Shallow inundation favours decomposition of *Phragmites australis* leaves in a near-natural temperate fen

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SUMMARY

Mowing is widely used in temperate fens to conserve typical flora and fauna by creating or maintaining low, sparse, treeless vegetation with a thin litter layer. In certain cases the removal of the mown biomass may not be feasible because of high costs, or not desirable because of increased disturbance. Few studies have addressed the decomposition of mown biomass, especially with regard to litter fragment size resulting from differences in cutting techniques. We studied biomass decomposition in a near-natural fen in north-eastern Germany, using litter bags with small and large fragments of common reed (*Phragmites australis* (Cav.) Trin. Ex. Steud.) in wet and dry locations for *ca*. 250 days. We observed a significant effect of water level on decomposition, but no effect of the size of litter fragments. The greatest decomposition occurred at the wet plots of the wettest site, the lowest at the dry plots of the driest site. The results demonstrate that water level is an important controlling variable in decomposition and that, in near-natural fens with vegetation dominated by *Phragmites*, decomposition is greatest in shallowly inundated sites. We conclude that in such sites, cut biomass may be left on site to maintain a thin litter layer but removal of biomass may still be required due to other considerations.

KEY WORDS: biomass removal; common reed; habitat management; litter breakdown; shredding

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INTRODUCTION

Loss of biodiversity due to successional overgrowth of formerly sparse and open sedge vegetation by dense and tall reed and shrub vegetation has recently become apparent in fens in countries such as Poland (Kloskowski & Krogulec 1999), Germany (Tanneberger *et al.* 2008) and Belarus (Fenchuk & Schäffer 2011). While restoring the natural resilience of open fens by reinstating their natural hydrology should be the principal conservation target (Kotowski *et al.* 2013), mowing is an effective tool to reduce the speed of succession in near-natural sites (Middleton *et al.* 2006, McBride *et al.* 2011). In recent years, the need for mowing of near-natural fen mires has been increasingly recognised as necessary for aims such as the conservation of habitat for typical fen birds (Kotowski 2002, Flade & Lachmann 2008, Bartoszuk & Kotowski 2009, Tanneberger *et al.* 2010, Sundberg 2012). At the same time, technologies for the use of biomass from wet fens are being developed, such as the use of sedges and reed for the production of fuel briquettes and pellets (Wichtmann *et al.* 2010, Tanneberger *et al.* 2014). However, in certain cases the removal and use of the mown biomass may not be feasible because of prohibitively high costs (Wichtmann & Schulz 2011) or to avoid disturbance to sensitive peat soils (Kotowski *et al.* 2013). Mowing without biomass removal may be a solution, and it has been shown that soil disturbance by mowing equipment can contribute more to the effects of management on plant species composition than the periodic removal of biomass (Güsewell & Le Nédic 2004). Mowing may, however, also lead to the accumulation of a thick litter layer that makes such sites unsuitable for light-demanding small plant species or particular rare bird species (Tanneberger *et al.* 2008, 2010). To assess the effects of mowing without biomass removal, it is crucial to evaluate the extent of decomposition and accumulation of the mown biomass.

Brinson *et al.* (1981) published a meta-analysis of 162 publications on production and decomposition in freshwater ecosystems which confirmed the critical role of the water regime and showed that the extent of production and decomposition varies substantially. Decomposition may be greater on either dry or wet sites. Many studies carried out on common reed (*Phragmites australis* (Cav.) Trin. Ex. Steud.) decomposition have focused on submerged litter (see Gessner 2000 and Kominkova *et al.* 2000 for a summary) or on the aerial decomposition of standing litter (Hietz 1992, Gessner 2001). Decomposition of biomass on wet sites with seasonally fluctuating water levels has received relatively little attention (Bedford 2005), and the effect of litter fragment size due to differences in cutting technique has been particularly poorly studied. Here, we present research on decomposition of *Phragmites australis* leaves and litter accumulation in a typical north-east German fen mire with a near-natural water regime, where the mown biomass is left on site. We tested two hypotheses: (i) prolonged wet conditions favour decomposition and (ii) shredding of biomass favours decomposition.

