Yang, L.H., 2014. Herbivores and nutrients control grassland plant diversity via light limitation. Nature 508 (7497), 517–520. 10.1038/nature13144.

Bossuyt, B., Honnay, O., 2008. Can the seed bank be used for ecological restoration?: An overview of seed bank characteristics in European communities. J Veg Sci 19 (6), 875–884. 10.3170/2008-8-18462.

Bott, R.C., Greene, E.A., Koch, K., Martinson, K.L., Siciliano, P.D., Williams, C., Trottier, N.L., Burk, A., Swinker, A., 2013. Production and Environmental Implications of Equine Grazing. Journal of Equine Veterinary Science 33 (12), 1031–1043. 10.1016/j.jevs.2013.05.004.

Burke, M.J.W. and Grime, J.P. 1996. An Experimental Study of Plant Community Invasibility. Ecology, 77, 776-790. 10.2307/2265501

Burnham, K.P.; Anderson, D.R. Multimodel Inference: Understanding AIC and BIC in Model Selection. Sociol. Methods Res. 2004, 33, 261–304.

Burnham, K.P., Anderson, D.R., 2016. Multimodel Inference. Sociological Methods & Research 33 (2), 261–304. 10.1177/0049124104268644.

Castle, M.E., 1976. A simple disc instrument for estimating herbage yield. Grass and Forage Sci 31 (1), 37–40. 10.1111/j.1365-2494.1976.tb01113.x.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D., Lautenbach, S., 2013. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. Ecography 36 (1), 27–46. 10.1111/j.1600-0587.2012.07348.x.

Dumont, B., Rossignol, N., Loucougaray, G., Carrère, P., Chadoeuf, J., Fleurance, G., Bonis, A., Farruggia, A., Gaucherand, S., Ginane, C., Louault, F., Marion, B., Mesléard, F., Yavercovski, N., 2012. When does grazing generate stable vegetation patterns in temperate pastures? Agriculture, Ecosystems & Environment 153, 50–56. 10.1016/j.agee.2012.03.003.

European Horse Network - Environmental and Rural Impact Available online: http://www.europeanhorsenetwork.eu/horse-industry/environmental-and-rural-impact/ (accessed on Dec 30, 2019).

Fenner, M., Thompson, K., 2011. The ecology of seeds, Digital print ed. Cambridge University Press, Cambridge.

Fleurance, G., Farruggia, A., Lanore, L., Dumont, B., 2016. How does stocking rate influence horse behaviour, performances and pasture biodiversity in mesophile grasslands? Agriculture, Ecosystems & Environment 231, 255–263. 10.1016/j.agee.2016.06.044.

Geobasis.nrw 2015. Digital elevation model (DEM50). Available online: https://www.bezreg-koeln.nrw.de/brk_internet/geobasis/hoehenmodelle/gelaendemodell/index.html, (Data accessed 2015-12-22).

German Federal Agency of Nature Conservation 2016: Erfassungsanleitung für den HNV-Farmland-Indikator. Version 7. Bonn

Grime, J.P., 1988. The C-S-R model of primary plant strategies — origins, implications and tests, in: Gottlieb, L.D., Jain, S.K. (Eds.), Plant Evolutionary Biology. Springer Netherlands, Dordrecht, pp. 371–393.

Grueber, C.E.; Nakagawa, S.; Laws, R.J.; Jamieson, I.G. Multimodel inference in ecology and evolution: Challenges and solutions: Multimodel inference. J. Evol. Biol. 2011, 24, 699–711.

Hautier, Y., Isbell, F., Borer, E.T., Seabloom, E.W., Harpole, W.S., Lind, E.M., MacDougall, A.S., Stevens, C.J., Adler, P.B., Alberti, J., Bakker, J.D., Brudvig, L.A., Buckley, Y.M., Cadotte, M., Caldeira, M.C., Chaneton, E.J., Chu, C., Daleo, P., Dickman, C.R., Dwyer, J.M., Eskelinen, A., Fay, P.A., Firn, J., Hagenah, N., Hillebrand, H., Iribarne, O., Kirkman, K.P., Knops, J.M.H., La Pierre, K.J., McCulley, R.L., Morgan, J.W., Pärtel, M., Pascual, J., Price, J.N., Prober, S.M., Risch, A.C., Sankaran, M., Schuetz, M., Standish, R.J., Virtanen, R., Wardle, G.M., Yahdjian, L., Hector, A., 2018. Local loss and spatial homogenization of plant diversity reduce ecosystem multifunctionality. Nature ecology & evolution 2 (1), 50–56. 10.1038/s41559-017-0395-0.

Hongo, A., Akimoto, M., 2003. The role of incisors in selective grazing by cattle and horses. J. Agric. Sci. 140 (4), 469–477. 10.1017/S0021859603003083.

Hunt, R., Hodgson, J.G., Thompson, K., Bungener, P., Dunnett, N.P., Askew, A.P., 2004. A new practical tool for deriving a functional signature for herbaceous vegetation. Appl Veg Sci 7 (2), 163.

Isselstein, J., Kayser, M., 2014. Functions of grassland and their potential in delivering ecosystem services. Grassland Science in Europe 19, 199-214.

Jacquemyn, H., van Mechelen, C., Brys, R., Honnay, O., 2011. Management effects on the vegetation and soil seed bank of calcareous grasslands: An 11-year experiment. Biological Conservation 144 (1), 416–422. 10.1016/j.biocon.2010.09.020.

Jouven, M., Vial, C., Fleurance, G., 2016. Horses and rangelands: Perspectives in Europe based on a French case study. Grass Forage Sci 71 (2), 178–194. 10.1111/gfs.12204.

Kalamees, R., Zobel, M. 1998. Soil seed bank composition in different successional stages of a species rich wooded meadow in Laelatu, western Estonia. Acta Oecologica 19 (2), 175-180. 10.1016/S1146-609X(98)80021-0.

Kampmann, D., Herzog, F., Jeanneret, P., Konold, W., Peter, M., Walter, T., Wildi, O., Lüscher, A., 2008. Mountain grassland biodiversity: Impact of site conditions versus management type. Journal for Nature Conservation 16 (1), 12–25. 10.1016/j.jnc.2007.04.002.

Kenny, LB., Robson, M., 2016. The effects of rotational and continuous grazing on horses, pasture condition, and soil properties. New Brunswick Electronic Theses and Dissertations.

Kiss R., Valko O., Tothmeresz B. and Török P. 2016: Seed bank research in Central-European grasslands - An overview. Seed Banks: Types, Roles and Research. Nova Science Publisher, pp. 1-34.

