Norges miljø- og
biovitenskapelige
universitet

Master's Thesis 2016 30 ECTS
Department of Ecology and Natural Resource Management

Power Line Clearings: Suitable Habitat for Semi-natural Grassland Species?

Stine Wiger Elvigen
Master in Management of Natural Resources

Acknowledgements

I wish to thank…

… Statnett for founding this thesis

… My main supervisor: Katrine Eldegard for all the help with the statistics, for useful comments on my manuscripts and for correcting my English.

… My co-supervisor: Marit Helene Lie for insightful comments on my manuscripts, for helpful discussions and for always having time for me.

Ås, May 2016

Stine Wiger Elvigen

Abstract

Owing to land-use changes, abandoning and intensification of agriculture, semi-natural grasslands are becoming increasingly scarce all over Europe. As a consequence many of the species associated with these habitats have become rare or threatened.

Power line clearings are in general viewed as a negative disturbance in forest landscapes. On the other hand, it has been suggested that power line clearings, road verges, and similar human-made landscape elements can act as replacement habitat for semi-natural grassland species.

We carried out a large-scale field experiment in power line clearings intersecting boreal forests. All the clearings had a history of management where all woody vegetation was cut every 5-10 years and all biomass was left to decay on site. We selected 19 sites in the main power line grid in southeast Norway. Three different treatments were applied on each site: 1) Cut: All woody vegetation was cut and the cut biomass removed 2) Cut + Remove: all woody vegetation was cut and left to decay on site 3) Uncut: uncut control.

We investigated the total species richness of vascular plants in the field layer and richness of semi-natural grassland species (this group also contains species from open forest) in the different treatments. We also investigated which factors affected total species richness and richness of semi-natural grasslands species in the power line clearings.

Treatments Cut and Cut + Remove had significantly higher species richness than Uncut. Increasing landscape fragmentation within a 1 km radius from the treatment plots had a significant positive effect on both total species richness and richness of semi-natural grassland species.

There was no difference among treatments the first year after the vegetation was cut for either total species richness, or richness of semi-natural grassland species. In the second and third year after cutting, however there was a significantly higher species richness in

the treatments Cut and Cut + Remove when compared to treatment Uncut for both total species richness and semi-natural grassland species.

We could not conclude that power line clearings can be a replacement habitat for semi-natural grassland species based on the species found in the clearings. However power line clearings can possibly act as a supplementary habitat and thereby mitigate loss of semi-natural grassland species.

In cases where the power line clearings intersect species poor, dense forest managed for timber production they will probably contribute to increased species richness on a local scale and possibly mimic open forest.

Contents

Introduction

Over the last 100-150 years we have seen a drastic reduction of semi-natural grasslands all over Europe. Land use changes, abandoning and intensification of agriculture is making hay meadows, unfertilized pastures and other types of semi-natural grasslands increasingly scarce (Moen 1998; Norderhaug et al. 1999; Stoate et al. 2001). The decrease in semi-natural grasslands is critical for species that depend on traditional management. Traditional management of semi-natural grasslands includes grazing and/or mowing of all vegetation and no fertilization. Mowing is normally done once per year in late summer or early autumn. Fertilization would alter the interspecific competition and lead to the exclusion of semi-natural grassland species that are typically weak competitors (Norderhaug & Isdal 1999). About 24 % (565 species) of the species on the Norwegian Red List for Species from 2010 has a substantial amount (>20%) of their populations in semi-natural grasslands, about 22% (124 species) of these are vascular plants (Henriksen & Hilmo 2015a; Henriksen & Hilmo 2015b).

Other managed habitats have been suggested as a replacement for the traditional semi-natural grasslands. A common feature of these potential alternative habitats – in addition to the fact that they are areas used by humans – is that the vegetation is cut more or less regularly for different purposes. Among these habitats are road verges (Auestad et al. 2011; Cousins 2006; Jantunen et al. 2006; Koyanagi et al. 2012; Tikka et al. 2000), ski slopes (Burt & Rice 2009) and power line clearings (Lampinen et al. 2015). Power line clearings that run through forest could possibly also act as a replacement habitat for species that belong in open forest or clearings in the forest.

Road verges have shown promise as replacement habitat for semi-natural grassland species, but there are several problems that make them less suitable. Roads are often salted in winter to prevent ice, and this can make the verges less suitable for most plants. Nutrient runoff from the road can make the verges more productive and alter the interspecific competition, which will make the verges less suitable for semi-natural grassland species (Framstad et al. 1998; Fremstad 1997; Norderhaug & Isdal 1999) Another problem is the disturbance of the soil when the road is established and that road verges is often sown for erosion control and often with alien or invasive species (Forman 2003; Hansen & Clevenger 2005). Although it does seem like road verges to some extent can act as reservoirs or refuges for grassland species, they are not entirely suitable as a replacement habitat (Auestad et al. 2011; Cousins 2006; Koyanagi et al. 2012).

Many of the problems associated with road verges are not a problem in power line clearings. There is no nutrient or salt runoff, and less disturbance of the topsoil.
As compared to road verges there have been done relatively few studies on the vegetation in power line clearings, and even fewer studies on the topic of power line clearings as replacement habitats for semi-natural grassland species. Cameron et al. (1997) reported that power line clearings consisted mainly of meadow species. Several studies have reported that the vegetation in power line clearings have been made up of a mixture of species from adjacent woodland, clearings and grasslands (Bramble & Byrnes 1983; Clarke & White 2008). Most studies concludes that power line clearings are more species rich than the adjacent forest (Eldegard et al. 2015; Hessing et al. 1982; Rubino et al. 2002; Wagner et al. 2014). But it is a concern that both road verges and power line clearings can act as a dispersal corridor for invasive species (Dube et al. 2011; Hansen & Clevenger 2005).

We wanted to look in to the potential for using power line clearings as a replacement habitat for semi-natural grassland species, and at the same time investigate the species richness of power line clearings. We have conducted an experiment with three different types of management: 1) one control where the vegetation is not cut, 2) one treatment where the woody vegetation is cut and left on site, and 3) one treatment where the woody vegetation is cut and removed from site. The woody vegetation in the last treatment was removed in an attempt to make the habitat more suitable for semi-natural grassland species. This by making the habitat less nutrient rich through removal of nutrients (decaying woody debris) and reducing shadowing of the ground (caused by woody debris). We also wanted to investigate what other habitat characteristics that influenced total species richness and richness of semi-natural grassland species in power line clearings. Our aim was to generate knowledge, which can aid improvement of the management of power line clearings to make them more suitable for semi-natural grassland species, and help identification of areas that are suitable for semi-natural grassland species.