METHODS

The study area is in the Lower Peene valley fen complex east of Anklam in Mecklenburg-Vorpommern, Germany (Figure 1). The area comprises three fen sites which have never been isolated from the river by dykes and where water levels largely fluctuate with river level. The three sites are: Murchiner Wiesen (155 ha), Ferne Wiesen (287 ha) and Schadefähre Island (94 ha). The fen complex was subject to low-intensity mowing and grazing from at least the 17th century (van Diggelen & Wierda 1994) and drainage by ditches is documented since the 18th century, but land use ceased in the 1950s/1960s (Bellebaum 2011). All three sites are characterised by *Phragmites* and sedge vegetation and part of the area is now mown for nature conservation (Tanneberger *et al.* 2012).

All litter bag experimental plots (N = 18) were located in areas that were mown in 2010. Plots with water level 2–10 cm below soil surface in September 2010 were classified as 'dry', and those with water levels 5–15 cm above soil surface as 'wet' ('water level', Table 1). Water level above soil surface was measured with a ruler with five replicates per plot, and water levels below soil surface were estimated on the basis of water levels in nearby depressions or ditches. We established three 'wet' and three 'dry' plots at each site. The sites consist largely of 'wet' areas, and 'dry' plots could be established only on old topsoil removal dams and the edges of ditches. We positioned the plots in each site close to a dipwell where water levels in the soil were measured permanently with a SEBA MDS DIPPER-2 data logger (distance to plots: 14–100 m; Figure 1). The altitude of the south-eastern corner of each plot and each dipwell was determined with a Leica NA824 levelling device. All altitude data were related to the water level in the Peene River, and hourly values for river level measured at gauges in Anklam and Karnin (Figure 1) were used to express altitude relative to Kronstadt gauge reference surface level ('cm HN' in German). To assess water levels at the plots throughout the exposure time of the litter bags, we estimated the number of flood days per plot based on the water levels measured by the appropriate data logger (Figure 2; Völlm 2012). Because of the inaccuracy in deriving water levels by levelling from those measured in dipwells up to 100 m away (estimated deviation: up to ± 6 cm) and some gaps and mismatches in the measured water levels (Völlm 2012), we use the number of flood days as an additional description of the plots, but not in statistical analyses. Flood days are presented as classes 0–30 days, 31–60 days, 61–90 days *etc*.

Phragmites leaves were harvested in the study area three days before the start of litter bag

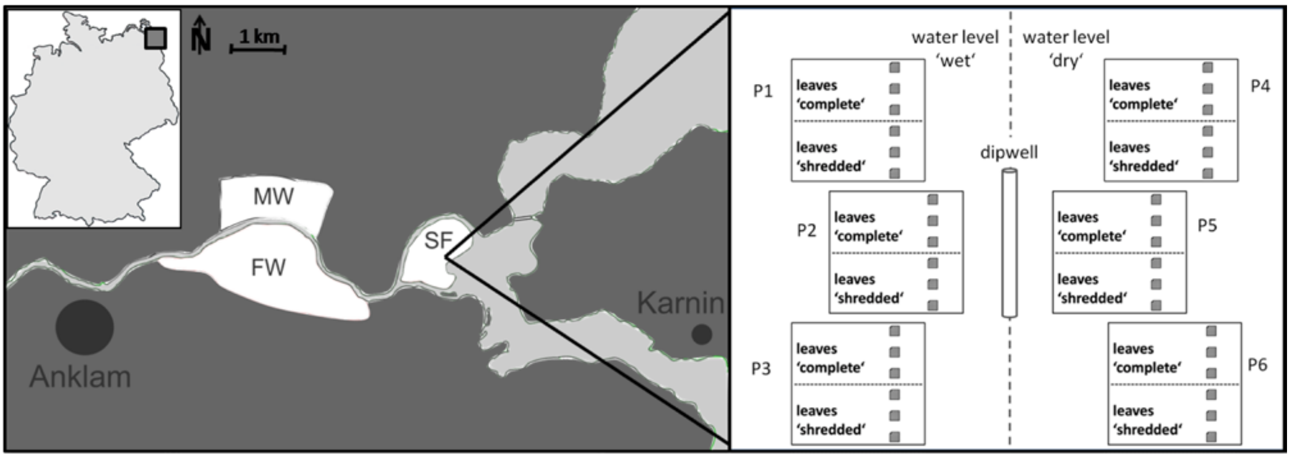

Figure 1. Left: locations of the study sites (white) Murchiner Wiesen (MW), Ferne Wiesen (FW) and Schadefähre Island (SF) along the Peene River (light grey) between the towns Anklam and Karnin in north-east Germany (inset). Right: schematic diagram of the litter bag experimental plots.