Kiss, R., Deák, B., Török, P., Tóthmérész, B. and Valkó, O. 2018, Grassland seed bank and community resilience in a changing climate. Restor Ecol, 26, S141-S150. 10.1111/rec.12694

Kleyer, M., Bekker, R., Knevel, I., Bakker, J., Thompson, K., Sonnenschein, M., Poschlod, P., Van Groenendael, J., Klimeš, L., Klimešová, J., Klotz, S., Rusch, G., Hermy, M., Adriaens, D., Boedeltje, G., Bossuyt, B., Dannemann, A., Endels, P., Götzenberger, L., Hodgson, J., Jackel, A.-K., Kühn, I., Kunzmann, D., Ozinga, W., Römermann, C., Stadler, M., Schlegelmilch, J., Steendam, H., Tackenberg, O., Wilmann, B., Cornelissen, J., Eriksson, O., Garnier, E. and Peco, B., 2008, The LEDA Traitbase: a database of life-history traits of the Northwest European flora. Journal of Ecology, 96: 1266-1274. 10.1111/j.1365-2745.2008.01430.x

Klimek, S., Lohss, G., Gabriel, D., 2014. Modelling the spatial distribution of species-rich farmland to identify priority areas for conservation actions. Biological Conservation 174, 65–74. 10.1016/j.biocon.2014.03.019.

Klimek, S., Marini, L., Hofmann, M., Isselstein, J., 2008. Additive partitioning of plant diversity with respect to grassland management regime, fertilisation and abiotic factors. Basic and Applied Ecology 9 (6), 626–634. 10.1016/j.baae.2007.11.005.

Klimek, S., Richter-Kemmermann, A., Hofmann, M., Isselstein, J., 2007. Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors. Biological Conservation 134 (4), 559–570. 10.1016/j.biocon.2006.09.007.

Landesdatenbank Nordrhein-Westfalen Bodennutzungshaupterhebung Available online: https://www.landesdatenbank.nrw.de/ldbnrw/online/data;sid=120F53FEBB1ECAD3E7473A272AFD6B20.ldb1?operation=statistikAbruftabellen&levelindex=0&levelid=1577708904302&index=3 (accessed on Dec 30, 2019)

Lepš, J., Šmilauer, P., 2003. Multivariate analysis of ecological data using CANOCO. Cambridge University Press, Cambridge.

Magurran, A.E., 2011. Measuring biological diversity, 9 [Nachdr.] ed. Blackwell, Malden, Mass. [u.a.].

Marion, B., Bonis, A., Bouzillé, J.-B., 2015. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? Écoscience 17 (3), 229–239. 10.2980/17-3-3315.

Nakagawa, S., Schielzeth, H., O'Hara, R.B., 2013. A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods Ecol Evol 4 (2), 133–142. 10.1111/j.2041-210x.2012.00261.x.

Nolte, S., Esselink, P., Smit, C., Bakker, J.P., 2014. Herbivore species and density affect vegetation-structure patchiness in salt marshes. Agriculture, Ecosystems & Environment 185, 41–47. 10.1016/j.agee.2013.12.010.

Ödberg, F.O., Francis-Smith, K., 1977. Studies on the formation of ungrazed eliminative areas in fields used by horses. Applied Animal Ethology 3 (1), 27–34. 10.1016/0304-3762(77)90068-2.

Oomes, M.J.A. & Ham, M. 1983: Some methods of determinating the seed bank. Acta Bot. Neerl. 32: 244.

Pinheiro, J.; Bates, D.; DebRoy, S.; Sarkar, D.; R Core Team. nlme: Linear and Nonlinear Mixed Effects Models; R package version, 2014. Available online: https://CRAN.R-project.org/package=nlme>

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G., Mills, J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biological Conservation 119 (2), 137–150. 10.1016/j.biocon.2003.11.010.

Scimone, M., Rook, A.J., Garel, J.P., Sahin, N., 2007. Effects of livestock breed and grazing intensity on grazing systems: 3. Effects on diversity of vegetation. Grass and Forage Sci 62 (2), 172–184. 10.1111/j.1365-2494.2007.00579.x.

Singer, J.W.; Bobsin, N.; Kluchinski, D.; Bamka, W.J. Equine stocking density effect on soil chemical properties, botanical composition, and species density. Commun. Soil Sci. Plant Anal. 2001, 32, 2549–2559. 10.1081/CSS-120000390.

Socher, S.A., Prati, D., Boch, S., Müller, J., Klaus, V.H., Hölzel, N., Fischer, M., Wilson, S., 2012. Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. J Ecol 100 (6), 1391–1399. 10.1111/j.1365-2745.2012.02020.x.

Symonds, M.R.E., Moussalli, A., 2011. A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. Behav Ecol Sociobiol 65 (1), 13–21. 10.1007/s00265-010-1037-6.

Tälle, M., Deák, B., Poschlod, P., Valkó, O., Westerberg, L., Milberg, P., 2016. Grazing vs. mowing: A meta-analysis of biodiversity benefits for grassland management. Agriculture, Ecosystems & Environment 222, 200–212. 10.1016/j.agee.2016.02.008.

Ter Braak, CJF, Smilauer, P. 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Ithaca NY.

Ter Heerdt, G.N.J.T., Verweij, G.L., Bekker, R.M., Bakker, J.P., 1996. An Improved Method for Seed-Bank Analysis: Seedling Emergence After Removing the Soil by Sieving. Functional Ecology 10 (1), 144. 10.2307/2390273.

Thompson, K., Bakker, J.P., Bekker, R.M. and Hodgson, J.G., 1998. Ecological correlates of seed persistence in soil in the north-west European flora. Journal of Ecology, 86: 163-169. 10.1046/j.1365-2745.1998.00240.x.

Valkó, O., Tóthmérész, B., Kelemen, A., Simon, E., Miglécz, T., Lukács, B.A., Török, P., 2014. Environmental factors driving seed bank diversity in alkali grasslands. Agriculture, Ecosystems & Environment 182, 80–87. 10.1016/j.agee.2013.06.012.

Vandvik, V., Klanderud, K., Meineri, E., Måren, I.E., Töpper, J., 2016. Seed banks are biodiversity reservoirs: Species-area relationships above versus below ground. Oikos 125 (2), 218–228. 10.1111/oik.02022.

Wellstein, C., Otte, A., Waldhardt, R., 2007 (a). Impact of site and management on the diversity of central European mesic grassland. Agriculture, Ecosystems & Environment 122 (2), 203–210. 10.1016/j.agee.2006.12.033.

Wellstein, C., Otte, A., Waldhardt, R., 2007 (b). Seed bank diversity in mesic grasslands in relation to vegetation type, management and site conditions. Journal of Vegetation Science 18 (2), 153–162. 10.1111/j.1654-1103.2007.tb02527.x.

Wesche, K., Krause, B., Culmsee, H., Leuschner, C., 2012. Fifty years of change in Central European grassland vegetation: Large losses in species richness and animal-pollinated plants. Biological Conservation 150 (1), 76–85. 10.1016/j.biocon.2012.02.015.

Wrage, N., Strodthoff, J., Cuchillo, H.M., Isselstein, J., Kayser, M., 2011. Phytodiversity of temperate permanent grasslands: Ecosystem services for agriculture and livestock management for diversity conservation. Biodivers Conserv 20 (14), 3317–3339. 10.1007/s10531-011-0145-6.

Zeiter, M., Preukschas, J., Stampfli, A., 2013. Seed availability in hay meadows: Land-use intensification promotes seed rain but not the persistent seed bank. Agriculture, Ecosystems & Environment 171, 55–62. 10.1016/j.agee.2013.03.009.

