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Vegetation change and effects of cattle grazing in the transition mire "Burgmoos"

Helen Küchler · Andreas Grünig · Rolf Hangartner · Meinrad Küchler

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Abstract Mires are highly threatened ecosystems in the lowlands of Central Europe. Reduced water levels and eutrophication promote shrub encroachment and the expansion of tall species, such as common reed (*Phragmites australis*). In the "Burgmoos", a Swiss mire of national importance, attempts have been made to reverse these developments through cattle grazing in parts of the mire area. To monitor overall vegetation change and to assess the influence of grazing (which started in 2004), the vegetation was surveyed in 1995, 2001 and 2007. Ecological indicator values of the vegetation changed considerably between 1995 and 2007: mean indicator values for nutrients and soil pH increased in 80 and 72% of the relevés, respectively, while mean indicator values for moisture, humus and light decreased in 81, 86 and 76% of the relevés, respectively. Plant species from bogs, transition mires and fens decreased, while trees, pasture species and *P. australis* increased. Grazing had a weak effect on *P. australis* and did not prevent an increase in abundance of this species. The abundance of transition mire species was maintained in the grazed area between 2001 and 2007, whereas it continued to decrease in the ungrazed areas. This positive effect of grazing was, however, compensated by several adverse effects: In the non-forested parts of the mire, grazing accelerated the increase of nutrient indicator values, the decrease of bog species and the increase of pasture species. We conclude that grazing has not been effective in preventing undesirable vegetation changes in the Burgmoos.

Keywords Ecological indicator values · Galloway cattle · *Phragmites australis* · Vegetation monitoring · Wetland management

Vegetationsveränderungen und Einfluss der Beweidung im Zwischenmoor "Burgmoos"

Zusammenfassung Das "Burgmoos" liegt im Schweizer Mittelland und ist ein Zwischenmoor von nationaler Bedeutung. Um den charakteristischen Vegetationskomplex zu erhalten, wird das Moor seit den 1970er Jahren jährlich gemäht und seit 2004 teilweise beweidet. Anhand von Vegetationsaufnahmen der Jahre 1995, 2001 und 2007 untersuchten wir die Gesamtentwicklung des Moores und den Einfluss der Beweidung. Zwischen 1995 und 2007 haben sich die mittleren ökologischen Zeigerwerte der Vegetation stark verändert: die mittlere Nährstoffzahl stieg in 80% der Probeflächen und die Reaktionszahl in 72% der Probeflächen. Die mittleren Zeigerwerte für Feuchte, Humus und Licht nahmen in 81%, 86% bzw. 76% der Probeflächen ab. Die mittlere Affinität der vorkommenden

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H. Küchler (✉) · M. Küchler
WSL, Swiss Federal Research Institute, Zürcherstrasse 111,
8903 Birmensdorf, Switzerland
e-mail: helen.kuechler@wsl.ch

M. Küchler
e-mail: meinrad.kuechler@wsl.ch

A. Grünig
ART, Swiss Federal Research Station, Reckenholzstrasse 191,
8046, Zurich, Switzerland
e-mail: andreas.gruenig@art.admin.ch

R. Hangartner
Köschenrütistrasse 147, 8052 Zurich, Switzerland
e-mail: r.j.hangartner@bluewin.ch

Pflanzenarten zu Hochmoorarten, Übergangsmoorarten und Flachmoorarten nahm ab, während die Affinität zu Bäumen, Weidepflanzen und Schilf (*Phragmites australis*) zunahm. Beweidung verstärkte im Zentrum des Moors den Anstieg der mittleren Nährstoffzahl. Die Humuszahl sank in beweideten Flächen schneller als in unbeweideten. Die Abundanz der Hochmoorarten nahm in beweideten Flächen stärker ab, während die Weidezeiger von der Beweidung profitierten. Die Abundanz der Übergangsmoorarten blieb zwischen 2001 und 2007 auf den beweideten Flächen erhalten, während sie auf den unbeweideten Flächen weiter abnahm. Der Einfluss der Beweidung auf das Vorkommen von Schilf war statistisch nicht signifikant und geringer als die entsprechende gesamthafte Veränderung. Der ungünstige Einfluss der Beweidung auf die Vegetation, beschrieben durch die mittleren Zeigerwerte und Affinitäten, lag im gleichen Bereich wie die gesamthafte Veränderung dieser Parameter. Die Beweidung des Burgmoos muss deshalb optimiert oder unterlassen werden.