exposure. 131 litter bags (10 × 13 cm, PET mesh PETEX 07-300/46 by SEFAR, mesh width 300 µm, 46 % open area, cf. Harmon *et al.* 1999) were filled with *ca*. 3 g (2.95–3.08 g) of fresh *Phragmites* leaf blades. We used fresh material because the sites are mown in summer (July/August). The leaves were either 'complete' (length *ca*. 20 cm) or 'shredded' (length *ca*. 3 cm). To relate fresh and dry weights, 23 litter bags were dried for 24 hours at 80 °C in a drying oven. The calibration result of 61.2 % was used to calculate the dry weights of the remaining 108 litter bags before exposure. We used six litter bags (three with 'complete' and three with 'shredded' leaves) per plot of 1 m². The litter bags were placed on the peat soil surface and fixed with wooden sticks and nylon filaments. The bags were exposed for 248–257 days between September 2010 and May 2011. After exposure, the bags were frozen at -18 °C until further processing. After thawing, they were dried for 24 hours at 80 °C in a drying oven and the dry weight of the contents was determined. The dry weight after exposure was expressed as a percentage of the dry weight before exposure ('percentage of litter dry weight remaining') to describe decomposition. The small mesh size limited accidental loss of biomass (Brinson *et al.* 1981, Bedford 2004) although decomposition is likely to be under-estimated due to exclusion of macroinvertebrates. Only 93 litter bags could be included in further analysis because 15 were lost, their contents were lost or they had been translocated to a drier or wetter location than intended. To compare our results to other studies, the decomposition rate k day^{-1} was calculated as (-k) = ln ('litter dry weight remaining'/'initial litter dry weight')/'number of days of exposure' (following Gessner 2000 and Bedford 2005). This negative exponential model assumes that decomposition rates remain constant throughout time. This assumption has been criticised as biologically unrealistic but allows broad comparisons to be made between studies (Bedford 2005).

Table 1. Site characteristics of the litter bag experimental plots (P) in Murchiner Wiesen (MW), Ferne Wiesen (FW), and Schadefähre Island (SF).

Plot	Water level above soil surface in September 2010 (cm)	Water level ('wet' or 'dry')	Altitude (cm HN = above Kronstadt gauge reference surface)	Estimated number of flood days
MW P1	9.6 ± 3.6	wet	22.5	241–256
MW P2	8.0 ± 2.5	wet	21.4	241–256
MW P3	10.2 ± 3.4	wet	20.4	241–256
MW P4	*ca*. -2	dry	28.9	241–256
MW P5	*ca*. -2	dry	30.4	211–240
MW P6	*ca*. -2	dry	33.0	151–180
FW P1	7.0 ± 2.7	wet	25.8	211–240
FW P2	9.0 ± 3.2	wet	24.3	211–240
FW P3	9.8 ± 2.4	wet	23.6	241–256
FW P4	*ca*. -10	dry	36.4	31–60
FW P5	*ca*. -10	dry	39.5	0–30
FW P6	*ca*. -10	dry	45.6	0–30
SF P1	15.4 ± 1.1	wet	15.7	211–240
SF P2	14.6 ± 1.8	wet	16.5	211–240
SF P3	13.4 ± 0.9	wet	15.8	211–140
SF P4	*ca*. -5	dry	30.9	61–90
SF P5	*ca*. -5	dry	32.7	31–60
SF P6	*ca*. -5	dry	33.0	31–60

Figure 2. Groundwater levels measured during litter bag exposure in the study sites and altitudes of the 'wet' (dashed line) and 'dry' (dotted line) plots (all data as cm HN, i.e. relative to Kronstadt gauge reference surface).