Zuur, A.F., 2009. Mixed Effects Models and Extensions in Ecology with R. Statistics for biology and health. Springer, New York.

General Discussion

This thesis aims to contribute empirical knowledge to the debate on the environmental impact of horse-husbandry as a land-use system by evaluating the quantitative and qualitative relevance of horses in managed grasslands.

To this purpose, we provided a more precise estimate of the share of grasslands managed in horse-husbandry in Germany. We further conducted two observational studies on a total of 156 grazed paddocks on farms in the Rhenish uplands. There, we examined the characteristics of aboveground vegetation and soil seed banks in grasslands grazed by horses under continuous and rotational grazing and compared them to grasslands grazed by cattle, a common grazer species.

In particular, this thesis addressed the following questions:

How much grassland is managed through horse husbandry in Germany?

How important is the patch-grazing effect of horses for species richness in grassland vegetation and soil seed banks?

Do grazing system (grazing with cattle, continuous or rotational grazing with horses) and grassland management considerably affect the species diversity and vegetation characteristics of the aboveground vegetation?

Do grazing system (grazing with cattle, continuous or rotational grazing with horses) and grassland management considerably affect the species diversity and characteristics of soil seed banks?

Quantification of grasslands managed for horses

Horses are recognized to play an increasing role as grazer species in Europe (Bomans *et al.* 2011, Elgåker *et al.* 2008, Jouven *et al.* 2016, Zazada *et al.* 2013). Since empirical information on horse husbandry and its spatial distribution is sparse (Hölker *et al.* 2016), a simple estimation expected 10% of German grasslands to be managed for horses so far. In our study, we were able to provide a more precise estimate, using a three-step approach. Our results indicate that the share of grasslands managed for horses has been systematically underestimated so far. Based on our results, we expect 15-20% of grasslands in Germany to be utilized as pastures or for fodder production within horse husbandry.

However, our estimates considerably depend on the quality of data provided by state authorities. Since there is a lack of systematic data on the horse population, results should be interpreted carefully. A specific phenomenon of horse-husbandry is the expanding private horse keeping sector that is not related to an agricultural context (Hölker *et al.* 2016, Jouven *et al.* 2016). A critical finding in this study is that those small farms quite often manage less than 5 hectares of agricultural area. Therefore they are not recorded as agricultural holdings in the state authorities' surveys. Thus, the importance of the equine sector is being systematically underestimated.

It is essential to consider that the grassland area managed for horses varied remarkably at the federal states' scale. Northrhine-Westfalia, Lower Saxony and the federal city states with a high population density are hot-spots of horse keeping, and therefore, the share of grasslands used in this context is noteworthy. Spatial accumulation of horse husbandry in metropolitan areas is suspected of causing considerable environmental impacts due to overstocking and the specific grazing behaviour of horses (Bomans *et al.* 2011, Elgåker *et al.* 2010, Zasada *et al.* 2013). Our results thus suggest that future research should analyse the stocking rates and shares of grasslands used by horses on an even finer regional scale.

Patch grazing effect

Horses have been recognized to be quite challenging as a grazer species in an agricultural context when compared to cattle due to their distinct patch grazing behaviour. As expected, we found that the specific selective foraging behaviour of the grazer species is reflected in the aboveground vegetation's botanical composition and characteristics.

We could show that horses establish a more pronounced floristic contrast between patch types in the aboveground vegetation than cattle. Since they strongly avoid grazing where they defecate, horses are known to create distinct latrine areas where excreta are accumulated, but vegetation remains ungrazed. This behaviour results in a nutrient transfer, contrasting conditions of light availability and a corresponding vegetation shift between patch types (Adler *et al.* 2001, Archer 1974, Borer *et al.* 2014).

Our study showed such floristic contrast to mediate species richness as well as HNV species richness on paddock scale since more species and more HNV species were found on paddocks with distinct heterogeneity. As plants of different strategy types and demands can coexist nearby, plant species diversity increases with heterogeneity at the paddock scale (Adler *et al.* 2001, Ludvíková *et al.* 2015, Marion *et al.* 2010, Rook *et al.* 2004, Scimone *et al.* 2007). This phenomenon is well described and highlighted as the key driver for biodiversity in managed grasslands at different spatial scales (Hautier *et al.* 2017, Klimek *et al.* 2008, Olff and Ritchie 1998, Wrage *et al.* 2011). However, other studies report an increase in ruderal weed species (Signer *et al.* 2001, Wellstein *et al.* 2007a) due to the grazing effect of horses, which we could not confirm. Future research might address the vegetation composition at the patch scale and frequencies of single species. This would help to better understand foraging preferences and how they can be controlled by management practices and relate to biodiversity benefits. Further, as reported for continuously cattle-grazed experimental paddocks, different stocking rates may considerably affect patch size and shape and subsequently species richness (Ludvíková *et al.* 2015). Therefore it would be very interesting to compare the size and shape of patch types in different grazing systems and grazing-intensity treatments and their subsequent effects on species richness.

We expected this distinct pattern to be reflected in the soil seed bank as well. No such patch effects were found for the viable seeds, though. In contrast to aboveground vegetation, soil seed bank was influenced more strongly by local site conditions and soil chemical parameters (Dölle *et al.* 2009, Hopfensperger 2007) than by patch grazing

Effect of grazing system and grassland management

Comparing the three grazing systems confirmed significantly higher species diversity on paddocks grazed by horses, independent of the applied grazing regime. It is well known that different grazer species can lead to contrasting plant community composition, diversity, and heterogeneity (Marion *et al.* 2010, Rook *et al.* 2004, Sebastià *et al.* 2008). Their two pairs of incisors enable horses to graze very selectively and especially select for grasses (Archer 1976, Bott *et al.* 2013, Hongo and Akimoto 2003) and so to increase the abundance of dicotyledons. In contrast, cattle graze dicotyledons to a greater extent, which is assumed to be due to their different digestive systems (Marion *et al.* 2010, Ménard *et al.* 2002). On continuously grazed paddocks, the horse's selectivity is most pronounced, particularly when grazing is not restricted in time and space (Signer *et al.* 2001). Apart from effects of trampling and nutrient deposition, this selectivity is reported to be the most „challenging" effect of horse grazing in an agronomic context, since grazing-related weeds like *Rumex obtusifolius* benefit and spread (Elsäßer 2010). However, in our study we found no differences in the share of ruderal weed species between the grazing systems. By contrast, continuously grazed horse paddocks contained more species, and especially more species of high nature value, which are mostly dicotyledons.

In an agronomic context, rotational grazing is preferred over continuous grazing to enforce a more uniform utilization of the sward, decrease patch structures and enhance forage quality for the sake of profitability (Kenny *et al.* 2016, Signer *et al.* 2001). Our data show no decrease in floristic contrast under rotational grazing. However, in terms of vegetation composition (strategy types and utilization indicator values), horse paddocks grazed in a rotational grazing system were equivalent to cattle-grazed paddocks. Therefore, a rotational grazing system in horse-grazed paddocks is an appropriate regime to maintain agronomic value, and benefits species richness at the same time. On the contrary, a continuous grazing regime with horses provided more benefits for species richness and HNV species but challenges the individual farmer's knowledge on and sensitivity for sustainable grassland management to avoid overgrazing.

