Department of Physics, Chemistry and Biology

Master Thesis

Is spring burning a viable management tool for species-rich grasslands?

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Sammanfattning/Abstract:

Semi- natural grasslands are species-rich and also one of the most threatened biotopes in Europe. The area of these grasslands has declined and grassland vegetation is threatened as a result of lack of management and land use change. Appropriate management is therefore required to maintain the conservation values and high species richness of semi- natural grasslands. Traditional management, that is, grazing or annual mowing is expensive, which motivates evaluation of alternative cheaper methods of management. Burning is less costly and therefore I evaluated burning along with the conventional methods. The study addressed the main question: is burning an option to mowing and grazing? I searched the literature for available studies suitable for metaanalysis, but located only detailed reports from a series of eleven Swedish long-term field trials. In addition, I collected data in the only one of these trials still running. To facilitate metaanalysis, l used different indicator systems of classification of grassland plants then calculating the odds for a random record being an indicator after one, eight, fourteen, twenty-eight and thirty-nine spring burns. The results show an increasing proportion of grassland indicators of good management in the mowed and grazed plots compared with the burnt plots, indicating a general negative effect of burning on grassland plants compared with mowing and grazing. Hence, burning is not an appropriate long-term management method if the aim is to maintain vegetation diversity in semi-natural grassland.

Nyckelord/Keyword:

Burning, grazing, indicators, management, mowing, semi-natural grasslands.

Content

1 Abstract

Semi- natural grasslands are species-rich and also one of the most threatened biotopes in Europe. The area of these grasslands has declined and grassland vegetation is threatened as a result of lack of management and land use change. Appropriate management is therefore required to maintain the conservation values and high species richness of semi-natural grasslands. Traditional management, that is, grazing or annual mowing is expensive, which motivates evaluation of cheaper alternative methods of management. Burning is less costly and therefore I evaluated burning along with the conventional methods. The study addressed the main question: is burning an option to mowing and grazing? I searched the literature for available studies suitable for metaanalysis, but located only detailed reports from a series of eleven Swedish long-term field trials. In addition, I collected data in the only one of these trials still running. To facilitate metaanalysis, I used different indicator systems of classification of grassland plants then calculating the odds for a random record being an indicator after one, eight, fourteen, twenty-eight and thirty-nine spring burns. The results show an increasing proportion of grassland indicators of good management in the mowed and grazed plots compared with the burnt plots, indicating a general negative effect of burning on grassland plants compared with mowing and grazing. Hence, burning is not an appropriate long-term management method if the aim is to maintain vegetation diversity in semi-natural grasslands.

Keywords: burning, grazing, indicators, management, mowing, semi-natural grasslands.

2 Introduction

Semi-natural grassland is one of the most species-rich biotopes in the agricultural landscapes in Europe and contains a high diversity of plant and animal species. For example, in Sweden, about 600 species of plants can be found in this type of habitat (Svensson 1988). Traditionally, species-rich grasslands have been used by farmers as hay meadows cut for winter fodder and more lately as pastures for grazing stock. Semi-natural grasslands, by their characteristic flora and fauna also provide ecosystem services such as pollination that support the entire agricultural landscape, making them essential for an ecologically sustainable agricultural production (Anonymous 2008).

In Northern Europe, management has particularly influenced plant species richness in rural landscapes where mowing and grazing have prevented natural succession to forests (Lindborg & Eriksson 2004). However, over the last century, the application of inorganic fertilizers has steadily increased in many grassland areas in order to increase yields (Calaciura & Spinelli 2008). This has resulted in a decline in the areas of semi-natural grasslands. In Sweden, the decline in area of semi-natural grasslands has also been attributed to ceased management of semi-natural grassland (Lindborg & Eriksson 2004), which in turn has resulted in conversion of grasslands into forests through tree planting or natural succession (Hansson & Fogelfors 2000).

Management of low productive semi-natural grasslands has decreased mainly due to economic reasons. Furthermore, inadequate grazing resulting from changes in stocking density and the neglect of traditional grazing regimes (Calaciura & Spinelli 2008), as well as the high cost of managing grasslands areas by mowing (Petermann 1995 cited by WallisDeVries et al 2002), has contributed to the abandonment and loss of large areas of these habitats (Calaciura & Spinelli 2008); the abandonment of such grasslands is likely to occur and persist due to lack of funds for conservation. Therefore, there is the need for alternative management methods.

Burning plays a role similar to mowing and has been considered as an alternative to mowing and grazing that is inexpensive, labour-efficient and provides a cheaper way to managing semi-natural grasslands (Larsson 2007). Spring burning has conventionally been used to remove accumulated dead plant material and to reduce woody plants encroachment in boreal grasslands (Antonsen & Olsson 2005). However, it has not been given full consideration as a potential viable management tool for semi-natural grasslands. One reason for this is that, evidence in support for burning as a long-term alternative management practice for grasslands is limited. Consequently, I set out to assemble the available information relevant for the long-term viability of spring burning as an option to grazing or mowing aiming for a metaanalysis and, in the end, decision support for managers.

The aim of the present study was to examine whether burning compared with selected management methods (mowing and grazing) maintains vegetation diversity and to evaluate if burning because of its lower cost provides a better option to mowing and grazing in the management of semi-natural grasslands. The central objective was to assess the efficacy of burning in conserving species richness of grasslands and to address the question “is spring burning a viable management tool for species-rich

grasslands?" Specifically, this was done by comparing species richness in burnt versus grazed plots and burnt versus mown plots. If burning preserves species richness as well as grazing and mowing, it will be recommended as a cost-effective tool for conservation in grasslands.