Materials and methods

Study area

The experiment was established late autumn 2012 and early spring 2013. All the study sites were located in southeast Norway, in the main power line grid (Figure 1). The sites were situated between latitudes 59.33°–61.12°N and longitudes 08.95–11.36°E and between 45 and 535 meters above sea level. All sites were in the boreal forest and situated in areas managed for timber production. The dominating tree species were Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch (*Betula spp.*). Average monthly precipitation was between 45mm and 86mm. Average temperatures range from -2,9 °C to -9,7 °C in January and from 10,8 °C to 15,5 °C in June-August.

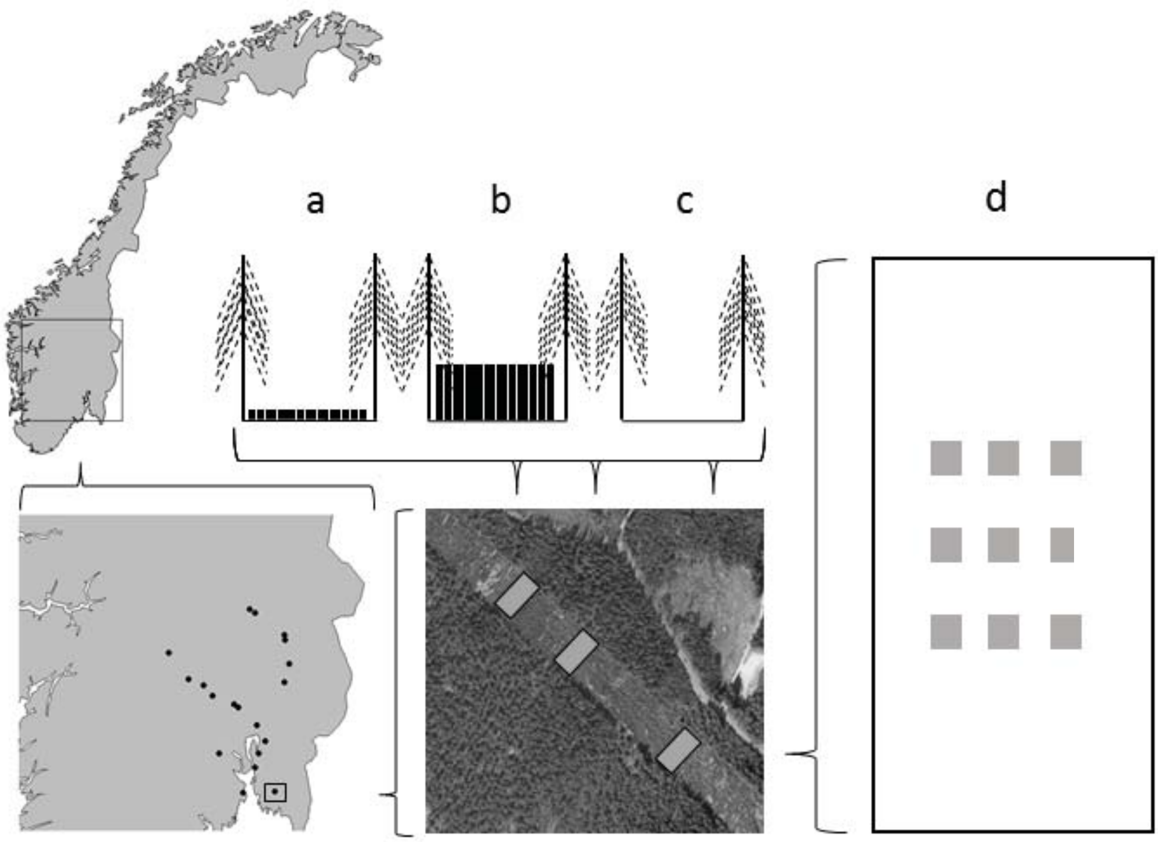

Figure 1: The location of the study sites. Illustration of the placement of the three different experimental sites in the power line clearing, and the different treatments. a) Cut: Cut according to the standard management practice and all biomass left on the ground. b) Uncut: Control, left uncut. c) Cut + Remove: Cut and biomass removed. d) Plant community data were sampled in the nine 1m² subplots (light grey colour) illustration from Sydenham et al. (2016).

Sampling design

The study sites were selected from areas that had, at the time they were selected, an area of minimum 200 metres of substantial regrowth of trees under the power lines and thus was going to be subjected to regular maintenance clearing within the next 1-2 years. In order to enable assessment of the effects of the treatments, the segment of power line clearing at each site was selected to be as homogenous as possible.

After establishment of the clearing, the study sites had all undergone the same type of management regime, i.e. maintenance clearing where all woody vegetation underneath the aerial power lines where cut manually every five to ten years, and no biomass was removed after the cutting. The clearings were established and maintained without the use of chemicals.

19 sites in power line clearings were selected, and three large rectangular plots were established for each site. The plots were 30 meters long, covered the whole with of the power line clearing (between approximately 40 and 80 metres) and were situated at least 30 meters apart. Each of the three plots were randomly assigned one of three treatments: 1) In treatment Cut all the trees were cut but no biomass removed. 2) In treatment Cut + Remove all the trees were cut and all of the biomass from the cut trees was removed. 3) Treatment Uncut was kept as an untreated control and no trees were cut or biomass removed.

In the centre of each experimental unit a grid of nine $1m^2$ subplots was established. The subplots were placed 5 meters apart and the centre plot was located in the middle of the experimental unit. All the squares were marked in the field with coloured plastic sticks and the geographic position of each subplot was determined by use of a hand-held GPS (Garmin GPSMAP® 62).

Data collection

Plant data

All species of vascular plants present in the nine $1m^2$ subplots at each site and treatment were registered. Percentage cover of each species was estimated visually and the species was determined on site. If the cover was estimated to less than one percent it was recorded as one percent. The registration of plant species was carried out in late June / early July in each of the three years: 2013, 2014 and 2015. Later the cover for each species in each subplot was summed to get an estimate for the total cover of each species in each treatment plot.

Classification

We divided the species registered in the field work in two lists, one containing all the plants and one containing only species that are favoured by management. The second list of species, which we refer to as semi-natural grassland species, contained species that are dependent of cutting or grazing to keep the habitat open. Some of these species are normally found in forest in addition to semi-natural grasslands. We did not exclude these species that are also found in forest as long as they were just moderately common in forests (Appendix 1). The selection of species for the semi-natural grassland species list was made according to Halvorsen et al. (2015) and Lid og Lid (2005).

Habitat characteristics

Productivity

Potential vegetation type was registered at the establishment of the project. Potential vegetation type is the type of vegetation that would have been at the site if it was not managed. It was later used to determine site productivity. This was done by calculating average productivity for the vegetation types using data from the national forest inventory and literature on relationships between vegetation types and productivity (Larsson & Søgnen 2003).