Additionally, the multi-year effect of mowing without biomass removal on litter accumulation was studied by assessing the thickness of the litter layer in the years 2006–2010. This metric reflects decomposition over full years, not only during the litter bag exposure period of September–May. We used ten permanent 25 m^2 vegetation structure monitoring plots per site, which were largely located in 'wet' areas. The thickness of the litter layer was measured in June with a ruler and four replicates per plot. The vegetation consisted primarily of *Phragmites* and sedges. Data collected in 2006 reflect the conditions after ≥10 years of abandonment and before the re-introduction of mowing. In all other years, all plots had been mown in the previous year without biomass removal. No data were collected at Schadefähre Island.

We applied linear mixed-effects models using plot within site as random effect and water level (wet/dry) and material size (complete/shredded) as fixed effects. The response variable 'litter dry weight remaining' was logit-transformed (Warton & Hui 2011). The software R 3.1.1 (R Development Core Team 2014) with packages nlme (Pinheiro *et al.* 2014), lattice (Sarkar 2010) and car (Fox & Weisberg 2011) was used.

RESULTS

Water levels in the experimental plots varied between *ca*. -10 cm in the 'dry' plots at Ferne Wiesen and 15.4 ±1.1 cm at the 'wet' plots on Schadefähre Island (Table 1). The plots were located at 15.7–45.6 cm above Kronstadt gauge reference surface. The number of flood days during exposure ranged from 20 in the 'dry' plots at Ferne Wiesen to 256 in the 'wet' plots at Murchiner Wiesen (Table 1, Figure 2).

Water level was the only factor that explained decomposition (Table 2). Decomposition was greatest in the 'wet' plots at Murchiner Wiesen (percentage of litter dry weight remaining: 40.1 ± 4.7 %), and lowest in the 'dry' plots at Schadefähre Island (56.4 ± 3.7 %; Figure 3). The mean decomposition rate (k day^{-1}) was 0.0029 ± 0.0006 in all plots (N = 93), 0.0033 ± 0.00037 at all 'wet' plots (N = 44), and 0.0026 ± 0.00051 at all 'dry' plots (N = 49; Table 3).

Litter accumulation at Murchiner Wiesen and Ferne Wiesen after mowing without biomass removal was very low (< 5 cm; Figure 4). At Murchiner Wiesen, litter thickness decreased from 16.3 ± 7.7 cm in 2006 to 0.9 ± 1.1 cm in 2010. On Ferne Wiesen, it was 8.4 ± 4.3 cm in 2006 and 2.7 ± 2.7 cm in 2010.

DISCUSSION

The results demonstrate that water level is critical for *Phragmites* decomposition in fens. According to Brinson *et al.* (1981), the greatest decomposition can be observed with either drier or wetter conditions in different experiments. In our study, the greatest decomposition was observed at the 'wet' plots of the wettest site, Murchiner Wiesen, which is consistent with the observations of Polunin (1984) and Bedford (2005). Water levels in the wet, shallowly inundated plots are apparently still low enough to maintain aerobic conditions (Stegmann *et al.* 2001) and to enable continuous microbial activity (Bedford 2005, Bedford & Powell 2005). The overgrowth of the litter bags at the wet plots by *Agrostis stolonifera* would have further favoured decomposition by oxygen release from roots growing through the litter bags (Augustin 2001). Substantially higher water levels than those in our

Table 2. Full linear mixed-effects model for 'percentage of litter dry weight remaining' (logit-transformed) with estimates and standard errors. Plot within site was used as random effect.

Term	Levels	Estimate	Standard error	p value
Intercept		-0.267	0.103	<0.001
Water level	wet	-		
	dry	0.323	0.068	<0.001
Size	complete	-		
	shredded	-0.015	0.044	0.735
Interaction of water level and size	dry, complete	0.085	0.061	0.164

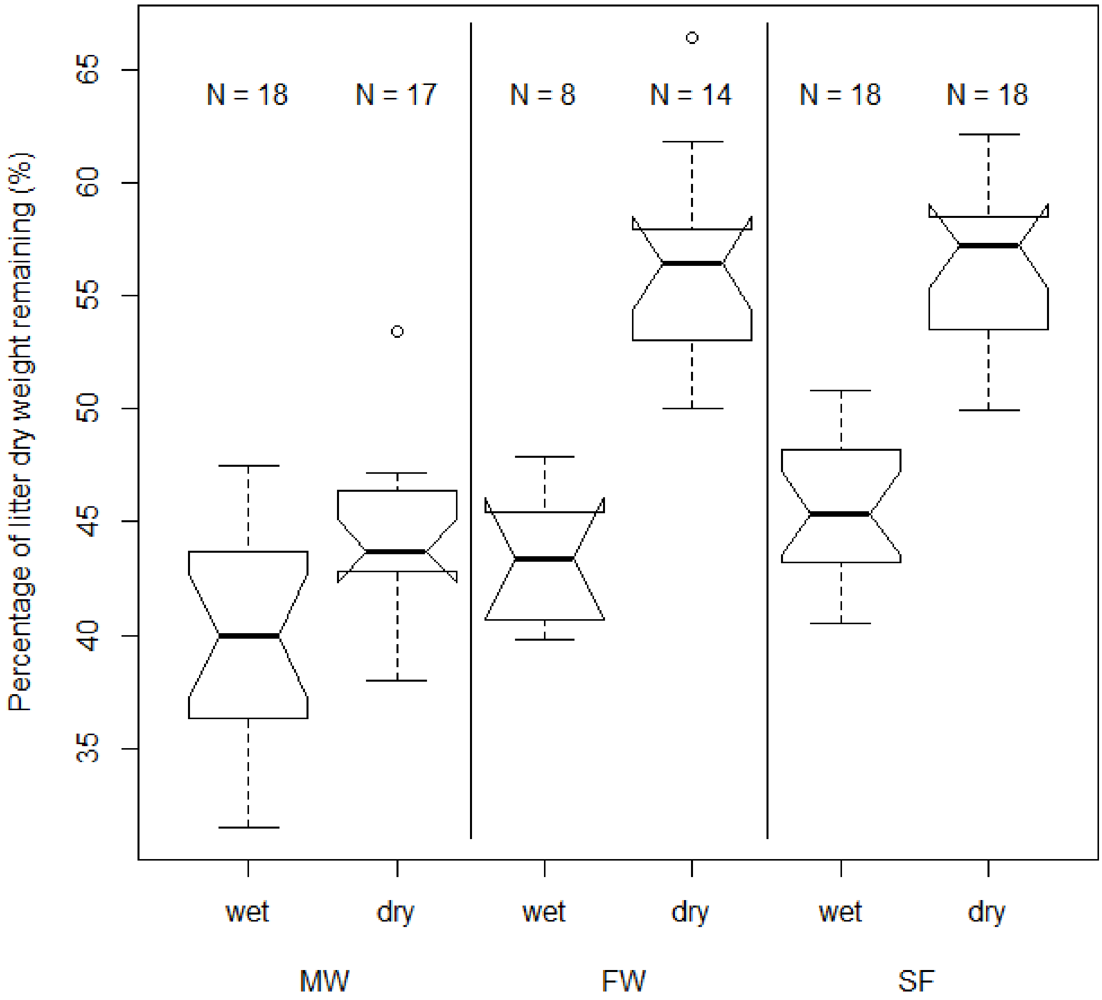

Figure 3. Percentage of litter dry weight remaining on 'wet' and 'dry' plots at Murchiner Wiesen (MW), Ferne Wiesen (FW) and Schadefähre Island (SF).

Table 3. Decomposition rates (k day^{-1}) of *Phragmites* leaf litter in studies using litter bags with similar mesh sizes.

Decomposition rate (k day^{-1})	Mesh size of litter bag (mm)	Site characteristics	Reference
0.0033 ± 0.00037	0.3	near-natural fen, 'wet'	this study
0.0026 ± 0.00051	0.3	near-natural fen, 'dry'	this study
0.0024	0.5	oligotrophic lake	Larsen & Schierup (1981)
0.0029	0.5	eutrophic lake	Larsen & Schierup (1981)
0.0014	0.25	managed reedbed, seasonally flooded	Bedford (2005)
0.0010	0.25	managed reedbed, never flooded	Bedford (2005)

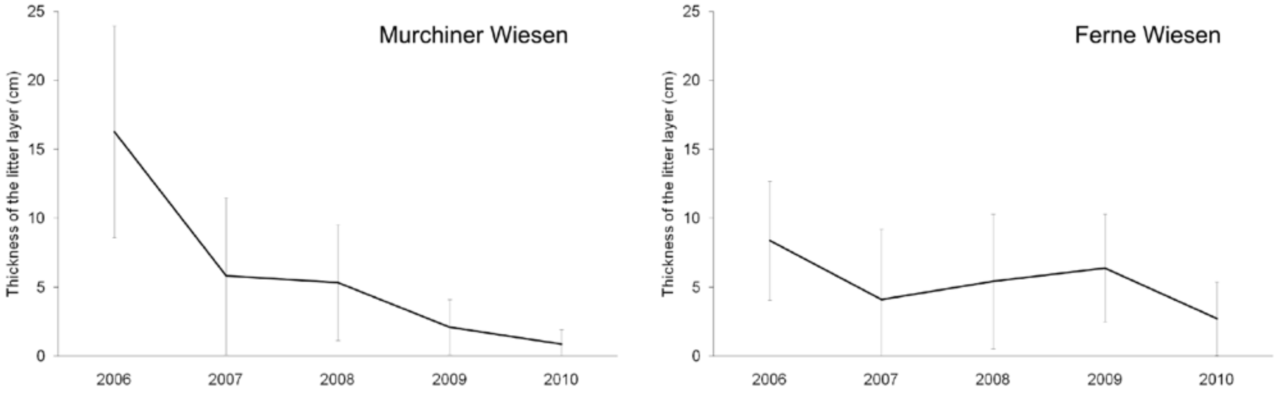

Figure 4. Thickness of the litter layer on vegetation structure monitoring plots at Murchiner Wiesen and Ferne Wiesen in June 2006–2010.

'wet' plots, in contrast, would result in more anaerobic conditions and probably inhibit decomposition (Brinson *et al.* 1981, Bedford 2005).

Although physical disintegration is a key step in decomposition (Blume *et al.* 2010), fragment size did not influence the degree of decomposition in our experiment. Physical disintegration increases the surface area available for microbial activity (Koppisch 2001) but in our experiment that increase was probably minor. The experimental shredding is also likely to differ from natural disintegration by invertebrates, which were largely excluded in our experiment. Despite the lack of a significant result, we assume that fragment size is important for litter decomposition because shredded biomass is likely to end up closer to the soil surface and thus be exposed to wetter conditions. Fragment size is also important for litter accumulation since shredded biomass is likely to become immobilised in the remaining vegetation and less likely to be translocated by floods (Völlm 2012).

The decomposition of *Phragmites* leaves was more rapid in our study than in other studies using litter bags with similar mesh size (Table 3), and it is possible that our results over-estimate the actual decomposition rates of mown biomass. The sedge vegetation that is common in some parts of the study area may have a lower decomposition rate than the *Phragmites* used in the experiment, as reported in other studies (Mason & Bryant 1975, Aerts & de Caluwe 1997). Also, in the first months after mowing, the mown biomass may decompose more slowly than the material in the litter bags because it is lying on the cut *Phragmites* stem bases, which often support it above the water level even in 'wet' sites. However, on the basis of the low litter accumulation measurements obtained in consecutive years (Figure 4), we suggest that the observations of rapid decomposition in the litter bags do not grossly mis-represent the actual situation in stands of either *Phragmites* or sedges.

We conclude that shallow inundation in near-natural fen mires favours rapid decomposition of *Phragmites* leaf litter. To create or maintain a thin litter layer for biodiversity conservation, it may not be necessary to remove the mown biomass. However, to reduce the thick litter layers that accumulate over several years without mowing, to lower the amount of nutrients in a site, or to secure income from biomass use to finance mowing for nature conservation, biomass removal may remain necessary.

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