3 Material & methods

3.1 Study sites

In total, eleven experimental sites situated at nine locations in southern Sweden were studied (Figure 1). Two of these locations, Ekenäs and Tagel, had two experimental sites each (Table 1). The sites comprise a long-term field experiment established about 40 years ago with an aim to compare different management methods of semi-natural grassland vegetation. The sites had different land use history and varied in nutrient and moisture conditions (Hansson 1991). The vegetation at most of the eleven sites is of the mesic meadow type (Table 1).

The management method experiments of ten of the sites were last assessed in 1986 while the eleventh site (Sättra) was last assessed in the year 2000. At Sättra, the field experiment has been managed continuously since 1973 and I conducted a survey of this vegetation site in 2011. The site is located about 55 km WSW of Linköping in the county of Östergotland in Southern Sweden (58° 16´N, 14° 49´E; 19 ha in size). The reserve contains species-rich meadows and pastures with stands of deciduous trees, *Quercus robur* being the most common tree species. Mowing is presumed to have occurred in the area for several hundred years (Hansson 1991) and the area was grazed by cattle in the 10-15 years prior to the initiation of the field experiment in the early 1970s (Wahlman & Milberg 2002). Apart from cattle, the area has also been grazed by horses in the year 2011.

3.2 Experimental design

The long- term experiment set up in the eleven sites was designed to assess the vegetation changes resulting from the introduction of six new management methods compared with continued grazing. The methods were annual mowing, mowing every third year, annual spring burning, mechanical removal of woody plants, herbicide treatment of woody plants and untreated control. The management techniques for all the sites were applied to 5m x 20 m plots set within a randomized block design with two replicates. All the plots at a site, with the exception of those grazed were within a fence enclosure.

In the present study, only three out of the seven management methods were evaluated, namely annual mowing, annual spring burning and grazing. Burning was done after snowmelt in March or April. The plots mowed once a year were mown in late July or early August. The grazing plots have been grazed over the years by cattle and horses with grazing pressure varying over time (Wahlman & Milberg 2002).

Data from field work conducted in 1973, 1975, 1980 and 1986 (Steen 1976, Fogelfors 1982, Hansson 1991) at the eleven experimental sites (Figure 1), as well as records from 2000 and 2011 at the experimental site at Sättra, were collated and used in the present study (Table 1).

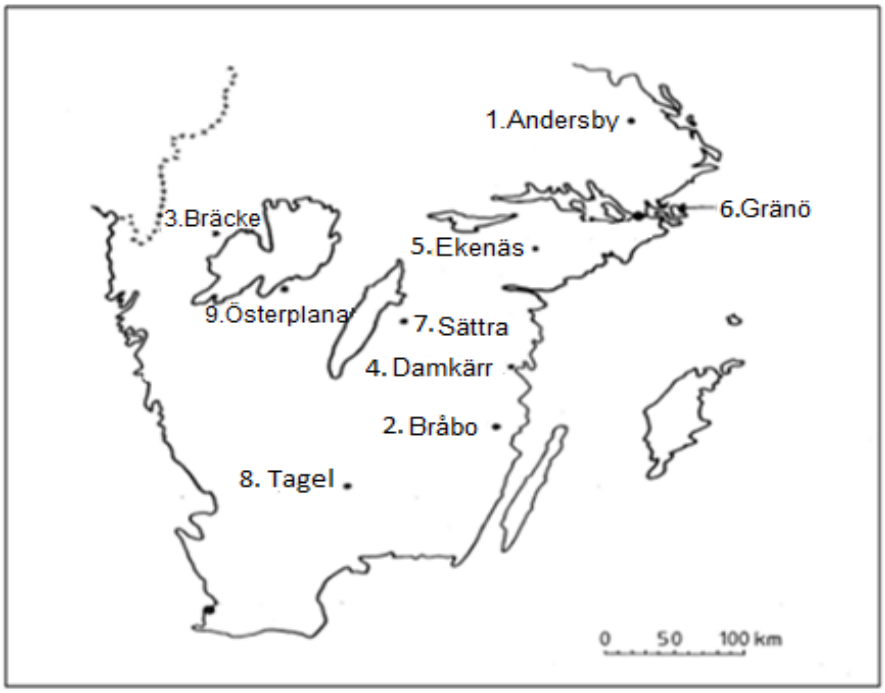

Figure 1. Location of the studied sites. Two of the locations, Ekenäs and Tagel, had two experimental sites each making a total of eleven sites.

3.3 Vegetation sampling at the eleven sites

In 1973, the plant survey in all the field experiments was done within the whole treatment plot except for the field experiments at Andersby and Österplana where five 1-m^2 subplots placed in each treatment plot was surveyed. All species in the field layer were recorded using two different methods: the Hult- Sernander-du Rietz scale for the sites where plants were surveyed in 1-m^2 subplots and percentage cover for sites where the entire treatment plots were surveyed. In the present analyses, cover estimates were not used; only presence or absence of species in the subplots was used. Full details of vegetation assessment are found in reports by Steen (1976), Fogelfors (1982) and Hansson (1991).

In 1980 and 1986, vegetation analyses in all the experimental sites except Bräcke, were carried out in five 1-m^2 permanent subplots established in each treatment plot. In Bräcke, each 5m x 20 m treatment plot was divided into two sections (5m x 10 m per subdivided plot) within which three 1-m^2 permanent subplots were placed. Vegetation sampling in the year 2000 at the experimental site in Sättra was conducted in 152 sample plots of 0.5 m x 1 m per treatment plot. Plants were identified to species level and presence of a species was recorded for each sample plot (Wahlman & Milberg, 2002).