Elevation and temperature

Elevation for each site was obtained from Norgeskart.no (Kartverket). Data on precipitation, January temperatures and growth season temperatures were obtained from the Norwegian Meteorological Institute (Norwegian Meteorological Institute).

Canopy cover

In order to determine canopy cover in the different sites and treatment plots, photos were taken with a fisheye lens. The pictures were taken in the approximate centre of each treatment plot at each site (fixed point just outside the centre 1-m^2 plant community sub-plot), in July in 2013 and in mid to late June 2014 and 2015. The software Hemisfer (Schleppi et al. 2007; Thimonier et al. 2010) was used to analyse the pictures and determine the amount of sunlight available in the growth season (Mai - September) in each site and treatment plot. The software distinguishes between pixels of sky and canopy and uses this together with coordinates, slope gradient and slope direction to calculate available sunlight (*Hemisfer features* 2014).

Landscape fragmentation

Ar5 maps (Ahlstrøm et al. 2014; Skog og landskap) and the software ArcMap (ESRI 2011) were used to determine the level of fragmentation in the landscape around the sites. We extracted information on total number and area of all polygons, as well as area and number of polygons of the land use types: fields, meadows, roads and open non-forested areas in radiuses of 150m, 300m, 500m, 1000m and 2000m from the centre of each site (i.e. the centre of the middle treatment plot). The land use types were chosen on the background of their potential as seed sources.

Statistical analyses

We first carried out exploratory analyses, following the protocol suggested by (Zuur et al. 2010) to check for outliers, zero-inflation, correlation among explanatory variables and other common statistical problems. We found no outliers and no serious zero-inflation. Substantial correlation was discovered between site temperature and site elevation, and between different measures of landscape fragmentation. We chose to use elevation and total number of polygons within 1 km radius from the plots as these explanatory variables showed the strongest relationship with the response variables.

Thereafter, we analysed the effect of treatment and some environmental variables on our two response variables: 1) total species richness and 2) richness of semi-natural grassland species. We fitted generalized linear mixed effect models (GLMM) with log link functions and Poisson distributed errors. We used the software R (R Core Team 2015) and the package lme4 (Bates et al. 2015). For each response variable a full model was fitted. The full model included: treatment, productivity, landscape fragmentation (number of polygons within 1-km radius from each site), elevation and the treatment-specific interaction terms: treatment * year, treatment * productivity, treatment * landscape fragmentation and treatment * elevation. In order to account for among-sites variability in environmental condition, the model included light availability for the Uncut treatment in 2013 and site as random effects. After fitting the full model, we carried out model selection by backward elimination (Crawley 2013) with a significance level of 0,05.

Results

During the three years after the experiment was initiated a total of 248 plant species were registered. Among these were 131 herbaceous plants and 59 graminoids (Table 1). Of the 248 species, were 84 associated with semi-natural grasslands or open forest affected by grazing (Halvorsen et al. 2015). Of these 84 were 27 species that are normally not found in unmanaged habitats (Appendix 1).

Table 1: The total number of species of vascular plants registered in the power line clearings from 2013, 2014 and 2015. The group termed semi-natural grassland species also includes species associated with open forest affected by grazing. Plant species were registered each year in the same nine 1m² sub plots in tree different treatment plots in each of the 19 sites.

	Total number of vascular plant species	Semi-natural grassland species
Graminoids	59	15
Herbaceous plants	131	67
Heather	8	-
Ferns	18	-
Trees and shrubs	32	2
Total	248	84

Invasive species

Two of the registered species are considered invasive species in the category SE (severe impact) according to the Norwegian black list of alien species (Gederaas et al. 2012): *Solidago canadensis* and *Ribes rubrum*. *Ribes rubrum* was only found on one location and had a cover of less than 1% at this site. *Solidago canadensis* was only found on one site but with higher cover. The cover of *Solidago canadensis* increased from just over 1 % in 2014 to nearly 3 % in 2015. The total cover of invasive species was under 1%, for all the years of the experiment.

Total species richness

Total species richness did not differ significantly between years, but the difference among treatments increased after the first year. Total species richness was significantly higher in treatments Cut and Cut + Remove when compared to treatment Uncut after the first year of the experiment (Figure 2). Estimates for total species richness in treatment Cut + Remove was slightly higher than estimates for total species richness in treatment Cut in 2015 (Table 3), but the difference was not significant.

Landscape fragmentation within 1 km radius from each site had a significant positive effect on total species richness (Table 2). There was no significant influence of elevation, productivity or precipitation. Neither for light availability, but light availability for the Uncut treatment from the first year was included as a random effect, to control for initial differences among sites.