We expected differences in seed bank characteristics between horse-grazed and cattle-grazed paddocks since horses expose swards to stronger disturbances than cattle. In particular, seed banks of horse-grazed paddocks were suspected of storing higher amounts of grazing-related ruderal weed species like *Rumex obtusifolius*. In the soil seed bank, just as in the aboveground vegetation, higher species richness and more High-Nature-Value (HNV) indicator species were found on the horse-grazed paddocks than on the cattle-grazed paddocks, but no differences were found in the vegetation's functional traits, composition and seed bank longevity. The average share of ruderal species in the analysed seed banks was quite high, but this was independent of the applied grazing regime. These findings could indicate that grasslands grazed with horses may have potential to preserve relatively species rich seed banks.

In addition to grazing system, we expected grassland management, and particularly grazing intensity and fertilization, to affect vegetation characteristics (Diaz *et al.* 2007, Dumont *et al.* 2009, Klimek *et al.* 2007, Olff & Ritchie 1998, Socher *et al.* 2013), but our study found no such effects. However, our results should not be misinterpreted in a sense that horse grazing would benefit biodiversity and other ecosystem services per se regardless of stocking rate. Socher *et al.* (2013) emphasize that grazing intensities might vary between livestock types depending on regions, contributing to "idiosyncratic" grazing effects in different geographical regions. Grazing intensities in our studies varied strongly in horse grazed paddocks within our region. Especially in metropolitan areas under certain circumstances grasslands are exposed to extremely high stocking rates in horse keeping (Bomans *et al.* 2011, Zasada *et al.* 2013). There, our results might be invalid.

Future studies might target more intensively grazed grasslands to identify the driving forces for sward degradation vs. biodiversity effect under high stocking density. Additionally, such studies might address the effects of grazing induced nutrient deposition.

Regional context and limitations

We studied managed grasslands in the Rhenish-Uplands in Northrhine-Westfalia, in a regional context. As mentioned, Northrhine-Westfalia is one of the hot-spots of horse keeping in Germany. Grasslands are the major land use in the study region's agricultural context and are known to be of relatively high nature value (German Federal Agency of Nature Conservation, 2016). Therefore, studying the effects of grassland management with horses to maintain grassland diversity seemed promising. However, other studies (Kleijn *et al.* 2009, Socher *et al.* 2013) demonstrated that conservation conclusions require careful consideration of regional peculiarities. Therefore, our results on effects on grazing intensity and fertilizer input should not be generalized across regions. Nevertheless, our study demonstrates that it is possible to manage grasslands in the context of horse husbandry and maintain relatively high nature value at the same time. An implication for future research would be to compare grazer species effects in different geographical regions with varying abiotic conditions, grassland productivity and regional diversity level.

Conclusion

Based on our results, we can conclude that there is a valuable quantitative and qualitative potential of horse husbandry as a land-use system for maintaining diverse and relatively species-rich grassland. Grazing management with horses can be used to affect biodiversity in managed grasslands. In particular, the patch-grazing effect of horses has been identified as a key driver for species richness on paddock scale. However, patch grazing behaviour of horses is more pronounced and therefore challenging for farmers than that of cattle.

This is the first study that quantifies the agricultural area managed through horse-husbandry. Moreover, no study so far has systematically examined the vegetation characteristics in horse-grazed paddocks with a sampling scale equivalent to ours. Therefore, the presented thesis can be considered as step towards a better understanding of grassland management with horses.

However, the quantity of grassland managed for horses and their specific effects as grazer species obtained in our studies clearly highlight the necessity to address further systematic research effort on horse husbandry as a land-use system. A better insight in the complexity of farm structures and management decisions as well as a supra-regional analysis of the effects of horse grazing will be needed to take advantage of its potential to provide ecological benefits in agricultural landscapes.

General Discussion and Conclusion References

Adler, P., Raff, D., Lauenroth, W., 2001. The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128 (4), 465–479. 10.1007/s004420100737.

Archer, M., 1973. The species preferences of grazing horses. Grass and Forage Sci 28 (3), 123–128. 10.1111/j.1365-2494.1973.tb00732.x.

Bomans, K., Dewaelheyns, V., Gulinck, H., 2011. Pasture for horses: An underestimated land use class in an urbanized and multifunctional area. Int. J. SDP 6 (2), 195–211. 10.2495/SDP-V6-N2-195-211.

Borer, E.T., Seabloom, E.W., Gruner, D.S., Harpole, W.S., Hillebrand, H., Lind, E.M., Adler, P.B., Alberti, J., Anderson, T.M., Bakker, J.D., Biederman, L., Blumenthal, D., Brown, C.S., Brudvig, L.A., Buckley, Y.M., Cadotte, M., Chu, C., Cleland, E.E., Crawley, M.J., Daleo, P., Damschen, E.I., Davies, K.F., DeCrappeo, N.M., Du, G., Firn, J., Hautier, Y., Heckman, R.W., Hector, A., HilleRisLambers, J., Iribarne, O., Klein, J.A., Knops, J.M.H., La Pierre, K.J., Leakey, A.D.B., Li, W., MacDougall, A.S., McCulley, R.L., Melbourne, B.A., Mitchell, C.E., Moore, J.L., Mortensen, B., O'Halloran, L.R., Orrock, J.L., Pascual, J., Prober, S.M., Pyke, D.A., Risch, A.C., Schuetz, M., Smith, M.D., Stevens, C.J., Sullivan, L.L., Williams, R.J., Wragg, P.D., Wright, J.P., Yang, L.H., 2014. Herbivores and nutrients control grassland plant diversity via light limitation. Nature 508 (7497), 517–520. 10.1038/nature13144.

Bott, R.C., Greene, E.A., Koch, K., Martinson, K.L., Siciliano, P.D., Williams, C., Trottier, N.L., Burk, A., Swinker, A., 2013. Production and Environmental Implications of Equine Grazing. Journal of Equine Veterinary Science 33 (12), 1031–1043. 10.1016/j.jevs.2013.05.004.

Diaz, S., Lavorel, S., McIntyre, S., Falczuk, V., Casanoves, F., Milchunas, D. G., Skarpe, C., Rusch, H, G., Sternberg, M., Noy-Meir, I., Landsberg, J., Zhang, W., Clark, H. and Campbell, B. D., 2007. Plant trait responses to grazing – a global synthesis. Global Change Biology, 13: 313–341. doi:10.1111/j.1365-2486.2006.01288.x

Dölle, M., Schmidt, W., 2009. The relationship between soil seed bank, above-ground vegetation and disturbance intensity on old-field successional permanent plots. Applied Vegetation Science 12 (4), 415–428. 10.1111/j.1654-109X.2009.01036.x.

Dumont, B., Farruggia, A., Garel, J.-P., Bachelard, P., Boitier, E., Frain, M., 2009. How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? Grass and Forage Science 64 (1), 92–105. 10.1111/j.1365-2494.2008.00674.x.