My field work in Sättra was carried out from 4th to the 14th July, 2011. Sampling of plants was done in plots similar in size compared to the survey in 1986, and with a higher accuracy comparable with the years 1980 and 1986. The five 1-m^2 subplots per treatment plot were placed 2m apart from each other within the plot. In each subplot, plants were identified to species level and the presence of each species was recorded. The frequency of each identified species in the five subplots per treatment plot was calculated and used in the analyses. This allowed comparison with data collected from the other experimental sites using the same or similar sampling procedures.

Table 1. General description and inventory years of the experimental sites established in Southern Sweden to compare different management methods of semi- natural grasslands vegetation.

	Site	Year of Inventory						Vegetation type	Soil category
		1973	1975	1980	1986	2000	2011		
1.	Andersby, Dannemora	x		x	x			moist meadow	humus rich light clay
2.	Bråbo, Oskarsham	x		x	x			mesic meadow	rock moraine
3.	Bräcke, Åmål	x		x	x			mesic meadow	silt
4.	Damkärr, Gamleby	x			x			mesic meadow	humus rich silt
5.	a. Ekenäs fuk, Flen				x			moist meadow	highly humus rich light clay
	b. Ekenäs Hag, Flen		x	x	x			dry-mesic meadow	humus rich loamy
6.	Gränö, Värmdö	x			x			moist meadow	slightly humus rich silt
7.	Sättra, Ödeshög	x		x	x	x	x	mesic meadow	slightly clayey sand
8.	a. Tagel Hag, Alvesta	x		x	x			mesic meadow	rocky sand
	b. Tagel tor, Alvesta				x			mesic meadow	-
9.	Österplana, Götene	x		x	x			dry meadow	gravelly clay loam

3.3.1 Classification of plants

Species recorded in these trials were classified as grassland indicators of (i) good management, (ii) excess nitrogen, and (iii) lack of management according to Bertilsson and Paltto (2003). Two other classifications of grassland plants of good management used were based on Larsson and Ekstam (1987) and Ekstam and Forshed (1992). For the latter, which is a complex system, the plant species of good management were those that belong to the succession categories A and B and that grow on sites poor in nitrogen (N1).

3.4 Statistical analysis

For each system of species classification, the total frequencies of indicator and non-indicator species recorded per subplot per treatment plot were calculated and the odds for a record in a treatment plot being an indicator species or non-indicator was calculated as

$$\text{Odds} = p / (1-p) \qquad (1)$$

p = probability for an occurrence belonging to an indicator species and

(1-p) = probability for an occurrence belonging to a non-indicator species.

To compare the treatment of burning with the management methods of mowing or grazing, random effects meta-analysis was performed using Comprehensive Meta-analysis version 2 (Biostat, Inc. 2006). Since the vascular plants data were gathered using different methods, analyzing proportions (odds ratio) provided a way to overcome these differences in data.

Effect sizes were measured as log OR (odds ratio)

$$\text{Log OR} = \log [(A * D) / (B * C)] \qquad (2)$$

where

A= frequency of indicators in burning treatment

B= frequency of non- indicators in burning treatment

C= frequency of indicators in mowing or grazing treatment

D= frequency of non- indicators in mowing or grazing treatment

All log OR were calculated per block and then entered into the meta-analysis.

Two separate analyses were conducted: 1) with the whole data set of all the eleven experimental sites and 2) with the data set of the Sättra field trial which was the only field experiment still running as at 2011.

4 Results

In total, 337 species of plants were recorded in the data of all the eleven sites considered in the present study. Grasslands indicators of good management classified by Ekstam & Forshed (1992), Bertilsson & Paltto (2003) and Larsson & Ekstam (1987) made up 18 %, 16.9 % and 15.7 % of the species respectively. Indicators of excess nitrogen accounted for 7.7 % and indicators of lack of management 2.0 % of the species.

The full lists of plant species recorded in the treatment plots in 1986 at all the eleven sites and at the Sättra field trial, are given in Appendices 1and 2, respectively. The 1986 inventory constitutes a complete set of data, collected in a uniform way, of all the eleven experimental sites; at a point in time when a possible treatment effects would be evident.

4.1 Management outcomes at the eleven experimental sites

The proportion of indicators of good management decreased over time in the burnt plots compared to mowed and grazed plots, the difference being apparent after seven and thirteen years (Figure 2a, b). This trend was most pronounced when contrasting burning or mowing, but less so when contrasting burning or grazing (Figure 2 a-c).

The indicators of lack of management were more common in burned compared to grazed and mowed plots (Figure 2e) but the proportion of indicators of excess nitrogen did not differ between the treatments (Figure 2d).

4.2 Management outcome at Sättra field trial

In contrast to the joint results of eleven trials, data from a single trial during a longer time period (39years) exhibited less clear and partly inconsistent results. Similarly to the joint results, the proportion of indicators of good management was higher in the mowed plots than in the burned plots. The proportion of one of the three indicators for good management (Ekstam & Forshed) decreased due to burning similarly to the decrease found in the joint results (Figure 3a), while the two other indicators for good management showed less clear trends, (Figure 3c, e).

It is important to note that the data for one of the blocks, for years 1986, 2000 and 2011 had been excluded from the analysis because the management had failed: burning could not be efficiently done due to the invasion of *Rubus idaeus* and *Aegopodium podagraria*. These two

dominant species outcompete grasses and result in a spring situation with no or very little combustible litter. Also, the second block of the grazing treatment had over time, become completely overgrown with trees and shrubs, effectively meaning that grazing had ceased because of grazers' preference.

There was a tendency for a higher proportion of negative indicator species (indicators of excess nitrogen and lack of management) in the burned plots compared to the mowed or grazed ones (Figure 3g-j). There was also an increase in the proportion of nitrogen indicators on the burned plots from 1973 to 2000 (Figure 3h).

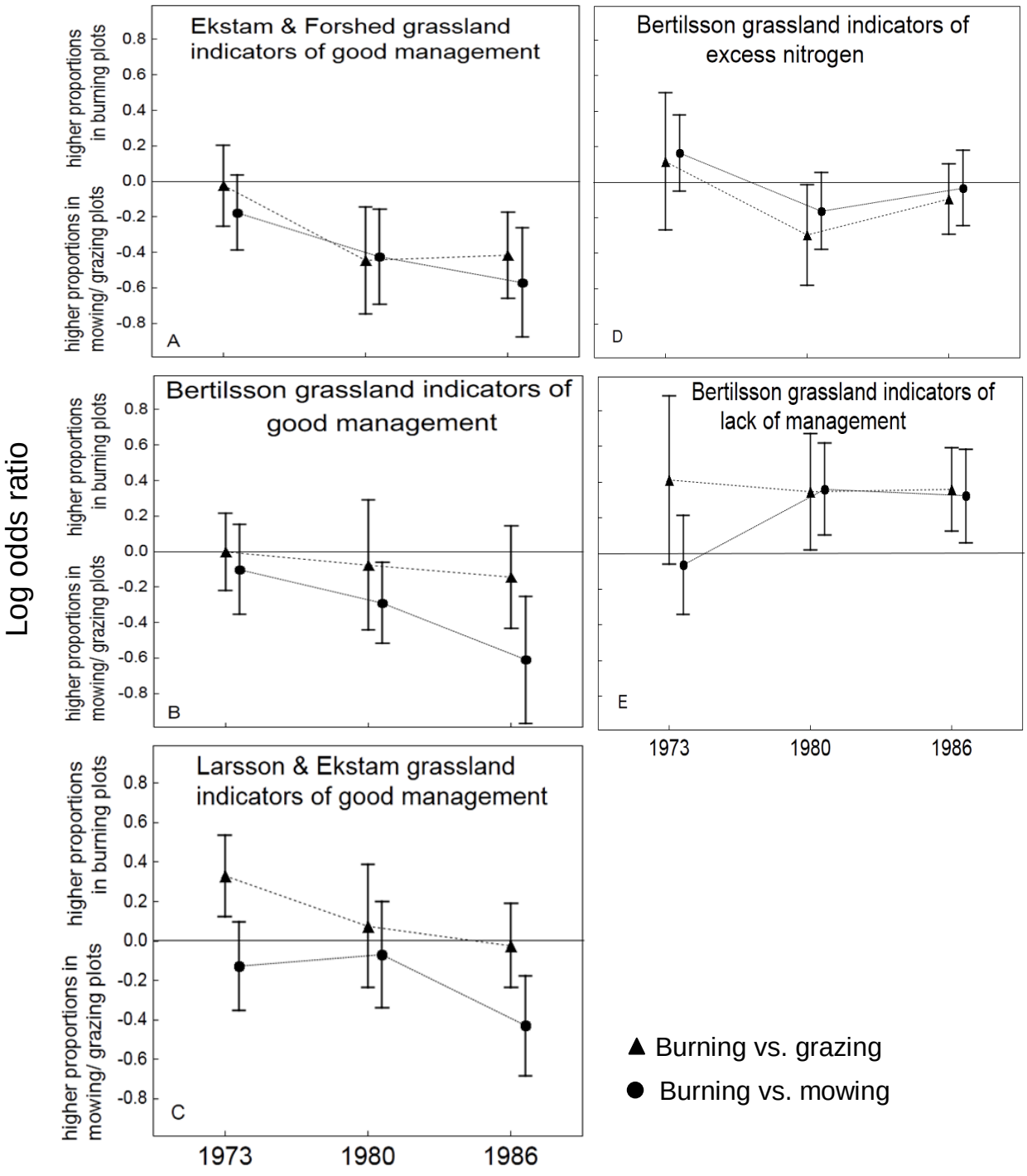

Figure 2. Log odds ratio plots comparing management treatments of burning vs. mowing and burning vs. grazing over time (years) of 11 field trials, each with two independent blocks, in southern Sweden inventoried in 1973, 1980 and 1986. The plots are based on five different indicator system classifications of species. Error bars represent 95% confidence intervals.

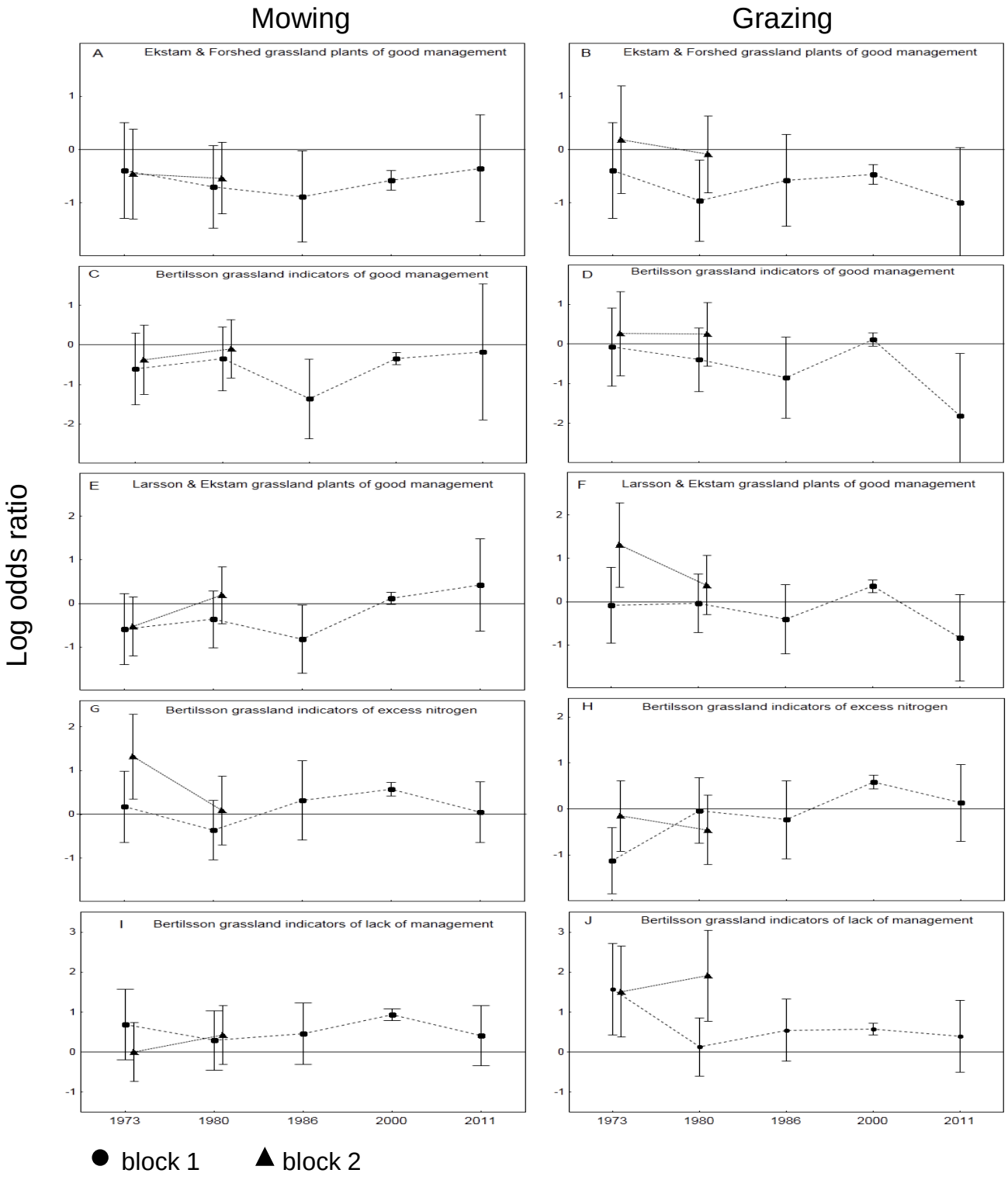

Figure 3. Log odds ratio (95% confidence interval) comparing treatment blocks related to management treatment of burning, mowing and grazing in Sättra over time (years) based on five different indicator systems. Panels A, C, E, G and I compare burning with mowing (positive and negative ratios show that the indicator is favoured by burning and mowing, respectively). Panels B, D, F, H and J compare burning with grazing (positive and negative ratios show that the indicator is favoured by burning and grazing, respectively). Closed triangle and circle represent two replicate blocks of the treatment plot.

5 Discussion

The study revealed that burning, at most sites would not be an efficient long-term management method to maintain vegetation diversity in semi-natural grasslands. Our results showed a general negative effect of burning of species that are indicators of good management and a positive effect on grassland plants indicating lack of management.

The mowing and grazing treatments plots generally had higher proportions of grassland plants indicating good management than burned plots when management treatments at the eleven sites were compared. Separate analyses of part of the same data from this series of field trials in studies conducted by Hanson & Fogelfors (2000) and Wahlman & Milberg (2002) reached similar conclusions that more species occurred in mown and grazed plots than burnt ones.

My results from the single trial in Sättra comparing mowing and burning partly confirmed this negative effect of burning on grassland plants. That there were fewer species in the indicator species list from Larsson & Ekstam (1987) used in the analysis could be the reason I found an increase in the proportion of grasslands good management plants in first block of the burned plots from 1986 to 2011. In general, the differences in treatment effect were more pronounced in the results based on the indicator species classification by Ekstam & Forshed (1992), the indicator species list containing most species.

When compared, the treatments of grazing and burning at the single trial in Sättra revealed less clear results, even though the evaluation is based on a higher number of years, (which in turn is expected to account for inter-annual differences better, and to an expected increased treatment effect over time). The reason for this could be that stocking density has been too low throughout the period, allowing some trees and shrubs to grow on the grazing plots. Grazing restricts the growth and establishment of woody species and favours diversity in species composition (Kahmen et al 2002, Hanson & Fogelfors 2000). During the field work at Sättra in 2011, I observed that while one of the grazing treatment plots was completely covered by large trees and shrubs, the vegetation on the other plot were shaded by an oak tree that had grown on the plot. Hence, data from the grazing treatment should be interpreted with this in mind.