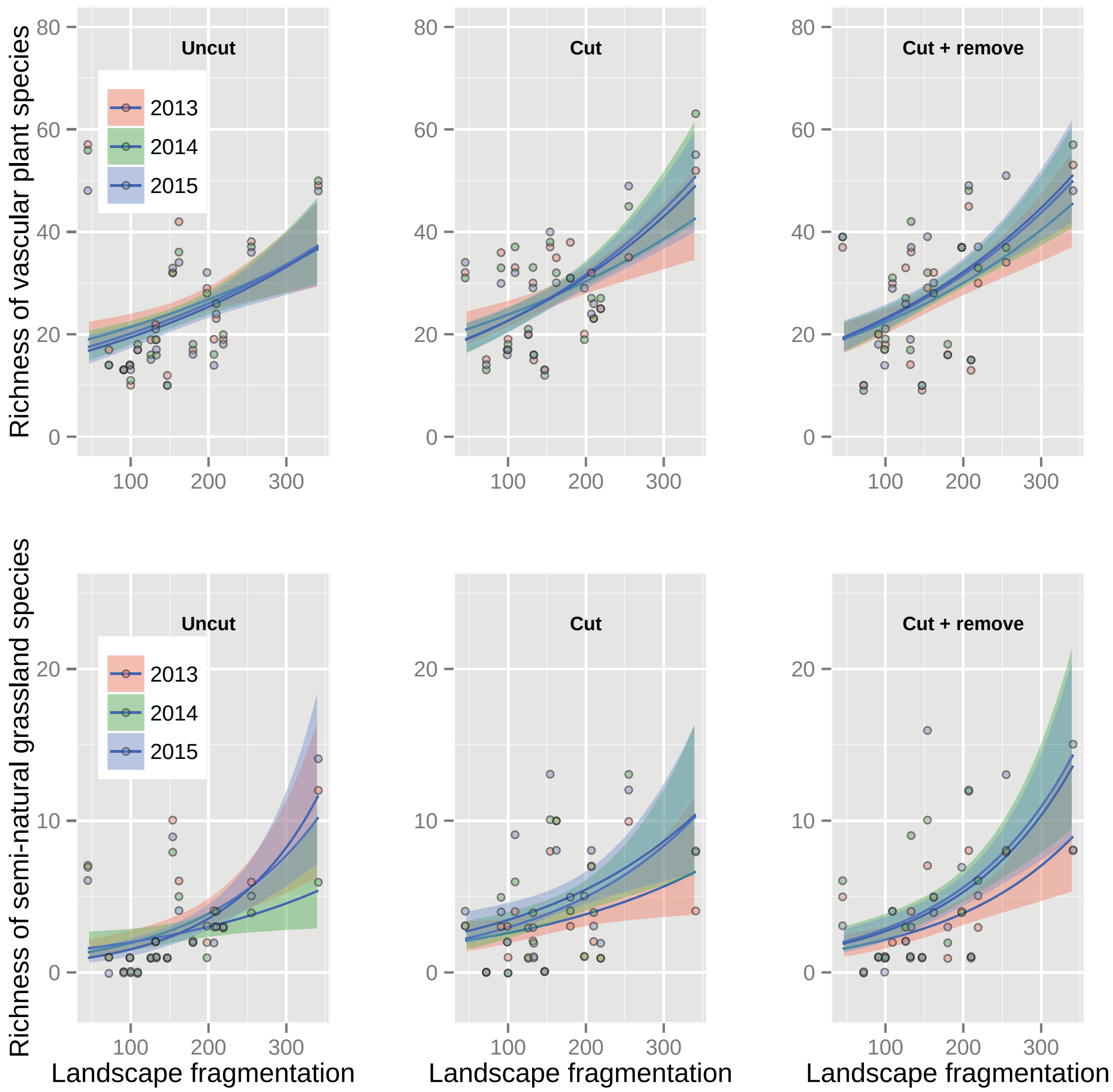

Figure 2: The effect of increasing landscape fragmentation within one km radius on species richness in the power line clearings, for each treatment, species group and year. We had tree different treatments in each of the 19 sites: Uncut: control where no vegetation is cut. Cut: all woody vegetation cut and left on site. Cut + Remove: all woody vegetation cut and removed. Registration of plant species was done in the same nine 1m² subplots each year in each site and treatment plot. Each point in the figure represents one treatment plot, note that some points is on top of each other because of overlapping values for species richness and level of fragmentation. The width of the lines are 95% confidence regions.

Richness of semi-natural grassland species

Results for semi-natural grassland species was much the same as for total species richness. There was a positive effect of treatment and landscape fragmentation within 1 km radius. Elevation, productivity and precipitation did not have a significant effect on richness of semi-natural grassland species. The same was true for light availability, but light availability in 2013, in the Uncut treatment was included as a random effect just as for total species richness.

There was no significant effect of year on richness of semi-natural grassland species. In the first year of the experiment (2013) there was no significant effect of treatment either, but treatments Cut and Cut + Remove had a significantly higher species richness compared to treatment Uncut in 2014 and 2015 (Table 3).

Table 2: Final Generalized Linear Mixed models (GLMMs) for total species richness for vascular plants and richness of semi-natural grassland species. Model selection was carried out by backwards elimination of the explanatory variables with a significance level of 0,05 The GLMMs were fitted with log link functions and Poisson distributed errors and were not over-dispersed.

	Estimate	z value	P
Total species richness			
Intercept (Treatment Uncut)	2.6	13.8	<0.0001
Treatment Cut	0.16	4.4	<0.0001
Treatment Cut + Remove	0.16	4.4	<0.0001
Landscape fragmentation within 1 km radius	0.0029	2.6	0.0084
Richness of semi-natural grassland species			
Intercept (Treatment Uncut)	-0.45	-1.0	0.32
Treatment Cut	0.33	3.3	0.0011
Treatment Cut + Remove	0.34	3.4	0.00067
Landscape fragmentation within 1 km radius	0.0076	3.0	0.0026

Table 3: Final Generalized Linear Mixed models (GLMMs) for total species richness for vascular plants and richness of semi-natural grassland species for each year separately. Model selection was carried out by backwards elimination of the explanatory variables with a significance level of 0,05 The GLMMs were fitted with log link functions and Poisson distributed errors and were not over-dispersed. Landscape fragmentation was excluded in this figure as it is not expected to vary much between years.

	Estimate	z value	P
Total species richness 2013			
Intercept (Treatment Uncut)	2.7	14.5	<0.0001
Treatment Cut	0.12	1.2	0.061
Treatment Cut + Remove	0.091	1.4	1.2
Total species richness 2014			
Intercept (Treatment Uncut)	2.6	0.20	<0.0001
Treatment Cut	0.18	2.7	0.0061
Treatment Cut + Remove	0.18	2.7	0.0061
Total species richness 2015			
Intercept (Treatment Uncut)	2.6	13.2	<0.0001
Treatment Cut	0.19	3.0	0.0028
Treatment Cut + Remove	0.22	3.4	0.00057
Richness of semi-natural grassland species 2013			
Intercept (Treatment Uncut)	-0.097	-0.22	0.83
Treatment Cut	0.032	0.18	0.86
Treatment Cut + Remove	0.016	0.089	0.93
Richness of semi-natural grassland species 2014			
Intercept (Treatment Uncut)	-0.31	-0.73	0.47
Treatment Cut	0.48	2.7	0.0075
Treatment Cut + Remove	0.59	3.3	0.0009
Richness of semi-natural grassland species 2015			
Intercept (Treatment Uncut)	-0.53	-1.1	0.26
Treatment Cut	0.46	2.7	0.0075
Treatment Cut + Remove	0.40	2.3	0.020

Discussion

Treatment effect

There was an increase in both total species richness and richness of semi-natural grassland species in the treatment Cut and Cut + Remove when compared with the Uncut control. This is the same succession pattern as in clear-cuts (Heinrichs & Schmidt 2009; Wagner et al. 2011; Widenfalk & Weslien 2009), except that the vegetation in power line clearings is always kept in early succession stages because of frequent cutting. The reason for the increased species richness is probably increased light availability and possibly reduced competition for water and recourses (Heinrichs & Schmidt 2009). The total species richness will probably continue to increase until next cutting (Widenfalk & Weslien 2009). The richness of semi natural grassland species on the other hand will probably start to decrease if competition increases and sunlight becomes limited because of shading from trees (Norderhaug & Isdal 1999).