Introduction

Mires are species-rich habitats with a high proportion of rare species (Landolt 1991; Olde Venterink and Vittoz 2008). All over Central Europe, these communities are endangered due to hydrological change, eutrophication and reduced management (Bokdam and Gleichman 2000). In many lowland mires, shrub encroachment and a spread of common reed (*Phragmites australis*) have been observed in the last decades. These tall plants additionally threaten the mire vegetation as they might displace typical fen or bog species (Güsewell and Klötzli 1998). Grazing by cattle has increasingly been introduced to manage the vegetation in nature reserves (Stammel et al. 2003; Güsewell et al. 2007). While grazing is a means to control the spread of common reed, it may also lead to an unintended change in the composition of the vegetation (Bokdam and Gleichman 2000). As Middleton et al. (2006) showed, overgrazing results in a permanent reduction of species richness. The introduction of cattle must, therefore, be done with care.

We chose the "Burgmoos", a Swiss mire of national importance, to explore the effect of grazing on mire vegetation. Previous vegetation studies have shown that the mire has recently developed towards more acidic, drier and increasingly nutrient-rich conditions (Höhn-Ochsner 1963; Kunz-Hasler 1990, unpublished thesis at the University of Berne). During the past few decades, common reed (*P. australis*) and alder (*Alnus glutinosa*) progressively invaded the mire. The Burgmoos has been regularly mown since the 1970ies to keep its character of a transition mire. However, reed and shrub invasion continued. Therefore, parts of the mire have been grazed by Galloway cattle since 2004 in order to control reed invasion more effectively.

The present study is based on vegetation surveys carried out in the mire in 1995, 2001 and 2007. We address the following questions:

- Did the previously reported change towards more acidic, drier and more nutrient rich conditions in the "Burgmoos" continue after 1995?
- Which species have increased and which ones have become less abundant?
- Did the trends in species composition differ between the grazed and ungrazed areas?
- How did grazing affect the abundance of individual plant species, especially *P. australis*?

Methods

Study area

The mire "Burgmoos" is situated in the Swiss Plateau between Herzogenbuchsee and Solothurn at an altitude of 465 m a.s.l. The site is located north-east of the Burgäschi lake.

The basin of the Burgmoos was formed during the last glacial period when it became filled with dead ice. When the ice eventually melted, a lake remained. The mire developed by aggradation of this former lake, partly through mineral deposits, partly through the formation of peat (Baumberger 1911). In 1942–1943, the water level of the Burgäschi lake was lowered as part of a drainage scheme (Von Büren 1949). This also influenced the hydrology of the nearby Burgmoos.

Despite its small size, the Burgmoos is today the most species-rich mire in the Swiss Plateau (Grossenbacher 1980). It consists of several vegetation types: ombrotrophic bog, transition mire, fen, tall-forb stands and forest (Höhn-Ochsner 1963). The mire has been protected since 1944. It is very isolated from other mires in the Swiss Plateau. Accordingly, great efforts have been made to preserve its character of a transition mire.

Vegetation surveys

Our data set consists of vegetation records from 157 patches covering the whole surface of the mire. Prior to field work, patches were delineated on aerial photographs, such that homogeneity in terms of colour and structure within a patch could be maximized (Küchler et al. 2004). Of these 157 patches, 76 are open vegetation ("centre"), and 81 are from the wooded border area ("border") (Fig. 1).

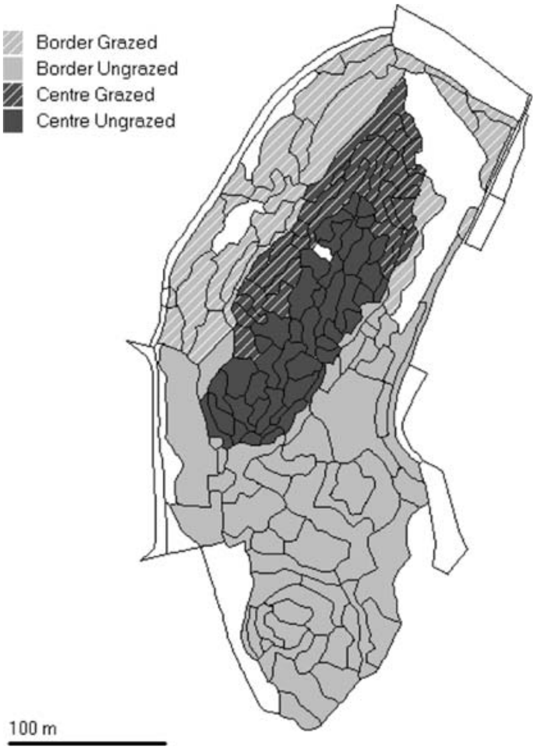

Fig. 1 Patches in the Burgmoos: centre (*dark grey*), border area (*light grey*), grazed patches (*hatched*), patches where data are missing in one or more surveys (*white*)

Part of the Burgmoos has been grazed by Galloway cattle since 2004. In the central area 33 patches were grazed, whereas 43 patches were protected from grazing by a fence. In the border area 29 patches were grazed and 52 were not grazed (Fig. 1). The grazing regime was varied slightly over the years; in average about five heifers grazed in the Burgmoos during 11 weeks (starting in June), 7 weeks in the border area and in between 4 weeks in the centre. The non-forested part of the mire was further mown in autumn for maintenance.

