Received: 16 December 2022 | Revised: 8 June 2023 | Accepted: 17 June 2023

DOI: 10.1111/avsc.12740

Applied Vegetation Science IAVS

RESEARCH ARTICLE

What is a suitable management for *Typha latifolia* control in wet meadows?

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Funding information
Deutsche Bundesstiftung Umwelt; Grantová Agentura České Republiky; Ministerstvo Zemědělství

Co-ordinating Editor: Péter Török

Abstract

Aim: *Typha latifolia* causes serious problems in wet meadows by overgrowing and suppressing other native plants. To determine suitable management for *T. latifolia* control, we addressed the following question: What are the effects of long-term cutting at different frequencies (once or twice per year and no management) and biomass removal on cover and other characteristics of *T. latifolia*, and on sward productivity and plant species composition?

Location: Malá Strana nature reserve, Jizerské hory Mountains, Czechia.

Methods: A long-term experiment arranged in a randomised block design with three blocks was established in 2005. Data were collected from five treatments: unmanaged control; cutting once a year in June without biomass removal and with biomass removal; cutting twice per year in June and August without biomass removal and with biomass removal. Percentage cover of *T. latifolia* and other vascular plant species was visually estimated and *T. latifolia* characteristics (tiller density, height, dry-matter biomass [DMB] yield and litter), sward height and DMB yield were measured during 2005–2018 at the end of June.

Results and Discussion: Regular cutting once or twice per year regardless of cut biomass removal led to reductions in tiller density, height, litter and DMB yield of *T. latifolia*. Biomass removal had only a slight tendency to affect *T. latifolia* characteristics. The higher frequency of cutting significantly decreased the mean *T. latifolia* cover, litter and DMB yield. Cutting once or twice per year regardless of biomass removal led to successive changes in plant species composition but had no effect on the species richness and evenness.

Conclusions: Cutting at least once per year without biomass removal seems to be sufficient to achieve a decrease in DMB yield and litter of *T. latifolia* plants, and thereby maintain the wet-meadow vegetation without loss of species richness and also preventing the overgrowth of shrubs and trees.

Managements for *Typha latifolia* control

KEYWORDS
biomass removal, cutting frequency, dry-matter biomass yield, Ellenberg indicator values, functional groups, plant species composition, species diversity, sward characteristics, *Typha latifolia* characteristics, wet meadow

1 | INTRODUCTION

Typha spp. are common species in wetland ecosystems, particularly in freshwater habitats, and occur in many parts of the world (Sale & Wetzel, 1983). This genus has a cosmopolitan distribution and includes species that can behave aggressively and may suppress other native species in their natural communities (Apfelbaum, 1985). Bansal et al. (2019) summarised the extensive knowledge regarding the ecological characteristics of *Typha* spp. and noted that the species can have considerable impacts on local fauna and flora, and also affect biogeochemical cycling, wetland hydrology and overall wetland functioning. Many other authors have mentioned the large impacts that *Typha* spp. have on natural wetland communities (Ball, 1990; Sharma & Kushwaha, 1990; Lishawa et al., 2017), but few of them have examined the effects of different managements on the characteristics of *T. latifolia* species by long-term experimentation.

Although *Typha latifolia* L. is a native species in Europe and North America, it may become a problematic weed species in many wetland habitats and can often significantly suppress the original vegetation (Murkin & Ward, 1980; Clevering & Toorn, 2000; Lishawa et al., 2017; Bansal et al., 2019). Reduction or total suppression of *T. latifolia* helps to increase habitat heterogeneity, the cover of other plant species (Apfelbaum, 1985) and species diversity (Lishawa et al., 2017). The harvested biomass of *T. latifolia* could also be used as a sustainable feedstock for use in renewable energy production or for bioremediation (Garver et al., 1988; Maddison et al., 2009; Bansal et al., 2019).

Typha latifolia tolerates a broad range of climatic conditions and soils that remain wet or saturated by water over a major part of the growing season (Grace & Harrison, 1986). It has a high growth rate (Sale & Wetzel, 1983), especially under conditions with favourable nutrient supply. Further, special photosynthetic acclimation to flooded conditions (Li et al., 2004) and high proliferation by vegetative growth (Sale & Wetzel, 1983) enable *T. latifolia* to outcompete other vascular plant species in many wet habitats.

Management approaches based on either cutting or herbicide application are considered appropriate for control of *Typha* spp., although there are other potentially suitable methods including flooding, burning and physical removal (Apfelbaum, 1985). Harvesting during the summer is most detrimental for *T. latifolia* plants, because they have only a short period to translocate nutrients and non-structural carbohydrates from the shoots to the belowground organs. These belowground reserves are necessary especially for the initial growth of new shoots in the following spring (Maddison et al., 2009), and to enable the plants to overcome disturbance (Toet et al., 2005). If the plants are cut below the water surface their ability to supply air to the rhizomes in deep water declines (Murkin & Ward, 1980; Grace, 1989). Other benefits of *T. latifolia* control by cutting include restricting plant growth to the immature phases and reducing transpiration rates (Martin et al., 2003). Cutting of shoots three times over the growing season is considered to be an optimal management technique for *Typha* spp. reduction (Apfelbaum, 1985; Sharma & Kushwaha, 1990).

The cut biomass of wet meadows should be removed to prevent it affecting the growth of other species present, the impact of which varies according to the thickness of the mown layer and the rate of biomass decomposition. The decomposition rate of *T. latifolia* is affected, as in other plants, by lignin concentrations (Murphy et al., 1998) and C:N ratio of litter (Lee & Bukaveckas, 2002), C:N:P content in plant detritus (Enríquez et al., 1993), pH (Batty & Younger, 2007) and by site-specific climatic conditions (Murphy et al., 1998). These include temperature and drought effects (Liski et al., 2003). The decomposition process also depends on microorganisms (bacteria, fungi) (Álvarez & Bécares, 2006) and surface water and sediment nutrient concentrations (Lee & Bukaveckas, 2002), all of which have indirect impacts on the plant growth.

The wet meadows in Central Europe provide a wide range of ecosystem services including plant and animal biodiversity, water retention and carbon storage; however, their area and species richness have declined rapidly during the last 50 years. There are two contrasting management regimes that negatively affect the diversity of wet meadows: (i) management intensification as a result of land drainage, increased fertilisation and increased mowing frequency (Wesche et al., 2012); and (ii) land abandonment (Swacha et al., 2018). As a result of these two contrasting but damaging developments, wet meadows are now among the most threatened grassland types (Wesche et al., 2012; Krause et al., 2015).

Although many previous studies have addressed the effects of regular cutting management on *T. latifolia* species when growing in deep water in different waterlogged areas, none of them have considered the long-term effect of cutting on this species when it is growing in wet meadows with shallow water supply. To address this important knowledge gap, a long-term experiment was established in the wet meadow alliance *Calthion* with *T. latifolia* dominance.

In the present paper we have focused on the following questions: (i) What is the effect of long-term cutting at different frequencies (once or twice per year, relative to no cutting management) on *T. latifolia* characteristics (cover, number and height of tillers, dry-matter biomass [DMB] yield and litter), and on the sward characteristics of wet meadow vegetation (species diversity, sward height, DMB yield, plant species composition and functional groups); and (ii) is there any effect of biomass removal after cutting on *T. latifolia* characteristics and on sward characteristics of wet meadow?

2 | METHODS

2.1 | Study site

The experiment was established in the Malá Strana nature reserve in the Jizerské hory Mts. (Czechia, 50°45′52″ N, 15°12′19″ E; 722 m a.s.l.). The area lies within a shallow mountain basin with gentle slopes between the brook and its surroundings. The site has a mean annual precipitation of 1373 mm. Average annual temperature is 4.4°C (Vesecký, 1961). Data for average monthly precipitation and temperature (meteorological station in Bedřichov, 7.5 km from study site) during the study period are presented in Appendix S1. The Rábenka brook, which is very close to the experiment (ca. 10–15 m), provides a continuous water supply to maintain groundwater, and the vegetation is growing in waterlogged conditions throughout the year even during periods of summer drought. The original drainage installations have ceased to function due to vegetation growth and water is no longer diverted away from the area of experiment. There is almost no effect of spring water and as the brook has a relatively low flow rate there is no spillover to the surrounding basin and almost no inundations. However, as there is usually snow cover in early spring (end of March/beginning of April) snowmelt provides some additional water at the beginning of the growing season. Although there were agricultural activities more than 50 years ago at the area of experiment, there is currently no source that could cause eutrophication. The bedrock is a porphyritic, medium granular granite and granodiorite (Chaloupský et al., 1989).

At the beginning of the 20th century a large area of the nature reserve was under agricultural management. Land drainage was installed, and the area divided into small fields with crops. Areas of grassland were subsequently grazed by cattle until the end of 1970 at places where there were small fields. Large areas of nature reserve were either left unmanaged for decades or were managed under extensive cutting for many years. This resulted in shrubs, young trees and *T. latifolia* encroachment and consequently the area of grassland was reduced. The area of this experiment had not been cut for many years before the experiment was established.

The vegetation of the experimental grassland is classified as *Calthion* (Chytrý et al., 2007). This alliance is also the most affected by *T. latifolia* expansion in nature reserve Malá Strana. However, despite its spread, only about 10% of the reserve is affected by this plant. At the start of the experiment the dominant vascular plant species were *T. latifolia*, *Filipendula ulmaria* and *Carex nigra*.

2.2 | Experimental design

The experiment was established in 2005 in three completely randomised blocks (Appendix S2). The area of each plot was 16 m^2 (4 m × 4 m) with a buffer zone row between plots of 0.5 m. This row was cut twice per year in June and August and the biomass was removed. The following treatments were applied: unmanaged control (U), one cut per year in June without biomass removal (1N), one cut per year in June with biomass removal (1R), two cuts per year in June and in August without biomass removal (2N), two cuts per year in June and August with biomass removal (2R). The cutting frequency reflected traditional management in these areas, and this was approved by the nature conservation agency, which is owner of the research site.

2.3 | Data collection

2.3.1 | Number and height of *Typha latifolia* tillers

The number of *T. latifolia* tillers was recorded in each experimental plot before the first cutting throughout the study period of 2008–2018, and the height of all presented *T. latifolia* tillers was measured in a 30-cm wide strip (15 cm to the left and 15 cm to the right along the diagonal transect) in each experimental plot before the first cutting throughout study period of 2008–2017.

2.3.2 | Dry-matter biomass yield and litter of *Typha latifolia*, dry-matter biomass yield and sward height

Herbage samples were taken in the years 2008–2017 except for *T. latifolia* litter, which was collected in the years 2009–2017. Dry-matter biomass yield of the first cut was measured in four subplots each with dimensions of 50 cm × 50 cm, randomly placed within each experimental plot. Cutting was done to a stubble height of 3 cm. To avoid any residual effect of herbage collection from the previous year in the unmanaged treatment, the biomass sampling site was outside of permanent plots in the surroundings and differed every year. The harvested herbage was sorted into *T. latifolia* herbage and litter (in the years 2009–2017), and other herbage. Separated fractions were then dried at 60°C until totally desiccated and DMB yield (t ha^{-1}) of all subsampled groups was then determined. The mean of four subsamples per experimental plot was used for statistical analyses.

Compressed sward height (cm) without *T. latifolia* was measured using a rising plate meter (Castle, 1976). Ten measurements were taken in each experimental plot before vegetation sampling in each vegetation season during the study period 2010–2018.

2.3.3 | Species diversity and botanical composition

The percentage cover of all vascular plant species was visually estimated in each plot before the first cut in June from 2005 to 2011, 2013, and 2017. Nomenclature of vascular plant species follows the regional flora (Kaplan et al., 2019). All plant species recorded in the experiment were classified into five functional groups: legumes, short graminoids (mean height less than 0.5 m), tall graminoids (mean height 0.5 m or more, and excluding *T. latifolia*) and similarly short and tall forbs, in accordance with the regional flora (Kaplan et al., 2019). The sum cover of species in each functional group was used in subsequent analyses. Legumes were represented by a single species with negligible abundance and thus not analysed. Species richness was calculated from the data of abundance. Buzas-Gibson's evenness was calculated as $E = e^{H'}/S$, where H' is the Shannon index of diversity and S is species richness.

2.3.4 | Ellenberg indicator values

The weighted mean of Ellenberg indicator values (EIV) for soil moisture and nutrients was calculated in each plot using the cover of each plant species (Ellenberg et al., 1992). *Typha latifolia* was excluded from these calculations to avoid trivial results caused by its very high cover, which is analysed separately. EIV for light was not considered, because its scale has limited use within a single grassland type with no canopy cover (Chytrý et al., 2018).

2.4 | Data analysis

Two sets of general linear mixed-effects models (GLMMs) were used to analyse the cover of *T. latifolia*, number of *T. latifolia* tillers, height of *T. latifolia* in transect (cm), *T. latifolia* DMB yield (t ha^{-1}), *T. latifolia* litter (kg ha^{-1}), compressed sward height (cm), DMB yield (t ha^{-1}), species richness, evenness index, sum cover of plant functional groups and mean EIV throughout the study period. All variables derived from species-cover data were analysed without the data from the first three years (2005–2007) in order to account for the delayed response of vegetation to the management treatments.

The first set of models included all five treatments in a single factor. Blocks and years were used as random factors; all interactions were included in the model to estimate appropriate residual mean square and degrees of freedom (Satterthwaite, 1946). If necessary, data were log-transformed to meet GLMM assumptions (Appendix S3). Benjamini–Hochberg's procedure was applied to control for false-discovery rate (Verhoeven et al., 2005). Further, to identify significant differences between individual treatments, a post-hoc comparison using Tukey's honestly significant difference (HSD) test was applied. The second set of models excluded the U treatment, thereby enabling to test for separate effects of frequency, biomass removal and of frequency * biomass removal interaction, with all other settings being same as in the first set. For all univariate statistical analyses, software Statistica 13.2 was used (Dell Inc., Round Rock, TZ, USA; 2019).

The effect of treatment on the community composition was analysed using partial redundancy analysis (RDA) in Canoco 5 (ter Braak & Šmilauer, 2012). The effect of treatment was used as an explanatory variable, while years and blocks were used as categorical covariates. Species cover (%) data were logarithmically transformed [$x' = \log_{10}(10^* x + 1)$]. The data of the first three years were excluded from the analysis to deal with the possibility of a delayed response of the vegetation to the managements applied at the beginning of the experiment. The effect of treatment (all constrained axes) was tested using 9999 Monte Carlo permutations in a hierarchical design where whole plots comprised samples from single plots across all years and were permuted within blocks.

All previous analyses filtered out the effect of time to focus on the part of the effect of treatment, which is consistent across years, excluding the initial years. To disclose the temporal dynamics, we supplemented the main analyses by plots of means and standard errors of selected parameters of *T. latifolia*, parameters of the sward, and abundance of selected dominant species (six dominant graminoids and six dominant forbs) in each year including the initial years. To illustrate the temporal dynamics in the whole community relative to the unmanaged control treatment, we present the diagram of principal response curves including the initial years (PRC; ter Braak & Šmilauer, 2012). In PRC, the interaction of treatment * year was used as explanatory variable and year as covariate. The same settings of permutation test as in RDA was used.

3 | RESULTS

3.1 | *Typha latifolia* characteristics

All characteristics of *T. latifolia* were significantly affected by treatment. The highest mean cover of *T. latifolia* was 37.2 ± 2.7% (mean ± standard error) in the U and 25.8 ± 2.1% in the 1N treatment and the lowest in both treatments cut twice per year (6.7 ± 0.6% in the 2R; 8.0 ± 0.8% in the 2N) (Table 1), where its cover decreased over time (Figure 1a). The higher frequency of cutting significantly reduced the mean cover of *T. latifolia* (22.8 ± 1.5% in the first cut; 7.3 ± 0.5% in the second cut) (Appendix S3).

The highest mean number of *T. latifolia* tillers was 186.3 ± 13.1 in the U treatment and the lowest was 66.7 ± 4.2 in the 2R treatment. The highest mean height of *T. latifolia* in the transects was 110.5 ± 3.4 cm in the U treatment and the lowest was in the treatments cut twice per year (81.1 ± 4.4 cm in the 2N; 84.2 ± 3.3 cm in the 2R) (Table 1; Figure 1b,c).

The mean *T. latifolia* DMB yield and *T. latifolia* litter were the highest (1.85 ± 0.19 t ha^{-1}; 738.4 ± 111.3 kg ha^{-1}) in the U treatment respectively (Table 1; Figure 1d,e). The higher cutting frequency resulted in significantly decreased mean DMB yield of *T. latifolia* (0.63 ± 0.04 t ha^{-1} in the one-cut; 0.33 ± 0.04 t ha^{-1} in the two-cut) and in *T. latifolia* litter (93.2 ± 7.8 kg ha^{-1} in the one-cut; 10.5 ± 2.3 kg ha^{-1} in the two-cut) (Appendix S3).

3.2 | Sward and plant community characteristics

The type of treatment significantly affected sward height (cm) and DMB yield (t ha^{-1}), where U had significantly higher values than other treatments; however, these did not differ from each other (Table 1; Figure 2a,b).

TABLE 1 Results of the general linear mixed-effects models (GLMM) of the *T. latifolia* characteristics and sward characteristics.

	p-Value	U	1N	1R	2N	2R
Typha latifolia						
Cover of *T. latifolia* (%)	<0.001	37.2 ± 2.7[a]	25.8 ± 2.1[a]	19.7 ± 1.8[ab]	8.0 ± 0.8[bc]	6.7 ± 0.6[c]
Number of *T. latifolia* tillers	0.022	186.3 ± 13.1[a]	177.4 ± 16.3[ab]	130.1 ± 6.8[ab]	78.7 ± 5.7[ab]	66.7 ± 4.2[b]
Height of *T. latifolia* in transect (cm)	0.022	110.5 ± 3.4[a]	91.0 ± 2.1[ab]	87.2 ± 1.9[ab]	81.1 ± 4.4[b]	84.2 ± 3.3[b]
T. latifolia DMB ($t\,ha^{-1}$)	<0.001	1.85 ± 0.19[a]	0.70 ± 0.08[b]	0.56 ± 0.06[bc]	0.38 ± 0.09[bc]	0.27 ± 0.04[c]
T. latifolia litter ($kg\,ha^{-1}$)	<0.001	738.4 ± 111.3[a]	115.4 ± 17.3[b]	71.0 ± 12.0[bc]	14.4 ± 4.7[c]	6.6 ± 1.5[c]
Sward						
Sward height (cm)	0.001	22.1 ± 0.8[a]	17.3 ± 0.7[b]	16.0 ± 0.7[b]	15.4 ± 0.4[b]	15.8 ± 0.6[b]
DMB yield ($t\,ha^{-1}$)	0.001	3.89 ± 0.30[a]	1.89 ± 0.12[b]	1.70 ± 0.14[b]	1.38 ± 0.10[b]	1.43 ± 0.08[b]
Species richness	0.520	25.6 ± 0.6	28.8 ± 0.7	29.9 ± 1.0	29.1 ± 0.6	28.6 ± 0.9
Evenness index	0.955	0.35 ± 0.02	0.35 ± 0.01	0.35 ± 0.01	0.36 ± 0.02	0.32 ± 0.03
Tall graminoids (%)	0.146	46.2 ± 1.7	26.9 ± 2.3	21.3 ± 1.9	13.4 ± 1.5	8.0 ± 1.0
Tall forbs (%)	0.342	32.6 ± 3.9	16.4 ± 1.8	16.9 ± 1.7	16.7 ± 3.3	11.8 ± 2.7
Short graminoids (%)	0.045	33.2 ± 2.4	45.7 ± 2.7	46.7 ± 3.8	53.6 ± 3.8	59.8 ± 3.2
Short forbs (%)	0.502	18.8 ± 3.0	26.2 ± 3.5	16.1 ± 2.4	17.6 ± 2.3	14.7 ± 2.1
EIV moisture	0.112	7.94 ± 0.04	8.23 ± 0.03	8.28 ± 0.06	8.17 ± 0.05	8.18 ± 0.04
EIV nutrients	0.106	4.18 ± 0.08	4.18 ± 0.09	3.90 ± 0.07	3.66 ± 0.15	3.33 ± 0.14

Note: *p*-Value – obtained probability value (see *F*- and *df*-values in Appendix S3). Significant *p*-values after controlling for a table-wise Benjamini–Hochberg's false-discovery rate are shaded. Applied treatments were: U (unmanaged control); 1N (cut once a year without biomass removal); 1R (cut once a year with biomass removal); 2N (cut twice a year without biomass removal); 2R (cut twice a year with biomass removal). Numbers in columns of treatments represent mean ± standard error of the mean of three blocks of all years excluding the first three years of the experiment. Significant differences (*p*-value < 0.05) between treatment levels according to the Tukey's post-hoc test are indicated by different lowercase letters.

Overall, 61 plant species were identified in the experiment during the study period 2005–2017. This total comprised 15 tall graminoids, 11 short graminoids, 11 tall forbs, 23 short forbs and one legume (Appendix S4).

The experimental treatments had no significant effect on the species richness, evenness index, cover of functional groups and EIV (Table 1). However, marginally non-significant differences in the cover of short graminoids were observed; the cover was higher in 1N and 1R compared to U, and even higher in 2N and 2R, whereas the cover of tall graminoids without *T. latifolia* showed the opposite trend (Table 1; Figure 3). Additionally, species richness diverged later, with U being less species-rich than the cut treatments in the final years of the experiment (Appendix S5). The development of selected dominant plant species throughout the study period of 2005–2017 also differed among treatments (Appendices S6 and S7).

In the RDA based on the vegetation data without observations from the first three years of the study period (2008–2017), the effect of the treatments on plant species composition explained 26.0% of the variability (*F*-value = 6.8, *p*-value = 0.014) on all constrained axes (Figure 4). Three groups of treatments with similar plant species composition were distinguished on the ordination diagram. The first ordination axis shows differences between U treatment (the first group with a single treatment only) and other cut treatments, the second axis shows differences between the second group of 1R and 1N treatments and the third group of 2R and 2N treatments. The first group was mainly represented by *T. latifolia*, *Bistorta officinalis*, *Holcus mollis*, *Scirpus sylvaticus* and *Myosotis nemorosa*, while it was avoided by e.g. *Carex canescens*, *Eriophorum angustifolium*, *Caltha palustris* or *Cardamine pratensis*. The second group was characterised mainly by *Mentha arvensis*, *Eriophorum angustifolium*, *Lychnis flos-cuculi* and *Carex rostrata*, but shared several species with the first group, e.g. *T. latifolia*, *Juncus filiformis* and *Valeriana excelsa* subsp. *sambucifolia*. The third group was characterised predominantly by *Anthoxanthum odoratum*, *Nardus stricta*, *Carex nigra*, and shared several species with the second group, e.g. *Carex canescens*, *Cardamine pratensis* and *Caltha palustris*.

The first axis of the PRC diagram showed that the effect of interaction of treatment and year was statistically significant (*F*-value = 0.3, *p*-value = 0.013). Principal response curves showed differences between the U treatment and all of the cut treatments (1N, 1R, 2N, 2R) in relation to plant species composition similar to the first axis of RDA, with rapid differentiation in the first three years and a relatively stable composition in the following years (Figure 5).

4 | DISCUSSION

4.1 | *Typha latifolia* characteristics

The results of our study confirmed the findings of previous short-term studies, that cutting is a suitable management for *T. latifolia* control; however, in terms of the frequency of cutting our results are

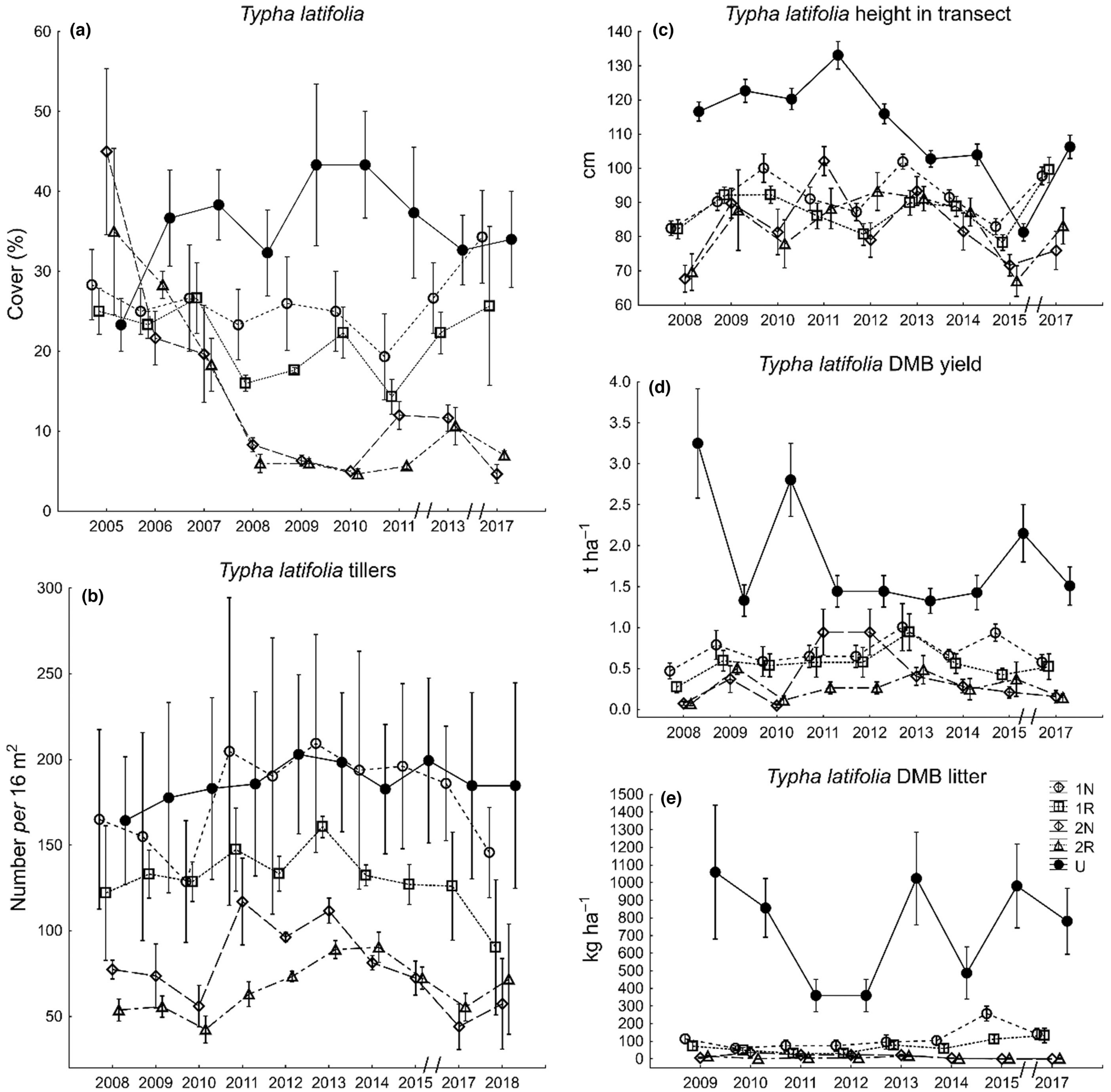

FIGURE 1 The mean of *T. latifolia* characteristics in the years 2005–2018. (a) Mean cover (%) of dominant plant species *T. latifolia*; (b) number of *T. latifolia* tillers; (c) height of *T. latifolia* in transect; (d) *T. latifolia* DMB yield; and (e) *T. latifolia* litter in investigated treatments. Error bars represent standard error of the mean. Note the gaps on the x-axis. Applied treatments were: U (unmanaged control); 1N (cut once a year without biomass removal); 1R (cut once a year with biomass removal); 2N (cut twice a year without biomass removal); 2R (cut twice a year with biomass removal).

not straightforward. Thus, although higher frequency of cutting significantly reduced *T. latifolia* cover and its DMB and litter yield, the number and height of its tillers remained unaffected (Appendix S3). A possible explanation for this could be that there are changes in *T. latifolia* morphology under the different cutting frequencies, for example in the number of leaves or thickness of plant stems, as well differences in stem or leaf tissue density. An effect of cutting on morphological traits was also detected in another wetland species such as *Phragmites australis* (Asaeda et al., 2003).

There was only a slight tendency for the removal of cut biomass to affect the characteristics of *T. latifolia* (apart from an effect on *T. latifolia* plant height) (Table 1, Figure 1). This might be due to favourable moisture and temperature conditions (Enríquez et al., 1993; Murphy et al., 1998; Liski et al., 2003) that would have promoted easier decomposition of above-ground biomass (including biomass of *T. latifolia*). Therefore, the undecomposed residues of above-ground cut biomass probably did not accumulate on the surface for sufficient time to adversely affect plant growth.

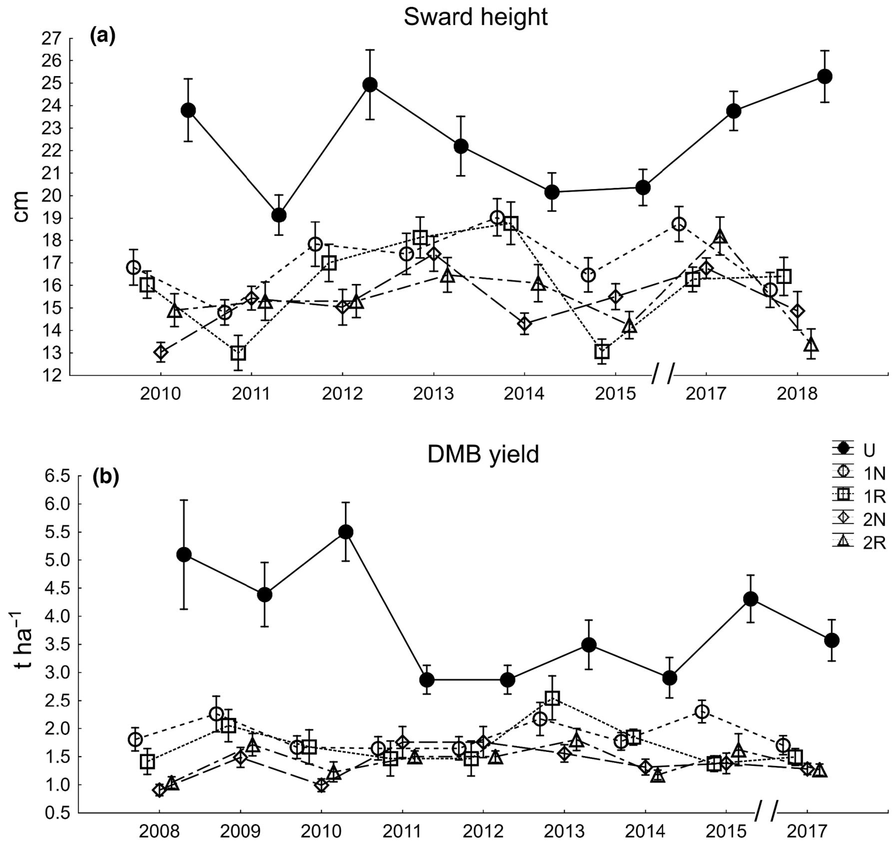

FIGURE 2 The mean of sward height and dry-matter biomass (DMB) yield in the years 2008–2018. (a) Sward height and (b) DMB yield in investigated treatments. Error bars represent standard error of the mean. Note the gaps on the x-axis. Applied treatments were: U (unmanaged control); 1N (cut once a year without biomass removal); 1R (cut once a year with biomass removal); 2N (cut twice a year without biomass removal); 2R (cut twice a year with biomass removal).

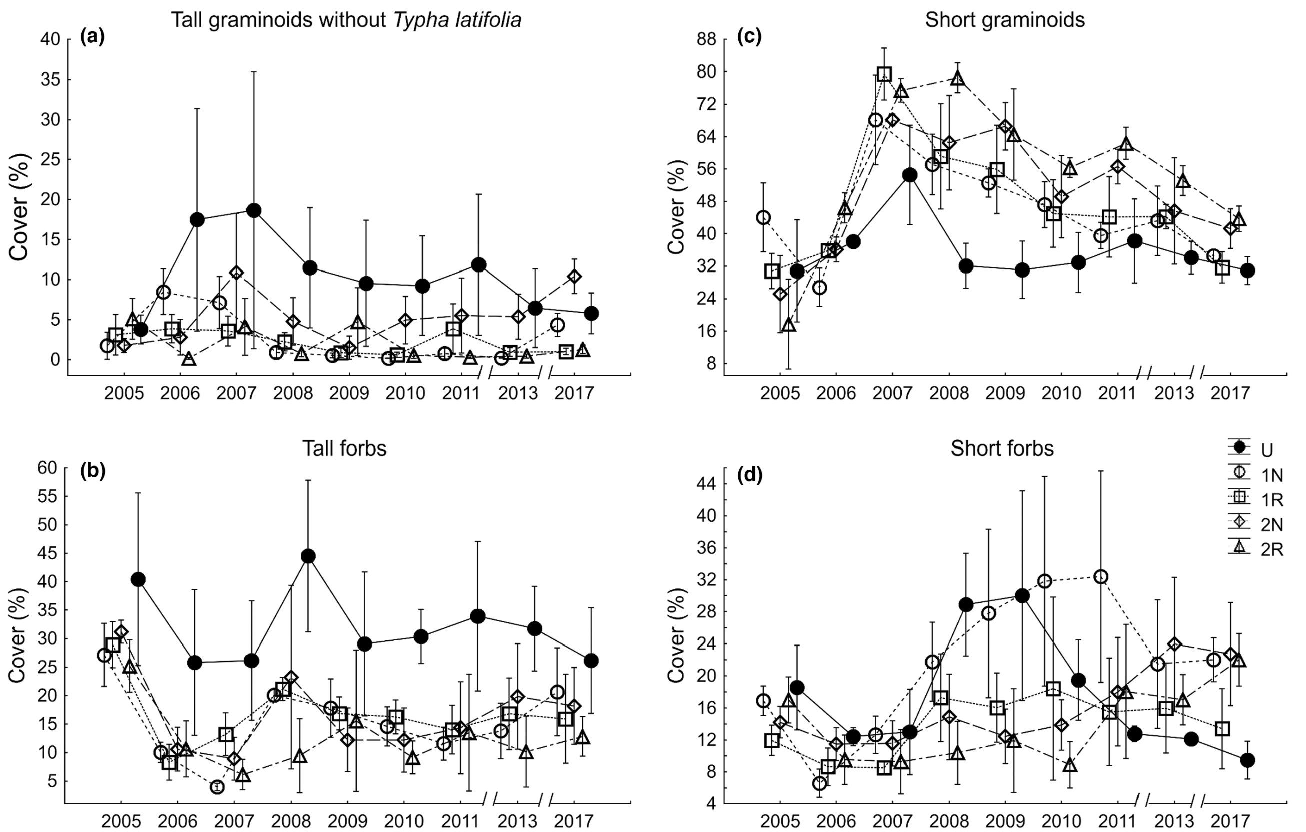

FIGURE 3 The mean cover (%) of main functional groups in the years 2005–2017. (a) Tall graminoids without *Typha latifolia*; (b) tall forbs; (c) short graminoids; and (d) short forbs in investigated treatments. Error bars represent standard error of the mean. Note the gaps on the x-axis. Applied treatments were: U (unmanaged control); 1N (cut once a year without biomass removal); 1R (cut once a year with biomass removal); 2N (cut twice a year without biomass removal); 2R (cut twice a year with biomass removal).

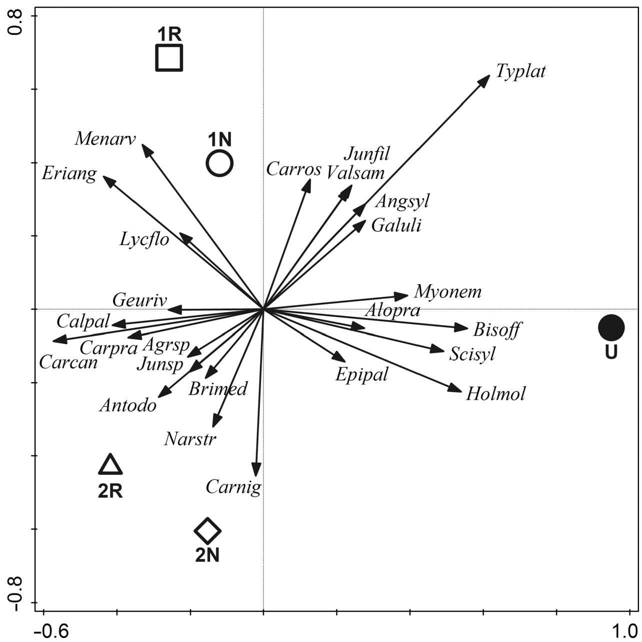

FIGURE 4 Redundancy analysis (RDA) ordination diagram. Results of RDA of plant species composition data collected in the years 2008–2017. Applied treatments were: U (unmanaged control); 1N (cut once a year without biomass removal); 1R (cut once a year with biomass removal); 2N (cut twice a year without biomass removal); 2R (cut twice a year with biomass removal). The 25 best fitting species are shown. Species abbreviations: *Agrsp*, *Agrostis* sp.; *Alopra*, *Alopecurus pratensis*; *Angsyl*, *Angelica sylvestris*; *Antodo*, *Anthoxanthum odoratum*; *Bisoff*, *Bistorta officinalis*; *Brimed*, *Briza media*; *Calpal*, *Caltha palustris*; *Carcan*, *Carex canescens*; *Carnig*, *Carex nigra*; *Carpra*, *Cardamine pratensis*; *Carros*, *Carex rostrata*; *Epipal*, *Epilobium palustre*; *Eriang*, *Eriophorum angustifolium*; *Galiuli*, *Galium uliginosum*; *Geuriv*, *Geum rivulare*; *Holmol*, *Holcus mollis*; *Junfil*, *Juncus filiformis*; *Junsp*, *Juncus* sp.; *Lycflo*, *Lychnis flos-cuculi*; *Menarv*, *Mentha arvensis*; *Myonem*, *Myosotis nemorosa*; *Narstr*, *Nardus stricta*; *Scisyl*, *Scirpus sylvaticus*; *Typlat*, *Typha latifolia*; *Valsam*, *Valeriana excelsa* subsp. *sambucifolia*. The first and second constrained axes explained 13.7% and 8.2% of the variability in species composition respectively.

4.2 | Sward and plant community characteristics

The results from our experiment confirm findings from previous research on mesophilous meadows that cutting reduces the height and yield of the sward in the next year (Pavlů et al., 2013; Kassahun et al., 2021); nevertheless, the higher cutting frequency did not further reduce either the height or yield of the first cut in our experiment.

In terms of plant species composition, no significant changes in the cover of short or tall species were detected, but there was a visible trend in favour of tall species in the unmanaged treatment at the expense of short species. Although there were no significant differences in species richness, after five years of different management treatments a trend can be seen of slow increase in the number of species on all cut treatments. However, a high increase in the number of species cannot be expected as almost all species occurring in the vicinity are represented in the experimental plots, and thus none of the treatments that were applied here can be found to substantially increase plant species diversity.

Due to the relatively low density of plants of *T. latifolia*, the light conditions in the sward were probably sufficient for supporting short and mostly competitively weak species in all treatments. Despite this fact, three groups with similar plant species composition that were distinguished on the ordination diagram were associated with the different cutting intensities (Figure 4). This was not only a result of light availability (Jensen & Meyer, 2001; Borer et al., 2014) but also as a direct response of individual species to the cutting management, as tall species are damaged by defoliation more than short ones (Gaisler et al., 2019; Pavlů et al., 2022). Biomass removal after cutting, compared with leaving the cut biomass on the sward surface, had no effect on plant species composition and this was probably because of rapid decomposition processes of the cut biomass on the sward surface under the environmental conditions of the site.

Dominant species of tall forbs such as highly productive *Filipendula ulmaria* (Merunková & Chytrý, 2012), *Bistorta officinalis* and *Angelica sylvestris* had a tendency to prefer unmanaged plots in our experiment (Appendix S7). *Bistorta officinalis* is able to suppress the surrounding vegetation by its above-ground cover of leaves, large amount of litter and depletion of nitrogen from the soil (Pecháčková & Krahulec, 1995) especially on meadows with an absence of cutting. The preference of *Filipendula ulmaria* in unmanaged plots is consistent with the life strategy of this species in wet meadows (e.g. Čop et al., 2009; Tatarenko et al., 2020; George et al., 2021).

Dominant species of short graminoids and short forbs showed no straightforward response to cutting management. This was probably because of their different adaptations to defoliation management. The positive effect of cutting on the cover of *Carex nigra*, *Carex canescens* and *Eriophorum angustifolium* (Appendix S6), is consistent with results of previous defoliation experiments (e.g. Marrs et al., 1988; Jungerius et al., 1995; Hedberg et al., 2012; Sienkiewicz-Paderewska et al., 2020). Similarly, the positive response of *Caltha palustris* to cutting reflects its preference for unshaded places at higher altitudes (Grime et al., 1988). Although short grass *Juncus filiformis* usually prefers sufficient availability of light (Poptcheva et al., 2009; Schrautzer et al., 2013), it was present at a high cover in the unmanaged treatment in our experiment (Appendix S6). Its occurrence in abandoned plots was probably positively influenced by the absence of cutting and at the same time by quite low density of *T. latifolia* that enabled light to penetrate into the lower layers of the sward.

4.3 | Management implications

Practical management should not be focused only on reduction of *T. latifolia*, but it should also take into account the requirements for nature conservation in terms of the target state of the whole plant community and the rarity and endangered status of individual plant

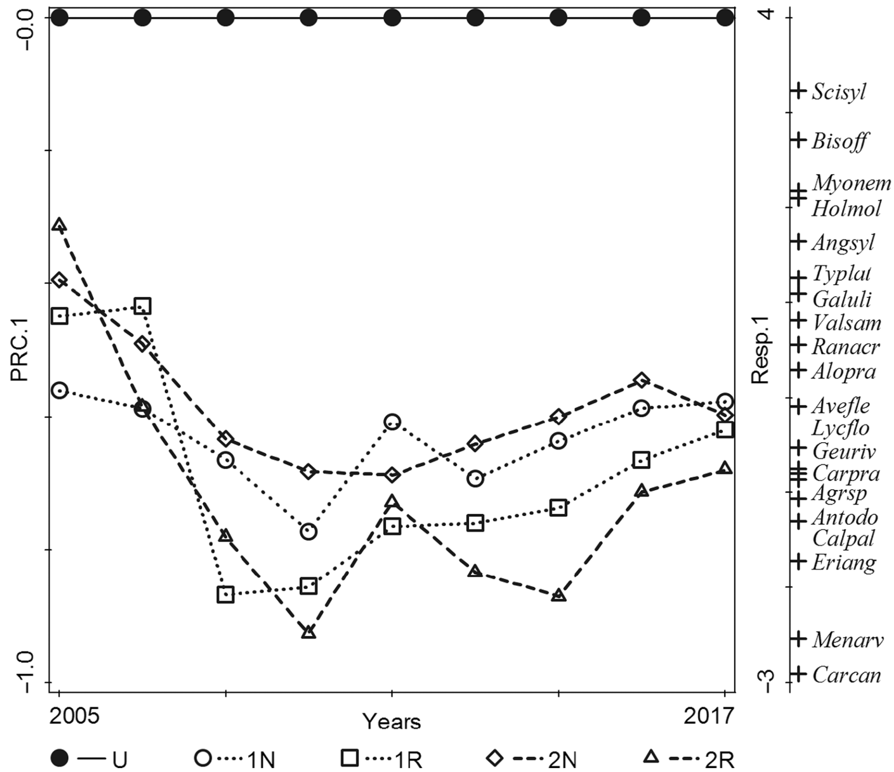

FIGURE 5 Principal response curves (PRC). Result of partial redundancy analysis (RDA) — PRC — first axis of plant species composition data collected in the years 2005–2017. Applied treatments were: U (unmanaged control); 1N (cut once a year without biomass removal); 1R (cut once a year with biomass removal); 2N (cut twice a year without biomass removal); 2R (cut twice a year with biomass removal). The 20 best-fitting species are shown. Species abbreviations: *Agrsp*, *Agrostis* sp.; *Alopra*, *Alopecurus pratensis*; *Angsyl*, *Angelica sylvestris*; *Antodo*, *Anthoxanthum odoratum*; *Avefle*, *Avenella flexuosa*; *Bisoff*, *Bistorta officinalis*; *Calpal*, *Caltha palustris*; *Carcan*, *Carex canescens*; *Carpra*, *Cardamine pratensis*; *Eriang*, *Eriophorum angustifolium*; *Galuli*, *Galium uliginosum*; *Geuriv*, *Geum rivulare*; *Holmol*, *Holcus mollis*; *Lycflo*, *Lychnis flos-cuculi*; *Menarv*, *Mentha arvensis*; *Myonem*, *Myosotis nemorosa*; *Ranacr*, *Ranunculus acris*; *Scisyl*, *Scirpus sylvaticus*; *Typlat*, *Typha latifolia*; *Valsam*, *Valeriana excelsa* subsp. *sambucifolia*.

species in the region. As the application of a higher frequency of cutting did not show a straightforward effect on *T. latifolia* control (Table 1, Appendix S3), the response of the whole community to the cutting frequency appears to be a very important factor in the choice of appropriate management.

Another factor that is important for plant species composition is biomass removal. The results from the present experiment led us to suggest that biomass removal does not necessarily have a significant effect on vegetation under certain conditions. It seems that wet edaphic conditions, as in our experiment, can probably accelerate the decomposition of unremoved cut biomass, and thereby preserve conditions of sufficient light penetration required for vegetation growth. Moreover, the issue of biomass removal is also closely linked to the soil nutrient status, as regular and long-term removal of biomass can result in oligotrophication (Hejcman et al., 2014; Titěra et al., 2020).

In wet meadows where there is a dominancy of *T. latifolia* we consider that extensive management (with cutting once per year without biomass removal) can be sufficient to maintain the plant species community in a desirable state. Furthermore, as a management technique, this is a relatively low-cost option compared with multiple cutting and biomass removal. Nevertheless, there are some types of plant species community that require a more intensive management regime (Sale & Wetzel, 1983; Apfelbaum, 1985), mostly in places with greater concentrations of nutrients in the soil. In these conditions it may be appropriate to apply different management regimes in one locality and thereby create a diverse vegetation structure.

5 | CONCLUSION

Regular cutting has been shown to be a suitable management for *T. latifolia* reduction; however, in this long-term experiment *T. latifolia* characteristics did not show a straightforward relationship with higher cutting frequency. Biomass removal had only a slight tendency to affect *T. latifolia* characteristics. Defoliation management cutting once or twice per year, regardless of whether or not the cut biomass was removed, led to the successive changes in plant species composition but had no effect on species richness and species evenness index.

In light of these results, we suggest that cutting at least once per year in early summer without biomass removal seems to be sufficient for control of *T. latifolia* in wet meadows and to protect the meadow vegetation from overgrowth by shrubs and trees. This extensive management is a relatively low-cost solution compared with annual multiple cutting and biomass removal. The results have relevance for the development and implementation of wet meadow nature conservation and sustainable management strategies for meadows with *T. latifolia* dominance.

AUTHOR CONTRIBUTIONS

Lenka Pavlů and Vilém V. Pavlů designed the study and established the experiment. Vilém V. Pavlů, Lenka Pavlů and Jan Titěra collected the data. Petr Blažek performed statistical analysis. Jan Titěra, Lenka Pavlů and Vilém V. Pavlů wrote the paper. All authors discussed the results and commented on the manuscript.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical support of the staff of the Crop Research Institute, namely Věra Ismanická, Irena Jonášová and František Paška for their assistance with the data collection.

FUNDING INFORMATION

Manuscript preparation and data analyses were financed by Deutsche Bundesstiftung Umwelt (DBU) from small grant project (No. 30021/963–43/0) and by the Ministry of Agriculture of the Czech Republic (MZE-RO0423). PB was supported by Czech Science Foundation (GACR project number: 20-02901S).

DATA AVAILABILITY STATEMENT

Data are accessible on request.

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REFERENCES

Álvarez, J.A. & Bécares, E. (2006) Seasonal decomposition of *Filipendula ulmaria* in a free-water surface constructed wetland. *Ecological Engineering*, 28, 99–105. Available from: https://doi.org/10.1016/j.ecoleng.2006.05.001

Apfelbaum, S.I. (1985) Cattail (*Typha* spp.) management. *Natural Areas Journal*, 5(3), 9–17.

Asaeda, T., Manatunge, J., Fujino, T. & Sovira, D. (2003) Effects of salinity and cutting on the development of *Phragmites australis*. *Wetlands Ecology and Management*, 11, 127–140. Available from: https://doi.org/10.1023/A:1024289025415

Ball, J.P. (1990) Influence of subsequent flooding depth on cattail control by burning and mowing. *Journal of Aquatic Plant Management*, 28, 32–36.

Bansal, S., Lishawa, S.C., Newman, S., Tangen, B.A., Wilcox, D., Albert, D. et al. (2019) *Typha* (cattail) invasion in north American wetlands: biology, regional problems, impacts, ecosystem services, and management. *Wetlands*, 39, 645–684. Available from: https://doi.org/10.1007/s13157-019-01174-7

Batty, L.C. & Younger, P.L. (2007) The effect of pH on plant litter decomposition and metal cycling in wetland mesocosms supplied with mine drainage. *Chemosphere*, 66(1), 158–164. Available from: https://doi.org/10.1016/J.CHEMOSPHERE.2006.05.039

Borer, E.T., Seabloom, E.W., Gruner, D.S., Harpole, W.S., Hillebrand, H., Lind, E.M. et al. (2014) Herbivores and nutrients control grassland plant diversity via light limitation. *Nature*, 508, 517–520. Available from: https://doi.org/10.1038/nature13144

Castle, M.E. (1976) A simple disc instrument for estimating herbage yield. *Journal of British Grassland Society*, 31, 37–40. Available from: https://doi.org/10.1111/j.1365-2494.1976.tb01113.x

Chaloupský, J., Červenka, J., Jetel, J., Králík, F., Líbalová, J., Píchová, E. et al. (1989) *Geology of the Giant and Jizerské hory mountains (Czech)*. Praha, Czechia: Československá Akademie Věd.

Chytrý, M., Kočí, M., Šumberová, K., Sádlo, J., Krahulec, F., Hájková, P. et al. (2007) *Vegetation of The Czech Republic 1. Grassland and heathland vegetation (Czech)*. Praha, CZ: Academia.

Chytrý, M., Tichý, L., Dřevojan, P., Sádlo, J. & Zelený, D. (2018) Ellenberg-type indicator values for the Czech flora. *Preslia*, 90, 83–103. Available from: https://doi.org/10.23855/preslia.2018.083

Clevering, O. & Toorn, J. (2000) Observations on the colonization of a young polder area in The Netherlands with special reference to the clonal expansion of *Phragmites australis*. *Folia Geobotanica*, 35, 375–387. Available from: https://doi.org/10.1007/BF02803550

Čop, J., Vidrih, M. & Hacin, J. (2009) Influence of cutting regime and fertilizer application on the botanical composition, yield and nutritive value of herbage of wet grasslands in Central Europe. *Grass and Forage Science*, 64, 454–465. Available from: https://doi.org/10.1111/j.1365-2494.2009.00713.x

Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W. & Paulissen, D. (1992) *Indicator values of plants in Central Europe (German), 2nd edition. Scripta Geobotanica, 18*. Göttingen, Germany: Erich Goltze KG.

Enríquez, S., Duarte, C.M. & Sand-Jensen, K. (1993) Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C:N:P content. *Oecologia*, 94, 457–471. Available from: https://doi.org/10.1007/BF00566960

Gaisler, J., Pavlů, L., Nwaogu, C., Pavlů, K., Hejcman, M. & Pavlů, V. (2019) Long-term effects of mulching, traditional cutting and no management on plant species composition of improved upland grassland in The Czech Republic. *Grass and Forage Science*, 178, 1–13. Available from: https://doi.org/10.1111/gfs.12408

Garver, E.G., Dubbe, D.R. & Pratt, D.C. (1988) Seasonal patterns in accumulation and partitioning of biomass and macronutrients in *Typha* spp. *Aquatic Botany*, 32, 115–127. Available from: https://doi.org/10.1016/0304-3770(88)90092-7

George, L., Rothero, E.C., Tatarenko, I., Wallace, H., Dodd, M., Reed, N. et al. (2021) Control of meadowsweet *Filipendula ulmaria* through a change of management from grazing to mowing at an English floodplain meadow. *Conservation Evidence Journal*, 18, 44–49. Available from: https://doi.org/10.52201/CEJ18HFGL5629

Grace, J.B. (1989) Effects of water depth on *Typha latifolia* and *Typha domingensis*. *American Journal of Botany*, 76, 762–768. Available from: https://doi.org/10.1002/j.1537-2197.1989.tb11371.x

Grace, J.B. & Harrison, J.S. (1986) The biology of Canadian weeds. 73. *Typha latifolia* L., *Typha angustifolia* L. and *Typha x glauca* Godr. *Canadian Journal of Plant Science*, 66, 361–379.

Grime, J.P., Hodgson, J.G. & Hunt, R. (1988) *Comparative plant ecology: a functional approach to common British plants*. London, UK: Unwin-Hyman. Available from: https://doi.org/10.1007/978-94-017-1094-7

Hedberg, P., Kotowski, W., Saetre, P., Mälson, K., Rydin, H. & Sundberg, S. (2012) Vegetation recovery after multiple-site experimental fen restorations. *Biological Conservation*, 147, 60–67. Available from: https://doi.org/10.1016/j.biocon.2012.01.039

Hejcman, M., Sochorová, L., Pavlů, V., Štrobach, J., Diepolder, M. & Schellberg, J. (2014) The Steinach grassland experiment: soil chemical properties, sward height and plant species composition in three cut alluvial meadow after decades-long fertilizer application. *Agriculture, Ecosystems & Environment*, 184, 76–87. Available from: https://doi.org/10.1016/j.agee.2013.11.021

Dell Inc. (2019) Dell STATISTICA (data analysis software system), version 13.1. software. dell.com. Tulsa, USA, Computer-aided design for software.

Jensen, K. & Meyer, C. (2001) Effects of light competition on the performance of *Viola palustris* and on species composition and diversity of an abandoned fen meadow. *Plant Ecology*, 155, 169–181. Available from: https://doi.org/10.1023/A:1013270628964

Jungerius, P.D., Koehler, H., Kooijman, A.M., Mücher, H.J. & Graefe, U. (1995) Response of vegetation and soil ecosystem to mowing and sod removal in the coastal dunes 'Zwanenwater', The Netherlands. *Journal of Coastal Conservation*, 1, 3–16. Available from: https://doi.org/10.1007/BF02835557

Kaplan, Z., Danihelka, J., Chrtek, J., Kirschner, J., Kubát, K., Štech, M. et al. (2019) *Key to the flora of The Czech Republic (Czech)*, 2nd edition. Praha, Czechia: Academia.

Kassahun, T., Pavlů, K., Pavlů, V., Pavlů, L., Novak, J. & Blažek, P. (2021) Restoration management of cattle resting place in mountain grassland. *PLoS One*, 16, e0249445. Available from: https://doi.org/10.1371/journal.pone.0249445

Krause, B., Culmsee, H., Wesche, K. & Leuschner, C. (2015) Historical and recent fragmentation of temperate floodplain grasslands: do patch size and distance affect the richness of characteristic wet meadow plant species? *Folia Geobotanica*, 50(3), 253–266. Available from: https://doi.org/10.1007/s12224-015-9220-1

Lee, A.A. & Bukaveckas, P.A. (2002) Surface water nutrient concentrations and litter decomposition rates in wetlands impacted by agriculture and mining activities. *Aquatic Botany*, 74, 273–285. Available from: https://doi.org/10.1016/S0304-3770(02)00128-6

Li, S., Pezeshki, S.R. & Goodwin, S. (2004) Effects of soil moisture regimes on photosynthesis and growth in cattail (*Typha latifolia*). *Acta Oecologica*, 25, 17–22. Available from: https://doi.org/10.1016/j.actao.2003.10.004

Lishawa, S.C., Carson, B.D., Brandt, J.S., Tallant, J.M., Reo, N.J., Albert, D.A. et al. (2017) Mechanical harvesting effectively controls young *Typha* spp. invasion and unmanned aerial vehicle data enhances post-treatment monitoring. *Frontiers in Plant Science*, 8, 1–14. Available from: https://doi.org/10.3389/fpls.2017.00619

Liski, J., Nissinen, A., Erhard, M. & Taskinen, O. (2003) Climatic effects on litter decomposition from arctic tundra to tropical rainforest. *Global Change Biology*, 9, 575–584. Available from: https://doi.org/10.1046/j.1365-2486.2003.00605.x

Maddison, M., Mauring, T., Remm, K., Lesta, M. & Mander, Ü. (2009) Dynamics of *Typha latifolia* L. populations in treatment wetlands in Estonia. *Ecological Engineering*, 35, 258–264. Available from: https://doi.org/10.1016/j.ecoleng.2008.06.003

Marrs, R.H., Bravington, M. & Rawes, M. (1988) Long-term vegetation change in the *Juncus squarrosus* grasslands at moor house, northern England. *Vegetatio*, 76, 179–187. Available from: https://doi.org/10.1007/BF00045478

Martin, J., Hofherr, E. & Quigley, M.F. (2003) Effects of *Typha latifolia* transpiration and harvesting on nitrate concentrations in surface water of wetland microcosms. *Wetlands*, 23, 835–844. Available from: https://doi.org/10.1672/0277-5212(2003)023[0835,EOTLTA]2.0.CO;2

Merunková, K. & Chytrý, M. (2012) Environmental control of species richness and composition in upland grasslands of the southern Czech Republic. *Plant Ecology*, 213, 591–602. Available from: https://doi.org/10.1007/s11258-012-0024-6

Murkin, H.R. & Ward, P. (1980) Early spring cutting to control cattail in a northern marsh. *Wildlife Society Bulletin*, 8(3), 254–256.

Murphy, K.L., Klopatek, J.M. & Klopatek, C.C. (1998) The effects of litter quality and climate on decomposition along an elevational gradient. *Ecological Applications*, 8(4), 1061–1071. Available from: https://doi.org/10.1890/1051-0761(1998)008[1061:TEOLQA]2.0.CO;2

Pavlů, L., Pavlů, V., Gaisler, J. & Hejcman, M. (2013) Relationship between soil and biomass chemical properties, herbage yield and sward height in cut and unmanaged mountain hay meadow (Polygono-Trisetion). *Flora*, 208, 599–608. Available from: https://doi.org/10.1016/j.flora.2013.09.003

Pavlů, L., Poetsch, E.M., Pavlů, V.V., Titěra, J., Hejcman, M., Gaisler, J. et al. (2022) The Admont grassland experiment: 70 years of fertilizer application and its effects on soil and vegetation properties in an alluvial meadow managed under a three-cut régime. *The Science of the Total Environment*, 808, 152081. Available from: https://doi.org/10.1016/j.scitotenv.2021.152081

Pecháčková, S. & Krahulec, F. (1995) Efficient nitrogen economy: key to the success of *Polygonum bistorta* in an abandoned mountain meadow. *Folia Geobotanica*, 30(2), 211–222. Available from: https://doi.org/10.1007/BF02812099

Poptcheva, K., Schwartze, P., Vogel, A., Kleinebecker, T. & Hölzel, N. (2009) Changes in wet meadow vegetation after 20 years of different management in a field experiment (North-West Germany). *Agriculture, Ecosystems & Environment*, 134, 108–114. Available from: https://doi.org/10.1016/j.agee.2009.06.004

Sale, P.J.M. & Wetzel, R.G. (1983) Growth and metabolism of *Typha* species in relation to cutting treatments. *Aquatic Botany*, 15, 321–334. Available from: https://doi.org/10.1016/0304-3770(83)90001-3

Satterthwaite, F.E. (1946) An approximate distribution of estimates of variance components. *Biometrics Bulletin*, 2(6), 110–114. Available from: https://doi.org/10.2307/3002019

Schrautzer, J., Sival, F., Breuer, M., Runhaar, H. & Fichtner, A. (2013) Characterizing and evaluating successional pathways of fen degradation and restoration. *Ecological Indicators*, 25, 108–120. Available from: https://doi.org/10.1016/j.ecolind.2012.08.018

Sharma, K.P. & Kushwaha, S.P.S. (1990) Effect of cutting of aboveground organs of *Typha angustata* Bory & Chaub on its growth and total chlorophyll content. *Aquatic Botany*, 36, 293–296. Available from: https://doi.org/10.1016/0304-3770(90)90044-L

Sienkiewicz-Paderewska, D., Paderewski, J., Suwara, I. & Kwasowski, W. (2020) Fen grassland vegetation under different land uses (Biebrza National Park, Poland). *Global Ecology and Conservation*, 23, e01188. Available from: https://doi.org/10.1016/j.gecco.2020.e01188

Swacha, G., Botta-Dukát, Z., Kącki, Z., Pruchniewicz, D. & Żołnierz, L. (2018) The effect of abandonment on vegetation composition and soil properties in *Molinion* meadows (SW Poland). *PLoS One*, 13(5), e0197363. Available from: https://doi.org/10.1371/journal.pone.0197363

Tatarenko, I., Dodd, M., Wallace, H., Bellamy, G. & Fleckney, A. (2020) Protecting small populations of rare species. Case study on *Dactylorhiza viridis* (*Orchidaceae*) in fancott woods and meadows SSSI, Bedfordshire, UK. *Nature Conservation Research*, 5, 165–171. Available from: https://doi.org/10.24189/ncr.2020.028

Ter Braak, C.J.F. & Šmilauer, P. (2012) *CANOCO 5, windows release (5.00). [software for canonical community ordination]*. Ithaca, NY: Microcomputer Power.

Titěra, J., Pavlů, V.V., Pavlů, L., Hejcman, M., Gaisler, J. & Schellberg, J. (2020) Response of grassland vegetation composition to different fertilizer treatments recorded over ten years following 64 years of fertilizer applications in the Rengen grassland experiment. *Applied Vegetation Science*, 23, 417–427. Available from: https://doi.org/10.1111/avsc.12499

Toet, S., Bouwman, M., Ceevaal, A. & Verhoeven, J.A. (2005) Nutrient removal through autumn harvest od *Phragmites australis* and *Typha latifolia* shoots in relation to nutrient loading in a wetland system used for polishing sewage treatment plant effluent. *Journal of Environmental Science and Health*, 40, 1133–1156. Available from: https://doi.org/10.1081/ESE-200055616

Verhoeven, K.J., Simonsen, K.L. & McIntyre, L.M. (2005) Implementing false discovery rate control: increasing your power. *Oikos*, 108, 643–647. Available from: https://doi.org/10.1111/j.0030-1299.2005.13727.x

Vesecký, A. (Ed.). (1961) *Climate of the Czechoslovak-Socialist Republic. Tables. (Czech).* Praha, Czechia: Hydrometeorologický Ústav.

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. Available from: https://doi.org/10.1016/j.biocon.2012.02.015

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. Weather conditions at the meteorological station in Bedřichov.

Appendix S2. Design of the experiment.

Appendix S3. Results of the two sets of general linear mixed-effects models (GLMM) of *Typha latifolia* characteristics and sward characteristics.

Appendix S4. Assignment of plant species to functional groups.

Appendix S5. Species richness and species evenness index in the years 2005–2017.

Appendix S6. The mean cover (%) of dominant graminoids species in the years 2005–2017.

Appendix S7. The mean cover (%) of dominant forb species in the years 2005–2017.

Appendix S8. Photos of experimental site: (a) 6photo of experimental site; (b) photo of unmanaged treatment; and (c) photo of experimental site after cutting.

How to cite this article: Titěra, J., Pavlů, L., Pavlů, V.V. & Blažek, P. (2023) What is a suitable management for *Typha latifolia* control in wet meadows? *Applied Vegetation Science*, 26, e12740. Available from: https://doi.org/10.1111/avsc.12740