It seemed to bee a slightly higher, but not significantly higher, species richness in the Cut + Remove treatment compared to the treatment where the woody vegetation was cut, but not removed. We have two possible explanations for this. The first is higher light availability because logging residue covers less area. This theory is in agreement with Korpela et al. (2015) who found that herbaceous flower coverage increased as a consequence of logging, but was negatively correlated with the amount of logging residue. The other theory is that the removing of logging residue has lead to less available nutrients in the Cut + Remove treatment compared to the Cut treatment. This could make the habitat more suitable for semi-natural grassland species, but this will probably be more important in the future because the logging residue in the Cut treatment has not been given much time to decompose (Koster et al. 2015; Laiho & Prescott 2004; Palviainen et al. 2008; Palviainen & Finer 2015). Cutting was conducted in late autumn after the leafs were shed, so it is likely that the nutrient availability in the Cut and the Cut + Remove treatment are still quite similar. At the other hand, most of our sites already have quite low productivity, and forest does generally have lower productivity than the cultural landscape (Fremstad 1997). It is possible that the productivity is already too low for the removing of biomass to make a statistical difference between the treatments within reasonable time.

The absence of effect of treatment the first year might be due to a random fluctuation in weather, but it is likely that the vegetation needed some time to establish. If this is the case it is possible that we will se an increase in species richness in the coming years as new species disperse inn from the surrounding landscape.

Effect of landscape fragmentation

We found a significant positive effect of landscape fragmentation within a 1 km radius from the plots on total species richness and on richness of semi-natural grassland species. Higher landscape fragmentation in our study did in general mean less cover of forest and a more diverse landscape. The results of Tikka et al. (2000) are in agreement with ours, they found a relationship between species richness in road and railway verges and surrounding environment, where the species richness was higher in non-forested areas. Hamre et al. (2010) on the other hand found that woodland was the vegetation type that had most semi-natural grassland species after semi-natural grasslands. Woodland could thereby act as a reservoir from which semi-natural grassland species could disperse. Cousins og Aggemyr (2008) too found that the surrounding landscape did influence richness of grassland species, and they found more semi-natural grassland specialists in grasslands in forested landscapes than in grasslands in open landscapes.

Even though there are differing results to what kind of landscape that leads too more semi-natural grassland species, there seem to be an agreement that the surrounding landscape influence the species richness of semi-natural grassland species. Nearby sources of semi-natural grassland species, that can act as seed sources, seem to be important both for successful restoration of semi-natural grasslands (Oster et al. 2009; Winsa et al. 2015) and for the occurrence of semi natural grassland species in other habitats.

Plant species richness

Of all the plant species we found were 34% associated with semi-natural grasslands (Halvorsen et al. 2015; Lid & Lid 2005). The cover was generally low, but the difference in species richness between treatments seemed to increase and over time the cover might potentially increase too. We found that the power line clearings were typically vegetated with a mixture of species from surrounding forest, clearings and meadows. This is in agreement with the findings from previous studies of the vegetation in power line clearings (Bramble & Byrnes 1983; Cameron et al. 1997; Clarke & White 2008).

Our definition of semi-natural grassland species is quite broad, and includes species found in forests affected by grazing, species from areas with infrequent management, semi-natural grassland species and semi-natural grassland species that can tolerate moderate amounts of fertilizer (Halvorsen et al. 2015; Halvorsen 2015). We decided to make the definition broad because many meadow species can be found in the forest, and thus, excluding all species that can be found in the forest would lead to exclusion of several meadow species.

The more management dependent species are often quite small in size and poor competitors and are therefore typically found in open areas with low vegetation (Norderhaug & Isdal 1999). These species would likely disappear quite fast if management ceases and the vegetation is no longer maintained at low height by cutting or grazing.

Our management regime is not expected to support the species, which are most strongly associated with traditional management practices: in the power line clearings, only the woody vegetation is cut – and only every five to ten years – in contrast to traditional agricultural land-use practices with mowing of all vegetation every year. Several of the species categorised as semi-natural grassland species in our study are hence species that are often found in areas where the traditional management practises have ceased or are infrequent, among these are species like *Anthriscus sylvestris, Filipendula ulmaria* and *Geum urbanum* (Ekstam & Forshed 1992). But some of the species like *Euphrasia stricta, Plantago lanceolata* and *Trifolium repens* are species that would quickly disappear if management stopped (Ekstam & Forshed 1992). We were surprised to find these strictly management dependent species, because of the management regime in the power line clearings. It is a possibility that these species was found on dry soil, where the vegetation is naturally low when trees are removed. But it is also a possibility that our management regime supports species that are more management dependent than we initially assumed.

It is possible that the cover of semi-natural grassland species (and other plant species) would have been greater if the fieldwork had been conducted later in the season. And it is possible that we would have seen an increase in species richness of both total species richness and semi-natural grassland species from 2014 to 2015 if it had not been for the lateness of the spring in 2015 (the field work was conducted around the same dates as previous years).

Some of our species are associated with open forest influenced by grazing (Appendix 1). Open forest is a habitat that many species are dependent of. Open forests are more species rich, with greater cover of herbaceous plants and are better for pollinating insects than dense forest managed for timber production (Hanula et al. 2015; Korpela et al. 2015; Økland et al. 2003). The power line clearings in our study mimic open forest to some degree and other studies from power line clearings note the same (Bramble & Byrnes 1983; Clarke & White 2008). Power line clearings that run through forests might be a suitable replacement habitat for species adapted to open forest.

Of all the plant species we found were 34% associated with semi-natural grasslands (Halvorsen et al. 2015; Lid & Lid 2005). The cover was generally low, but the difference in species richness between treatments seemed to increase and over time the cover might potentially increase too. We found that the power line clearings were typically vegetated with a mixture of species from surrounding forest, clearings and meadows. This is in agreement with the findings from previous studies of the vegetation in power line clearings (Bramble & Byrnes 1983; Cameron et al. 1997; Clarke & White 2008).

The proportion of semi-natural grassland species is similar to the results from Lampinen et al. (2015), 37% of the species they found in power line clearings were semi-natural grassland species. As in our study, the cover of semi-natural grassland species was generally low. Tikka et al. (2000) found about the same proportion of semi-natural grassland species, as we found in power line clearings, in both road verges and semi-natural grasslands, but they found that the species composition between the two habitats were different.

Several studies have examined the possibility of using road verges as a replacement or substitute habitat for semi-natural grassland species (Auestad et al. 2011; Hamre et al. 2010; Jantunen et al. 2006; Koyanagi et al. 2012; Norderhaug et al. 2000; Tikka et al. 2001). All of these have found several semi-natural grassland species in road verges. As in our power line clearings, the semi-natural grassland species found in road verges were not strict grassland species but more common species, and the species composition in the road verges were reported not to be comparable to semi-natural grasslands. Hence were road verges not suitable as replacement for semi-natural grassland for most semi-natural grassland species (Auestad et al. 2011; Jantunen et al. 2006; Koyanagi et al. 2012; Norderhaug et al. 2000; Tikka et al. 2000; Tikka et al. 2001). Even though road verges were not suitable as replacement habitat for semi-natural grasslands, all the abovementioned studies concluded that road verges are important for semi-natural grassland species.