Several studies have established that losses of nitrogen through successive annual burning lower the soil nutrient level (Blair 1997, Turner et al. 1997). According to Hansson & Fogelfors (2000), the low nutrient status of grasslands is one of the main factors accountable for the high species diversity features of these habitats. Contrary to expectation

that burning would remove nitrogen and result in a decrease in nitrogen indicators on the burnt plots, the joint results of the eleven trials did not reveal any clear trends for nitrogen indicators. In fact, the single trial at Sättra showed a notable increase in nitrogen indicators on the burnt plots from 1973 to 2000 relative to the grazed plots.

The higher proportions of excess nitrogen indicators in the annually burnt plots may be an indication that these species respond to the growth stimulating effect of burning such as enhanced light availability and increases soil temperature, rather than the effects of the fire-induced changes to the soil nutrient status. Although nitrogen is lost to the atmosphere during burning in semi-natural grasslands, spring burning might be an insignificant means of releasing nitrogen to the atmosphere because the loss of nitrogen depends on the amount of grass litter available for combustion (Hobbs et al. 1991). Due to the low levels of aboveground biomass and low amount of nitrogen in the grass litter burned in spring compared with green biomass, the amount of nitrogen freed during spring burning may be equal or even lower compared to those from atmospheric deposition (Boerner 1982). Furthermore, the observed increase in excess nitrogen indicators after 1980 was probably due to random variation among the individual species between the years that did not depend on burning. On the other hand, the increase might also be a response to increased nitrogen deposition which peaked after 1980. Many authors have suggested that there is a general increase in atmospheric nitrogen deposition in Sweden (e.g. Falkengren-Grerup et al. 1998, Malmer & Wallen 2005) with the open field deposition of nitrogen in the south of Sweden estimated to be 10 -15 kg N ha^{-1} yr^{-1} (Lövblad et al. 1995).

For spring burning to be recommendable as an alternative to the management methods of mowing and grazing, I expected the indicators of good management to stay the same or increase and indicators of excess nitrogen and lack of management to stay the same or decrease in the burnt plots. My findings suggest that burning as a management method was worse and therefore, cannot be a long-term option to mowing and grazing. This was not unexpected because a previous study at Sättra revealed that burning produced a community structure which was very different from one created by mowing and grazing (Wahlman and Milberg 2002). This is also in agreement with other studies which have established that burning was not suitable for maintaining plant diversity in grassland communities (Antonsen & Olsson 2005, Moog et al. 2002). Nevertheless, burning might be valuable for eliminating accumulated litter (Hansson & Fogelfors 2000) and to prevent extensive spreading of shrubs (Moog et al. 2002).

To conclude, the evidence from the present study suggests that spring burning is not a viable long-term alternative to mowing or grazing in the management of semi-natural grasslands. However, it might still be a useful tool to apply for a single year, for example, when conventional management has failed in the previous year.

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Appendix 1. *Frequency(%) of plant species recorded in subplots (1-m^2) per treatment in the 11 field experiments in 1986.There was a total of 107, 123 and 123 subplots for the mowing, burning and grazing treatments respectively. The species were classified according to five indicator systems of grassland plants.*

Plant species	Indicator system classification of grassland plants					Mowing	Burning	Grazing
	Bertilsson & Paltto			Larsson & Ekstam: Good manage-ment	Ekstam & Forshed: Good manage-ment			
	Good manage-ment	Lack of manage-ment	Excess nitrogen					
Agrostis capillaris						64	45	69
Rumex acetosa			x			62	36	43
Achillea millefolium						51	41	59
Anthoxanthum odoratum	x			x	x	50	5	26
Veronica chamaedrys		x				45	14	54
Plantago lanceolata						44	8	29
Ranunculus acris			x			41	14	44
Dactylis glomerata			x			39	33	34
Festuca rubra						37	23	37
Vicia cracca						36	44	27
Poa pratensis			x			35	20	41
Taraxacum vulgaria			x		x	34	24	41
Festuca ovina					x	34	12	30
Anthriscus sylvestris			x			34	28	28
Potentilla erecta						33	21	29
Phleum pratense			x		x	33	12	23
Trifolium medium		x		x		32	28	28
Lathyrus pratensis						29	21	28
Festuca pratensis			x			27	15	30
Hypericum maculatum		x				26	28	30
Lathyrus linifolius	x			x	x	26	14	17
Stellaria graminea						25	5	39
Deschampsia caespitosa			x			25	11	28
Galium verum						25	32	24
Galium boreale		x				23	25	16
Briza media	x			x	x	23	6	11
Trifolium pratense					x	21	4	30
Galium album			x			21	14	13
Alchemilla sp.						21	8	23

Geum rivale							21	16	19
Primula veris	x				x		21	11	12
Leucanthemum vulgare	x				x		21	3	8
Filipendula ulmaria		x					20	19	19
Trifolium repens			x				19	4	54
Ranunculus auricomus							19	9	20
Cerastium fontanum							19	0	11
Elymus repens							18	17	14
Galium uliginosum	x					x	17	12	17
Anemone nemorosa			x				16	5	25
Viola canina					x	x	15	9	15
Luzula multiflora					x		15	0	7
Molinia caerulea							15	13	2
Fragaria vesca							14	7	20
Arrhenatherum pratense							14	2	15
Rosa sp.							14	10	11
Centaurea jacea					x		14	16	8
Carex pallescens							13	15	23
Poa trivialis							13	7	11
Carex panicea	x					x	13	2	6
Filipendula vulgaris	x				x		12	9	7
Nardus stricta	x				x	x	12	7	6
Poa compressa							12	5	6
Pimpinella saxifraga	x				x	x	11	7	18
Geranium sylvaticum							11	11	13
Cirsium palustre							11	2	8
Vaccinium vitis-idaea							11	0	0
Poa angustifolia							10	12	9
Prunella vulgaris							9	1	13
Potentilla reptans							9	9	8
Inula salicina					x		9	8	7
Ranunculus repens							8	4	13
Fraxinus excelsior							8	0	11
Deschampsia flexuosa							8	2	8
Vaccinium myrtillus							8	0	7
Linum catharticus	x				x	x	8	2	5
Campanula persicifolia	x				x		8	0	4
Alopecurus pratensis			x				8	2	0

Hypericum perforatum					x	7	6	8
Geranium sanguineum				x		7	7	6
Scorzonera humilis	x			x	x	7	2	5
Carex montana					x	7	3	3
Arabis hirsuta	x				x	7	2	1
Campanula rotundifolia	x			x	x	7	2	15
Hieracium pilosella					x	7	2	12
Carum carvi			x			7	2	8
Equisetum arvense						7	6	8
Geum urbanum						7	0	3
Luzula campestris	x				x	7	3	2
Rhinanthus minor	x			x	x	7	0	2
Luzula pilosa						7	1	0
Agrostis canina					x	6	5	7
Cynosurus cristatus						6	2	6
Alchemilla vulgaris						6	2	4
Cirsium arvense			x			6	13	3
Lysimachia vulgaris						6	2	2
Anthyllis vulneraria					x	6	0	2
Melampyrum pratense						5	1	6
Rumex longifolius			x			5	1	6
Agrostis sp.						5	5	5
Carex flacca	x				x	5	2	4
Ajuga pyramidalis	x			x	x	5	0	3
Equisetum sylvaticum						5	5	3
Melampyrum cristatum				x	x	5	0	2
Galium palustre						5	0	2
Hieracium vulgatifor						5	2	1
Polygala vulgaris	x			x	x	5	1	1
Succisa pratensis	x			x		5	2	0
Thalictrum flavum						5	7	0
Agrostis stolonifera						4	2	8
Carex leporina				x		4	1	8
Rosa canina						4	8	5
Polygonum amphibium						4	5	2
Rubus saxatilis						4	3	2
Medicago lupulina						4	2	2
Valeriana officinalis						4	7	2

Melampyrum sylvaticum						4	0	0
Poa palustris						4	1	0
Viola hirta				x		4	2	0
Carex nigra						3	5	5
Knautia arvensis						3	4	5
Populus tremula						3	6	5
Agrostis gigantea						3	2	4
Pteridium aquilinum		x				3	7	3
Barbarea vulgaris						3	2	1
Helianthemum numml.				x	x	3	0	1
Potentilla argentea						3	0	1
Corylus avellana						3	0	0
Hieracium silvaticifolia						3	1	0
Maiathemum bifolium						3	0	0
Plathanthera bifolia	x			x	x	3	2	0
Vaccinium uliginosum						3	1	0
Veronica officinalis					x	2	1	14
Carex sp.						2	4	7
Quercus robur						2	2	7
Alchemilla glauscencens					x	2	0	4
Glecoma hederacea						2	0	3
Juncus conglomeratus						2	2	3
Arrhenatherum pubescens						2	2	2
Danthonia decumbens	x			x	x	2	0	2
Rumex crispus			x			2	0	2
Betula pubescens						2	2	1
Myosotis arvensis						2	2	1
Viola riviniana						2	0	1
Carex caryophyllea	x				x	2	0	0
Hieracium sp.						2	1	0
Leontodon hispidus	x			x	x	2	0	0
Potentilla thuring						2	0	0
Rubus idaeus			x			2	0	0
Salix repens	x					2	2	0
Silene nutans	x				x	2	0	0
Vicia sepium						1	1	7
Lotus corniculatus						1	2	5

Carex disticha	x						1	5	4
Convallaria majalis		x					1	3	4
Achillea ptarmica							1	0	2
Calamagrostis canescens							1	6	2
Cardamine pratensis	x						1	0	2
Trollius europeaus	x			x			1	0	2
Urtica dioica			x				1	7	2
Viola sp.							1	0	2
Acer platanoides							1	0	1
Campanula patula				x			1	0	1
Carex muricata					x		1	0	1
Gnaphalium sylvaticum							1	0	1
Hieracium umbellatum							1	0	1
Myosotis laxa/caespitosa							1	0	1
Pinus sylvestris							1	0	1
Plantago media				x			1	2	1
Trifolium hybridum							1	5	1
Carex pilulifera					x		1	0	0
Centaurea scabiosa							1	0	0
Crepis praemorsa	x			x	x		1	0	0
Dianthus deltoides	x			x	x		1	0	0
Fragaria viridis	x			x	x		1	0	0
Hieracium tridentata							1	0	0
Heracleum sphondylium							1	0	0
Salix aurita							1	0	0
Thalictrum simplex	x			x	x		1	0	0
Tilia cordata							1	0	0
Vaccinium oxycoccus							1	1	0
Viola palustris							0	6	13
Leontodon autumnalis							0	0	9
Carex hirta							0	2	7
Galeopsis spp							0	6	7
Potentilla anserina							0	1	7
Veronica serpyllifolia							0	1	7
Carex echinata							0	0	6
Gnaphalium uliginosum							0	0	6
Polygonum lapathifolium							0	0	5
Polygonum hydropiper							0	0	4

Aegopodium podagraria			x			0	0	3
Hieracium auricula				x		0	1	3
Betula pendula						0	4	2
Melica nutans						0	0	2
Plantago major						0	2	2
Ranunculus bulbosus	x			x		0	0	2
Rubus fruticosus						0	0	2
Stellaria media						0	1	2
Carex spicata	x					0	0	2
Mentha arvensis						0	0	2
Phalaris arundinacea						0	0	2
Polygonum viviparum				x	x	0	0	2
Ranunculus polyanthemos	x			x	x	0	0	2
Satureja acinos					x	0	0	2
Scrophularia nodosa						0	0	2
Sedum acre						0	2	2
Sedum reflexum						0	0	2
Stellaria pallida						0	0	2
Agrimonia eupatoria						0	0	1
Alnus glutinosa						0	0	1
Brachypodium pinnatum						0	0	1
Calluna vulgaris	x					0	0	1
Campanula rapunculoides						0	0	1
Campanula trachelium				x		0	0	1
Carex acuta						0	1	1
Epilobium angustifolia						0	2	1
Geum sp.						0	0	1
Glyceria maxima						0	0	1
Juncus bufonius						0	0	1
Juncus effusus						0	0	1
Juniperus communis						0	0	1
Lathyrus palustris						0	0	1
Myosotis ramosissima					x	0	0	1
Potentilla crantzii				x	x	0	0	1
Ranunculus flammula						0	0	1
Rhamnus catharticus						0	0	1
Rosa dumalis						0	0	1

Satureja vulgaris						0	0	1
Scutellaria galericulata						0	0	1
Sedum album						0	0	1
Solidago virgaurea						0	0	1
Sorbus aucuparia						0	0	1
Anthyrium filix-femina						0	1	0
Arrhenatherum elatius			x			0	11	0
Bidens tripartita						0	1	0
Calamagrostis arundinacea						0	0	0
Carex caespitosa	x					0	1	0
Chenopodium polyspermum						0	1	0
Cirsium vulgare			x			0	1	0
Galeopsis bifida						0	1	0
Galeopsis speciosa						0	1	0
Iris pseudacorus						0	1	0
Linaria vulgaris						0	1	0
Lychnis viscaria	x				x	0	1	0
Lythrum salicaria						0	2	0
Milium effusum						0	0	0
Myosotis scorpioides						0	1	0
Myosotis sp.						0	1	0
Phleum bertolini					x	0	0	0
Picea abies						0	0	0
Potentilla palustris						0	2	0
Prunus spinosa						0	1	0
Salix caprea						0	0	0
Salix sp.						0	1	0
Sedum tel.ssp. maxim						0	1	0
Stachys palustris						0	6	0
Tragopogon pratensis						0	1	0
Veronica spicata				x	x	0	1	0

Appendix 2. *Frequency of plant species recorded in five subplots per treatment plot at Sättra in1986. Species were classified according to five indicator systems of grassland plants.*

Plant species	Indicator system classification of grassland plants							
	Bertilsson & Paltto			Larsson& Ekstam: Good manage-ment	Ekstam & Forshed: Good manage-ment	Mowing	Burning	Grazing
	Good manage-ment	Lack of manage-ment	Excess nitrogen					
Trifolium medium		x		x		5	5	5
Agrostis sp.						5	4	5
Galium boreale		x				5	4	5
Rumex acetosa			x			3	1	5
Veronica chamaedrys		x				5	0	5
Geranium sylvaticum						5	5	4
Hypericum maculatum		x				5	5	4
Lathyrus pratensis						2	3	4
Scorzonera humilis	x			x	x	4	2	4
Vicia cracca						4	2	4
Potentilla erecta						3	2	4
Alchemilla sp.						4	1	4
Anthoxanthum odoratum	x			x	x	5	0	4
Festuca ovina					x	4	0	4
Lathyrus linifolius	x			x	x	1	0	4
Aegopodium podagraria			x			0	0	4
Poa pratensis			x			0	0	4
Vicia sepium						0	1	3
Achillea millefolium						5	0	3
Campanula persicifolia	x			x		5	0	3
Campanula rotundifolia	x			x	x	2	0	3
Ranunculus auricomus						0	0	3
Veronica officinalis					x	0	1	2
Plantago lanceolata						5	0	2
Taraxacum vulgaria			x		x	4	0	2
Ranunculus acris			x			2	0	2
Trollius europeaus	x			x		1	0	2
Anemone nemorosa			x			0	0	2
Deschampsia caespitosa			x			0	0	2
Polygonum viviparum				x	x	0	0	2

Stellaria graminea					0	0	2
Dactylis glomerata		x			4	5	1
Knautia arvensis					1	3	1
Primula veris	x		x		1	2	1
Galium verum					0	2	1
Arrhenatherum pratense					0	1	1
Betula pendula					0	1	1
Phleum pratense		x		x	0	1	1
Campanula rapunculoides					0	0	1
Deschampsia flexuosa					0	0	1
Festuca rubra					0	0	1
Hieracium vulgatifor					0	0	1
Lotus corniculatus					0	0	1
Melampyrum pratense					0	0	1
Ranunculus polyanthemos	x		x	x	0	0	1
Carex montana				x	4	3	0
Anthriscus sylvestris		x			1	2	0
Briza media	x		x	x	3	1	0
Leucanthemum vulgare	x		x		5	0	0
Melampyrum sylvaticum					4	0	0
Ajuga pyramidalis	x		x	x	2	0	0
Hieracium silvaticifolia					2	0	0
Rhinanthus minor	x		x	x	2	0	0
Cerastium fontanum					1	0	0
Helianthemum numml.			x	x	1	0	0
Hieracium umbellatum					1	0	0
Pimpinella saxifraga	x		x	x	1	0	0