Vegetation surveys were carried out in 1995, 2001 and 2007. The abundance of vascular plant and bryophyte species in each of the 157 patches was estimated on a logarithmic scale from 1 to 4, where "1" denotes less than 0.1% cover, "2" denotes 0.1–1% cover, "3" denotes 1–10% cover, and "4" denotes more than 10% cover. For calculations the codes were transformed to mean percentage cover as follows: "1" = 0.03%, "2" = 0.32%, "3" = 3.16%, "4" = 31.62%.

Assessment of ecological conditions

To assess changes in ecological conditions based on the vegetation data, we used the ecological indicator values for vascular plants of Switzerland (Landolt 1977). These are scaled in ordinal levels from 1 to 5 for moisture, light, nutrients, soil reaction and humus content. Küchler et al. (2004) calibrated them for mire habitats on the basis of 20,000 relevés from the Swiss mire monitoring program. The scale of these adjusted values is continuous. We computed the 10%-trimmed means of the indicator values for all records in the three surveys. The 10%-trimming, i.e. excluding the 10% highest and the 10% lowest values in the concerned data, was applied to enhance the robustness against extreme observations.

We further developed an alternative approach for the assessment of ecological conditions, which was not based on expert opinion but on detailed records of species co-occurrences in the 20,000 vegetation relevés from the Swiss mire monitoring program. The idea was to evaluate the ecological suitability ("affinity") of vegetation patches for particular target species based on the list of species present in the patch and their co-occurrences with the target species in the 20,000 reference relevés. The affinity of a given species $S1$ to a target species S_t was defined as the probability that S_t would occur if $S1$ is present (=$P(S_t|S1)$). We estimated this probability from the quotient $a/(a + b)$, where a is the number of reference relevés with common occurrence of both species, and b is the number of relevés where $S1$ is present but S_t is absent.

The ecological suitability of a patch for the target species S_t was assessed by the 10%-trimmed mean of the affinity values of all species recorded in the patch to S_t. The overall change in ecological conditions for the target species S_t was assessed by comparing the mean of the affinity values of all patches to this species among the three surveys. Patches with affinities to S_t lower than 0.1 (=10%) in all three surveys were excluded from the analysis of change so that conclusions about ecological conditions for a species would only be derived from patches where this species had a chance to occur. We computed affinity values for all vascular plant species that are frequent in the Burgmoos and representative of certain vegetation types or growth forms (see grouping given in the next section or Table 2).

Abundance of species groups

To describe the vegetation composition of a patch, the percentage cover of each plant species was divided by the sum of cover values of all species in the patch to obtain relative abundance values. For the analysis and interpretation of vegetation change, we considered the sum of relative abundance values for groups of species that are typical of a particular vegetation type, growth form or management. Patches with a relative abundance of 0% for a certain species group in all three surveys were excluded from the analysis of change for this group. The groups analysed were:

- Bog: *Andromeda polifolia, Drosera rotundifolia, Eriophorum vaginatum, Vaccinium oxycoccos, Polytrichum strictum, Sphagnum magellanicum*
- Transition mire: *Carex lasiocarpa, Carex limosa, Eriophorum angustifolium, Eriophorum gracile, Menyanthes trifoliata, Potentilla palustris, Rhynchospora alba, Scheuchzeria palustris*
- Fen: *Carex panicea, Epilobium palustre, Equisetum fluviatile, Lysimachia thyrsiflora, Molinia caerulea, Parnassia palustris, Succisa pratensis*
- Tall forbs: *Angelica sylvestris, Eupatorium cannabinum, Filipendula ulmaria, Lycopus europaeus, Lysimachia vulgaris, Lythrum salicaria*
- Trees: *Alnus glutinosa, Betula pubescens*
- Reed: *Phragmites australis*
- Peat mosses: *Sphagnum spp.* The abundance of these species, typical of bogs and poor fens, was quantified by their proportion of the total cover of all bryophytes.
- Pasture: *Anthoxanthum odoratum, Holcus lanatus, Lathyrus pratensis, Poa trivialis*

Statistical analysis

To assess the overall change in vegetation in the Burgmoos, we computed the differences in the various variables between 1995 and 2007. From these calculations we obtained the differences $d_{07\text{-}95}$ in the indicator values, the mean affinity to single target species and the relative abundance of species groups. To test their significance, we used the Wilcoxon rank sum test as implemented in the computer program VEGEDAZ (Küchler 2008), with Bonferroni correction for multiple testing if necessary. For affinity values, the test was only applied if at least five records with data were available after excluding the patches with low values for a particular target species.