We did not find an effect of elevation on species richness. This does not concur with the findings of Grytnes (2003) and Austrheim (2002). They found an effect of elevation on species richness where species richness increased with elevation until it peaked at mid-elevations (above forest-limit). Our gradient in elevation was ranging from 45-535 meters above sea level, but this gradient was might not large enough to show an influence on plant species richness. The two above mentioned studies reported peaks in species richness at elevations higher than our highest elevation. If we had a wider range of elevation values, this variable could possibly show an effect.

Invasive species

We found only two invasive species in the power line clearings and the total cover of invasive species was less than 1%. Other studies concur with ours to varying degrees, several have found that power line clearings have held more invasive species than adjacent forest, but still a relatively low degree of invasive species (Cameron et al. 1997;

Eldegard et al. 2015; Hessing et al. 1982; Wagner et al. 2014). Cameron et al. (1997) suggests that power line clearings are more susceptible to non-native species than forests are, but they did not find that the cover of non-native species was big enough to be of any concern.

Lampinen et al. (2015) found a somewhat greater number of invasive species, about 5 % of the species encountered in the power line clearings were invasive, but the cover varied. Their study was conducted in an urbanised area and they found a positive correlation between productivity and the amount of invasive species. Our study was carried out in forested areas surrounded by a more rural landscape, and Norwegian power lines are mostly situated in areas with low productivity (Kristian Sommerstad, Stanett, personal communication). Our results regarding to invasive species could possibly have been different if our experiment had been conducted in more urban areas.

Even though the above-mentioned studies found a generally low cover of invasive species they all found higher cover than what we found. This may be due to differences in the management practise. Norwegian power line clearings are generally managed by manual clearing, which is a relatively gentle practise that leaves the ground vegetation of the clearing mostly intact. In other countries it is more common to use herbicides and mechanical cutting (machines) for maintaining the vegetation low in the clearings (Bramble & Byrnes 1983; Cameron et al. 1997; Clarke & White 2008; Wagner et al. 2014). Machine cutting can cause damage to the ground vegetation and leave open soil, and the application of herbicides can leave gaps in the vegetation. This can make it easier for invasive species to establish.

Areas where the topsoil is disturbed in the establishment of for example a road seem to be more susceptible to invasive species than structures with lower degree of disturbance (Burt & Rice 2009). The establishment of roads does normally lead to more disturbance of the topsoil than the establishment of power lines (Forman 2003). In addition road verges and other such disturbed areas are often sown for erosion control, and often with exotic and even invasive species (Burt & Rice 2009; Hansen & Clevenger 2005). To sum up, invasive species do not appear to be a problem with the current management practices in Norway, but may potentially be a challenge if new clearings are established in other (urban) landscapes or if management practices are changed. Even so, other types of linear infrastructure, like roads, are generally more problematic with respect to occurrence and spread of invasive species.

Conclusions

Cutting of woody vegetation did lead to higher species richness and removing of biomass after cutting seem to further increase species richness. Even though richness of semi-natural grassland species did increase after cutting, we could not conclude that power line clearings were suitable as replacement habitat for semi-natural grassland species with the current management regime. This conclusion is based on the observed species composition in the power line clearings. However, power line clearings can possibly act as a supplement habitat for semi-natural grassland species and thereby contribute to mitigate the loss of semi-natural grassland species.

Power line clearings in dense forests managed for timber production can have a positive influence on species richness. The power line clearings offer a more or less suitable habitat for species adapted to open forest and clearings in the forest. In addition power line clearings increases the diversity of vegetation types and habitats and will thereby increase species diversity at a local scale (Kouba et al. 2014).

Implications for management

With proper management practices, power line clearings can potentially, act as a replacement habitat for semi-natural grassland species as shown by Svensson et al. (2015). This requires yearly mowing, or at least more frequent management than the current management regime, and not all power line clearings are equally suitable. The productivity should neither be too low nor too high and the landscape context – i.e. land use and fragmentation of the surrounding landscape – must be taken into account.

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Appendix

Appendix 1: List of all species registered in the power line clearings from 2013 to 2015. Semi-natural grassland species are marked with an x. The group termed semi-natural grassland species also includes species associated with open forest affected by grazing. Plant species were registered each year in the same nine 1m² sub plots in tree different treatment plots in each of the 19 sites.
I: Natural land, no sign of management. II: Natural land, but clear signs of grazing, forest affected by grazing. III: Semi-natural grassland, management with moderate intensity. IV: Semi-natural grasslands. V: Semi-natural grassland that show traces of fertilization, but still have substantial cover of species that have low or moderate tolerance for fertilizer. The numbers reflects how common each species are in the different habitats (Halvorsen et al. 2015; Halvorsen 2015).

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Achillea millefolium	0	2	3	4	5	3	X
Actaea spicata	3	2	0	0	0	0	
Agrostis canina	na	na	na	na	na	na	
Agrostis capillaris	2	4	4	5	3	1	X
Agrostis gigantea	na	na	na	na	na	na	
Agrostis sp	na	na	na	na	na	na	
Agrostis vinealis	na	na	na	na	na	na	
Ajuga pyramidalis	3	3	3	3	1	0	X
Alnus glutinosa	na	na	na	na	na	na	
Alnus incana	na	na	na	na	na	na	
Andromeda polifolia	na	na	na	na	na	na	
Anemone nemorosa	5	5	4	2	1	1	
Angelica sylvestris	na	na	na	na	na	na	
Antennaria dioica	3	3	3	3	1	0	X
Anthoxanthum nipponicum	na	na	na	na	na	na	X
Anthoxanthum odoratum	2	3	4	5	3	1	X
Anthriscus sylvestris	0	2	2	1	2	3	X
Athyrium filix-femina	5	3	1	0	0	0	
Athyrium sp	na	na	na	na	na	na	
Avenella flexulosa	na	na	na	na	na	na	
Betula nana	na	na	na	na	na	na	
Betula pendula	na	na	na	na	na	na	
Betula pubescens	na	na	na	na	na	na	
Bistorta vivipara	2	3	3	4	2	0	X
Botrychium lunaria	0	0	1	1	1	0	X
Brachypodium pinnatum	na	na	na	na	na	na	
Calama sp	na	na	na	na	na	na	