Elgåker H., Pinzke S., Lindholm G. & Nilsson C., 2010. Horse keeping in Urban and Peri-Urban Areas: New Conditions for Physical Planning in Sweden. Danish Journal of Geography 110 (1), 81–98.

Elsäßer, M. (2010): Typisch Pferdeweide. (K)ein Bild des Jammers. In: Pferdebetrieb.Extra: Pferdeweiden optimal bewirtschaften. 5-9.

German Federal Agency of Nature Conservation 2016: Erfassungsanleitung für den HNV-Farmland-Indikator. Version 7. Bonn

Hautier, Y., Isbell, F., Borer, E.T., Seabloom, E.W., Harpole, W.S., Lind, E.M., MacDougall, A.S., Stevens, C.J., Adler, P.B., Alberti, J., Bakker, J.D., Brudvig, L.A., Buckley, Y.M., Cadotte, M., Caldeira, M.C., Chaneton, E.J., Chu, C., Daleo, P., Dickman, C.R., Dwyer, J.M., Eskelinen, A., Fay, P.A., Firn, J., Hagenah, N., Hillebrand, H., Iribarne, O., Kirkman, K.P., Knops, J.M.H., La Pierre, K.J., McCulley, R.L., Morgan, J.W., Pärtel, M., Pascual, J., Price, J.N., Prober, S.M., Risch, A.C., Sankaran, M., Schuetz, M., Standish, R.J., Virtanen, R., Wardle, G.M., Yahdjian, L., Hector, A., 2018. Local loss and spatial homogenization of plant diversity reduce ecosystem multifunctionality. Nature ecology & evolution 2 (1), 50–56. 10.1038/s41559-017-0395-0.

Hölker, S., Wiegand, K., Spiller, A., Münch, C., 2016. Typologie der deutschen Pferdehaltung - Eine empirische Studie mittels Two-Step-Clusteranalyse. Berichte über Landwirtschaft 94 (3).

Hongo, A., Akimoto, M., 2003. The role of incisors in selective grazing by cattle and horses. J. Agric. Sci. 140 (4), 469–477. 10.1017/S0021859603003083.

Hopfensperger, K.N., 2007. A review of similarity between seed bank and standing vegetation across ecosystems. Oikos 116 (9), 1438–1448. 10.1111/j.2007.0030-1299.15818.x.

Jouven, M., Vial, C., Fleurance, G., 2016. Horses and rangelands: Perspectives in Europe based on a French case study. Grass Forage Sci 71 (2), 178–194. 10.1111/gfs.12204.

Kenny, LB., Robson, M., 2016. The effects of rotational and continuous grazing on horses, pasture condition, and soil properties. New Brunswick Electronic Theses and Dissertations.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E.D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E.J.P., Tscharntke, T., Verhulst, J., 2009. On the relationship between farmland biodiversity and land-use intensity in Europe. Proceedings. Biological sciences 276 (1658), 903–909. 10.1098/rspb.2008.1509.

Klimek, S., Marini, L., Hofmann, M., Isselstein, J., 2008. Additive partitioning of plant diversity with respect to grassland management regime, fertilisation and abiotic factors. Basic and Applied Ecology 9 (6), 626–634. 10.1016/j.baae.2007.11.005.

Klimek, S., Richter-Kemmermann, A., Hofmann, M., Isselstein, J., 2007. Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors. Biological Conservation 134 (4), 559–570. 10.1016/j.biocon.2006.09.007.

Ludvíková, V., Pavlů, V., Pavlů, L., Gaisler, J., Hejcman, M., 2015. Sward-height patches under intensive and extensive grazing density in an Agrostis capillaris grassland. Folia Geobot 50 (3), 219–228. 10.1007/s12224-015-9215-y.

Marion, B., Bonis, A., Bouzillé, J.-B., 2015. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? Écoscience 17 (3), 229–239. 10.2980/17-3-3315.

Menard, C., Duncan, P., Fleurance, G., Georges, J.-Y., Lila, M., 2002. Comparative foraging and nutrition of horses and cattle in European wetlands. Journal of Applied Ecology 39 (1), 120–133. 10.1046/j.1365-2664.2002.00693.x.

Olff, H., Ritchie, M.E., 1998. Effects of herbivores on grassland plant diversity. Trends in Ecology & Evolution 13 (7), 261–265. 10.1016/S0169-5347(98)01364-0.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G., Mills, J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biological Conservation 119 (2), 137–150. 10.1016/j.biocon.2003.11.010.

Scimone, M., Rook, A.J., Garel, J.P., Sahin, N., 2007. Effects of livestock breed and grazing intensity on grazing systems: 3. Effects on diversity of vegetation. Grass and Forage Sci 62 (2), 172–184. 10.1111/j.1365-2494.2007.00579.x.

Sebastià, M.-T., Bello, F. de, Puig, L., Taull, M., 2008. Grazing as a factor structuring grasslands in the Pyrenees. Appl Veg Sci 11 (2), 215–222. 10.3170/2008-7-18358.

Singer, J.W.; Bobsin, N.; Kluchinski, D.; Bamka, W.J. Equine stocking density effect on soil chemical properties, botanical composition, and species density. Commun. Soil Sci. Plant Anal. 2001, 32, 2549–2559. 10.1081/CSS-120000390.

Socher, S.A., Prati, D., Boch, S., Müller, J., Klaus, V.H., Hölzel, N., Fischer, M., Wilson, S., 2012. Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. J Ecol 100 (6), 1391–1399. 10.1111/j.1365-2745.2012.02020.x.

Socher, S.A., Prati, D., Boch, S., Müller, J., Baumbach, H., Gockel, S., Hemp, A., Schöning, I., Wells, K., Buscot, F., Kalko, E. K.V., Linsenmair, K. E., Schulze,E-D., Weisser, W.W., Fischer, M. 2013. Interacting effects of fertilization, mowing and grazing on plant species diversity of 1500 grasslands in Germany differ between regions. Basic and Applied Ecology,14 (2), Pages 126-136. 10.1016/j.baae.2012.12.003.

Wellstein, C., Otte, A., Waldhardt, R., 2007 (a). Impact of site and management on the diversity of central European mesic grassland. Agriculture, Ecosystems & Environment 122 (2), 203–210. 10.1016/j.agee.2006.12.033.

Wrage, N., Strodthoff, J., Cuchillo, H.M., Isselstein, J., Kayser, M., 2011. Phytodiversity of temperate permanent grasslands: Ecosystem services for agriculture and livestock management for diversity conservation. Biodivers Conserv 20 (14), 3317–3339. 10.1007/s10531-011-0145-6.

Zasada, I., Berges, R., Hilgendorf, J., Piorr, A., 2013. Horsekeeping and the peri-urban development in the Berlin Metropolitan Region. Journal of Land Use Science 8 (2), 199–214. 10.1080/1747423X.2011.628706.

Summary

Grazing is a well known management tool to increase and maintain species richness in grasslands. Generally, livestock grazing enhances sward structural heterogeneity due to dietary choices, trampling, nutrient cycling and propagule dispersal, resulting in a stable mosaic of grazed and avoided sward patches. This enables grassland species of different demands to establish in close proximity, hence increasing species diversity at the paddock scale. However, dealing with phytodiversity in grazed grassland, it is important to consider the type of grazing livestock. Grazer species are known to differ in their grazing behaviour, which can lead to differences in sward structure and vegetation characteristics.

In Middle and Western Europe, cattle are considered the most common grazer species in grasslands and several studies have targeted their (patch-) grazing effect for biodiversity benefits. For several decades, horses have played an increasing role as a grazer species in managed grasslands, too. However, the share of grasslands managed for horses and the horses' effects on grassland vegetation remain unclear. Various studies address horses' grazing effects in nature conservation projects, but only little systematic research has been conducted on their typical grazing effects on vegetation and diversity in agriculturally managed grasslands, so far. Given this background, the aim of this thesis was to estimate the share of grasslands managed in the framework of horse husbandry in Germany (Chapter 1) and to investigate the grazing effects of horses compared to those of cattle on aboveground vegetation characteristics (Chapter 2) as well as on soil seed banks (Chapter 3) in agriculturally managed grasslands.

So far, information on the share of grasslands managed with horses in Germany has been based on a rule-of-thumb estimate of approximately 10% of the grassland area. In Chapter 1, this estimate was refined following two approaches. First, in a theoretical approach, the forage demand of horse stock was calculated for each federal state in Germany. Given this information, the surface area required to meet that demand was estimated using the average productivity of grasslands in each federal state. Stepwise sensitivity analyses were performed for different demand and productivity scenarios. In a second approach, real-life data on grassland management of 700 horse keepers were collected via online survey. Joining these data with information on horse population and grassland productivity allowed a more realistic estimation. Our results point out that the grassland area managed for horses has been systematically underestimated, since we can conclude that 15-20% of the German grasslands are managed for horse husbandry. In general, stocking rates were relatively low and grassland area per farm quite small compared to typical dairy farming systems. Therefore, we conclude that horse husbandry can be considered to play an important role for maintening extensive and small scattered grasslands.

Grazer species have been observed to differ in their grazing effects on grassland vegetation. Still, surprisingly little systematic research has addressed the grazing effect of horses or compared it to that of cattle. To answer the questions whether grazer species and grazing management differ in their effects on managed grassland, an observational study (comprising Chapters 2 and 3) was conducted on farms in the Rhenish Uplands in Germany in the years 2012-2014. A stratified triplet design allowed us to directly compare grassland vegetation of paddocks grazed by cattle or horses and to distinguish effects of grazing system (cattle grazing, rotational grazing with horses, continuous grazing with horses) from those of site conditions and grassland management. Information on grassland management was obtained through standardized interviews.

In Chapter 2, aboveground vegetation was monitored on short, grazed and tall, avoided patches two times at a total of 156 paddocks arranged in 28 triplets. More species and more High-Nature-Value (HNV)-Indicator species were found on horse-grazed paddocks than on cattle-grazed paddocks in the aboveground vegetation. The vegetation composition was significantly different between continuous and rotational grazing of horses; the later being similar to that of paddocks grazed by cattle. Significant differences were found for Grime's strategy types and grassland utilization values between continuously grazed horse paddocks and cattle-grazed paddocks. The floristic contrast between short and tall patches was shown to be stronger on horse grazed paddocks and to be the important driver of species richness on paddock scale.

For Chapter 3, a subset of 30 paddocks was chosen in 2012 to analyse the long-term effects of the different grazer species to be found in soil seed banks. Soil samples were collected in short and tall patches and seed bank analysis was performed via germination method. Since horses are known to expose swards to stronger disturbances due to their distinct grazing behaviour, we expected differences in seed bank characteristics between horse-grazed and cattle-grazed paddocks. Here, more species and more vital seeds of HNV Indicator species emerged from samples of the horse-grazed paddocks compared to the cattle-grazed paddocks. However, we found no differences between grazing systems in the seed bank's functional traits, composition and seed bank longevity.

In conclusion, horses play an important role as grazer species in managed grasslands in Germany. They do not merely claim a significant share of agricultural surface area but are of high potential for biodiversity in agricultural landscapes.

List of Publications

Peer-reviewed journal articles

Hüppe, C., **Schmitz, A.**, Tonn, B., Isselstein, J., 2020: The Role of Socio-Economic Determinants of Horse Farms for Grassland Management, Vegetation Composition and Ecological Value. Sustainability 2020, 12(24), 10641¸ https://doi.org/10.3390/su122410641

Schmitz, A., Isselstein, J., 2020. Effect of grazing system on grassland plant species richness and vegetation characteristics: Comparing horse and cattle grazing. Sustainability 12, 3300, 1-17; https://www.mdpi.com/2071-1050/12/8/3300; doi:10.3390/su12083300

Schmitz, A., Tonn, B., Schöppner, A.K., Isselstein, J., 2020. Using a citizen science methodology with German horse owners to study the locomotion behaviour of horses on pasture. Sustainability 12, 1835, 1-14, https://www.mdpi.com/2071-1050/12/5/1835; doi:.org/10.3390/su12051835

Schöppner, A.-K., Tonn, B., Isselstein, J., **Schmitz, A.**, 2020: Einfluss von Pferdetyp und Weidesystem auf das Bewegungsverhalten von Pferden auf der Weide – Short Communication. Züchtungskunde, 92, 26-301.

López-Sánchez A., Perea R., Roig S., Isselstein J., **Schmitz A.**, 2020. Challenges on the conservation of traditional orchards: tree damage as an indicator of sustainable grazing. Journal of Environmental Management, 257, 110010. https://doi.org/10.1016/j.jenvman.2019.110010

Paesel, H., **Schmitz, A.**, Isselstein, J. 2018: Heterogeneity and diversity of orchard grassland vegetation in Central Germany: role of tree stock, soil parameters and site management. Agroforest Syst. https://doi.org/10.1007/s10457-017-0178-2

Schmitz, A., Isselstein, J., 2018: Wieviel Grünland wird in Deutschland für Pferde genutzt? Versuch einer Quantifizierung anhand von Bestands- und Praxisdaten. Berichte über Landwirtschaft 96, 1-31, ISSN 2196-5099, http://dx.doi.org/10.12767/buel.v96i1.186.g379

Conference proceedings

Schmitz, A., Lott, S. Wellinghoff, J., Leuschner, C., Isselstein, J., 2020: Prospect of field margins to reintroduce plant species richness in intensive grassland production. Grassland Science in Europe, 25, 556-558.

Schmitz, A., Morgenstern, L., Wiegmann, H.-C., Isselstein, J., 2019. Einstellungen von Landwirt*innen zu biodiversitätsfördernden Maßnahmen im Kontext intensiver

Grünlandwirtschaft. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 20, 145-148.

Schmitz, A., Isselstein, J. 2018: Evaluation of Horse farmer's knowledge and attitude towards grassland management. Grassland Science in Europe Vol. 23

Hoffmeister, D., Curdt, C., Lussem, U., Tonn, B., **Schmitz, A**. 2018: Feasibility of UAV based low-cost monitoring in a horse grazed grassland. Grassland Science in Europe Vol. 23

Schmitz, A., Brinsa, C., Hüppe, C., Dingfeld, J., Florek, J., Maulhardt, J., Recktenwald, C. und Isselstein, J. 2018: „Wie gut ist mein Heu?" – Zu Raufutterqualitäten in der pferdehaltenden Praxis. Kongressband Göttinger Pferdetage 2018.

Schmitz, A., Hüppe, C., Recktenwald, C., Dingfeld, J., Brinsa, C., Florek, J., Maulhardt, J., Isselstein, J. 2017: „50 shades of green". -Qualität und floristische Diversität von Heu der pferdehaltenden Praxis. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 61, S. 227–229.

Schmitz A., Hüppe C., Recktenwald C., Dingfeld J., Brinsa C., Florek J., Maulhardt J., Isselstein J. 2017: „Die neue Kuh?!" - zur Bedeutung und Charakteristika der Grünlandbewirtschaftung durch Pferdehalter. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 61, S. 223-226.

Morgenstern L., **Schmitz A.**, Tichter A., Isselstein J 2017: Zusammenhang zwischen Betriebsstruktur und Milchleistung ökologisch wirtschaftender Betriebe und der Pflanzenartenvielfalt des Grünlands. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 61, S. 111-116.

Schmitz A. , López-Sánchez A., Roig S., Isselstein J .2016: Grazer effects on plant species richness and tree healthiness within orchard pastures. Grassland Science in Europe, Vol. 21

Schmiedgen, A., **Schmitz A.** , López-Sánchez A., Roig S., Isselstein J . (2016): Tree-livestock interaction promotes nutrient shift and plant species richness in orchard pastures. Grassland Science in Europe, Vol. 21

Schmitz, A.; Isselstein, J. 2016: Nachhaltige Beweidung von Streuobstgrünland: Zum Einfluss unterschiedlicher Weidetiere (Rind, Schaf, Pferd) auf die pflanzliche Artenvielfalt und Baumgesundheit. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 60, S. 175-178.

Paesel, H.; **Schmitz, A.**; Isselstein, J. 2016: Einfluss des Baumbestands, der Bodeneigenschaften und der Flächennutzung auf die Diversität und Heterogenität der Grünlandvegetation in Streuobstgrünland. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 60, S. 93-96.

Langner, S.; **Schmitz, A.**; Tonn, B.; Ebeling, D.; Isselstein, J. 2016: Auswirkungen von Beweidungsintensität auf Struktur und Artenzusammensetzung der Diasporenbank einer heterogenen Rinderstandweide. In: Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 60, S. 171-174.

Schmitz, A., Isselstein, J. 2015: Besser als ihr Ruf? Artenvielfalt und Vegetationskomposition von Pferdeweiden im direkten Vergleich zu Rinderweiden der Praxis. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 59, S. 208-211.

Schmitz, A., Isselstein, J. 2014: Ballungsraumnähe und Besatzstärke beeinflussen maßgeblich die Vielfalt der Vegetation des Grünlands pferdehaltender Betriebe. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 58, S. 173-176.

Schmitz, A., Isselstein, J. 2014: Artenvielfalt auf Pferdeweiden – eine Frage des Weidemanagements? In: Tagungsband zur 1. Internationalen Netzwerktagung Pferdewissen.

Schmitz, A., Isselstein, J. 2013: Effects of management on vegetation structure in horse pastures. In: The role of grasslands in a green future. Grassland Science in Europe, Vol. 18; p 394-396.

Schmitz, A., Isselstein, J. 2013: Einfluss des Weidemanagements auf den Leguminosenbestand von Pferdeweiden. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 57, S.190-193.

Schmitz, A.; Schmidt, A.L. und Isselstein, J. 2013: Diasporenbank unter Pferde- und Rinderweiden im Vergleich. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 57, S. 86-92.

Schmitz, A., Isselstein, J. 2013: Einfluss des Weidemanagements auf die Vegetationsstruktur und pflanzliche Artenvielfalt von Pferdeweiden. Kongressband Göttinger Pferdetage 2013.

Schmitz, A., Isselstein, J. 2012: Effekte des Managements auf die Vegetationsstruktur von Pferdeweiden. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau 13, 182-187.

Acknowledgements Danksagung

Diese letzten beiden Seiten meiner Dissertation richten sich an die vielen guten Menschen, die mich auf dem langen Weg der letzten Jahre und während der gesamten kuriosen Laufbahn begleitet, gefordert und unterstützt haben. Euch allen gilt mein aufrichtiger und herzlicher Dank, alleine hätte ich es nicht geschafft.

Als allererstes gilt mein uneingeschränkter Dank Prof. Dr. Johannes Isselstein: Ohne Dein Zu- und Vertrauen hätte ich mich gar nicht erst getraut. Ich danke Dir für Inspiration, immer konstruktive Unterstützung und vor allem Verständnis auch auf langen steinigeren Pfaden. Ich bin so dankbar für all das was ich in den vergangenen Jahren erleben und mitgestalten durfte. Das ist sicher nicht selbstverständlich.

Prof. Dr. Nicole Wrage-Mönnig gebührt großer Dank für die Übernahme des Koreferats. Deine ansteckende Begeisterung für Wissenschaft und so positive Einstellung wird mir immer Inspiration und Vorbild sein. Auch Prof. Dr. Martina Gerken sei herzlich gedankt für viele konstruktive Gespräche bereits seit dem Masterstudium und in der Rolle der Drittgutachterin.

Die Deutsche Bundesstiftung Umwelt hat mein Promotionsprojekt im Rahmen des Promotionsstipendienprogrammes finanziert. Ohne diese Finanzierung wäre die Arbeit so nicht möglich gewesen. Das Besondere am Promotionsstipendium ist aber die ideelle Förderung in regelmäßigen Kolloquien und Seminaren an wundervollen Orten in ganz Deutschland. Besonderer Dank gilt daher der DBU und Dr. Hedda Schlegel-Starmann, die mir immer eine konstruktive und motivierende Ansprechpartnerin und Betreuerin war.

Von Beginn an durfte ich auf Tagungen und Veranstaltungen so viele gute Kontakte knüpfen. An dieser Stelle sei denjenigen gedankt, die jährlich mit konstruktiven und anregenden Diskussionen beigetragen haben.

Ganz besonderer Dank gilt all den Landwirten und Pferdehaltern, ohne die die vorliegende Arbeit nicht möglich gewesen wäre. Deren Flächen ich untersuchen durfte und die sich so rege an unseren Projekten beteiligen, jedem einzelnen sei herzlich gedankt. Unsere Pferde-Forschung lebt von der Praxis. Es braucht vielerlei Hinsicht das Mitwirken der Praxis, der Verbände und Landwirtschaftskammern. Ich habe dieses Miteinander in den letzten Jahren als ungemein fruchtbar empfunden und möchte den vielen Kollegen für viele konstruktive Gespräche und Diskussionen danken. Besonderer Dank gilt Sonja Schütz (VfD), die sich unermüdlich im Dienste des Naturschutzes in der Pferdehaltung engagiert, sowie Hubert Kivelitz (LWK NRW), der mich seit Jahren in vielen, vielen Gesprächen, Diskussionen und Exkursionen ausgesprochen motiviert und unterstützt hat.

Während der Datenerhebung im Feld hatte ich fleißige Helfer und „Bodyguards“. Marcel „KoMa“ Komischke, Adam Cymmer und Carlo Wissmann meinem lieben, tapferen Patenkind sei sehr gedankt für anpackende Hände und wachsame Augen.

Barbara Hohlmann sei vielmals gedankt für ihre Unterstützung bei Probenlogistik und Material. Andreas Henn sei herzlich gedankt für die fachkundige und augenzwinkernde Unterstützung im Gewächshaus mit vielen Nützlingen. Ebenso danke ich den vielen herzlichen Kollegen auf dem Gewächshausgang – für helfende Hände und großartige Momente voller Lachen. Hans-Georg Stroh sei vielmals gedankt für seine botanische Expertise im Gewächshaus und für alles was ich von ihm bislang in Sachen Botanik lernen durfte. Ina Spiegel und Anna-Lena Wiedermann gebührt Dank für jegliche Unterstützung im Gewächshaus.

Trotz aller Freude an der Sache waren die letzten Jahre beileibe nicht immer einfach. Ich bin unendlich dankbar dafür, auf dem etwas kuriosen Weg von so vielen guten Menschen begleitet worden zu sein. Unter Geographen, im Philosophikum, unter Pferdewissenschaftlern und im Stallbau. Und ich bin mehr als froh in vielen meiner Göttinger Kollegen wunderbare Freunde gefunden zu haben. Es sind mittlerweile mehrere „Generationen“, im Grasland, der Wildbiologie, der Agronomie und der

Ökosystemforschung - alle mit Namen zu nennen würde Seiten füllen. Ihr alle habt einen Beitrag geleistet und ich möchte mich von Herzen bei Euch bedanken. Dafür, dass Ihr mit jedem guten Wort, jedem Code, jeder Schokolade, jedem Bier/Wein/Schnapps, der verdammt nochmal richtigen Achterbahn, jedem echten Lachen und jedem Beat zur Stelle seid.

Ganz besonders danke ich denjenigen, ohne die ich es nicht geschafft hätte und da sei zu allererst Dr. Bettina Tonn genannt. Ohne Deine Freundschaft, Deine Nerven, Deine Redaktion, Deinen unerschütterlichen Glauben und beinharten Humor – ich mag mir nicht vorstellen, wie es ohne Dich gewesen wäre. Ohne Dr. Sabrina Jerrentrupp hätte ich es gar nicht erst gewagt und ohne Dr. Laura Breitsameters weise Worte, hätte ich nicht durchgehalten. Ich danke Euch von ganzem Herzen.

Dr. Thorsten Scheile und Dirk „Kaptain" Koops, meinem allerliebsten Heide-Pack für, ach ihr wisst schon, alles. All den Quatsch, jedes Snickers und jede Achterbahn. Ihr seid unbezahlbar und unersetzlich.

Dr. Sara Heshmati meine gute Seele, ich danke Dir für Deine Freundschaft und jede gehaltene Hand.

Ich bin dankbar für eine so vielfältige und freundliche Arbeitsgruppe mit großartigen Kollegen. Eine solche Atmosphäre ist nicht selbstverständlich und ich danke Euch für alle guten und gemeisterten Momente. Dr. Monika Carlson, Dr. Ute Petersen, Doro Ebeling, Dr. Aida Lopez-Sanchez, Sala Lamega, Rahel Sonnenschein Sutterlütti, Manu Heinze, Isabelle Nölke und Dr. Martin Komainda danke ich von Herzen für jedes gute Gespräch, jede Unterstützung, jedes Lachen und Eure Freundschaft. Meinen zauberhaften Bürokolleginnen über die Jahre, Dr. Friede Riesch, Sophie Langner, Heike Paesel und Dr. Juliane Horn danke ich besonders für Inspiration und jeden versüssten Alltag– und für die ein oder andere Lachfalte mehr, ich danke Euch sehr. Dr. Laura Sutcliffe sei gedankt für super produktives Schreiblabor in Ellenbergs Dachgeschoss, Sally Lott für die immer gute Zusammenarbeit in hammerharten wie fabelhaften Feldkampagnen im Norden, sowie Lucie Morgenstern für die allerbeste Unterkunft und wunderbar verquatschte Abende.

Während der Promotionsjahre haben eine ganze Reihe von wundervollen Studierenden die Lehrerin in mir gekitzelt. Einige begleiten mich nach wie vor, und es ist eine Freude Euch als motivierte junge Wissenschaftler im Kollegium und anderswo zu erleben, - Friederike Sieve, Cecilia Hüppe, Ann-Kathrin Schöppner, Ihr macht mich wahnsinnig stolz.

Adam Cymmer danke ich aufrichtig für die guten Momente über lange Jahre .
Ganz besonderer Dank gilt Bettina Krudewig, meine Beste seit Jahren für Alles, Alles, Alles und Immer.

Ich danke zuletzt den allerwichtigsten Menschen - meiner Familie. Meinen Eltern, meinen Schwestern und ihren Familien. Ohne Euch und Eure Unterstützung wäre vieles nicht möglich gewesen. Ich bin Euch so unendlich dankbar für alles Gute in jedem Moment. Und meinen geliebten Ponies, den isländischen sturen Felsen in der Brandung.

Et es wie et es, et kütt wie et kütt, äver de Haupsaach es, et Hätz es jot!

Und finally: Ohne Dich geht GAR nichts. Danke, **Kaffee**.

“Und man sieht mir die letzten Jahre an. Ungesunder Lifestyle.
Der schlechte Schlaf, jede durchzechte Nacht.
Jedes echte Lachen. Alles hinterlässt etwas.
Strich für Strich, weil du gelebt hast.
Kein unbeschriebenes Blatt mehr, nicht weit vom Stamm gefallen.
Alles anders machen wollen und scheitern, ist wohl ganz normal.
Wie wir wohl drauf sind wenn wir älter sind?
Ob wir uns wundern, dass die gute Zeit so schnell verging?
Man sieht uns alles an, auch wenn wir uns gut gehalten haben.

So stehn wir da, Landkarten im Gesicht. Viel rumgekommen. Nur Angsthasen tun das nicht.
Und was wir auch tun, um es zu verbergen. Man wird sehen, ob wir getanzt haben
oder nicht.“

Moop Mama *face dance* 2017, Lyrics by Lucas Roth

Erklärungen

1. Hiermit erkläre ich, dass diese Arbeit weder in gleicher noch in ähnlicher Form bereits anderen Prüfungsbehörden vorgelegen hat.

   Weiter erkläre ich, dass ich mich an keiner anderen Hochschule um einen Doktorgrad beworben habe.

   Göttingen, den ....

   ....
   (Unterschrift)

2. Hiermit erkläre ich eidesstattlich, dass diese Dissertation selbständig und ohne unerlaubte Hilfe angefertigt wurde.

   Göttingen, den ....

   ....
   (Unterschrift)