All analyses were performed for the whole mire and separately for the centre and the border (Fig. 1). Since data had been collected in adjacent patches (Fig. 1), spatial autocorrelation was likely to occur. A spherical correlogram (Venables and Ripley 2002) gave a range of about 60 m for the mean indicator values. Therefore, the given P values may underestimate the true error probabilities in stating significant changes; they have to be interpreted as an additional illustration of the changes, rather than a strict conclusive statistic.

To assess the influence of grazing, we compared grazed and ungrazed patches. We computed the differences in values of the variables between 1995 and 2001 ($d_{01\text{-}95}$), and between 2001 and 2007 ($d_{07\text{-}01}$) separately for grazed and ungrazed patches. Grazing started in 2004, so that if grazing had an impact, this would become evident in the course of the second period. If the grazed and ungrazed patches developed similarly in the first period but differently in the second period, we considered this as evidence for grazing having an impact. More generally, if the development of the grazed patches compared with the ungrazed patches changed between the first and second period, an influence of grazing could be assumed. To test such effects, we computed the differences between the changes in the first and in the second period ($d_\text{d} = d_{07\text{-}01} - d_{01\text{-}95}$), separately for the grazed and the ungrazed patches (Table 4). If d_d (e.g. of the nutrient value) was greater for grazed patches than for ungrazed patches, we conclude that grazing promoted an increase in the (nutrient) value. We used the Wilcoxon rank sum test again to compare the differences d_d of the two groups.

In disturbed areas, the interpretation of mean indicator values as a surrogate for measured site conditions may be invalid, since species may occur temporarily at places that do not correspond to their main habitats (Landolt 1977). In the “Burgmoos”, changes in mean indicator values may result from the transport of plants or propagules by cattle moving from one place to another, without necessarily altering the site conditions. Such possible effects were checked whenever a test result showed a significant impact of grazing on an indicator value. The check consisted in repeating the calculations after excluding species which were probably brought in by cattle. We excluded the species found mainly (i.e. at least 50% of the findings) in the grazed area in 2007. Additionally we removed rare species with less than three occurrences in the whole data set.

Results

Overall change between 1995 and 2007

The mean indicator value for moisture, light and humus decreased in most patches between 1995 and 2007, whereas the mean nutrient value increased in the majority of the patches. All indicator values changed significantly across the whole mire area (Table 1). Changes were similar in the non-forested centre and in the forested border area (Table 1).

The mean affinity to bog species decreased from 1995 to 2007 (Table 2). For example, the mean affinity to *Andromeda polifolia* decreased in 81% of the patches. This means that species with high affinity to *A. polifolia* have decreased since 1995, or that species with low affinity to *A. polifolia* have increased. Likewise, the mean affinity to species typical of transition mires and fens and to tree species decreased. Conversely, the mean affinity to tall forbs, pasture species and common reed (*P. australis*)

Table 1 Change in the indicator values from 1995 till 2007

	Whole area ($N = 157$)			Centre ($N = 76$)			Border ($N = 81$)		
	1995	$d_{07\text{-}95}$	Incr. (%)	1995	$d_{07\text{-}95}$	Incr. (%)	1995	$d_{07\text{-}95}$	Incr. (%)
Moisture	3.96	−0.13***	19	4.30	−0.13***	12	3.63	−0.13***	26
Light	3.30	−0.09***	24	3.69	−0.10***	12	2.93	−0.07**	35
Soil reaction	2.82	+0.12***	72	2.54	+0.15***	74	3.08	+0.09***	70
Nutrients	2.55	+0.17***	80	2.07	+0.20***	84	2.99	+0.14***	75
Humus	4.20	−0.17***	14	4.67	−0.21***	11	3.76	−0.14***	17

Differences between 1995 and 2007 were tested with paired Wilcoxon rank sum tests with Bonferroni correction: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Incr. percentage of patches with increased values

increased. Trends were similar in the centre and border of the mire (Table 2).

The relative abundance of species groups changed significantly for most groups (Table 3). Species characteristic of bogs, transition mires and fens as well as peat mosses decreased. Conversely, pasture species, trees and common reed increased. Again, trends in the centre and in the border of the mire were similar.

Effects of grazing

In the centre of the mire, the mean nutrient indicator values of the vegetation increased similarly in grazed and ungrazed patches during the first period (1995–2001). In the second period (2001–2007), however, the nutrient value increased significantly faster in the grazed patches than in the ungrazed ones, suggesting an increase in nutrient availability due to grazing (Fig. 2). In the border area, the nutrient value also changed differently in grazed and ungrazed patches, but in the opposite way: Between 2001 and 2007, the nutrient value tended to decrease in the grazed patches, whereas it continued to increase in the ungrazed patches (Fig. 2). Furthermore, the mean humus value decreased significantly faster in the grazed patches than in the ungrazed ones in the centre of the mire (Table 4). After excluding the species probably brought in by cattle, the differences between grazed and ungrazed patches ($d_{\mathrm{dgrazed}} - d_{\mathrm{dungrazed}}$) in the development of nutrient and humus values were reduced by 0.06 and 0.05, respectively.

The mean affinity of vegetation patches to *Andromeda polifolia*, *Eriophorum vaginatum, Polytrichum strictum, Menyanthes trifoliata and Molinia caerulea* decreased faster in grazed than in ungrazed patches in the centre of the mire (Table 4). This suggests that ecological conditions for these bog and fen species deteriorated faster with grazing. Concomitantly, changes in affinity values suggest that grazing improved the ecological conditions for *Carex panicea, Anthoxanthum odoratum, Holcus lanatus, Poa trivialis* and *Lathyrus pratensis* (Table 4).

The abundance of species groups also changed differently in grazed and ungrazed patches (Table 4). The proportion of bog species generally increased between 1995 and 2001 and decreased between 2001 and 2007 (Fig. 3). The decrease during the second period was faster in the grazed patches than in the ungrazed ones (Fig. 3; Table 4). The proportion of species from transition mires generally decreased between 1995 and 2001. Between 2001 and 2007, it remained stable in the grazed patches, whereas it continued to decrease in the ungrazed patches (Fig. 3; Table 4). Trees (*A. glutinosa* and *Betula pubescens*) decreased in the grazed patches compared with ungrazed ones in the centre of the mire (Table 4). Pasture species increased since 2001 in the grazed patches compared with ungrazed ones (Table 4).

Common reed (*P. australis*) was less abundant in the grazed area even before grazing started. Throughout the observation period (1995–2007), its abundance increased less in the grazed patches than in the ungrazed ones (Fig. 3). Therefore, an influence of grazing on the abundance of *Phragmites* could not be proved. The differences d_{d} ($d_{07\text{-}01} - d_{01\text{-}95}$) were not significantly different between grazed and ungrazed patches.

Discussion

Overall change

The changes in ecological indicator values indicate that the trend towards drier and increasingly nutrient-rich conditions reported earlier (Höhn-Ochsner 1963, Kunz-Hasler 1990, unpublished thesis) has continued. The increased nutrient values may be largely the result of peat decomposition due to drier conditions. Nutrient input from the air and from the nearby agricultural area may have also taken place. The ongoing tree encroachment and the hot summer in 2003 may have contributed to the drier conditions (Edom et al. 2007; Bragazza 2008). On the other hand,

Table 2 Changes in the mean affinity of the vegetation to single species from 1995 till 2007

	Whole area				Centre				Border			
	N	1995	$d_{07\text{-}95}$	Incr. (%)	*N*	1995	$d_{07\text{-}95}$	Incr. (%)	*N*	1995	$d_{07\text{-}95}$	Incr. (%)
Bog												
Andromeda polifolia	37	13.1	−2.4***	19	34	13.2	−2.2***	21				
Drosera rotundifolia	78	17.7	−3.7***	15	68	18.2	−3.6***	18	10	14.0	−4.6*	0
Eriophorum vaginatum	122	26.1	−4.5***	16	75	30.3	−4.3***	21	47	19.3	−4.9***	6
Vaccinium oxycoccos	68	15.2	−3.0***	16	59	15.6	−2.9***	17	9	12.3	−3.5	11
Polytrichum strictum	119	24.3	−4.4***	14	75	27.7	−4.2***	19	44	18.6	−4.6***	7
Sphagnum magellanicum	122	25.0	−4.1***	25	75	28.3	−3.9***	28	47	19.6	−4.5***	19
Transition mire												
Carex lasiocarpa	11	10.4	−1.2	18	11	10.4	−1.2	18				
Carex limosa	6	10.0	−1.9	0	6	10.0	−1.9	0				
Eriophorum angustifolium	136	24.3	−3.0***	23	76	31.1	−3.1***	22	60	15.6	−2.7***	23
Menyanthes trifoliata	83	15.2	−2.2***	14	73	15.7	−2.2***	15	10	11.4	−2.6*	10
Potentilla palustris	52	11.1	−1.7***	13	51	11.2	−1.6***	14				
Fen												
Carex panicea	157	33.2	−0.7	46	76	37.4	+0.3	54	81	29.3	−1.6*	38
Epilobium palustre	117	12.1	−0.1	52	70	12.3	+0.7*	64	47	11.7	−1.2**	34
Equisetum fluviatile	53	10.1	−0.2	43	46	10.0	−0.1	48	7	10.8	−1.4	14
Molinia caerulea	157	49.3	−2.7***	25	76	57.4	−3.0***	22	81	41.7	−2.4***	27
Parnassia palustris	90	14.4	−1.5***	21	75	14.9	−1.4***	21	15	11.5	−2.4*	20
Succisa pratensis	157	21.7	−0.9***	39	76	25.3	−0.4	41	81	18.4	−1.3**	37
Tall forbs												
Angelica sylvestris	157	18.1	+0.7***	67	76	14.3	+1.0***	75	81	21.7	+0.4	59
Filipendula ulmaria	157	33.2	+2.2***	69	76	26.7	+3.0***	76	81	39.3	+1.6*	62
Lysimachia vulgaris	144	16.7	+0.2	57	64	13.3	+1.3	67	80	19.4	−0.7	49
Lythrum salicaria	121	12.8	−0.1	51	49	11.1	+0.7	59	72	14.0	−0.6	46
Trees												
Alnus glutinosa	10	9.7	−0.1	50					10	9.7	−0.1	50
Betula pubescens	147	14.0	−0.5*	46	74	13.9	−1.0***	31	73	14.2	0.0	60
Reed												
Phragmites australis	140	19.6	+1.1**	61	62	13.8	+2.7***	69	78	24.3	−0.1	55
Pasture												
Anthoxanthum odoratum	157	41.9	+1.2	54	76	42.7	+2.5***	71	81	41.2	0.0	38
Holcus lanatus	136	15.4	+1.4***	71	57	12.3	+1.9***	75	79	17.6	+1.1*	68
Lathyrus pratensis	137	17.3	+1.6***	67	59	13.7	+2.8***	81	78	20.1	+0.6	56
Poa trivialis	145	20.3	+2.8***	79	64	13.4	+3.8***	83	81	25.7	+2.1***	75

Differences between 1995 and 2007 were tested with paired Wilcoxon rank sum tests with Bonferroni correction: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Incr. percentage of patches with increased values, *empty fields* insufficient data for testing

contrary to previous reports, the Burgmoos did no longer develop more acidic conditions. Nutrient inputs and peat decomposition following water loss probably reduced the acidification. The proportion of peat mosses in the bryophyte layer has also decreased, which possibly reduced the acidifying effect of bryophytes (Kooijman and Bakker 1994).

Our results confirm that the ecological suitability for the species of bog, transition mire and fen species has decreased, whereas it has increased for pasture species, tall forbs and trees. Despite the observed decrease in the mean moisture indicator value, *P. australis* has spread since 1995, and especially since 2001 (Fig. 3). The aboveground biomass of *Phragmites* has been shown to positively correlate with the nitrogen indicator value of the vegetation, but not with the soil moisture indicator value (Güsewell and Klötzli 1998). Since *Phragmites* can reach the groundwater table with its rhizomes down to 1.5 m or

Table 3 Changes in the proportions of species groups from 1995 till 2007

	Whole area				Centre				Border			
	N	1995	$d_{07\text{-}95}$	Incr. (%)	*N*	1995	$d_{07\text{-}95}$	Incr. (%)	*N*	1995	$d_{07\text{-}95}$	Incr. (%)
Bog	83	27.8	−4.1*	42	70	30.9	−3.6	44	13	10.7	−6.8*	31
Transition mire	91	14.5	−7.8***	37	74	17.3	−9.2***	38	17	2.4	−1.6	35
Fen	129	9.0	−3.1**	46	76	10.9	−1.8	47	53	6.4	−5.0***	43
Tall forbs	130	3.6	−2.0	55	59	3.5	−0.8	64	71	3.7	−3.1*	46
Trees	139	6.8	+3.6***	76	74	3.0	+0.9***	78	65	11.2	+6.6***	74
Reed	113	4.0	+3.0***	70	76	4.8	+4.9***	80	37	2.3	−0.7	49
Peat mosses	114	73.9	−17.9***	19	71	89.2	−13.3***	21	43	48.7	−25.4***	16
Pasture	92	0.8	+4.3***	93	44	0.1	+1.2***	93	48	1.4	+7.1***	94

Differences between 1995 and 2007 were tested with paired Wilcoxon rank sum tests: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Incr. Percentage of patches with increased values

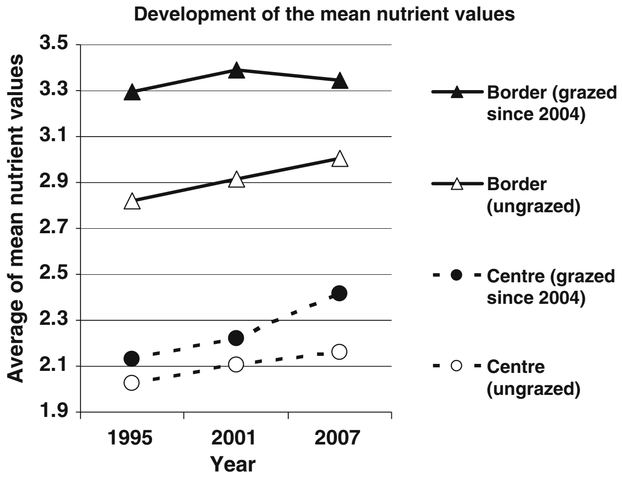

Fig. 2 Changes in mean nutrient indicator values of the vegetation in grazed and ungrazed patches within the forested border and the non-forested centre of the mire

more, it may grow fairly well at sites drying out close to the surface (Haslam 1972). This may explain why it has become more abundant in spite of the drier conditions.

Contradictory results were obtained for changes in the abundance of trees. The vegetation composition indicated a decreasing suitability for *Betula* and *Alnus*, whereas their actual abundance has increased. Not only can the roots of shrubs and trees grow more deeply into the soil that those of herbaceous species; their spread is also highly dependent on management.

Effects of grazing

In the central part of the mire, grazing accelerated the increase of the mean nutrient value and the decrease of the humus value. The influence of grazing on the nutrient value was similar to the overall changes observed between 1995 and 2007. For example, in the ungrazed patches of the centre, the mean nutrient value increased by 0.14 between 1995 and 2007, while the difference between grazed and ungrazed patches in the change from 2001 to 2007 was 0.13.

Grazing also had negative effects on the vegetation. In the grazed patches the conditions for bog species deteriorated faster than in the ungrazed patches, whereas pasture species increased significantly faster in the grazed patches (Table 4). The only positive effect of grazing regarded the abundance of transition-mire species, which remained about constant in the grazed patches of the centre, whereas they continued to decrease in the ungrazed patches. However, considering the overall changes in site conditions and vegetation, this positive impact is unlikely to be sustainable.

The tendency for *Phragmites* to spread more slowly in the grazed patches during the grazing period indicates that grazing might inhibit the spread of *Phragmites*, but it was not sufficient to stop the invasion completely. Furthermore, the estimated effect of grazing was smaller than the overall change in *Phragmites* abundance (Table 4). An important restriction to these results is that they are based on percentage cover and do not take into account the size of the shoots, which is essential for the shading effect of *Phragmites* on other species, and which tends to be reduced by management (Güsewell 2003).

Recommendations for conservation management

Grazing was introduced in 2004 to reduce invasion by *P. australis*. The disturbance caused by grazing appeared to be stronger than the inhibitive effect on *P. australis*. There was some success in maintaining the transition-mire species, but in general, the present grazing regime appeared to cause more harm than benefit. If grazing is to be continued, the grazing regime should be optimized to reduce trampling,

Table 4 Effects of grazing on changes in vegetation properties

	N	1995	2001	2007	$d_{01\text{-}95}$	$d_{07\text{-}01}$	$d_{\mathrm{d}} = d_{07\text{-}01} - d_{01\text{-}95}$	$d_{\mathrm{dgrazed}} - d_{\mathrm{dungrazed}}$
Mean indicator values								
Mean nutrient value								
Border, grazed	29	3.29	3.39	3.34	+0.10	−0.05	−0.15	−0.14*
Border, ungrazed	52	2.82	2.92	3.00	+0.09	+0.09	−0.01	
Centre, grazed	33	2.13	2.22	2.41	+0.09	+0.20	0.11	0.13*
Centre, ungrazed	43	2.03	2.10	2.16	+0.08	+0.06	−0.02	
Mean humus value								
Centre, grazed	33	4.60	4.53	4.34	−0.07	−0.19	−0.12	−0.12**
Centre, ungrazed	43	4.72	4.63	4.55	−0.09	−0.09	0.00	
Mean affinity values								
Andromeda polifolia								
Centre, grazed	9	11.4	12.5	9.1	+1.1	−3.4	−4.4	−3.5*
Centre, ungrazed	25	13.8	13.1	11.6	−0.6	−1.5	−0.9	
Eriophorum vaginatum								
Centre, grazed	33	27.2	26.8	21.9	−0.4	−4.9	−4.4	−3.1*
Centre, ungrazed	42	32.7	31.6	29.2	−1.1	−2.5	−1.3	
Polytrichum strictum								
Centre, grazed	33	25.8	24.5	20.1	−1.3	−4.4	−3.1	−2.5*
Centre, ungrazed	42	29.1	27.9	26.1	−1.2	−1.9	−0.6	
Menyanthes trifoliata								
Centre, grazed	32	15.1	14.1	12.5	−1.0	−1.7	−0.7	−1.7**
Centre, ungrazed	41	16.1	14.7	14.3	− 1.4	−0.4	1.0	
Molinia caerulea								
Centre, grazed	33	57.3	55.7	52.1	−1.6	−3.6	−2.0	−2.5**
Centre, ungrazed	43	57.5	56.6	56.2	−0.9	−0.4	0.5	
Carex panicea								
Centre, grazed	33	38.6	37.1	39.1	−1.5	+2.1	3.6	+2.1*
Centre, ungrazed	43	36.4	35.7	36.5	−0.7	+0.8	1.5	
Anthoxanth. odoratum								
Centre, grazed	33	42.6	43.3	46.8	+0.7	+3.5	2.8	+3.1*
Centre, ungrazed	43	42.7	43.4	43.9	+0.7	+0.4	−0.3	
Holcus lanatus								
Centre, grazed	32	11.7	11.9	14.3	+0.2	+2.3	2.1	+1.9*
Centre, ungrazed	25	13.1	13.6	14.2	+0.4	+0.7	0.2	
Poa trivialis								
Centre, grazed	33	12.8	14.3	18.2	+1.4	+4.0	2.5	+2.5**
Centre, ungrazed	31	14.0	15.0	16.0	+1.0	+1.0	0.0	
Lathyrus pratensis								
Centre, grazed	31	13.1	13.7	16.7	+0.6	+3.0	2.4	+2.2*
Centre, ungrazed	28	14.4	15.3	16.3	+0.8	+1.1	0.2	
Proportions of species groups								
Bog								
Centre, grazed	30	28.3	34.9	19.1	+6.6	−15.8	−22.3	−15.4*
Centre, ungrazed	40	32.9	36.6	33.6	+3.8	−3.1	−6.9	
Tansition mire								
Centre, grazed	32	17.6	7.5	8.8	−10.1	+1.3	+11.4	+12.6**
Centre, ungrazed	42	17.0	12.9	7.5	−4.1	−5.3	−1.2	

Table 4 continued

	N	1995	2001	2007	$d_{01\text{-}95}$	$d_{07\text{-}01}$	$d_\text{d} = d_{07\text{-}01} - d_{01\text{-}95}$	$d_\text{dgrazed} - d_\text{dungrazed}$
Fen								
Centre, grazed	33	11.5	7.6	7.9	−3.9	+0.3	+4.2	−4.4
Centre, ungrazed	43	10.4	5.9	10.0	−4.5	+4.1	+8.6	
Tall forbs								
Centre, grazed	30	3.4	4.9	2.8	+1.5	−2.1	−3.6	−1.3
Centre, ungrazed	29	3.5	4.1	2.4	+0.6	−1.7	−2.3	
Trees								
Centre, grazed	33	5.7	6.7	4.5	+1.0	−2.1	−3.1	−3.6*
Centre, ungrazed	41	0.8.	1.8	3.3	+1.0	+1.5	+0.5	
Reed								
Centre, grazed	33	3.2	1.3	5.6	−1.9	+4.3	+6.1	−1.5
Centre, ungrazed	43	6.0	5.6	12.8	−0.4	+7.2	+7.6	
Peat mosses								
Centre, grazed	33	88.4	80.7	69.8	−7.7	−10.9	−3.1	−2.4
Centre, ungrazed	38	89.8	85.8	81.2	−4.0	−4.7	−0.7	
Pasture								
Centre, grazed	28	0.0	0.0	1.1	0.0	+1.0	+1.0	+0.6*
Centre, ungrazed	16	0.1	0.6	1.5	+0.5	+0.9	+0.4	

Differences between 1995 and 2007 were tested with paired Wilcoxon rank sum tests: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. 1995, 2001, 2007: values in the respective year. $d_{01\text{-}95}$: difference of the value (2001) and the value (1995) = change from 1995 to 2001. $d_{07\text{-}01}$: difference of the value (2007) and the value (2001) = change from 2001 to 2007. d_d: difference of $d_{07\text{-}01}$ and $d_{01\text{-}95}$ which shows if change has accelerated or decelerated. $d_{\text{dgrazed} - \text{dungrazed}}$ with significance level: shows differences in the development of grazed and ungrazed patches

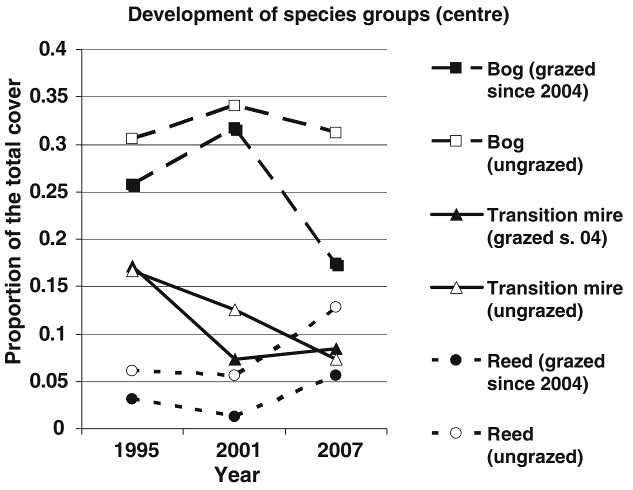

Fig. 3 Changes in the proportion of species groups in the vegetation of grazed and ungrazed patches in the non-forested centre of the mire

i.e. through shorter grazing periods adjusted to the phenology of reed. In addition, restoring the water regime and preventing further nutrient imports might improve the resistance of the vegetation against disturbance effects. Unless these measures are successful, grazing should be stopped. The vegetation monitoring program should be continued as a basis for future decisions.

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