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Calamagrostis arundinacea	na	na	na	na	na	na	
Calamagrostis canescens	na	na	na	na	na	na	
Calamagrostis epigejos	na	na	na	na	na	na	
Calamagrostis purpurea	na	na	na	na	na	na	
Calluna vulgaris	6	5	2	1	0	0	
Caltha palustris	na	na	na	na	na	na	
Campanula persicifolia	2	2	3	1	0	0	X
Campánula rotundifólia	3	3	4	5	3	0	X
Cardamine amara	na	na	na	na	na	na	
Cardamine dentata	na	na	na	na	na	na	
Cardamine pratensis	na	na	na	na	na	na	
Carduus vulgare	na	na	na	na	na	na	
Carex brunnescens	na	na	na	na	na	na	
Carex canescens	na	na	na	na	na	na	
Carex digitata	5	5	3	1	0	0	
Carex echinata	na	na	na	na	na	na	
Carex globularis	na	na	na	na	na	na	
Carex leporina	0	2	2	3	4	2	X
Carex loliacea	na	na	na	na	na	na	
Carex nigra	na	na	na	na	na	na	
Carex pallescens	3	3	3	4	2	0	X
Carex panicea	na	na	na	na	na	na	
Carex pauciflora	na	na	na	na	na	na	
Carex paupercula	na	na	na	na	na	na	
Carex pilulifera	na	na	na	na	na	na	
Carex rhynchophysa	na	na	na	na	na	na	
Carex rostrata	na	na	na	na	na	na	
Carex sp	na	na	na	na	na	na	
Carex vaginata	na	na	na	na	na	na	
Carex vesicaria	na	na	na	na	na	na	
Carophyllaceae sp	na	na	na	na	na	na	
Cerastium arvénse	0	0	1	2	2	1	X
Cerastium fontanum	3	3	4	4	4	4	X

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Chamaepericlymenum suecicum	4	3	1	0	0	0	
Chamerion angustifolium	2	4	4	3	2	2	X
Chrysosplenium alternifolium	na	na	na	na	na	na	
Circaea alpina	3	2	0	0	0	0	
Cirsium arvense	0	0	0	0	1	2	X
Cirsium heterophyllum	na	na	na	na	na	na	
Cirsium palustre	na	na	na	na	na	na	
Clinopodium vulgare	1	1	3	0	0	0	X
Comarum palustre	na	na	na	na	na	na	
Convallaria majalis	6	5	2	0	0	0	
Corylus avellana	na	na	na	na	na	na	
Crataegeus scandinavicus	na	na	na	na	na	na	
Cystopteris fragilis	na	na	na	na	na	na	
Dactylis glomerata	0	2	3	3	4	5	X
Dactylorhiza maculata	na	na	na	na	na	na	
Daphne mezereum	na	na	na	na	na	na	
Deschampsia cespitosa	2	5	5	4	5	6	X
Diphasiastrum complanatum	na	na	na	na	na	na	
Dryopteris carthusiana	na	na	na	na	na	na	
Dryopteris dilatata	na	na	na	na	na	na	
Dryopteris expansa	5	4	1	0	0	0	
Dryopteris filix-mas	4	3	2	0	0	0	
Dryopteris sp	na	na	na	na	na	na	
Elymus caninus	2	2	2	0	0	0	X
Elytrygia repens	na	na	na	na	na	na	
Empetrum nigrum	5	4	2	1	0	0	
Epilobium montanum	2	3	2	1	1	0	X
Epilobium sp	na	na	na	na	na	na	
Epipactis atrorubens	na	na	na	na	na	na	
Equisetum arvense	na	na	na	na	na	na	
Equisetum palustre	na	na	na	na	na	na	
Equisetum pratense	na	na	na	na	na	na	

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Equisetum sylvaticum	na	na	na	na	na	na	
Eriophorum angustifolium	na	na	na	na	na	na	
Eriophorum vaginatum	na	na	na	na	na	na	
Euphrasia sp	na	na	na	na	na	na	
Euphrasia stricta	0	1	2	2	1	0	X
Festuca ovina	5	5	4	5	2	0	
Festuca pratensis	na	na	na	na	na	na	
Festuca rubra	2	4	5	4	5	4	X
Filicatae sp	na	na	na	na	na	na	
Filipendula ulmaria	na	na	na	na	na	na	
Fragaria ananássa	na	na	na	na	na	na	
Fragaria vesca	4	5	4	4	2	0	
Fragnula alnus	na	na	na	na	na	na	
Fraxinus excelsior	na	na	na	na	na	na	
galeopsis sp.	na	na	na	na	na	na	
Galium aparine	0	0	0	0	0	1	
Galium boreale	3	3	4	4	2	1	X
Galium palustre	na	na	na	na	na	na	
Galium uliginosum	1	1	1	2	2	0	X
Galium verum	2	2	2	3	2	0	X
Geranium sylvaticum	5	5	5	5	5	3	
Geum rivale	3	4	4	3	3	1	X
Geum urbanum	1	2	2	0	0	0	X
Glechoma hederacea	0	1	2	2	2	1	X
Glyceria fluitans	na	na	na	na	na	na	
Gnaphalium sp	na	na	na	na	na	na	
Gymnocarpium dryopteris	6	4	2	0	0	0	
Hepatica nobilis	4	3	1	0	0	0	
Hieracium lactucella	0	1	1	4	3	1	X
Hieracium pilosella sp	3	3	3	4	2	1	X
Hieracium sp	na	na	na	na	na	na	
Hieracium Sylvatica sp	na	na	na	na	na	na	
Hierarcium umbellatum	na	na	na	na	na	na	

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Hierarcium vulgatum	na	na	na	na	na	na	
Holcus lanatus	0	0	0	1	2	1	X
Huperzia selago	na	na	na	na	na	na	
Hypericum maculatum	1	2	3	4	3	2	X
Hypericum perforatum	1	1	2	2	1	0	X
Hypochoeris maculata	na	na	na	na	na	na	X
Impatiens noli-tangere	na	na	na	na	na	na	
Juncus compressus	na	na	na	na	na	na	
Juncus conglomeratus	na	na	na	na	na	na	
Juncus effusus	na	na	na	na	na	na	
Juncus filiformis	na	na	na	na	na	na	
Juncus inflexus	na	na	na	na	na	na	
Juniperus communis	na	na	na	na	na	na	
Knautia arvensis	0	1	2	4	2	1	X
Lamium purpureum	na	na	na	na	na	na	
Lamium sp	na	na	na	na	na	na	
Lapsana communis	na	na	na	na	na	na	
Lathyrus linifolius	3	3	4	3	2	0	X
Lathyrus pratensis	0	1	2	2	4	4	X
Lathyrus vernus	2	1	0	0	0	0	
Leontodon autumnale	na	na	na	na	na	na	
Leucanthemum vulgare	0	1	2	4	3	1	X
Linaria vulgaris	0	0	3	2	3	3	X
Linnaea borealis	4	5	2	0	0	0	
Listera ovata	1	1	1	2	1	0	X
Luzula campestris	na	na	na	na	na	na	
Luzula multiflora	1	2	3	5	5	2	X
Luzula pilosa	5	5	4	2	0	0	
Luzula sudetica	na	na	na	na	na	na	
Lycopodium annotinum	4	3	1	0	0	0	
Lycopodium clavatum	na	na	na	na	na	na	
Lysimachia vulgaris	na	na	na	na	na	na	
Maianthemum bifolium	5	5	3	0	0	0	
Melampyrum pratense	5	5	4	3	1	0	

