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Review: Effects of mowing and grazing on plant diversity and vegetation composition in Central European semi-natural wet grasslands

Review: Wirkung von Mahd und Beweidung auf Diversität und Komposition der Vegetation mitteleuropäischer semi-natürlicher Feuchtgrünländer

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Abstract

Extensive land-use is crucial to conserve semi-natural wet grasslands, which are hotspots of Central European biodiversity and a habitat for numerous rare species. Yet, as extensive land-use became economically unviable, insufficient or inappropriate management increasingly threatens these habitats, resulting in habitat degradation. Ongoing species losses, also in managed wet grasslands, suggest that current regimes might need optimization. Efficient conservation of remaining wet grasslands requires management concepts that are both cost-effective and sustainable, and simultaneously ensure high biodiversity.

While annual mowing is widely used and generally considered suitable, grazing is viewed more critically and remains less commonly implemented. However, grazing is gaining attention as a cost-effective alternative that additionally ensures biomass utilization. For both mowing and grazing, uncertainties remain concerning optimal intensity, timing, techniques or livestock type, particularly in interaction with site-conditions.

We reviewed 60 peer-reviewed studies conducted in 16 European countries to assess the effects of mowing and grazing on species diversity and vegetation composition in wet to moist, oligo- to eutrophic grasslands. We compared these findings to selected conservation-oriented (German-language, mostly non-peer-reviewed) management recommendations. Finally, we evaluated critical factors for successful conservation and identified research gaps.

Mowing had increasingly positive effects with up to two annual cuts, especially in meso- to eutrophic grasslands. Negative effects were often linked to suboptimal timing, affecting species disproportionately. Spatial and temporal diversification of mowing was beneficial to balance necessary nutrient depletion with protection of sensitive species.

Grazing, was frequently achieving conservation goals, too. Yet, grazing was described as less predictable and more complex due to multiple interacting factors. Continuous monitoring and flexible on-demand management was essential for successful grazing.

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Across both regimes, high soil moisture, increasing risks for soil compaction by machinery or trampling, and fine-scale heterogeneity in productivity and disturbance sensitivity posed challenges. Mosaic mowing or adaptive grazing through herd management or fencing effectively minimized these risks and maximized biodiversity outcomes.

In sum, both mowing or grazing can effectively maintain species-rich wet grasslands, but grazing only if funding and logistics allow continuous adaptations to site-conditions. Indeed, a combination of both regimes holds the highest conservation potential, because their flexible, complementary use supports a wider range of species and mitigates regime-specific limitations such as biomass utilization in mowing or uneven vegetation structures under grazing.

Keywords: *Calthion*, *Caricion*, Conservation, Grazing, Management, Meadow, *Molinion*, Mowing, Pasture

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

Semi-natural wet grasslands are among the most species-rich grassland communities in Central Europe (Dengler et al. 2020, Janssen et al. 2016). They are vital for conservation as habitats for numerous specialized species (Ryslavy et al. 2020, Schneider et al. 2023, Straubinger et al. 2023) and provide key ecosystem services like carbon sequestration (Soussana et al. 2007) and water retention (Zhao et al. 2020).

Species-rich wet grasslands developed through traditional extensive (i.e. low input, low output; Lepš 1999) land use on moist or wet soils with organic or mineral topsoil layers (Ellenberg et al. 2010). Until the 18th century, they were typically managed by combinations of mowing and grazing (Middleton et al. 2006, Kapfer 2010b, Messlinger et al. 2018, Strohwasser 2018, Biró et al. 2019). Over the past two centuries, grazing became less common, and wet grasslands have been primarily mown for hay or bedding material (Dierschke & Briemle 2008, Kapfer 2010a, Poschlod et al. 2009).

Following agricultural intensification, extensive wet grassland management has largely become economically unviable (Zimmermann 2016, Donath et al. 2021). This is due to wet grasslands' relatively low forage value (Burkart et al. 2004, Wagner & Britz 2024, cf. Bowskill et al. 2023), the declining demand for bedding material in livestock farming (Kiessling & Zehm 2014), and the difficulty of accessing wet soils with heavy machinery (Närmann et al. 2021, Bowskill et al. 2023). Consequently, both abandonment and agricultural intensification (e.g., via drainage) have resulted in substantial habitat loss (Poschlod et al. 2009, EEA 2020).

Nowadays, the remaining wet grasslands are among the most endangered habitat types in the EU (Janssen et al. 2016, Brondízio et al. 2019, Schneider et al. 2023) and face ongoing declines in habitat quality and species richness (Janssen et al. 2016, Metzing et al. 2018, Diekmann et al. 2019, Klinkovská et al. 2024). Besides hydrological deterioration (Joyce et al. 2016, Dengler et al. 2020, Mauchamp et al. 2024) and eutrophication (Bergamini et al. 2009, Diekmann et al. 2019), inappropriate management is considered a main threat (McGinlay et al. 2017, Messlinger et al. 2018, Herzon et al. 2022, NLWKN 2024).

While extensive biomass removal is a prerequisite to conserve species-rich, semi-natural wet grasslands (Ellenberg et al. 2010), this is now rarely integrated in sustainable socio-economic cycles (Kiessling & Zehm 2014, Herzon et al. 2022). The ecosystem service of *biomass provisioning* has become a disservice (Haines-Young & Potschin 2018), as the labor- and cost-intensive removal of biomass now typically requires financial subsidies or other support for conservation-oriented management (Hansson et al. 2012, Schneider et al. 2023, NLWKN 2024). Moreover, the optimal intensity of mowing and grazing must be adjusted to the site-specific productivity, vegetation composition, and conservation objecttives (Grime 1973, Dierschke & Briemle 2008). As a result, there is frequent need for cost-effective, sustainable management concepts that simultaneously ensure the highest possible conservation value.

Fluctuating groundwater levels and periodically waterlogged soils pose another challenge in wet grasslands. The intensity, timing, and technique of mowing or gazing must be adjusted to prevent sward damage and soil compaction (Stammel & Kiehl 2004, Närmann et al. 2021). In mowing regimes, the mowing frequency and timing influence total and per-event nutrient removal (Bowskill et al. 2023) and affect species selectively by interfering with different stages of their life cycles. Similarly, mowing should be scheduled during drier periods of low groundwater levels and conducted with appropriate equipment to protect sensitive (e.g., periodically inundated) areas (Dierschke & Briemle 2008). In grazing regimes, key factors to optimize management include stocking rates, grazing duration and timing (Bunzel-Drüke et al. 2019, Di Virgilio et al. 2019), and livestock type, along with species-specific foraging behavior (Rook et al. 2004) and trampling effects (Biró et al. 2019, Sienkiewicz-Paderewska et al. 2020). Stocking rates and grazing periods must be adapted to site productivity and grazing tolerances of typical flora and fauna (Di Virgilio et al. 2019). Additionally, selective foraging behavior can create heterogeneous vegetation structures with simultaneous over- and under-grazed areas (Metera et al. 2010, Schaich & Barthelmes 2012, Mirski 2022). Thus, grazing often needs additional fencing or herding techniques (‘adaptive grazing’) to align with conservation objectives (Di Virgilio et al. 2019).

Annual mowing in summer is often regarded the optimal management for species-rich wet meadows (Burkart et al. 2004, Dierschke & Briemle 2008, Schneider et al. 2023) and predominantly implemented in Central Europe (Rasran et al. 2007a, Hejcman et al. 2013, Kapfer, 2010a, Tälle et al. 2016, Dullau et al. 2019, Hartmann & Metz 2025). In contrast, extensive grazing of wet grasslands remains rare (Zahn 2014, Biró et al. 2019) and is often considered unsuitable (Middleton et al. 2006, Rasran et al. 2007a), due to the vulnerability of wet soils and certain characteristic species (Biró et al. 2019, Närmann et al. 2021, Stammel et al. 2006, Meysel & Martin 2021). However, considering that historical management of wet grasslands often combined grazing and mowing (Biró et al. 2019, Kapfer 2010a, Strohwasser 2018, Zimmermann 2016) and current positive management experiences with grazing (e.g., Enge 2009, Wolff et al. 2020, Adert et al. 2022, Neuhäuser et al. 2022, Wagner & Britz 2024, Schrautzer & Martens 2025), extensive grazing might also effectively maintain species-rich wet grasslands.

Grazing is gaining attention for wet grassland conservation (Steidl 2002, Zahn 2014, Biró et al. 2019, Adert et al. 2022, Schrautzer & Martens 2025) mainly due to the high costs of mowing (Török et al. 2011) and biomass removal (Kiessling & Zehm 2014, Wehn et al. 2018). These labor-intensive tasks are often not fully compensated by subsidies (Adert et al. 2022, Herzon et al., 2022, Bowskill et al. 2023, Schneider et al. 2023) and increase the risk for inadequate management decisions (Dullau et al. 2019). The financial limitations become further exacerbated by landscape eutrophication and prolonged growing seasons with climate change, as both increase site productivity and likely necessitate higher mowing frequencies (Bergamini et al. 2009, Bowskill et al. 2023, Bochniak et al. 2024, Hartmann & Metz 2025). Besides utilization for biogas production (DVL 2014, 2024, Närmann et al. 2021), large-scale extensive grazing emerges as a potentially cost-effective management strategy (Steidl 2002, Mann & Tischew 2010a, Zahn 2014, Bunzel-Drüke 2019).

Identifying the most suitable management requires to carefully evaluate the effectiveness of various management options for conserving species-rich wet grasslands (Burton & Riley 2018, Biró et al. 2019, Kun et al. 2019). To this aim, a systematic literature review of topic-related research is a valuable approach (Pullin & Stewart 2006). Previous reviews have analyzed general effects and relevant parameters for mowing (Tälle et al. 2018), grazing (Di Virgilio et al. 2019, Metera et al. 2010, Newton et al. 2009), or burning (Valkó et al. 2014) on semi-natural grasslands in general (Rosenthal et al. 2012). However, as management effects vary depending on the biotic and abiotic conditions of the grassland type (Tälle et al. 2018), a reviews' conclusions improve when it solely includes studies conducted in a focal habitat (Tälle et al. 2018). To our knowledge, only one review accounted for the conditions unique to wet grasslands and evaluated grazing and burning specifically for oligo- to mildly mesotrophic fens (Middleton et al. 2006). Therefore, the available knowledge about management effects on meso- to eutrophic wet and moist grasslands deserves a synthesis.

This systematic literature review aims to fill this gap and derive management recommendations for wet grassland conservation. Therefore, we analyzed 60 studies that i) were conducted within a conservation context; ii) investigated the effects of mowing and/or grazing on iii) vegetation composition and/or species diversity iv) within oligo- to eutrophic, wet and moist grasslands v) in Europe. The suitability of the measures for conserving species-rich wet grasslands is evaluated, discussed, and the synthesized results are compared to management recommendations and practical experiences from applied (non-peer reviewed) literature.

The following research questions were addressed: (1) What is the current state of research? Which mowing or grazing regimes and adaptations have been studied or compared? (2) How do mowing and grazing, with their different adaptations, affect species diversity and vegetation composition in wet grasslands? (3) Is the effectiveness and suitability of mowing and grazing judged differently in scientific peer-reviewed studies than in practice-oriented 'grey' literature? (4) What gaps in existing research should be addressed?

2. Material and Methods

2.1 Search strategy

To investigate the effects of mowing and grazing on species diversity and vegetation composition in semi-natural wet grasslands, we performed a systematic literature search (Pullin & Stewart 2006), following the PRISMA approach (Moher et al. 2010).

The Web of Science™ database (Clarivate 2023) was searched for peer-reviewed publications with the following keywords in the title, abstract, or topic search (TS) field: *wet* OR *humid* AND *meadow** OR *fen* OR *grassland** OR *pasture** AND *management* OR *mow** OR *cut** OR *graz** OR *land use*; (* indicates a wild card). This search yielded 997 publications (March 29, 2023; Fig. 1).

Only studies meeting the following criteria were assessed: (i) the research was conducted in Europe, (ii) within a conservation context (e.g., conservation or restoration), (iii) in the below defined focal or associated habitat types, and (iv) examined the effects of mowing and/or grazing on (v) vegetation diversity and/or composition.

34 publications (3,4%) met all criteria, a proportion comparable to other ecological reviews (e.g., Tälle et al. 2016: ~1%; Valkó et al. 2014: ~1.3%; van Klink et al. 2015: ~17%). To identify additional relevant studies, we used their reference lists and added those cited studies that met our criteria, resulting in the inclusion of further 26 publications. In total, 60 studies were included into the analysis, which we consider to be representative rather than complete, based on our knowledge of the relevant literature.

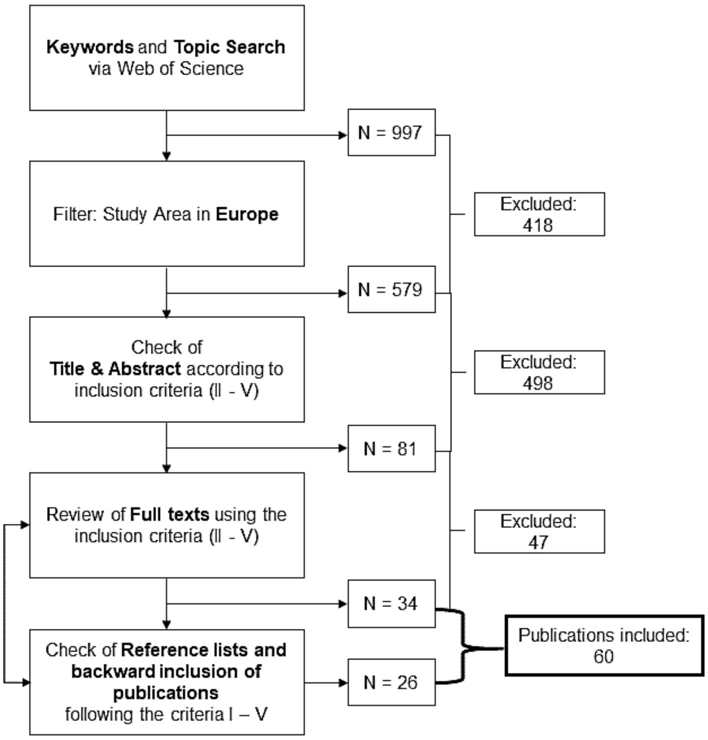

Fig. 1. Flow Chart of the systematic literature search of peer-reviewed studies.

Abb. 1. Schematischer Ablauf der systematischen Literaturrecherche innerhalb peer-reviewter Studien.

In a final step, we compared the results that were synthesized from peer-reviewed scientific literature to commonly used conservation practices (chapter 3.3 and 3.5). To that aim, we used grey literature deemed representative for the topic based on our expertise. We focused on comprehensive overviews and management guidelines from public authorities or NGOs and less frequently used opinion papers or single case studies.

2.2 Focal Habitats

The *focal habitats* of this review comprise moist to semi-wet grasslands ranging from oligo- to eutrophic conditions (Fig. 2), corresponding to EUNIS habitat types R37, R35, and R36 and the phytosociological alliances *Molinion caeruleae*, *Calthion palustris*, and *Deschampsion cespitosae* (EUNIS classifications: Chytrý et al. 2020; phytosociological nomenclature: Mucina et al. 2016). In addition, we included publications examining ecologically related habitat types (hereafter called *associated habitats*). These include: i) wetter grasslands characterized by tall or small sedge communities (e.g., EUNIS type Q53, Q41) which develop into focal habitats under extensive management; ii) mesic grasslands with slightly drier soil conditions (e.g., EUNIS type R 22), as the focal habitats might develop into them if hydrologically deteriorated; and iii) wet tall-herb fringes, which establish following abandonment of focal habitats.

To account for varying classification systems across publications, we synthesized different pan-European classification systems (Table 1). In case a publication characterized the study area based on plant species composition, we classified them as either focal or associated habitats by comparing the described floristic assemblages to the dominant, characteristic and differential species typical of our focal or associated habitat types.

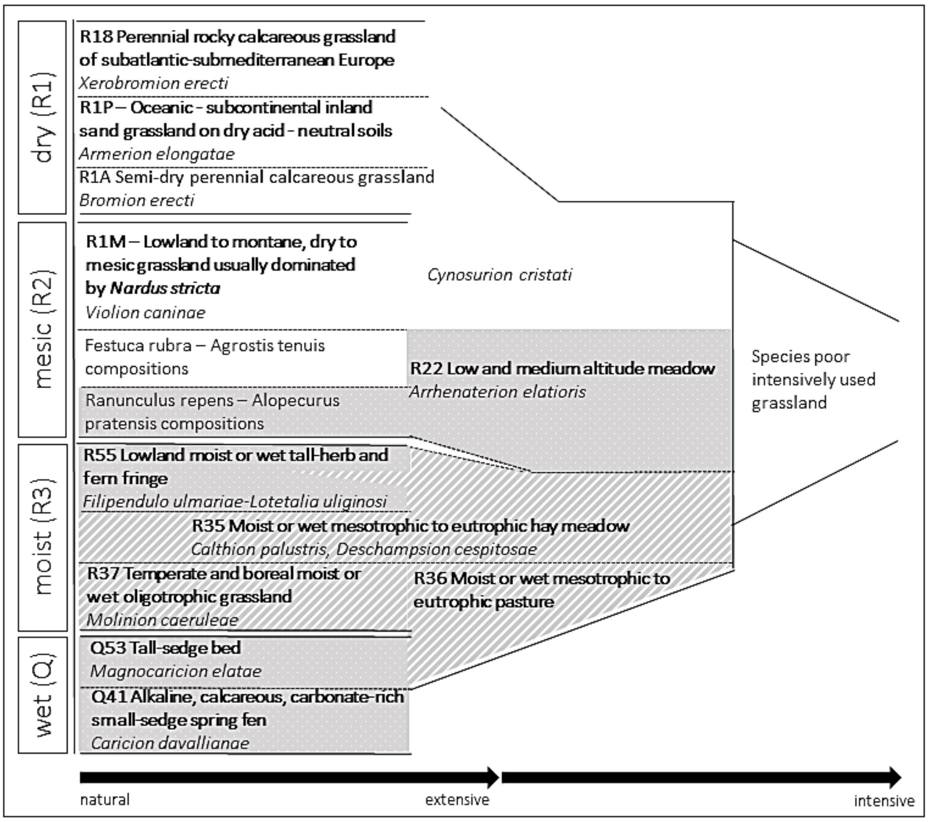

Fig. 2. Focal (hatched) and associated habitat types (dotted) of this review. Ecogram axes represent soil moisture and land-use intensity. The boundary lines should be interpreted as transition zones between plant communities. Ecogram created following the model of Dierschke & Briemle (2008: 60), with habitat names according to EUNIS habitat classification (Chytrý et al. 2020) and phytosociological names given in italics (Mucina et al. 2016).

Abb. 2. Kernhabitate (gestreift) und Randhabitate (gepunktet), auf die sich dieses Review bezieht. Die Achsen des Ökogramms zeigen die Bodenfeuchtigkeit und Nutzungsintensität. Grenzlinien sind als Übergangsbereiche zwischen Pflanzengesellschaften zu interpretieren. Das Ökogramm orientiert sich an der Vorlage von Dierschke & Briemle (2008: 60); Habitatnamen gemäß EUNIS-Klassifikation (Chytrý et al. 2020) angepasst; pflanzensoziologische Namen (kursiv) nach Mucina et al. 2016.

2.3 Assessment of the Effects of Mowing and Grazing

We analyzed the publications' full texts, mainly focusing on the result and discussion sections, for the following aspects: We assessed whether mowing and grazing increased plant diversity (Supplement S1 – col. 6, Supplement S2 – col. 5) and promoted vegetation compositions indicative of higher habitat quality (Supplement S1 – col. 7, Supplement S2 – col. 6 and Supplement S2 – cols. 5 & 6), we synthesized the studies´ significant effects or, in case studies were non-quantitative, their descriptive results. In addition, we documented details *how* vegetation responded to management (Supplement S1 and S2, col. named *description of vegetation development and example species*) and recorded the authors' overall conclusions (Supplement S1 – col. 5, Supplement S2 – subheadings in green, pale green and red lines, Table 2 – col. 4) regarding the success of the applied regimes in maintaining or

Table 1. Synthesis of different habitat classification systems: EUNIS (Chytrý et al. 2020), European Red List of habitat types (Janssen et al. 2016), Habitat types listed in Annex I of the EU Habitats Directive (92/43/EEC) and phytosociological names of related alliances (Mucina et al. 2016); in accordance with (EEA 2022).

Tabelle 1. Synopse verschiedener Lebensraumklassifikationssysteme: EUNIS (Chytrý et al. 2020), Europäische Rote Liste der Lebensraumtypen (Janssen et al. 2016), Anhang-I-Lebensraumtypen der Fauna-Flora-Habitat-Richtlinie (92/43/EWG) sowie zugehörige pflanzensoziologische Verbände (Mucina et al. 2016); in Übereinstimmung mit den Angaben der Europäischen Umweltagentur (EEA 2022).

Name	Alliances	EUNIS code	Annex I habitat code	Red List Habitat Type	conservation status EU 28+
Low and medium altitude hay meadow; mesic permanent pasture of lowlands and mountains	*Arrhenaterion*	R22 R21	6270 6510	E 2.1a E 2.2	vulnerable
Moist or wet mesotrophic to eutrophic hay meadow and pastures	*Calthion*, *Deschampsion*	R35 R36	6510 6450 6440	E 3.4a E 3.4b	endangered
Temperate and boreal moist or wet oligotrophic grassland	*Molinion*	R37	6410	E 3.5	endangered
Small-sedge base-rich fen and calcareous spring mire	*Caricion*	Q41	7230	D 4.1a	endangered
Tall-sedge beds	*Magnocaricion*	Q53	x	C 5.2	vulnerable

restoring species-rich wet grasslands. In each last column (Supplement S1, S2 and Table 2) we collected contraints, additional measurements that had been conducted or other observations that were highlighted by the respective authors. In cases where the focal or associated habitats were embedded within heterogeneous vegetation complexes – particularly common in grazing studies – we also considered the authors' conclusions on the conservation effectiveness of the management regime at the study area level.

We opted for a qualitative synthesis over a meta-analysis for two main reasons: (i) the heterogeneity and incomplete reporting of relevant key factors (e.g., frequency, timing, machinery etc.) limited a nuanced meta-analysis (Box 1a, c), while (ii) an exploratory approach better reflected/comprised the site-specific complexity in wet grassland management that we considered of greater value for applied conservation.

3. Results and Discussion

3.1 Dataset Description

The 60 reviewed publications investigated grasslands across 16 European countries, with a focus on Central Europe (63%; Fig. 3). The defined focal habitat type was investigated in 55%, associated habitat types characterized by wetter conditions in 30%, and more mesic habitat types were analyzed in 16% of studies (Fig. 4).

Site descriptions often lacked key environmental details, such as hydrology (e.g., groundwater levels, flooding regimes) and soil characteristics (e.g., soil type, pH, nutrient content). Moreover, standardized habitat classifications were frequently missing. Thus, habitat types had to be synthesized, or, in some cases, reconstructed based solely on species inventories. The missing standardized terminology hampers cross-study comparability and constrains habitat-specific reviews, as relevant studies may be missed in literature searches

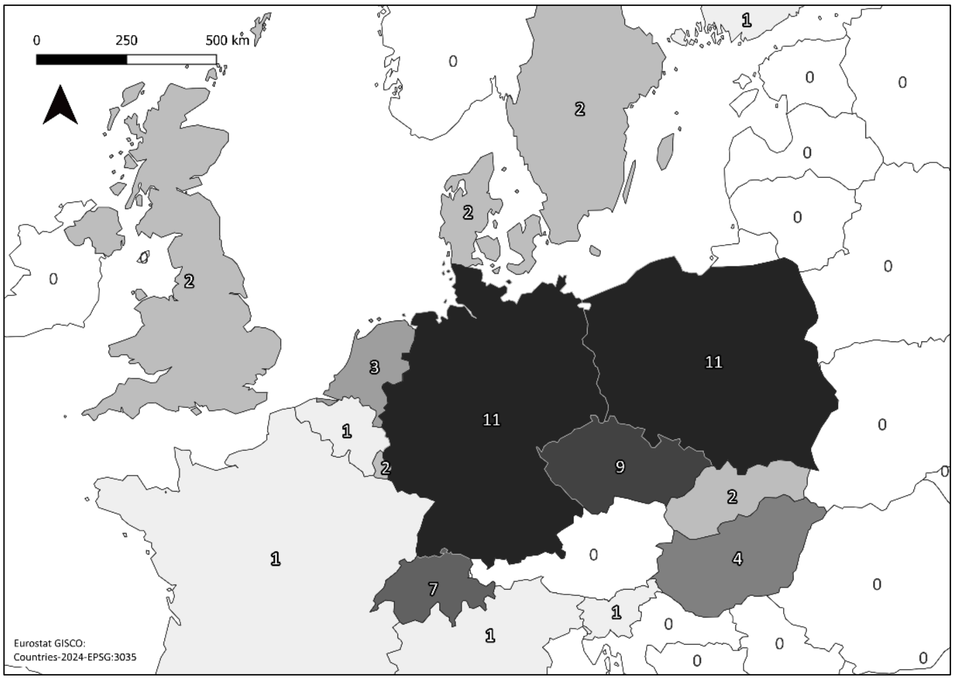

Fig. 3. Distribution of the 16 study countries. The total number exceeds the total publications due to two study countries reported in Hájková et al. (2022).

Abb. 3. Verteilung der 16 Untersuchungsländer. Die Summe übersteigt die Anzahl der eingeschlossenen Publikationen, da in Hájková et al. (2022) zwei Länder berücksichtigt wurden.

(Pullin & Stewart 2006). To enhance comparability, a unified framework like the EUNIS classification system should be employed consistently across Europe in both peer-reviewed and applied research (Chytrý et al. 2020).

A total of 67% of the reviewed publications ($n = 40$) investigated mowing regimes (Supplement S1), 23% ($n = 14$) focused on grazing (Supplement S2). The effects of mowing were mostly assessed ($n = 33$) by comparing mown areas with unmown controls. 16 mowing studies compared reintroduced mowing to previous abandonment. 18 studies compared different mowing regimes, including mowing once per year *versus* twice per year, mowing *versus* mulching, or mowing with *versus* without fertilization. Grazing effects were evaluated by comparing grazed *versus* abandoned sites ($n = 3$) or by examining transitions between former and current management regimes, like the switch from mowing to grazing ($n = 4$). Five studies assessed grazing effects through exclosures within the same area and three documented developments under grazing over time.

Notably, only 10% of the 60 reviewed publications directly compared mowing and grazing simultaneously within the same habitat (Table 2). This is consistent with broader patterns in grassland research (Tälle et al. 2016). The persisting scarcity of comparative studies – despite calls for them as early as two decades ago (Jantunen 2003) – underscores the continued need for experimental and large-scale designs evaluating these management regimes side by side (Box 1c, d).

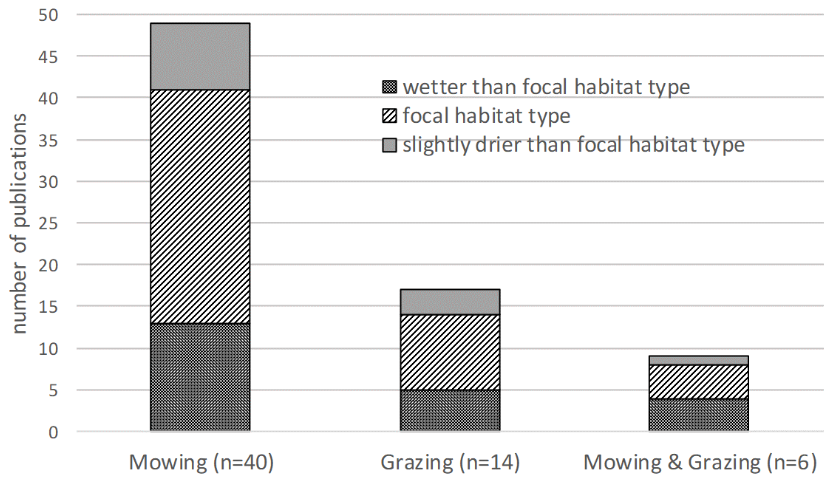

Fig. 4. Distribution of habitat types within the 60 reviewed publications, grouped by investigated management regime. The total exceeds the number of publications, as study sites were heterogeneous or studies investigated several sites. For definitions of the focal and associated habitat types see Figure 2.

Abb. 4. Verteilung der Habitattypen in den 60 analysierten Publikationen, gruppiert nach Bewirtschaftungsregime. Die Summe übersteigt die Anzahl der Publikationen, da Untersuchungsgebiete heterogen waren oder mehrere Standorte berücksichtigt wurden. Die Kern- und Randhabitate sind in Abbildung 2 definiert.

The median duration since the management regimes had been implemented within study sites was five years (range: 1–27 years; Fig. 5). Only 27% of the mowing regimes and 27% of the grazing regimes had durations of three years or less, while more than half of the studies (regardless of management regime) covered management durations of seven years or more.

Thus, the majority of studies assessed management effects in habitats that were unlikely to be biased by initial deterioration following reintroduced management (Jantunen 2003), and sufficiently developed to reflect also time-lagged vegetation responses (Gibson & Brown 1992, Zobel et al. 1996), particularly as target species re-establish slowly (Schrautzer et al. 2016, Velbert et al. 2017, Schwartze et al. 2021).

Regarding study duration, 43% of all studies qualified as long-term *sensu* Bakker et al. (1996) with > 10 observational years, while 33% compared the different managements only at a single timepoint, although often across multiple locations. Due to short-term funding, study durations below five years are common in ecological research (De Bello et al. 2020), despite their limited ability to disentangle management effects from interannual variation (Di Virgilio et al. 2019). This underscores the continued importance of long-term ecological research (Zhang et al. 2023; Box 1c, d). In sum, we consider the reliability and generalizability of the included studies as relatively high, particularly due to the extended durations of management applications in most sites.

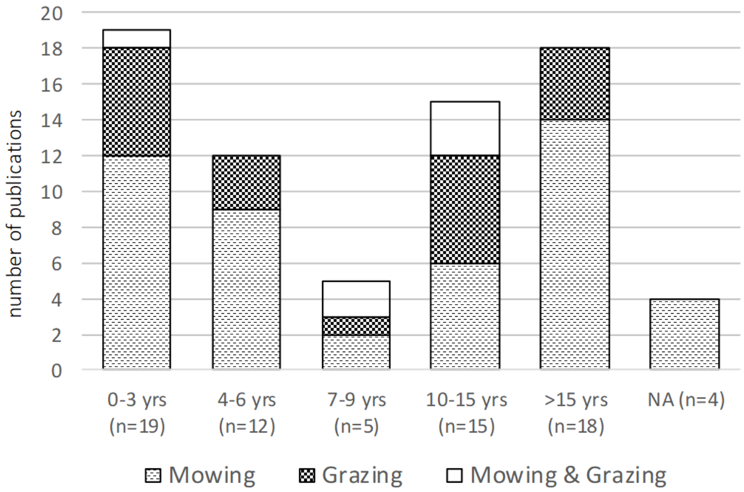

Fig. 5. Duration since investigated management regimes were implemented, where reported; in some cases, durations were estimated by the authors. Note that this does not always reflect the actual study length, as 20 studies compared the different regimes only within a single year. The total number exceeds that of reviewed publications, as some included multiple sites with distinct management histories.

Abb. 5. Zeitraum seitdem die untersuchten Bewirtschaftungsregime eingesetzt waren, sofern angegeben; in einigen Fällen wurden Zeiträume geschätzt. Diese Angaben spiegeln nicht zwingend die Studiendauer wider, da 20 Arbeiten die unterschiedlichen Bewirtschaftungen nur innerhalb eines Jahres verglichen. Die Summe übersteigt die Anzahl der Studien, da teilweise mehrere Standorte eingeschlossen waren.

3.2 Effects of Mowing

In 85% of mowing studies, mowing increased plant species richness, and in 70% it improved vegetation composition. Mowing promoted rare habitat specialists such as *Dactylorhiza majalis*, *Parnassia palustris*, *Lychnis flos-cuculi*, and rare *Carex* species, while it reduced generalist species, dominant competitors, and mean Ellenberg indicator values for nutrients (Supplement S1).

3.2.1 Mowing Frequency

65% of mowing studies examined the effects of annual mowing, while 33% investigated mowing twice per year (Fig. 6, Supplement S1 and Table 2). Only two studies assessed higher mowing frequencies, while five tested less frequent mowing (e.g., every two – three years). Three studies examined mowing in combination with aftermath grazing, and four evaluated mulching as a management tool. Two studies did not specify mowing frequency.

Overall, the positive effects of mowing increased up to a frequency of two cuts per year. Mowing frequencies every two to three years were generally insufficient to suppress successional processes, harboring only about half as many specialized species than annually mown sites. Nonetheless, compared to complete abandonment, low-frequency mowing resulted in smaller losses of specialists – about half as severe – and was thus considered preferable when abandonment is the only alternative.

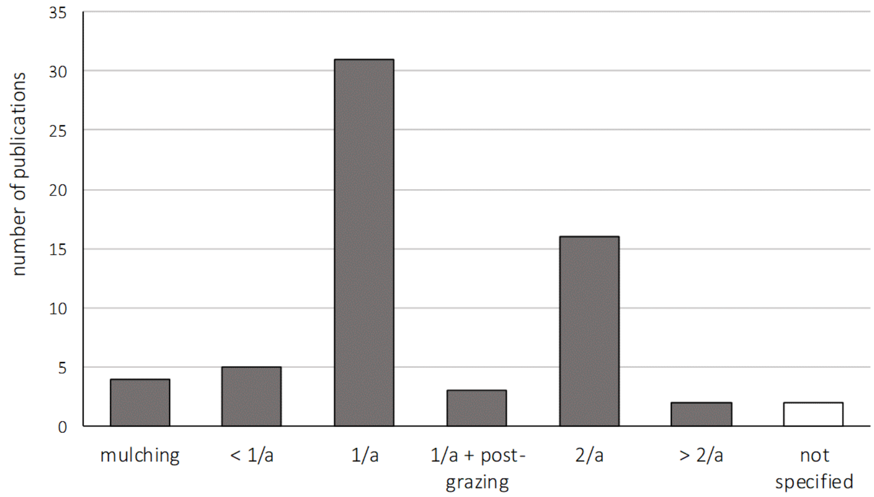

Fig. 6. The frequency of different mowing regimes tested in 60 reviewed publications (Supplement S1), including studies comparing mowing and grazing (Table 2). The total exceeds the number of publiccations, as some studies examined multiple regimes. Mulching means cutting without biomass removal, < 1/a is mowing less than once per year, 1/a is mowing once per year, 1/a + postgrazing is mowing once plus aftermath grazing later in the season, 2/a is mowing twice per year, > 2/a more frequent mowing than twice per year.

Abb. 6. Häufigkeit der in den 60 Publikationen untersuchten Mahdregime (Beilage S1), einschließlich Studien mit Vergleich von Mahd und Beweidung (Tab. 2). Die Summe übersteigt die Anzahl der Publikationen, da einige Studien mehrere Mahdregime untersuchten. Mulchen bezeichnet das Mähen ohne Biomasseentnahme, < 1/a weniger als einmal jährlich, 1/a einmal jährlich, 1/a + Nachbeweidung einmalige Mahd mit anschließender extensiver Beweidung im weiteren Jahresverlauf, 2/a zweimal jährlich, > 2/a häufiger als zweimal jährlich.

Compared to abandonment or mulching, mowing once and mowing twice per year positively affected vegetation composition. While these results appear expectable for semi-natural habitats, the eight studies comparing mowing once directly to mowing twice per year provide important insights into suitable mowing frequencies: They consistently reported improved outcomes for mowing twice. Namely, mowing twice per year was more effective at suppressing dominant species and increasing nutrient depletion, and benefited more low-growing specialists than mowing once. Also, mowing twice shifted vegetation composition faster towards the target communities and increased species richness more substantially. However, most of these studies were conducted in rather nutrient-rich or slightly drier habitats (e.g., *Calthion*, *Arrhenatheretalia*) or (at least slightly) degraded habitats (Box 1c). Particularly under such conditions, mowing twice proved effective in facilitating the development of species-rich wet grasslands. Studies reporting negative effects of mowing twice per year attributed this to co-occurring fertilization or the limited availability of target species in the seedbank.

Table 4. Overview of studies comparing mowing and grazing: habitat type, compared treatments, general conclusions, effects on diversity and composition, as well as details on vegetation development and additional remarks. + = positive; - = negative; ~ = similar; R3 = EUNIS type R3 (seasonally wet and wet grasslands) and subtypes; focal habitat; R2 = EUNIS type R2 (mesic grassland) and subtypes; mesic direction from focal habitat; Q = EUNIS type Q (wetlands) and subtypes (mainly Q4, some Q5); wet direction from focal habitat.

Tabelle 4. Überblick über Studien die Beweidung und Mahd verglichen: Habitattyp, Vergleichsgrößen, generelle Bewertung, Wirkung auf Diversität und Komposition, inklusive Details zu Vegetationsentwicklungen und Anmerkungen. + = positiv; - = negativ; ~ = ähnlich; R3 = EUNIS-Typ R3 (Feucht- und Nassgrünland) und Subtypen; Focushabitat; R2 = EUNIS-Typ R2 (mesophiles Grünland) und Subtypen; mesische Richtung vom Focushabitat; Q = EUNIS-Typ Q (Sümpfe und Moore) und Subtypen (im wesentlichen Q4, einiige Q5); nasse Richtung vom Fokushabitat.

reference	habitat type	comparison of		general conclusion	effects on diversity		effects on composition		constraints/ additional measurements/ authors notes
					mowing	grazing	mowing	grazing	
Stammel et al. 2003	R3; Q	annual mowing in autum	summer grazing	both regimes	+		comparable effects on red list species positive: less dominant species; more low-growing species; more late-blooming species; grazing promoted grazing indicator species		
Schaich & Barthelmes 2012	R3; R2	2x mowing	year-round grazing	comparable results; combination recommended	~		comparable number and abundances of specialized species positive: higher evenness	positive: more geophytes and late-blooming species negative: more ruderal and nitrophilous species; higher vegetation	selective foraging behaviour and grazing patterns along hydrological gradient
Reutimann et al. 2023	R3	annual mowing in summer	summer grazing	comparable results; combination recommended on landscape scale	~		positive: less soil compaction negative: more ruderal species	negative: higher indicator values for nitrogen; more dominant species	management regimes are realized by manag. contracts with local farmers and thus variable but range within conservation-oriented schemes
Bergamini et al. 2009	Q	annual mowing	summer grazing	comparable results; combination recommended	+		comparable effects on red list and specialized species	negative: less herbs, more grasses	in both regimes negative development due to eutrophication and deteriorating hydrological conditions
Seer & Schrautzer 2014	Q	annual mowing	grazing (summer & year-round)	comparable results; combination recommended	~		comparable effects on specialized species: in both regimes indicators of low productivity decreased		authors suggest 2x mowing per year or 2 LU (summer pasture) or 0,7 LU year-round grazing
Sienkiewicz-Paderewska et al. 2020	R3; Q	mowing every 2^{nd} - 4^{th} y.	year-round grazing	NA	NA		positive: more specialized species negative: more tall-growing species	negative: *Scheuzerio-Caricetea* developed to *Molino-Arrhenatheretea*	no good comparability because grazing was mainly in *Scheuchzerio caricetea* ; and mowing mainly in *Molinion*

3.2.2 Mowing time

In single-cut regimes, mowing typically occurred between May and September, peaking in June – July (57%). In two-cut systems, the first cut typically occurred between May and July, followed by a second cut in August or September.

Notably, negative effects of mowing on species richness or composition were frequently attributed to suboptimal timing. The timing of biomass removal determines how effectively mowing counteracts eutrophication and the dominance of tall-growing species (Bowskill et al. 2023). Late-season mowing is less effective in nutrient depletion, as more nutrients have already been translocated to belowground organs (Martínez-Vilalta et al. 2016), whereas early summer mowing more effectively suppresses competitive species but can harm late-flowering species (e.g., *Succisa pratensis*, *Sanguisorba officinalis*, *Betonica officinalis*). Two-cut systems, which avoid late-flowering species in the first cuts, can be beneficial. In annual early-cut regimes, higher regrowth until the next season or thick litter layers occasionally inhibited the germination of light-demanding species in the following spring. In such cases, late autumn mowing helped to reduce litter accumulation, benefitting light-demanding target species, such as *Dactylorhiza majalis*.

3.2.3 Mowing Technique

Only 55% of the publications reported the mowing technique. Hand scythes were the most common technique reported (n = 14), followed by brush cutters and sickle mowers (n = 4 each), and tractor-mounted mowers (n = 3). Mowing with hand scythes generally led to positive outcomes, while sickle mowers showed the highest proportion of negative outcomes. However, due to the limited sample size and potential confounding factors such as fertilization or mowing frequency, no general conclusions could be drawn regarding the effects of mowing technique (Box 1a, c).

3.3 Assessment of mowing in practice-oriented 'grey' literature

Practice-oriented recommendations generally align with the findings of the peer-reviewed studies but are often tailored more tightly to specific plant communities.

Two-cut regimes are recommended for mesotrophic to moderately eutrophic wet grasslands, such as *Alopecurus pratensis* – dominated meadows (Närmann et al. 2021), moist variants of *Arrhenatheretalia* (Strobel & Hölzel 1994, Szépligeti et al. 2016), and *Caltha palustris* or *Cirsium oleraceum* – rich meadows (Schneider et al. 2023). These species-rich habitats often combine species of productive grasslands and wetland communities (*Arrhenatheretalia*, *Molinietalia*, *Calthion*) that are well-adapted to extensive two-cut regimes (Strobel & Hölzel 1994, Dullau et al. 2019, Burkart et al. 2004, NLWKN 2024). In contrast, single-cut regimes are advised for low-productive, wet habitats harboring specialists like *Trollius europaeus*, *Scorzonera humilis*, or small *Carex* species (Strobel & Hölzel 1994, Schwartze et al. 2021). These regimes are also advised for *Scirpus sylvaticus* meadows, sedge-rich fens, and *Molinia* meadows (NLWKN, 2022, 2024).

Typically, two-cut systems have their initial cut from mid to late June, followed by a second cut from late August onwards. Many species are adapted to this regime and may even flower twice per year (Strobel & Hölzel 1994). On more productive sites, an earlier first cut (late May to early June) followed by a minimum ten-week interval allows for seed maturation while promoting light-demanding, less competitive species. Long-term data (e.g., Schwartze et al. 2021) confirm that such a regime – conducted over decades - can support rare species like *Dactylorhiza majalis* and *Ophioglossum vulgatum*.

However, several authors cautioned that applying typical two-cut regimes constantly with fixed temporal or spatial application hampers species where seeds mature only after late June, and suggested to delay mowing until July (Janečková et al. 2006, Dullau et al. 2019, Wagner & Britz 2024). Also, delaying mowing into July is recommended to protect the nestlings of meadow birds. However, later mowing may not remove enough nutrients and promote species disproportionally, for instance by favoring unwanted, invasive or poisonous species (Wagner et al. 2023) and excluding target species (Burkart et al. 2004, NLWKN 2024). Therefore, late single cuts are advised chiefly for *Molinion* communities on nutrient-poor, wet soils, while the same timing on meso- to eutrophic sites promotes tall-herb (e.g., *Filipendulion*) and reed communities (e.g., *Magnocaricion*) and ultimately reduces species richness (Zimmermann 2016, Schneider et al. 2023).

To avoid that certain species are persistently promoted and others repeatedly suppressed, several practice-oriented studies theoretically recommend spatially and temporally variable mowing regimes (Zimmermann 2016, NLWKN 2024). However, in practice, such flexible regimes are often unattainable, mainly because subsidy regulations (e.g., AUKM in Germany) restrict mowing to fixed dates or phenological stages of certain species. Such regulatory frameworks incentivize uniform management even though flexibility would be ecologically preferable. Indeed, flexible regimes match traditional management practices (Zimmermann 2016, Burton & Riley 2018, Wehn et al. 2018) and ease to avoid soil degradation by aligning management timing to suitable (i.e., drier) hydrological conditions (Nitsche & Nitsche 1994, Strobel & Hölzel 1994). Particularly in permanently wet sites or rainy seasons, and where heavy machinery is used, delaying mowing times into mid to late summer is recommended (Dierschke & Briemle 2008, Schneider et al. 2023). To enable both, flexible and soil-conserving management, the use of or support for specialized mowing equipment (e.g., lightweight; adapted tire systems) is advised (Middleton et al. 2006, Närmann et al. 2021).

3.4 Effects of Grazing

The following results and discussions relate to extensive grazing, with stocking rates between 0.2 and 1.5 livestock units per hectare as defined by Dierschke & Briemle (2008). Only 7 out of the 14 studies quantified stocking rates directly, ranging from 0.12 to 1.12 livestock units per hectare for year-round grazing and 0.35 to 0.9 LU/ha for summer grazing. The remaining studies described their grazing regimes as extensive.

Half of the studies reported exclusively positive effects, with grazing contributing to the development of target communities (Supplement S2 and Table 2). This was primarily attributed to the creation of establishment niches for or the increase of rare and characteristic species, and effective suppression of dominant species. Grazing increased species richness in 71% of the studies and improved species composition in 79%. Four studies cautiously assessed grazing overall positive, but mentioned high nutrient availability and limited seed banks as establishment barriers for target species. However, 29% reported deteriorating species composition due to increasing grasses and ruderals. Three studies reported reduced species richness due to trampling of sensitive, rare species or (organic) soil compaction (1 study).

Grazing in heterogeneous landscapes with varying productivity and grazing sensitivity in patches presented challenges. Three studies in heterogeneous sites assessed grazing negatively, reasoning that moist patches with lower forage quality were avoided, causing undergrazing in moist sites and overgrazing in preferred patches. On the contrary, other studies in heterogeneous sites highlighted increased structural and compositional diversity by grazing.

3.4.1 Grazing Period

Eight studies investigated year-round grazing, eight summer grazing (May – October), two studies assessed rotational grazing (i.e., short grazing intervals of 1–2 weeks), and two studies did not specify the grazing period (Supplement S2 and Table 2).

Year-round grazing improved species composition, with increases in both generalists and specialists. The higher grazing pressure during winter was breaking established grazing patterns and suppressing dominant species such as *Carex acuta* and *Cirsium arvense*. However, supplementary feeding in winter was required due to low forage value and might introduce excess nutrients.

Summer grazing yielded positive results in three of the five studies (Supplement S2), promoting rosette-forming and low-growing target species. Grazing also effectively suppressed dominants (e.g., *Phragmites australis*), when it coincided with their sensitive life stages (e.g., early growth). Rotational grazing yielded mixed results: one study reported positive effects, while another – using sheep – found negative outcomes due to unsuitable foraging behviour in moist patches.

3.4.2 Livestock Type

Most studies (93%) used cattle, with varying outcomes. The specific effects of horses remain unclear due to mixed grazing with cattle and ambiguous evaluations (positive: Mann & Tischew, 2010; moderately positive: Gilhaus et al. 2014). The only study involving sheep and goats (Koch et al. 2017) reported negative effects, although without explicitly linking them to livestock type. Török et al. (2014) mentioned greater biodiversity for traditional (Hungarian Grey cattle) than commercial breeds.

3.5 Assessment of grazing in practice-oriented 'grey' literature

Practice-oriented literature corroborates the findings of the reviewed studies: extensive grazing (*sensu* Dierschke & Briemle 2008) can be effective for maintaining wet grasslands (Närmann et al. 2021) and enhance faunal and floral diversity (Schwartze et al. 2021). In this literature, successful grazing regimes involved besides cattle also water buffalo (Enge 2009, Flöper 2024, NABU Brandenburg 2024), sheep (Närmann et al. 2021), and mixed herds with cattle and horses (Zahn 2014, Neuhäuser et al. 2022, Schrautzer & Martens 2025).

Concerns persisted primarily that trampling effects, might cause soil compaction, sward damage (Strobel & Hölzel 1994), and harm to valuable species (Bunzel-Drüke et al. 2019, Meysel & Martin 2021, Schwartze et al. 2021, Wagner & Britz 2024). However, there is evidence that carefully adapted grazing may also support rare specialists, such as *Caltha palustris* (Enge 2009), *Drosera rotundifolia*, gentians, and orchids (*Dactylorhiza*, *Orchis*) (Schley & Leytem 2004).

A key prerequisite for success is careful, site-adapted grazing management, where fencing or guiding herds can prevent harm to sensitive species and vulnerable patches

(Närmann et al. 2021, Neuhäuser et al. 2022). Moreover, timing grazing periods to avoid sensitive juvenile or flowering phases of target species and match periods with lower water tables was emphasized for successful grazing (Stammel et al. 2003, Närmann et al. 2021).

While year-round grazing can diminish competitive species due to low forage quality in winter, it also increases trampling pressure. Consequently, practical recommendations generally consider continuous grazing unsuitable for wet grasslands (NLWKN 2024). Instead, rotational grazing with short grazing phases during low water levels (e.g., late June to August) is recommended (Quinger et al. 1995, NLWKN 2024). If hydrological conditions permit, autumn grazing, when most wet grassland species (flora and fauna) have completed their development, may also be considered (Strobel & Hölzel 1994). Another benefit of rotational grazing is the greater flexibility to adjust grazing intensities to sensitive species or patches (Zahn 2014, Närmann et al. 2021) to prevent over- and undergrazing in heterogeneous sites.

Notably, it was consistently emphasized that even carefully optimized grazing will hardly reproduce the structural and compositional characteristics of traditionally mown systems (Steidl 2002, Metera et al. 2010, Zahn 2014, Hájková et al. 2022). Thus, grazing is repeatedly considered unsuitable or only moderately suitable for maintaining typical *Calthion* (Rasran et al. 2007b, Schneider et al. 2023) or *Molinion* meadows (Burkhart et al. 2004, NLWKN 2022).

Box 1. Research Gaps

a) Insufficient detail on management strategies:
Key parameters were often missing across mowing and grazing studies, such as precise cutting dates, frequency, and mowing techniques, as well as stocking density, grazing duration, livestock breed, and demographics. This lack of standardized reporting limits both comparability across studies and the transferability of findings to management practice.

b) Underrepresentation and limited diversity in grazing studies:
Grazing was addressed in only 33% of the reviewed publications (Supplement S2 and Table 2) and primarily involved cattle. Besides a general underrepresentation of grazing studies (Zhang et al. 2023), effects of different livestock types (Isselstein et al. 2007) and different breeds or ages within species (Pauler et al. 2020, Koncz et al. 2020) remain largely unexplored.

c) Need for nuanced, site-specific comparisons:
Most studies compared management effects only to abandonment, offering limited insight into optimal regimes. There is a clear need for more systematic comparisons of frequency, density, timing and technique or livestock types, particularly regarding site-specific conditions (e.g., Milberg et al. 2017, Marriott et al. 2014). This gap is striking, given that many studies highlight the importance of flexible, adaptive management to achieve conservation goals.

d) Conclusion:
A clear need persists for controlled, replicable, and ideally long-term field studies to disentangle the complex interactions between alternative management options and site conditions, and to facilitate evidence-based, site-adapted management strategies.

4. Synthesis

As a prerequisite that mowing or grazing can effectively contribute to wet grassland conservation, site conditions (i.e., hydrology, nutrients, seed bank quality and species pool) need to match the envisioned target community (Supplement S1, S2 and Table 2; last column). Both management regimes were evaluated positively in cases where they reduced nutrients, aboveground biomass, competitive, tall-growing species, and increased low-growing, light-demanding specialists.

High soil moisture posed a key challenge in wet grassland management, as it increased the risk of sward damage or soil compaction from trampling or heavy machinery. Additionally, many wet grasslands harbored heterogeneous microtopographies and edaphic conditions and a mosaic of plant communities with different productivity and disturbance sensitivity. This heterogeneity necessitated spatially and temporally differentiated management, for instance via mosaic cutting patterns or active herd management.

4.1 Synthesis for Mowing

Compared to abandonment, both single- and two-cut regimes had overall positive effects on the composition and species richness of wet grasslands. The 'grey' literature and peer-reviewed studies agreed that two-cut and flexible mowing regimes were best suited for meso- to eutrophic moist meadows, while wetter and oligotrophic *Molinion* meadows rather required single-cut regimes. Negative effects of mowing resulted mostly from suboptimal timing, e.g. late cuts removed not enough nutrients and single summer cuts allowed too dense regrowth in the following season. Conversely, fixed-timed early or two-cut mowing occasionally impeded late-flowering species. To reconcile the required nutrient removal (achieved via early or two-cut mowing) with the protection of valuable flora and fauna, spatially and temporally diversified mowing regimes were recommended.

Our results demonstrate a mismatch between common practice and conservation requirements because single-cut mowing – mostly conducted in mid- to late June – is the dominant management practice in European wet grasslands (Kapfer 2010a, Hejcman et al. 2013, Tälle et al. 2016). High nutrient availability and competition often hampered rare specialists in single-cut (summer) regimes (Bergamini et al. 2009, Bochniak et al. 2024, Hartmann & Metz 2025). Despite their ecological benefits, two-cut regimes with flexible timing are often impossible in practice because subsidy regulations impose fixed mowing dates and because a second cut outside the drier summer period may necessitate costly specialized machinery (Kiessling & Zehm 2014, Närmann et al. 2021, Bowskill et al. 2023). Moreover, in areas where the use of biomass as bedding material has been re-established (DVL 2014, 2024, Kiessling & Zehm 2014), technical limitations may arise as early cut material is often too wet for this purpose (Närmann et al. 2021).

4.2 Synthesis for Grazing

Peer-reviewed and 'grey' literature largely agreed that extensive cattle grazing can promote wet grassland conservation when appropriate nutrient levels and sufficient target species are present. In addition to overall increasing plant diversity, grazing can benefit habitat specialists by lowered competition and additional seed dispersal and establishment niches (Mann & Tischew 2010, Köhler et al. 2023). Only few studies reported negative effects, namely trampling damage to sensitive species (Küchler et al. 2009, Koch et al. 2017, Sienkiewicz–Paderewska et al. 2020) and compaction of organic soils (Stammel et al. 2003).

However, especially 'grey' literature emphasized the complexity of grazing as multiple factors like area size and heterogeneity, livestock type and breed, foraging behavior, and livestock health interact dynamically. Further, practice-oriented literature considered year-round grazing less suitable, while recommending spatially and temporally flexible regimes like rotational grazing (Zahn 2014, Närmann et al. 2021). Such regimes might better achieve conservation targets as they reduce trampling pressure and promote more homogeneous vegetation patterns (Hájková et al. 2022).

Although grazing can meet conservation objectives, both peer-reviewed and practice-oriented sources emphasized that it requires constant monitoring and flexibility to adjust grazing regimes (Schrautzer et al. 1996, Bunzel-Drüke et al. 2019, Sienkiewicz–Paderewska et al. 2020, Meysel & Martin 2021, Adert et al. 2022, Schrautzer & Martens 2025) and thus experienced livestock managers. The continuous need to adjust grazing parameters and the higher uncertainty about vegetation responses may partly explain the cautious perception of grazing despite its generally positive ecological outcomes. Whether such continuously adapted, extensive grazing regimes can be more cost-efficient than mowing, remains questionable. In addition, the limited number of studies (Box 1b) and the recurrent emphasis on site-specificity and complexity, make it difficult to derive robust, broadly applicable management recommendations.

4.3 Mowing or Grazing?

To assess whether mowing or grazing is more suitable for maintaining a good conservation status of species-rich wet grasslands, the six studies directly comparing both regimes provide particularly valuable insights. Five of these found mowing and grazing to be equally effective. More notably, they highlighted that combining both regimes supported especially high biodiversity, as each benefitted different species groups. Recommendations for such combined regimes are also found in practice-oriented literature, specifically extensive mowing with aftermath grazing (Närmann et al. 2021, Schneider et al. 2023). Given that regimes with grazing before and after mowing had been widespread for centuries, it is plausible that this combination promotes both higher species diversity and ecological resilience (Kapfer 2010b, Messlinger et al. 2018, Strohwasser 2018).

Moreover, grazing and mowing regimes fulfill different conservation aims: Mowing creates more homogeneous vegetation patterns (Tälle et al. 2016), which eases the evaluation of conservation efforts (Steidl 2002) but reduces beta diversity (Touzard et al. 2002, Güsewell & Le Nédic 2004, Vannucchi et al. 2022, Bochniak et al. 2024). Grazing systems, even if well-managed, result in unconsumed plant residues (Zahn 2014), patchy swards (Vickery et al. 2001), and spatially variable vegetation patterns (Metera et al. 2010). Thus, grazing systems support higher structural heterogeneity and a broader range of species (Tälle et al. 2016) but are less predictable regarding their outcomes.

In general, regimes that are spatially and temporally diversified and tailored to site conditions offer the greatest conservation potential while minimizing the risk of favoring unwanted, invasive or poisonous species or excluding target species. This is especially critical today, as only few, often small fragments of species-rich wet grasslands remain. These sites need to fulfill multiple ecological functions simultaneously, such as harboring rare species, buffering against climate impacts, and preserving genetic diversity. In the past, wet grasslands were abundant, thus, species losses in one site could be compensated by populations in neighboring sites. Nowadays, the remaining fragments can no longer afford such losses. Local declines are more likely to cause irreversible genetic erosion or local extinction. To sustain high species diversity under these conditions, particularly in the face of climate change (Wehn et al. 2018), it is crucial to establish financial and policy frameworks that support flexible, site-specific management alongside with long-term ecological monitoring (Bowskill et al. 2023).

Erweiterte deutsche Zusammenfassung

Problemstellung – Extensive Landnutzung ist von zentraler Bedeutung für den Erhalt von artenreichen Feuchtgrünländern, die einen Hotspot der mitteleuropäischen Biodiversität darstellen und zahlreichen seltenen Arten einen Lebensraum bieten. Da eine extensive Nutzung jedoch wirtschaftlich kaum mehr tragfähig ist, sind Feuchtgrünländer zunehmend durch unzureichende oder ungeeignete Bewirtschaftung gefährdet. In der Folge verschlechtert sich die Habitatqualität und wertgebende Arten gehen zurück. Zum Erhalt der verbliebenen Feuchtgrünländer sind Managementkonzepte notwendig, die sowohl kosteneffizient und nachhaltig als auch förderlich für die Biodiversität sind.

Die annuelle Mahd wird derzeit am häufigsten eingesetzt und gilt als geeignet für den Erhalt von Feuchtgrünland. Eine Beweidung wird hingegen seltener umgesetzt und häufig kritischer bewertet. Der anhaltende Rückgang wertgebender Arten trotz naturschutzfachlicher Pflege wirft jedoch die Frage auf, ob und wie bestehende Managementregime überdacht und angepasst werden müssen. In diesem Zusammenhang rückt die Beweidung zunehmend als potenziell kosteneffiziente und nachhaltige Alternative zur Mahd in den Fokus – nicht zuletzt, weil sie zugleich eine Verwertungsmöglichkeit der anfallenden Biomasse bietet. Sowohl für Mahd als auch für Beweidung bestehen jedoch weiterhin offene Fragen zu optimaler Intensität, Zeitpunkt, Technik bzw. eingesetzten Tierarten, insbesondere in Abhängigkeit von standörtlichen Gegebenheiten.

Methode – Um die Wirkungen von Mahd und Beweidung auf Artenvielfalt und Vegetationszusammensetzung in oligo- bis eutrophen, feuchten bis nassen Grünländern (Abb. 2) zu bewerten, wurden 60 Studien aus 16 europäischen Ländern analysiert. Die Ergebnisse wurden mit ausgewählten praxisnahen, meist nicht-peer-reviewten, deutschsprachigen Veröffentlichungen aus dem Naturschutz verglichen. Auf dieser Grundlage wurden zentrale Faktoren für ein naturschutzfachlich erfolgreiches Management identifiziert sowie bestehende Forschungslücken (Box 1) benannt.

Ergebnisse – **Voraussetzung** für einen erfolgreichen Beitrag von Mahd und/oder Beweidung zum Erhalt von Feuchtgrünland war, dass wesentliche Standortfaktoren, wie Wasserhaushalt, Nährstoffverfügbarkeit und das verfügbare Artenspektrum mit den Bedingungen des Zielhabitats übereinstimmten oder angepasst wurden.

Mahd: Positive Effekte auf die Artenvielfalt und Komposition nahmen bis zu einer Frequenz von zwei Schnitten pro Jahr zu, insbesondere in meso- bis eutrophen Feuchtgrünländern. Für oligotrophere und nassere Standorte waren meist einschürige Regime geeigneter. Negative Effekte der Mahd waren meist auf ungünstige Schnittzeitpunkte zurückzuführen, da diese entweder nicht ausreichend Nährstoffe entzogen oder bestimmte Artengruppen (z. B. spätblühende Arten) überproportional zurückdrängten. Um den Zielkonflikt zwischen effizientem Nährstoffentzug und dem Schutz sensibler Arten zu entschärfen, waren räumlich und zeitlich diversifizierte (zweischürige) Mahdregime besonders wirksam. Außerdem zeichnet sich ab, dass ein (standortangepasstes) Abweichen von der aktuell dominierenden Bewirtschaftungsform der einschürigen Mahd im (frühen) Sommer dem Artenreichtum europäischer Feuchtwiesen zuträglich sein könnte.

Beweidung: Auch die Beweidung wirkte in vielen Fällen naturschutzfachlich positiv. Jedoch wurde sie von wissenschaftlicher wie praxisnaher Literatur als schwerer kalkulierbar und komplexer in der Umsetzung beschrieben. Als entscheidende Erfolgsfaktoren erwiesen sich ein kontinuierliches Monitoring sowie ein aktives, flexibel anpassbares Herdenmanagement – insbesondere hinsichtlich Besatzdichte, Beweidungszeitpunkt und -dauer. Die Notwendigkeit, Beweidungsparameter regelmäßig an standörtliche Gegebenheiten anzupassen, verbunden mit der Unsicherheit bezüglich resultierender Vegetationsmuster, erklärt womöglich die verbreitete Zurückhaltung gegenüber der Beweidung. Hinzu kommt eine vergleichsweise geringe Zahl an replizierten und hinsichtlich Anpassungsoptionen differenzierten Beweidungsstudien (Box 1), sodass sich insgesamt nur eingeschränkt generalisierte, belastbare Handlungsempfehlungen ableiten lassen.

Herausforderungen: Unabhängig vom gewählten Regime stellte die hohe Bodenfeuchte in Feuchtgrünländern eine zentrale Herausforderung dar, da sie die Gefahr von Bodenverdichtung oder Schädigung der Grasnarbe – etwa durch schwere Maschinen oder Trittschäden – deutlich erhöhte. Hinzu kam die kleinteilige strukturelle Heterogenität dieser Lebensräume: Unterschiede in Produktivität und Störungssensitivität führten dazu, dass einzelne Bereiche leicht über- oder unternutzt wurden. Beide Herausforderungen konnten durch räumlich und zeitlich differenzierte Managementansätze adressiert werden – beispielsweise durch mosaikartige Mahd oder standortangepasste Beweidung mithilfe gezielter Herdenführung.

Fazit – Ob Mahd oder Beweidung besser geeignet ist, um artenreiche Feuchtgrünländer langfristig zu erhalten, lässt sich am treffendsten wie folgt beantworten: (i) Beide Regime wirken grundsätzlich positiv – sofern ausreichende personelle, finanzielle und logistische Ressourcen vorhanden sind, um eine kontinuierliche und flexible Anpassung an lokale Standortbedingungen zu gewährleisten. Dies gilt insbesondere für die Beweidung, bei der teils kürzere Anpassungsintervalle erforderlich sind. ii) Die Kombination beider Regime bietet das größte naturschutzfachliche Potenzial. Durch ihren komplementären Einsatz können unterschiedliche Artengruppen gefördert und zugleich regimebedingte Schwächen ausgeglichen werden – etwa hinsichtlich der Verwertung anfallender Biomasse bei der Mahd oder der Entstehung heterogener Vegetationsstrukturen unter Beweidung.

Authors contributions

LJH and ACJ conceived the ideas and designed the methodology; ACJ collected the data; ACJ and LJH analyzed the data and created figures and tables. ACJ created a first manuscript as her master thesis. LJH supervised structure and content of the thesis. JM contributed to revising the text and structure of the final manuscript. LJH wrote the final manuscript.

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Supplements

Supplement S1. Overview of mowing studies.
Beilage S1. Überblick über die Studien zur Mahd.

Supplement S2. Overview of grazing studies.
Beilage S2. Überblick über die Studien zur Beweidung.

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Supplement S1. Overview of mowing studies: habitat type, mowing frequency per year (e.g., 0x = abandonment), compared management (mowing frequency or other), overall evaluation of the authors which regime performed better (= better results), effects on diversity and composition, as well as a description of observed developments or author-reported notes and limitations.
Code details: + = positive; - = negative; ~ = similar; α = alpha-diversity; β = beta-diversity; R3 = EUNIS type R3 (seasonally wet and wet grasslands) and subtypes; focal habitat; R2= EUNIS type R2 (mesic grassland) and subtypes; mesic direction from focal habitat; Q = EUNIS type Q (wetlands) and subtypes (mainly Q4, some Q5); wet direction from focal habitat; A = former use as arable land; H = authors mentioned heterogeneous area (several types).

Beilage S1. Überblick über die Studien zur Mahd: Habitattyp, Mahdfrequenz, Vergleichsgröße, Gesamtbewertung, welches Regime bessere Ergebnisse erzeugte, Wirkung auf Diversität und Komposition, Beschreibung der beobachteten Entwicklungen und von den Autor*innen hervorgehobene Bemerkungen oder Einschränkungen. Erklärungen zu den Codierungen am Tabellenende.
Code-Details: + = positiv; - = negativ; ~ = ähnlich; α = alpha-Diversität; β = beta-Diversität; R3 = EUNIS-Typ R3 (Feucht- und Nassgrünland) und Subtypen; Focushabitat; R2= EUNIS-Typ R2 (mesophiles Grünland) und Subtypen; mesische Richtung vom Fokushabitat; Q = EUNIS-Typ Q (Sümpfe und Moore) und Subtypen (im wesentlichen Q4, einige Q5); nasse Richtung vom Fokushabitat; A = frühere Nutzung als Acker; H = Autoren erwähnten heterogenes Areal (mehrere Typen).

reference	habitat type	mowing freq./yr	compared to	better results	effects on		description of vegetation development and example species (if given)	constraints/ additional measures/ authors notes
					div.	comp.		
Jensen & Meyer 2001	R3	2x – 3x	0x	2x > 0x	+ α	+	positive: less dominant species (*Carex acuta, Phragmites australis, Carex canescens*); more specialized species (*Lotus pendunculatus, Lychnis flos-cuculi,Viola palustris*)	
Čop et al. 2009	R3, R2	4x (R2), 3x, 2x	4x (R2), 3x, 2x plus fertilizer	fertilized > mown	+ α (3x) - α (4x)	 -	positive: in R3 plus fertilizer increase in diversity when mown 3x instead of 2x negative: more tall-growing, generalist species (e.g., *Filipendula ulmaria*) in R3 and more grasses in R2	in R2 economic & ecological aims were met; in R3 mowing 2x without fertilizer is better
Sand-Jensen et al. 2019	R3	2x	0x	2x > 0x	+ α	+	positive: less dominant species; lowered indicator values for nitrogen; more specialized and rare species (*Dactylorhiza majalis; Selinum carvifolia, Carex* spp.)	
Pavlů et al. 2016	R2	2x	mulch. (1x-3x); 0x	2x > 3x mulch. > 2x mulch. > 1x mulch. > 0x	+ α	NA	positive: more target species	
Berendse et al. 1992	R3, A	2x	mulch. (1x-2x)	2x > 2x mulch. > 1x mulch.	+ α	+	positive: less generalist species (*Lolium perenne, Poa pratensis*); more specialized species (*Ranunculus repens, Lychnis flos-cuculi, Thalictrum flavum, Ajuga reptans, Carex panicea; C. hostiana*)	initial hydrological improvements & topsoil removal
Oomes et al. 1996	R3, A	2x	mulch. (2x)	2x > 2x mulch.	+ α	+	positive: i) more specialized, ii) more low-growing, III) more rare species (e.g., *Viola persicifolia*); lowered indicator values for nitrogen	initial hydrological improvements & topsoil removal
Oelmann et al. 2009	R3	2x	2x plus fertilizer	2x > 2x plus fertilizer	~/+ α	(+)	positive: more stress tolerant species; lowered indicator values for nitrogen	no new establishment of species due to limited seedbank
Bochniak et al. 2024	H (R3, R2)	2x	1x, 0x	2x > 1x > 0x	+ α - β	+	positive: less dominant species; more specialized species (*Crepis biennis* , *Lotus corniculatus*)	
Hájková et al. 2009	Q	2x	1x, 0x	2x > 1x> 0x	+ α - β	+	positive: more specialized species (*D. majalis, Linum catharticum, Polygala amarella*)	
Hájková et al. 2022	R3, Q	2x	1x, 0x	2x > 1x> 0x	+ α	+	positive: more specialized species *(Carex flava, C. nigra, Eriophorum latifolium, Parnassia palustris)*	
Poptcheva et al. 2009	R3	2x	1x, 0x	2x > 1x > 0x	+ α	+ (2x) ~ (1x)	positive: less dominant species; more stress tolerant species; more specialized species (*L. flos-cuculi, Ranunculus flammula* , *Juncus filiformis);* lowered indicator values for nitrogen negative: annual mowing im summer (July): litter accumulation; annual mowing in autumn (Sept): more tall-growing species	
Kulik et al. 2019	H (R3, Q, R2)	2x	1x, 0x	2x > 1x > 0x	+ α	NA		
Szépligeti et al. 2016	R2	2x	1x spring; 1x autumn; 0	2x > autumn > spring > 0x	+ α	+	positive: less tall-growing species (here *Solidago gigantea*); more low-growing species	
Velbert et al. 2017	R3	2x	1x spring; 1x autumn; 0	2x > autumn > spring > 0x	+ α (2x) ~ α (1x) - β	+	positive: less dominant, tall-growing species; more light-demanding, low growing species	
Pech et al. 2015	R3	1x – 2x	0x	1x > 0x	+ α	+	positive: less dominant species (*M. caerulea);* more low-growing species (*Luzula multiflora*)	
Billeter et al. 2007	Q	1x	0x	1x > 0x	+ α	+	positive: less dominant species (grasses); more specialized species *(D. majalis, Parnassia palustris, Carex davalliana)* negative: decline of late-blooming species (*Succisa pratensis*)	
Galvánek et al. 2015	Q	1x	0x	1x > 0x	+ α	+	positive: more specialized species (e.g., *Primula farinosa*); more generalist species negative: consistently high abundances of *P. australis*	
Peintinger & Bergamini 2006	Q	1x	0x	1x > 0x	+ α	+	positive: less phytomass; more specialized species (e.g., *C. panicea, Linum catharticum*)	
Valkó et al. 2012	H (R3, R2	1x	0x	1x > 0x	+ α - β	+	positive: less phytomass; more specialized species (e.g., *Linum catharticum, Viola canina)* negative: decline of late-blooming species (*Succisa pratensis*)	
Török et al. 2009	R3	1x	0x	1x > 0x	+ α	+	positive: less phytomass; more specialized species (*Leontodon hispidus, Viola canina*); increase in seedbank quality	
Opdekamp et al. 2012	R3	1x	0x	1x > 0x	+ α - β	+	positive: more low-growing, light-demanding species	
Gerard et al. 2008	R3	1x	0x	1x > 0x	+ α	+	positive: less dominant species; more low-growing grasses; more rosette-forming species	regular inundation increases seedbank quality
Lepš 1999	R3	1x	1x plus fertilizer, dom. removal, 0x	1x > dominant removal > 1x plus fertilizer > 0x	+ α	+	positive: more low-growing species; more establishment niches negative: less late-blooming species (*Sanguisorba officinalis, Betonica officinalis*)	
Lepš 2014	R3	1x	1x plus fertilizer, dom. removal, 0x	1x > dominant removal > 1x plus fertilizer > 0x	+ α - β	+	positive: more low-growing species; more establishment niches negative: less late-blooming species (*Sanguisorba officinalis, Betonica officinalis*)	
Horak & Safarova 2015	R3	1x	0x	~	~	~	no significant differences in the first year after mowing	
Kołos 2012	Q	1x	0x	1x > 0x	~ α	~	positive: more specialized species (*Myosotis palustris, Crepis paludosa, Galium uliginosum, Poa palustris*) limitations: permament flooding counteracted mowing and re-established sedge beds	effects of hydrological cond. stronger than mowing
Kołos 2018	Q	1x	0x	1x > 0x	~ α	~	positive: more specialized species limitations: permanent flooding reduced diversity and promoted tall-growing sedges	effects of hydrological cond. stronger than mowing
Kołos & Banaszuk 2013	R3	1x	0x	1x > 0x	+ α	-	positive: less dominant species; more specialized species (*D. majalis*) negative: after 10 yrs of earlier mowing and hydrological deterioration increased dominant species; less specialized species	effects of hydrological cond. stronger than mowing
Vannucchi et al. 2022	R2	1x	0x	1x > 0x	- α, - β	~/+	positive: more annuals and late-blooming species; lowered litter layer negative: abandonment increased diversity of generalist species and ruderals	
Touzard et al. 2002	R3	1x & post-g.	0x	1x > 0x	+ α - β	k.A.	positive: less phytomass; less dominant species (*Phalaris arundinacea, Agrostis stolonifera*); lowered litter layer	
Sundberg 2012	R3	1x & g.	grazing	1x & g. > grazing	+ α	+	positive: less tall-growing species (*M. caerulea*); less nitrophilous species (*U. dioica*); more specialized species (*Carex flacca, Primula farinosa*)	
Kulik 2014	R3	1x & post-g.	1x, 0x	0x > 1x > post-g.	+/~ α	-	partly positive: more generalist species negative: less specialized species; less specialized, rare species (*D. majalis, Gentiana pneumonanthe*)	negative effects due to hydrological conditions and early mowing dates
Edwards & Kučera 2019	R3, Q	max. 1x	0x 2x - 3x	1x > 0x 2x > 1x	+ α - α	+ -	positive: more specialized species (e.g., *Lychnis flos-cuculi*); constant abundance of *C. acuta;* negative: less structures and lowered diversity	comparison of different regimes in time (1x 2019; 2-3x 1965)
Swacha et al. 2018	R3	biannual	0x	biannual > 0x	+ α	+	positive: less dominant species (*Solidago gigantea*) and shrubs	
Milberg et al. 2017	R3, R2	triannual.	1x 0x	1x > triannual triannual > 0x	- α + α	- +	species loss when mown ev. 3rd y. is only one third compared to species loss when abandoned	
Güsewell & Le Nédic 2004	H (R3, Q)	triannual	0x	triannual > 0x	+ α - β	-	positive: more specialized species; less litter negative: less specialized species; more generalist species; more shrub seedlings; general homogenisation	increase of species in wet areas often in lanes
Kozub et al. 2019	Q	NA	0x	mowing > 0x (eutroph. areas) 0x > mowing (oligotr. areas)	+ α - α	+ -	positive: less dominant species; more specialized species (in eutrophic areas) negative: less specialized and rare species; less late-blooming species (in oligotrophic areas)	
Diemer et al. 2001	Q	NA	0x	mowing > 0x	+ α	+	positive: less dominant species (here *M. caerulea*); lowered vegetation height; more specialized *Juncaceae* and *Cyperaceae*	
Bódis et al. 2021	R3	once	mulching, burning	~	~ α	~	positive: less litter (when mown 30%, when burned 83%); no effect on diversity after mowing once	study focused on reduction of litter
Menichino et al. 2016	Q	once	0x	once >/~ 0x	+/~ α	+/~ α	positive: lowered vegetation height; slightly more specialized species (*L. salicaria*) negative: more dominant species (*P. australis*)	heterogeneity of the area leads to varying effects

Supplement S2. – Overview of grazing studies, organized by the general effect of grazing (positive, moderately positive, negative), and including habitat type, regime, comparison treatment, effects on diversity and composition, as well as details on vegetation development and additional remarks.
Code datails: + = positive; - = negative; ~ = similar; α = alpha-diversity; β = beta-diversity; R3 = EUNIS type R3 (seasonally wet and wet grasslands) and subtypes; focal habitat; R2 = EUNIS type R2 (mesic grassland) and subtypes; mesic direction from focal habitat; Q = EUNIS type Q (wetlands) and subtypes (mainly Q4, some Q5); wet direction from focal habitat; A = former use as arable land; H = authors mentioned heterogeneous area (several types).

Beilage S2. Überblick über die Studien zur Beweidung, geordnet nach grundsätzlicher Wirkung der Beweidung (positiv, eingeschränkt positiv, negativ) und Habitattyp, Regime, Vergleichsgröße, Wirkung auf Diversität und Komposition, inklusive Details zur Vegetationsentwicklung und Anmerkungen.
Code-Details: + = positiv; - = negativ; ~ = ähnlich; α = alpha-Diversität; β = beta-Diversität; R3 = EUNIS-Typ R3 (Feucht- und Nassgrünland) und Subtypen; Focushabitat; R2= EUNIS-Typ R2 (mesophiles Grünland) und Subtypen; mesische Richtung vom Fokushabitat; Q = EUNIS-Typ Q (Sümpfe und Moore) und Subtypen (im wesentlichen Q4, einige Q5); nasse Richtung vom Fokushabitat; A = frühere Nutzung als Acker; H = Autoren erwähnten heterogenes Areal (mehrere Typen).

reference	**habitat type**	**regime**	**compared to**	**effects on**		**description of vegetation development and example species (if given)**	**constraints/ additional measures/ authors notes**
				div.	**comp.**		
positive effects, development towards target habitat							
Ausden et al. 2005	Q	year-round grazing	exclosure	+ α; + β	(+)	less phytomass and lowered vegetation height; increase in species richness but constant number of low-growing or rare species; more specialized species	grazing patterns; increase in beta-diversity
Kulik et al. 2023	R3	year-round grazing	earlier management (1x mow)	+ α	+	more specialized species due to establishment niches; higher indicator values for nitrogen	
Mann & Tischew 2010	R3, A	year-round grazing + adjacent donor sites	former arable land, grazing as restauration with comparison of different methods	+ α	+	less ruderal species (*C. arvense*); more specialized species (*Cnidium dubium*)	after 5 years abundances of specialized species comparable to sites with hay-transfer
		year-round grazing + sowing		(- α)	(-)	sowing negatively affected establishment of specialized species	effects of hydrological conditions stronger than grazing
		year-round grazing + hay transfer		+ α	+	more specialized species	
Schaich et al. 2010	H (R3, R2)	year-round grazing + improvements of hydrology	exclosure	+ α	+	less dominant species; more specialized and rare species	effects of hydrological conditions stronger than grazing
Pykälä 2005	R2	continuous grazing (not specified)	abandonment	+ α	+	higher diversity in life-forms (more Chamae-;Hemikryptophytes, but less Geophytes); more low-growing species; less tall-growing species	continuous grazing better than re-established grazing; re-established grazing better than abandonment
Török et al. 2014	R3	summer grazing	exclosure	+ α	+	lowered vegetation height; less dominant species (*P. australis; Elytrigia repens*); more specialized species	
Vinther & Hald 2000	R3	summer grazing	abandonment	+ α	+	new establishment of specialized species; higher abundances of specialized species; more herbs, hemikryptophytes and geophytes; more sedges	initial mowing before grazing started
~ partly positive effects; limitations and neccessity of further measurements							
Bakker & Ter Heerdt 2005	R3, A	rotational grazing	development over time	~ α	(+)	lowered indicator values for nitrogen; higher abundances of specialized species; no new establishment of specialized species and constant species richness **Limitations: positive development but missing of targets due to high site productivity and depleted seedbank**	
Gilhaus et al. 2014	R3, A	year-round grazing (two different intensities)	former intensive use; results after 15 years of grazing in two different intensities	+ α higher intensity ; + β	(+)	with slightly higher grazing intensity more low-growing and rosette forming species typical for target habitat; but also more unpalatable species	grazing patterns; increase in beta-diversity
				- α lower intensity ; + β	-	with lower grazing intensity more structural diversity and more tall-growing species (e.g., *Solidago gigantea*)	
						Limitations: no establishemt of rare specialized species due to high site productivity and depleted seedbank; more grazing indicator species;	
Pykälä 2003	R2	continuous grazing (not specified)	abandonment	+ α	~	more low-growing species; constant amount of rare species **Limitations: no establishment of rare specialized species due to high site productivity and depleted seedbank**	continuous grazing better than re-established grazing; re-established grazing better than abandonment
Rasran et al. 2007	R3, Q	moderate grazing (not specified)	exclosure	NA	~/(+)	slighty higher abundances of specialized species	
		grazing + topsoil removal		NA	+	less generalist species; more specialized species (*Lotus penduculatus*)	large effects of topsoil-removal and hay-transfer and their combination
		grazing + hay transfer		NA	+	higher abundances and amount of specialized species (*Caltha palustris*)	
						Limitations: marginal establishment of specialized species due to high site productivity and depleted seedbank	
negative effects							
Koch et al. 2017	Q	rotational grazing	comparison with status in 1991 and 2014	~ α	-	more grasses; less specialized species (*D.majalis*) **negative development: grazing patterns from sheep negatively affected wet areas**	
Küchler et al. 2009	H (Q)	summer grazing	exclosure	NA	-	less specialized species; more grazing indicator species and dominant species (*P. australis*); shrub encroachment **negative development: too high site productivity led to negative feedback with grazing patterns**	deteriorated hydrological cond. led to mineralisation and too high site productivity
Schrautzer et al. 2016	H (R3, Q)	summer grazing on organic soils	long-term monitoring of 3 different areas	- α; ~ β	-	less specialized species; more nitrophiluous species (*U. dioica)*	improvements in hydrological conditions; herding techniques or fencing neccessary for conservation of high value grasslands
		summer grazing on mineral soils		+ α; + β	+	less tall growing species and ruderal species	
						negative development on organic and mineral soils because heterogeneity of sites led to over- and undergrazing patterns with degradation of valuable Calthion-patches	