Species	**I**	**II**	**III**	**IV**	**V**	**VI**	**Semi-natural grassland species**
Melampyrum sylvaticum	5	5	3	3	1	0	
Melica nutans	5	4	2	0	0	0	
Milium effusum	3	3	3	1	1	0	X
Moehringia trinervia	1	1	1	0	0	0	X
Molinia caerulea	na	na	na	na	na	na	
Mycelis muralis	3	2	1	0	0	0	X
Nardus stricta	0	1	2	5	2	1	X
Omaloteca sylvatica	na	na	na	na	na	na	
Orthilia secunda	5	5	2	0	0	0	
Oxalis acetosella	5	4	3	0	0	0	
Oxycoccus palustris	na	na	na	na	na	na	
Paris quadrifolia	3	3	2	0	0	0	X
Peucedanum palustre	na	na	na	na	na	na	
Phegopteris connectilis	5	4	2	0	0	0	
Picea abies	na	na	na	na	na	na	
Pimpinella saxifraga	2	2	3	5	4	1	X
Pinus sylvestris	na	na	na	na	na	na	
Plantago lanceolata	0	0	1	3	2	1	X
Platanthera bifolia	1	2	2	3	2	0	X
Poa angustifolia	na	na	na	na	na	na	
Poa nemoralis	4	4	3	0	0	0	
Poa pratensis	0	3	3	3	4	4	X
Poa remóta	na	na	na	na	na	na	
Poa trivialis	0	2	2	2	3	3	X
Poaceae sp	na	na	na	na	na	na	
Polygala sp	na	na	na	na	na	na	
Polygala vulgaris	2	2	2	4	2	0	X
Populus tremula	na	na	na	na	na	na	
Potentilla erecta	4	4	4	3	2	1	
Prunella vulgaris	1	3	3	2	3	4	X
Prunus avium	na	na	na	na	na	na	
Prunus padus	na	na	na	na	na	na	
Pteridium aquilinum	na	na	na	na	na	na	
Pyrola minor	4	4	2	1	0	0	

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Pyrola rotundifolia	3	3	1	0	0	0	X
Pyrola Media	na	na	na	na	na	na	
Quercus robur	na	na	na	na	na	na	
Quercus sp	na	na	na	na	na	na	
Ranunculus acris	4	4	4	5	5	6	
Ranunculus auricomus	3	3	3	4	4	2	X
Ranunculus repens	2	3	3	3	5	6	X
Ranunculus sp	na	na	na	na	na	na	
Rhamnus catharticus	na	na	na	na	na	na	
Ribes nigrum	na	na	na	na	na	na	
Ribes rubrum	na	na	na	na	na	na	
Ribes spicatum	2	2	1	0	0	0	X
Rosa majalis	na	na	na	na	na	na	
Rosa sp	na	na	na	na	na	na	
Rubus chamaemorus	na	na	na	na	na	na	
Rubus fruticosus coll.	na	na	na	na	na	na	
Rubus idaeus	3	3	4	1	2	1	X
Rubus saxatilis	5	4	3	1	0	0	
Rubus sp	na	na	na	na	na	na	
Rumex acetosa	1	3	3	4	5	6	X
Rumex acetosella	2	2	2	3	3	2	X
Salix aurita	na	na	na	na	na	na	
Salix caprea	na	na	na	na	na	na	
Salix cinerea	na	na	na	na	na	na	
Salix lapponum	na	na	na	na	na	na	
Salix myrsinifolia	na	na	na	na	na	na	
Salix sp	na	na	na	na	na	na	
Sambucus racemosa	na	na	na	na	na	na	
Scrophularia nodosa	3	2	2	0	0	0	
Scutellaria gallericulata	na	na	na	na	na	na	
Sedum telephium	na	na	na	na	na	na	
Silene dioica	2	4	4	4	4	4	X
Silene rupestris	na	na	na	na	na	na	
Solanum dulcamara	na	na	na	na	na	na	

Species	I	II	III	IV	V	VI	Semi-natural grassland species
Solidago canadensis	0	0	1	1	2	2	
Solidago virgaurea	4	5	4	3	2	0	
Sorbus aucuparia	na	na	na	na	na	na	
Stachys palustris	0	0	0	0	0	2	
Stachys sylvatica	3	3	2	1	1	0	X
Stellaria graminea	0	2	3	3	4	3	X
Stellaria longifolia	na	na	na	na	na	na	
Stellaria media	na	na	na	na	na	na	
Stellaria nemorum	4	4	2	1	0	0	
Succisa pratensis	3	3	3	4	2	1	X
Tanacetum vulgaris	na	na	na	na	na	na	
Taraxacum sp	0	2	3	3	4	5	X
Thlaspi caerulescens	*	*	1	3	4	2	X
Trichophorum alpinum	na	na	na	na	na	na	
Trientalis europaea	5	5	2	1	2	2	
Trifolium medium	0	1	3	2	2	1	X
Trifolium pratense	0	2	3	4	4	4	X
Trifolium repens	0	3	3	4	5	5	X
Tussilago farfara	na	na	na	na	na	na	X
Urtica dioica	1	2	3	4	5	5	X
Urtica sp	na	na	na	na	na	na	X
vaccinium myrtillus	6	5	2	1	0	0	
Vaccinium oxcycoccus	na	na	na	na	na	na	
Vaccinium uliginosum	3	3	1	1	0	0	
Vaccinium vitis-idaea	6	5	3	1	0	0	
Valeriana sambucifolia	na	na	na	na	na	na	
Veronica beccabunga	na	na	na	na	na	na	X
Veronica chamaedrys	2	4	4	3	3	2	X
Veronica officinalis	3	3	3	3	2	0	X
Veronica scutellata	na	na	na	na	na	na	
Viburnum opulus	na	na	na	na	na	na	
Vicia cracca	1	2	2	4	5	5	X
Vicia sepium	2	3	4	3	4	4	X
Vicia sp	na	na	na	na	na	na	

Species	**I**	**II**	**III**	**IV**	**V**	**VI**	**Semi-natural grassland species**
Viola canina	1	2	3	4	3	0	X
Viola mirabilis	3	3	2	0	0	0	X
Viola palustris	2	2	4	4	3	1	X
Viola riviniana	5	4	3	2	1	0	
Viola sp	na	na	na	na	na	na	
Viola tricolor	*	*	1	3	3	1	

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway