Conservation and restoration of *Nardion* grasslands in the Swiss northern Prealps

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Abstract

Species-rich *Nardion* grasslands are high nature value habitats that are endangered and protected throughout Europe. In the canton of Bern (Switzerland), they are under protection since 2001. In 2014, despite their strict protection status, the Bernese authorities noted a dichotomous degradation trend in *Nardion* grasslands: over time, they tended to be dominated either by *Nardus stricta* or by eutrophic plant species, with a progressive loss of more variegated, intermediate plant associations. In particular, this induced a disappearance of typical and often rare Nardion plant species. We investigated the underlying causes of this ongoing degradation process. Vegetation composition, cover of *N. stricta* and eutrophic species were assessed in 20 species-rich and 28 degraded *Nardion* grasslands and linked to various environmental descriptors (topography, soil, management regime, etc.). Additionally, a *Nardion* quality index, ranking from 0 (highly degraded) to 1 (high ecological quality), was developed to enhance *Nardion* grassland characterization.

The results demonstrate that *Nardion* managed by mowing (typical hay meadows) harbour a higher quality and are rarely degraded, compared to grazed *Nardion* (pastures) which are often degraded, especially pastures at an altitude below 1600 m. The most problematic *Nardion* grasslands were those harbouring extensive *N. stricta* cover. They mostly occurred on north-exposed slopes with low soil pH. Additionally, *N. stricta* appeared to be more abundant in pastures grazed during one long extensive grazing period than in pastures grazed during two short grazing periods a year (early summer and autumn). Eutrophic species were most abundant at a soil pH around 4.4

and low soil C/N ratio, indicating higher nutrient availability. Previous studies have demonstrated that *Nardion* grassland degradation is more pronounced in pastures with spatially heterogeneous grazing pressure because this promotes suitable conditions for eutrophic species in more heavily grazed patches with high dung deposition and for *N. stricta* in less grazed areas. In order to prevent further degradation and to restore balanced *Nardion* grasslands we recommend a yearly management regime that consists of two short grazing periods (early summer and autumn). Fencing a pasture that has areas covered by *Nardion* grassland into subunits would facilitate controlling grazing pressure by homogenizing it as well as dung deposition across the pasture. A future experimental study should test whether such grazing regimes could effectively lead to lowering the excessive cover of *N. stricta* and eutrophic species.

Key words: degradation; dry meadows and pastures; grassland management; mountains; *Nardion strictae*; vegetation changes

1. Introduction

Species-rich, ecologically important *Nardion* grasslands (the species-rich *Nardion strictae* habitat; Delarze *et al.* 2015) occur in almost all European countries and make up a large proportion of protected alpine grasslands in Europe (Galvánek & Janák 2008). They develop on acidic, nutrient-poor and shallow soils on calcareous or siliceous substrate. *Nardion* grasslands are mostly extensively managed meadows or moderately used pastures and are therefore semi-natural (Eggenberg *et al.* 2001; Delarze *et al.* 2015). *Nardus stricta*, a short growing, horst forming, perennial grass is the characteristic plant species of this habitat (Fig. 1). *Nardion* grasslands are inhabited by specialized, acidophilic and oligotrophic plant species (Fig. 2 Delarze *et al.* 2015). Throughout Europe, species-rich *Nardion* grasslands (habitat type 6230 according to Natura 2000, a European network protecting habitats in Europe across borders, Galvánek & Janák 2008) are threatened and listed as “vulnerable” in the European Red List of habitats (Janssen *et al.* 2016). On the one hand, threats are imposed by an intensification of the management practises and on the other hand through undergrazing or land abandonment. Both trends have severe negative impacts leading to species-poor or banal vegetation composition (Galvánek & Janák 2008; Delarze *et al.* 2015). Additionally, soil and air pollution, trampling damage by livestock, sport infrastructures, afforestation and reduction of habitat connectivity are known to further degrade *Nardion* grasslands (European Commission DG Environment 2013).

In Switzerland, *Nardion* grasslands occur mainly in the alpine and subalpine zones. Species-rich *Nardion* grasslands (not all *Nardion* are species-rich) are under conservation concern because they are relatively scarce and some harbour specialized and rare plant species such as *Botrychium lanceolatum, B. multifidum* and *Gentiana pannonica* (Delarze *et al.* 2015). These species are classified as either "critical endangered" or "vulnerable" according to the IUCN Red List of the Swiss vascular plants (Bornand *et al.* 2016).

In the canton of Berne (Swiss northern Prealps), species-rich *Nardion* grasslands covered 129 ha and made up 4.8% of all dry grassland in 2006 (Dipner-Gerber, Schibli & Eggenberg 2006). A first inventory was made in 1982 and was regularly updated since 1988. In 2001, contracts between the cantonal authorities and the farmers were arranged to guarantee their protection. The contracts stipulated that farmers have to manage the grasslands extensively with practices such as late mowing and low intensity grazing, they also prohibited fertilizer input, liming (application of $CaCO_3$) and the use of herbicides in exchange of financial support (Regierungsrat des Kantons Bern 2001). Between 2011 and 2014, the inventory of all species-rich *Nardion* grasslands of the canton of Berne was revised (BIOP Support 2015). From originally 169 species-rich *Nardion* grasslands, 63 were subsequently classified as degraded according to the federal classification criteria and for this reason contracts between the authorities and the farmers of these grasslands were not renewed anymore (for details see Fig. 3 Eggenberg *et al.* 2001). The cantonal survey revealed two main causes (Fig. 4). First, the cover of *N. stricta* strongly increased in some of the grasslands, which triggered a decrease of the total number of plant species (BIOP Support 2015). *N. stricta* is avoided by livestock due to its poor digestibility and can thus become very dominant, reaching a cover of up to 80–90% (Maag, Nösberger & Lüscher 2001). Furthermore, the extremely dense root system of this grass inhibits the invasion of other plant species (Fischer & Wipf 2002). Second, *N. stricta* and other typical *Nardion* grassland species disappeared in favour of more common plant species better adapted to eutrophic edaphic conditions (BIOP Support 2015). In the past, research focussed mainly on how to convert *Nardion* grasslands into more productive meadows and pastures with higher agricultural value (e.g. Perkins 1968; Dietl 1977; Dietl 1998). Therefore, knowledge on conservation and restoration of species-rich *Nardion* grasslands is scarce (BIOP Support 2015). Regarding management, it is known that fertilization, mowing and grazing are important factors determining the cover of *N. stricta* and eutrophic species (European Commission DG Environment 2013). However, it remains unclear what grazing or mowing intensity and regimes (e.g. number of grazing periods, type of livestock) are most suitable to conserve or restore *Nardion* grasslands (Galvánek & Janák 2008). In the canton of Berne, more pastures than meadows are degraded (Table A1), suggesting that pastures are more prone to degradation. Unfortunately, mowing is often not feasible in the Bernese Prealps due to the steep slopes and remoteness of the grasslands. Several studies have shown that grazing regimes resulting in over- or undergrazing can cause severe species declines in these pastures (Fischer & Wipf 2002; Rudmann-Maurer et al. 2008; Stevanovic et al. 2008).

The aim of this study was twofold: 1) to identify the management practices which have proven to be ideal to conserve *Nardion* grasslands in the Bernese Prealps, considering also the different environmental and soil conditions found in this area; and 2) to identify the underlying causes of the degradation that occurred in some of these grasslands. Ultimately, we wanted to frame management recommendations that can prevent further degradation and even restore *Nardion* species-rich grasslands.

Previously, *Nardion* grasslands have always been categorised into species-rich or degraded, although there is a continuous gradient from species-rich to both degradation types. Therefore, a new index was developed, enabling a continuous ranking of grasslands according to their quality (*Nardion* grassland quality index). This index allowed a better assessment of the effect of the management practises, soil conditions and surrounding environment on the overall ecological quality of the *Nardion*.

2. Methods

2.1 Study sites and experimental design

Between 2011-2014, the canton of Berne revised the inventory of all species-rich *Nardion* grasslands (BIOP Support 2015). This control revealed that from originally 169 species-rich *Nardion* grasslands, 63 are degraded according to Eggenberg *et al.* (2001). The vegetation of degraded grassland is either strongly dominated by *N. stricta* or eutrophic species and is lacking typical *Nardion* grassland species (for details see Fig. 3). Out of this inventory, 52 *Nardion* grasslands (36 pastures and 16 meadows) were selected as study sites. They were all on calcareous substrate and situated in six different regions which represent different valleys in the Bernese Prealps (Diemtigtal, Kandertal, Tschingel, Lenk, Niesen, Zweisimmen; see Fig. 5). The annual rainfall of these regions was 1338 mm between 1981−2010 (Bundesamt für Meterologie und Klimatologie 2016). The average size of the studied *Nardion* grassland sites was 2.2 ha (range: 0.3–17 ha) and altitude ranged from 1000 to 2013 m. The mean minimal distance between two grasslands was approximately 1.25 km. Based on the inventory of the canton of Berne; the pastures were divided into three categories: species-rich, *N. stricta* dominated, and eutrophic species dominated pastures. Selected triplets always consisted of one pasture per category within the same region. To balance the design for elevation, the same numbers of triplets below and above the median elevation (1620 m) were selected. Because only eight declassified meadows were listed, all were considered in this study. Six of the declassified meadows were dominated by *N. stricta* and two were dominated by eutrophic species. For each of the declassified meadows, a species-rich meadow in the same or nearest region (if none in the same region) and in the same elevation belt (1000–1620 or 1620–2013 m) was randomly chosen for comparison. After visiting all 52 selected grasslands, four meadows had to be excluded from analyses because their management have been abandoned or the vegetation composition was drastically different from any typical Nardion grassland vegetation (strong vegetation change or wrongly catalogued). Furthermore, one meadow had been converted into a pasture and thus was included as an additional pasture. Altogether, 48 (37 pastures and 11 meadows) of the 52 intended grasslands were investigated (Table A2).

2.2 Vegetation survey

To assess the current state of the *Nardion* grasslands, vegetation surveys on all 48 grasslands were performed adopting the methods used for the Swiss inventory of dry meadows and pastures (Eggenberg *et al.* 2001). Within a representative area of the grassland, a 3-m radius sampling plot (28.26 m^2) was randomly placed and all vascular plants present in the plot were recorded and their absolute cover estimated. Based on the vegetation survey, we classified the grasslands into species-rich or degraded *Nardion* grasslands according to the federal classification criteria (Eggenberg *et al.* 2001). Within degraded grasslands, two types were differentiated: grassland dominated by *N. stricta* (*N. stricta* cover > eutrophic species cover) or grasslands dominated by eutrophic species (eutrophic species cover > *N. stricta* cover).

2.3 Management and environmental variables

To obtain information on management practises, all land managers (farmers) of the 52 grasslands were interviewed. They were asked to give detailed information on the current management practises applied in 2016 and for how long they are already managing the grassland in the respective manner (see Table A3 for the details list of questions).

From soil samples taken on each grassland, soil pH, C/N-ratio, nitrogen, sulphur, carbon and phosphate concentration were measured. 10 soil samples of 10 cm depth were taken on a transect crossing the vegetation plot. The soil was dried overnight in an oven at 105 °C, grounded and sieved (mesh size < 1 mm). 10 g of soil were mixed with 25 ml of 0.01 molar calcium chloride ($CaCl$) solution and the pH of the suspension was measured after two hours. To get the plant accessible phosphorous concentration, only the phosphate content in the soil was measured with the Olson method (Pansu & Gautheyrou 2007). Total organic carbon, nitrogen and sulphur were measured with a CNS elemental analyser (vario EL cube, Elementar) on 12 mg of homogenized and dried samples.

Furthermore, the exposition and slope were measured within each vegetation plot with a compass and a water level. The exact position of the vegetation plot was localized with a GPS device and the altitude was obtained from ArcGIS.

2.3 *Nardion* grassland quality index

A *Nardion* grassland quality index, ranking grasslands according to their quality, was defined as continuous index containing four different aspects (eq. 1 below). It sums up the Shannon index of the total vegetation survey (Sv) and of the *Nardion* indicator species (Si) and add the reciprocal value of the *N. stricta* cover (N) and of the cover of other unfavourable species (U) which are mainly eutrophic species. The definition of *Nardion* indicator species and unfavourable species is adopted from Eggenberg et *al.* (2001) (Table 1). In this definition, *Nardion* indicator species are specialized, acidophil species typically growing in oligotrophic habitats characterized by *N. stricta* (species-rich *Nardion strictae*) whereas eutrophic species are more common species which are adapted to eutrophic soil conditions normally growing in grasslands dominated by *Arrhenatherum elatius*. Since *N. stricta* cover is only a negative attribute if it is strongly dominating the vegetation, its reciprocal value was added only if its cover exceeded the threshold of 24.3%. 24.3 is the median of 26.8 and 21.9, 26.8 is the mean *N. stricta* cover of all degraded pastures and 21.9 the mean *N. stricta* cover of species-rich pastures. Only the difference between the *N. stricta* cover and this threshold was subtracted from one. Each of these four parameters were standardized with the 95 percentile of the values from all grasslands (range: 0–1) and combined into the quality index based on the method proposed by Hering et *al*. (2006):

$$Nardion\ grassland\ quality\ index\ = \frac{Sv + Si + (1 - N) + (1 - U)}{4} \qquad (\mathrm{Eq.}\ 1)$$

The quality index ranges from zero to one, one being the best possible quality and zero the poorest. In other words, a quality index of one represents a grassland with a high Shannon index of the overall vegetation and of *Nardion* indicator species, a *N. stricta* cover lower or equal to 24.3% and absence of eutrophic species. To calculate the Shannon index of vegetation survey and of the *Nardion* indicator species, the function ‘diversity’ from the package ‘vegan’ in R was used in R (Oksanen *et al.* 2016) . Relative covers for all plant species (i.e the absolute cover divided by the total vegetation cover per plot) were calculated and used for the quality index and all other analyses.

2.4 Data analysis

Due to different numbers of replicates and explanatory variables, pastures and meadows were analysed separately. For model selection of the pasture data, all explanatory variables listed in Table 2 were considered. The variables *N. stricta* cover, eutrophic species cover and the *Nardion* grassland quality index were the response variables of interest. Strongly right-skewed variables were either log-transformed (count data) or arcsin-square-root transformed (proportional data). To improve model convergence, all variables were standardized (mean = 0, standard deviation = 1). If two variables had a Spearman correlation coefficient $|rs| > 0.6$, only the biologically more meaningful variable was retained for the model selection analysis. The high proportion of explanatory variables resulted in a high number of possible models. Therefore, statistical analysis was conducted in two steps.

In a first step, a pre-selection of the explanatory variables was done: univariate linear mixed-effects models from the 'nlme' R-package version 3.1-128 (Pinheiro *et al.* 2015) were applied to identify which of the explanatory variables show tendency ($P < 0.1$) to influence *N. stricta* cover, eutrophic species cover and the *Nardion* grassland quality index (Table 2) (Guyot *et al.* 2017). Explanatory variables were only tested as linear terms and region was always included as random effect. Additionally, quadratic terms were retained if the two-way anova test revealed better performance (significance level of 0.1) of the model including the linear and quadratic term compared to the model including only the linear term.

In a second step, three global models with all retained variables from the first step ($P < 0.1$ in univariate model) were built to detect the most influential variables. For these three global models, model selection was conducted with the 'dredge' function of the 'MuMIn' R-package version 1.15.6 (Barton 2016) by using the Akaike's Information Criterion corrected for small sample size (AICc). The goodness-of-fit of each model with a ΔAICc lower than two was estimated from marginal and conditional R^2 calculated with the function 'sem.model.fits' from the piecewiseSEM R-package (Lefcheck 2015) following Nakagawa and Schielzeth (2013).

Models within ΔAICc of two were further averaged with the 'model.avg' function of the 'MuMIn' R-package (Barton 2016) using full-average. The remaining variables were regarded as key variables if they had an estimate with a confidence interval not including zero. With the 'corrplot' function of the 'corrplot' package (Wei & Simko 2016), correlations between these key variables and all continuous explanatory and response variables (Table 2) were tested using the Spearman correlation test on a significance level of 0.1. For this purpose, the number of grazing periods was transformed into a continuous variable.

For meadows, only the first step of the same statistical analysis of the pastures was conducted due to low number of replicates. To analyse links between different management variables (e.g. days of grazing and number of grazing periods), linear mixed effect models with region as random effect were used. To check model assumptions, residual plots and Tukey-Anscombe plots were conducted. All statistical analyses were performed in R Studio version 1.0.44 (RStudioTeam 2015).

3. Results

Overall, 252 vascular plant species with an average of 48 species per plot of 28 m^2 (range: 32–64) were found. *N. stricta* cover ranged from 1–70 % (mean: 24%) and eutrophic species cover between 3–66 % (mean: 21%). Mean number of *Nardion* indicator species per plot was four (range: 0–10). All investigated grasslands had acidic soils (mean soil pH: 4.1, range: 3.2–5.2).

3.1 Management practices

In 2016, the current management practises of pastures had been applied for on average for 20 ± 2 years. Out of 37 pastures, three were currently fertilized. These three degraded pastures were not under a governmental contract prohibiting the application of fertilizer anymore and therefore the application of fertilizer was possible. Additionally, 19 pastures laid within the so called “Sömmerungsgebiet”, which are mountain pastures not part of the common utilized agricultural area where the application of mineral nitrogen fertilization is already prohibited since 1996 (Schweizerischer Bundesrat 1996). Pastures were mostly grazed by cattle (cows and calves), only three pastures were grazed by goats, horses or lamas. 18 pastures were grazed during one and the other 19 during two or more grazing periods. Pastures with one grazing period were grazed during 66 ± 1 day whereas pastures with two or more grazing periods were grazed in total for 36 ± 5 days (sum of all grazing periods). On average, the time of first grazing (average date at which the livestock is on the pastures for the first time) was on the 23th of June but was not significantly linked to number of grazing periods. A significant correlation between number of grazing periods and grazing days was detected (P = 0.007). All meadows were mown once a year and the management practises from 2016 have been applied for 39 ± 11 years. Mowing occurred around the 4th of August. Degraded meadows were on average mown 12 days later than species-rich meadows, although this difference was not significant (P = 0.121). Meadows had a very low degradation rate (7 degraded and 60 species-rich) compared to pastures (46 degraded and 56 species-rich; see Table A1). Meadows have a mean *Nardion* grassland quality index of 0.72 whereas pastures have an index of 0.69 on average.

Based on the vegetation survey of this study and applying federal classification criteria (Eggenberg *et al.* 2001), five of the 37 investigated pastures would be classified as species-rich and 32 as degraded (15 *N. stricta* dominated and 17 dominated by eutrophic species). From a total of 11 meadows, four would be classified as species-rich and 7 as degraded (1 *N. stricta* dominated and 6 dominated by eutrophic species; Fig. 6).

3.2 *N. stricta* cover, eutrophic species cover and *Nardion* grassland quality index in pastures

The model selection with *N. stricta* cover as response variable revealed that the time of first grazing (average date at which livestock is on the grassland for the first time), exposition and number of grazing periods are the three key variables with decreasing importance (Table 4). Grasslands that are north-exposed (Fig. 7) and grazed during only one grazing period have a higher *N. stricta* cover (Fig. 8). Furthermore, pastures with time of first grazing around the 28th of June have lower cover of *N. stricta* than earlier or later grazed pastures (Fig. 7).

For eutrophic species cover, the following predictors remained from the model selection: area, soil C/N ratio, soil pH, soil nitrogen concentration and number of grazing periods (Table 4). Key variables for the eutrophic species cover are area, soil C/N ratio and soil pH with decreasing importance (Table 4 and Fig. 9). The highest cover of eutrophic species was found in small pastures with a soil pH of 4.4 and a low soil C/N ratio.

The *Nardion* grassland quality index was best explained by altitude, number of grazing days, area and livestock unit per area grazed (Table 4). Altitude was the most important and the only variable significantly influencing the quality index (Table 4 and Fig. 10) indicating that pastures at higher altitudes had a higher quality index.

3.3 *N. stricta* cover, eutrophic species cover and *Nardion* grassland quality index in meadows

N. stricta cover in meadows was significantly positively influenced by elevation, slope, travel time, and negatively by soil pH, whereas eutrophic species were positively linked to soil pH. The quality index was not affected by any variable (Table 5).

3.4 Correlation of key variables

Significant correlations between key variables and all other explanatory variables are shown in Figure 11 for pastures and in Figure 12 for meadows. In pastures, the number of grazing periods was positively correlated with soil pH and negatively with days of grazing and elevation. There was a negative correlation between days of grazing and soil pH, slope and time of first grazing and between the exposition and soil pH. The correlation between elevation and soil nitrogen, sulphur and carbon concentration and the correlation between elevation and travel time was positive. Soil C/N ratio was positively connected to area and carbon concentration. There was a negative correlation between soil pH and area and between soil pH and soil phosphate concentration.

4. Discussion

In this study, potential drivers of the ongoing degradation of *Nardion* grasslands in the Bernese Prealps were identified. Based on the observed links between management practices and the vegetation composition, soil and environmental condition, specific management actions to restore degraded *Nardion* grassland could be framed and should be further confirmed in experimental studies. Additionally, the analyses of the Bernese inventory of *Nardion* grassland displayed that mown *Nardion* grasslands are crucial to ensure the persistence of this rare habitat and should be further protected by the cantonal authorities with the existing measurements.

4.1 Dichotomous degradation processes in pastures

The observed dichotomous degradation processes of species-rich *Nardion* grasslands towards dominance of *N. stricta* or eutrophic species was driven by management practices and soil and environmental conditions of the investigated pastures. In the canton of Berne, for 39 of total 56 degraded pastures (Table A1) too high abundance of *N. stricta* was the degradation reason. The cover of *N. stricta* was mainly influenced by the number of grazing periods and exposition. Specifically, pastures experiencing one single grazing period yearly, instead of two or more, had higher *N. stricta* cover. In addition, pastures with one grazing period had significantly more total grazing days than those with two or more grazing periods. Pastures with one grazing period are traditionally used as summer pastures and are therefore grazed throughout summer. Typically, this grazing regime is applied on big pasture. In pastures with many grazing days on a wide area, selective feeding by livestock is presumably high because livestock prefer feeding on plants with high nutrient content and simultaneously they can avoid eating unpalatable species like *N. stricta*. Spatial heterogeneous grazing pressure consequently enhances the abundance of unpalatable species on certain parts of the pastures (Gusewell, Jewell & Edwards 2005). Unfortunately, it was not possible to estimate grazing pressure on the *Nardion* grassland itself due to two reasons. First, the investigated *Nardion* grasslands were often a subset of the whole pasture. For this reason, it is unknown how much time the livestock actually spend on the *Nardion* itself. Second, farmers often change the location of the fences on their summer pastures over and within the years. It is therefore impossible to calculate the exact feeding pressure per m^2 or ha in the investigated areas.

The time of first grazing (independent of the number of grazing periods) was another important management factor affecting *N. stricta* cover in pastures. In the study region, the lowest *N. stricta* cover was reported in pastures with the time of first grazing around the 28th of June. This is consistent with the findings of Meisser et *al*. (2014) demonstrating that *N. stricta* is well eaten by livestock in early summer when its nutrient levels are still high and the leaves are not too tough yet. Grazing later in the year enforces the dominance of *N. stricta* because its nutrient levels strongly decrease during the season and it is barley eaten by livestock anymore (Bovolenta *et al.* 2008). Furthermore, north-exposed pastures had higher *N. stricta* covers and were often grazed during one grazing period only. This may indirectly explain why *N. stricta* reaches such high covers in north-exposed pastures. Additionally, the north-exposed pastures tended to have very acidic soils, which may favour the growth of *N. stricta* and lead to the disappearance of typical *Nardion* grassland species (de Graaf *et al.* 1998; Delarze *et al.* 2015). It is well known, that soil acidification through chronic nitrogen deposition can alter soil pH and decreases species-richness in *Nardion* grasslands (Duprè *et al.* 2010; Stevens *et al.* 2010; Roth *et al.* 2015). The low soil pH in north-exposed grasslands is most likely explained by the fact that the region in the North of the Bernese Prealps is characterized by more intensive farming and larger settlements, resulting in higher amounts of air pollution (EKL 2014). Therefore, north-exposed pastures are probably more exposed to air pollutants such as nitrogen or sulphur dioxide leading to a lower soil pH. Alternatively, north exposition could be connected to high soil moisture and low light availability but these two factors are unlikely to increase the cover of the light demanding *N. stricta*, (light indicator value of 4 according to Landolt *et al.* 2010) which grows preferably on semi-humid soils (3w+ according toLandolt *et al.* 2010). In summary, very high *N. stricta* cover was most problematic in north exposed pastures, with low soil pH where grazing took place during one period only but with many grazing days, probably resulting in low selective feeding pressure on *N. stricta*.

In the Bernese Pre-Alps, 18 of in total 56 degraded pastures were strongly dominated by eutrophic species and therefore degraded. High eutrophic species cover was mainly linked to the area of the pastures, followed by the soil C/N ratio and by soil pH in the studied grasslands. In *Nardion* grasslands with a large area, less eutrophic species were found. The speed of invasion may be slower in these grassland, because invasion success is smaller with increasing distance of the seed source to the place of invasion ("distance effect" Maag, Nösberger & Lüscher 2001 and citations therein) but this effect alone may not explain the low cover observed for eutrophic species. It is rather explained by the fact that small pastures were associated with a low soil C/N ratio and higher soil pH. Plant species adapted to eutrophic edaphic conditions profit from a low C/N ratio in the soil, indicating high nutrient availability (Blume *et al.* 2002). Spatially different grazing pressure and therefore patchy dung depositions through livestock causes a decrease in the soil C/N ratio especially in locations where more palatable species are already growing (Gusewell, Jewell & Edwards 2005; Parolo *et al.* 2011). Therefore, grazing patterns and selective feeding may be important drivers determining the abundance of eutrophic species through altering the soil C/N ratio. Moreover, eutrophic species reached highest abundances at soil pH around 4.4 and decreased in more acidic or neutral soils. In very acidic soils, the cation uptake and the nitrification process through autotrophic bacteria is largely inhibited (Fitter & Hay 2012; Gregory & Nortcliff 2013). Consequently, eutrophic species face problems in accessing nitrogen and are outcompeted by typical *Nardion* grassland species under very acidic soil conditions. Acidophilic plants species such as *N. stricta*, species of the genus *Erica* and other typical *Nardion* grassland species are adapted to absorb nitrogen under very acid condition and are thus more competitive (Gigon & Rorison 1972; Weigelt, Bol & Bardgett 2005).

Overall, if grasslands were classified into species-rich or degraded *Nardion* grasslands based on the vegetation survey of this study using the federal classification criteria (Eggenberg *et al.* 2001), more grasslands would have been classified as degraded than by the cantonal assessment of 2011-2014 (Fig. 6). The differences in assessments between the presented study and the cantonal survey can most likely be explained by three factors. First, the assessment of the cantonal authorities was done between 2011–2014. During this time period and the presented study, the vegetation might have undergone some changes. Second, cover estimates can differ between observers and therefore lead to different assessments. Third, plot locations were randomly chosen within a representative area in the presented study, whereas experts of the cantonal authorities subjectively placed their locations. This might further explain the differences in the number of indicator species found within the vegetation survey. In summary, differences may be explained by minor differences in the methodology and some vegetation changes which occurred between the two assessments.

4.2 Quality within *Nardion* grassland pastures

In this study, overall quality of a *Nardion* grassland was defined using a continuous index ranging from 0 (low quality) to 1 (high quality). In grasslands with a high index, many typical *Nardion* grassland species are growing and the Shannon index of the overall vegetation is high. Additionally, *N. stricta* cover is in a preferable range (below 24.3 %) and few or no eutrophic species are occurring. The *Nardion* grassland quality index was only directly influenced by elevation, indicating that pastures at higher elevation have better quality. Similar conclusions were drawn by Korzeniak *et al*. (2016), who pointed out that conservation measurements are especially needed to reduce nutrient levels in *Nardion* grasslands in the lower montane zone. This is consistent with other findings from the same region as the presented study, showing that the eutrophic species defined by Eggenberg *et al*. (2001) tended to have their distributional optima at lower altitudes (Heer *et al.* 2016). Overall, pastures at low elevations tend to have lower soil C/N ratio and therefore may be prone to degradation through eutrophic plant species.

Furthermore, there were positive correlations between elevation and travel time (accessibility indicator: time it takes the land manager to reach the grassland from its place of residence), soil nitrogen concentration and a grazing regime with one grazing period (Fig. 11). Traditionally, due to the later phenology, pastures at high elevations are used as summer pastures. The high elevation leads to a longer travel distance for farmers to reach their fields. The correlation between elevation and nitrogen availably was weak ($R = 0.12$, $P < 0.1$) and it is difficult to interpret soil nitrogen concentration alone because only a small proportion (about 1%) is available for the plants (Blume *et al.* 2002).

4.3 Management recommendations for pastures

To give management recommendations, knowledge on the factors determining either eutrophic species or *N. stricta* cover must be combined with the influence of soil and environmental conditions. The results of this study indicate that a grazing regime with two short grazing periods with the time of first grazing around the 28th of June are ideal to maintain *N. stricta* in a preferable range. Eutrophic species are mainly problematic in pastures at low altitudes where their cover is influenced by soil conditions. They profited from low soil C/N ratio and soil pH of 4.4. Other studies found that low C/N ratio can be enhanced through heterogeneous grazing behaviour and dung deposition of livestock. Therefore, dividing pastures into smaller parts by fences might be a helpful approach preventing patchy eutrophication and dominance of eutrophic species within these patches. Moreover, results of previous studies suggest that the feeding pressure could be more equal over the whole pastures in pastures where the livestock is restricted to an alternating proportion by fencing and therefore grazing pressure on *N. stricta* would be augmented (Gusewell, Jewell & Edwards 2005; Parolo et al. 2011). For this reason, fences may be a good approach to keep both eutrophic species and *N. stricta* in a preferable range. An alternative to fences is to increase the number of livestock units per area and simultaneously decrease the time span of grazing. This approach may lead to a more equal grazing pressure over the whole area. However, a disadvantage might be the elaborative logistic work. Further experimental studies should test whether one of these management recommendations might be useful to restore and maintain species-rich *Nardion* grasslands pastures.

Perkins (1968) found that in pastures with a high *N. stricta* dominance, soil conditions are altered strongly for its favour and maybe hard to reverse. Although it is well known that intensive fertilization leads to the disappearance of typical *Nardion* grassland species (Spiegelberger *et al.* 2006; Hejcman *et al.* 2007; Tenz *et al.* 2010), the investigated farmers claimed that low amounts of fertilization in the past inhibited the complete dominance of *N. stricta* without leading to a disappearance of typical *Nardion* grassland species (BIOP Support 2015). Therefore, the total ban of fertilizer input may have enhanced the dominance of *N. stricta* in certain grasslands. Hence, already very species-poor *Nardion* grasslands with very low soil pH may profit from low fertiliser input or liming with $CaCO_3$. A slight increase of soil pH and nutrient availability may allow species to re-establish which cannot cope with as extreme soil conditions as *N. stricta*. However, the re-establishment of once disappeared species due to high amounts of liming or fertilizing is very slow and therefore the effects of different amount of fertilizing or liming should be investigated carefully to avoid too high applications, which can cause the nearly irreversible disappearance of still existing, typical *Nardion* grassland species (Spiegelberger *et al.* 2006).

4.4 Meadows

The investigated meadows had higher mean quality than pastures and in the canton Berne meadows are by far less often degraded than pastures. It is generally known that mown *Nardion* grasslands harbour more flowering species than pastures therefore have higher ecological value (Eggenberg *et al.* 2001). Moreover, studies have demonstrated that after converting a meadow into a pasture, the cover of *N. stricta* increases with time, accompanied by a reduction in overall number of species (Fischer & Wipf 2002; Gustavsson, Lennartsson & Emanuelsson 2007). Overall, mowing is a better management option than grazing to maintain *Nardion* grassland quality and should be applied whenever possible.

Within meadows, the cover of *N. stricta* and eutrophic species were clearly linked to soil pH. Meadows with acid soils had high *N. stricta* covers whereas meadows with neutral soils were dominated by eutrophic species. These findings are consistent with the analyses of pastures. Moreover, *N. stricta* was positively linked to slope, elevation and travel time. The distribution optimum of *N. stricta* in the study region is at about 1900 m (Heer *et al.* 2016), thus an increase in cover with elevation can be expected. This distribution is most likely explained by the lower soil pH found in meadows at high elevation (Fig. 12). The steepness of meadows was associated with low elevation and high soil pH. Therefore, lower cover of *N. stricta* was found in steep meadows. Overall, soil pH is the only factor influencing both *N. stricta* and eutrophic species cover within meadows but these results should be interpreted carefully due to low replicate number (n = 11).

4.5 Conclusions

To maintain species-rich *Nardion* grasslands in the Bernese Prealps, the cantonal authorities should continue to protect meadows with the current measurement. Most meadows still have high quality and are only rarely degraded. To restore *Nardion* grasslands, action measure should focus on low elevated pastures where the degradation process is most severe. The results of this study indicate that if a trend towards a *N. stricta* dominated pastures exists, two short grazing periods with first grazing time around the 28^{th} of June represents the most promising grazing regime to keep *N. stricta* in a preferable range. The dominance of eutrophic species is linked to low C/N ratio and intermediate soil pH. In addition to the presented recommendations, previous studies suggested that suitable soil condition enhancing the dominance of eutrophic species can be enforced or caused by an unequal grazing pressure and dung deposition over the whole pasture (Gusewell, Jewell & Edwards 2005; Parolo *et al.* 2011). Therefore, they propose that dividing the pastures into smaller parts using fences can equalize grazing pressure and dung deposition and might therefore mitigate preferable soil conditions for eutrophic species and make soil condition more suitable for species-rich *Nardion* grasslands. Simultaneously, a more spatially homogeneous grazing might increase the grazing pressure on *N. stricta* as proposed by Parolo et *al.* (2011). Notably, all results of this study are based on observations and further studies should test the applicability of these measures and their effectiveness in conserving and restoring species-rich *Nardion* grassland.

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6. References

Esri, HERE, Garmin,Intermap, INCREMENT P, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, GIS User Community.

Barton, K. (2016) MuMIn: Multi-Model Inference. R package version 1.15.6. https://CRAN.R-project.org/package=MuMIn.

BIOP Support (2015) Optimierung der Bewirtschaftung von artenarmen, sauren Borstgrasrasen (*Nardion strictae*): Know-how aus der Literatur.

Blume, H.-P., Brümmer, G.W., Schwertmann, U., Horn, R., Kögel-Knabner, I., Stahr, K., Auerswald, K., Beyer, L., Hartmann, A., Litz, N., Scheinost, A., Stanjek, H., Welp, G. & Wilke, B.-M. (2002) *Lehrbuch der Bodenkunde*. Spektrum Akademischer Verlag Heidelberg, Berlin.

Bornand, C., Eggenberg, S., Gygax, A., Juillerat, P., Jutzi, M., Möhl, A., Rometsch, S., Sager, L. & Santiago, H. (2016) Rote Liste Gefässpflanzen. Gefährdete Arten der Schweiz. pp. 178. Bundesamt für Umwelt, Bern und Info Flora,, Genf.

Bovolenta, S., Spanghero, M., Dovier, S., Orlandi, D. & Clementel, F. (2008) Chemical composition and net energy content of alpine pasture species during the grazing season. *Animal Feed Science and Technology,* **146,** 177 – 177.

Bundesamt für Meterologie und Klimatologie (2016) Klimanormwerte Adelboden Normperiode 1981−2010.

de Graaf, M.C.C., Bobbink, R., Roelofs, J.G.M. & Verbeek, P.J.M. (1998) Differential effects of ammonium and nitrate on three heathland species. *Plant Ecology,* **135,** 185 – 196.

Delarze, R., Gonseth, Y., Eggenberg, S. & Vust, M. (2015) *Lebensräume der Schweiz* Third Edition edn. ott, Bern.

Dietl, D. (1998) Wichtige Pflanzenbestände und Pflanzenarten der Alpweiden. *Agrarforschung 5*, pp. I-VIII.

Dietl, W. (1977) Vegetationskunde als Grundlage der Verbesserung des Graslandes in den Alpen. *Application of Vegetation Science to Grassland Husbandry*, pp. 405-458. Springer.

Dipner-Gerber, M., Schibli, C. & Eggenberg, S. (2006) Trockenwiesen und -Weiden der Schweiz Vorgehen und Ergebnisse Kanton Bern. TWW PPS GmbH, atena, oekoskop, Maillefer & Hunziker, plus, UNA.

Duprè, C., Stevens, C.J., Ranke, T., Bleeker, A., Peppler-Lisbach, C., Gowing, D.J.G., Dise, N.B., Dorland, E., Bobbink, R. & Diekmann, M. (2010) Changes in species richness and composition in European acidic grasslands over the past 70 years: the contribution of cumulative atmospheric nitrogen deposition. *Global Change Biology,* **16,** 344-357.

Eggenberg, S., Dalang, T., Dipner, M. & Mayer, C. (2001) Kartierung und Bewertung der Trockenwiesen und -weiden von nationaler Bedeutung. Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

EKL (2014) Ammoniak-Immissionen und Stickstoffeinträge. Eidgenössische Kommission für Lufthygiene (EKL), Bern.

European Commission DG Environment (2013) Interpretation manual of European Union habitats - EUR28. European Environmental Information and Observation Network.

Fischer, M. & Wipf, S. (2002) Effect of low-intensity grazing on the species-rich vegetation of traditionally mown subalpine meadows. *Biological Conservation,* **104,** 1-11.

Fitter, A.H. & Hay, R.K. (2012) *Environmental physiology of plants*. Academic press.

Galvánek, D. & Janák, M. (2008) Management of Natura 2000 habitats. 6230 *Species-rich Nardus grasslands. European Commission.

Gigon, A. & Rorison, I. (1972) The response of some ecologically distinct plant species to nitrate-and to ammonium-nitrogen. *The Journal of Ecology***,** 93-102.

Gregory, P.J. & Nortcliff, S. (2013) *Soil Conditions and Plant Growth*. Blackwell Publishing Ltd,.

Gusewell, S., Jewell, P.L. & Edwards, P.J. (2005) Effects of heterogeneous habitat use by cattle on nutrient availability and litter decomposition in soils of an Alpine pasture. *Plant and Soil,* **268,** 135-149.

Gustavsson, E., Lennartsson, T. & Emanuelsson, M. (2007) Land use more than 200 years ago explains current grassland plant diversity in a Swedish agricultural landscape. *Biological Conservation,* **138,** 47-59.

Guyot, C., Arlettaz, R., Korner, P. & Jacot, A. (2017) Temporal and Spatial Scales Matter: Circannual Habitat Selection by Bird Communities in Vineyards. *Plos One,* **12**.

Heer, N., Zwahlen, C., Boch , S., Prati , D. & Fischer, M. (2016) Testing for plant community patterns along 10 elevational grassland and forest transects in the Swiss Alps using species response curves. Master Thesis University of Berne.

Hejcman, M., Klaudisova, M., Stursa, J., Pavlu, V., Schellberg, J., Hejcmanova, P., Hakl, J., Rauch, O. & Vacek, S. (2007) Revisiting a 37 years abandoned fertilizer experiment on Nardus grassland in the Czech Republic. *Agriculture Ecosystems & Environment,* **118,** 231-236.

Hering, D., Feld, C.K., Moog, O. & Ofenbock, T. (2006) Cook book for the development of a Multimetric Index for biological condition of aquatic ecosystems: Experiences from the European AQEM and STAR projects and related initiatives. *Hydrobiologia,* **566,** 311-324.

Janssen, J., Rodwell, J., Criado, M.G., Gubbay, S. & Arts, G. (2016) European Red List of Habitats. European Union.

Korzeniak, J. (2016) Mountain Nardus stricta grasslands as a relic of past farming - the effects of grazing abandonment in relation to elevation and spatial scale. *Folia Geobotanica,* **51,** 93-113.

Landolt, E., Bäumler, B., Erhardt, A., Hegg, O., Klötzli, F., Lämmler, W., Nobis, M., Rudmann-Maurer, K., Schweingruber, F. & Theurillat, J.-P. (2010) *Flora indicativa: Ecological inicator values and biological attributes of the flora of Switzerland and the Alps: ökologische Zeigerwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen*. Haupt Verlag, Bern.

Lefcheck, J.S. (2015) piecewiseSEM: Piecewise structural equation modeling in R for ecology, evolution, and systematics. Methods in Ecology and Evolution.

Maag, S., Nösberger, J. & Lüscher, A. (2001) Mögliche Folgen einer Bewirtschaftungsaufgabe von Wiesen und Weiden im Berggebiet. *Ergebnisse des Komponentenprojektes D, Polyporjekt PRIMALP*, pp. 60.

Meisser, M., Deleglise, C., Frelechoux, F., Chassot, A., Jeangros, B. & Mosimann, E. (2014) Foraging behaviour and occupation pattern of beef cows on a heterogeneous pasture in the Swiss Alps. *Czech Journal of Animal Science,* **59,** 84-95.

Nakagawa, S. & Schielzeth, H. (2013) A general and simple method for obtaining R2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution,* **4,** 133-142.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E. & Wagner, H. (2016) vegan: Community Ecology Package. R package version 2.4-1. https://CRAN.R-project.org/package=vegan.

Parolo, G., Abeli, T., Gusmeroli, F. & Rossi, G. (2011) Large-scale heterogeneous cattle grazing affects plant diversity and forage value of Alpine species-rich Nardus pastures. *Grass and Forage Science,* **66,** 541-550.

Perkins, D.F. (1968) Ecology of *Nardus stricta L*.: I. Annual growth in relation to tiller phenology. *The Journal of Ecology*, 633 – 646.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. & RCoreTeam (2015) nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-122 http://CRAN.R-project.org/package=nlme.

Regierungsrat des Kantons Bern (2001) Verordnung über Beiträge an Trockenstandorte und Feuchtgebiete (FTV) 426.112.

Roth, T., Kohli, L., Rihm, B., Amrhein, V. & Achermann, B. (2015) Nitrogen deposition and multi-dimensional plant diversity at the landscape scale. *Royal Society open science,* **2,** 150017-150017.

RStudioTeam (2015) RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Rudmann-Maurer, K., Weyand, A., Fischer, M. & Stocklin, J. (2008) The role of landuse and natural determinants for grassland vegetation composition in the Swiss Alps. *Basic and Applied Ecology,* **9,** 494-503.

Schweizerischer Bundesrat (1996) Verordnung über Bewirtschaftungsbeiträge an die Landwirtschaft mit erschwerten Produktionsbedingungen (Verordnung Bewirtschaftungsbeiträge) 910.21.

Schweizerischer Bundesrat (2013) Verordnung über landwirtschaftliche Begriffe und die Anerkennung von Betriebsformen 910.91. (ed. Landwirtschaftliche Begriffsverordnung).

Spiegelberger, T., Hegg, O., Matthies, D., Hedlund, K. & Schaffner, U. (2006) Long-term effects of short-term perturbation in a subalpine grassland. *Ecology,* **87,** 1939-1944.

Stevanovic, Z.D., Peeters, A., Vrbnicanin, S., Sostaric, I. & Acic, S. (2008) Long term grassland vegetation changes: Case study Nature Park Stara Planina (Serbia). *Community Ecology,* **9,** 23-31.

Stevens, C.J., Dupre, C., Dorland, E., Gaudnik, C., Gowing, D.J.G., Bleeker, A., Diekmann, M., Alard, D., Bobbink, R., Fowler, D., Corcket, E., Mountford, J.O., Vandvik, V., Aarrestad, P.A., Muller, S. & Dise, N.B. (2010) Nitrogen deposition threatens species richness of grasslands across Europe. *Environmental Pollution,* **158,** 2940-2945.

Tenz, R., Elmer, R., Huguenin-Elie, O. & Lüscher, A. (2010) Auswirkungen der Düngung auf einen 'Borstgrasrasen'. *Agrarforschung Schweiz,* **1,** 176–183.

Wei, T. & Simko, V. (2016) corrplot: Visualization of a Correlation Matrix R package version 0.77. https://CRAN.R-project.org/package=corrplot.

Weigelt, A., Bol, R. & Bardgett, R.D. (2005) Preferential uptake of soil nitrogen forms by grassland plant species. *Oecologia,* **142,** 627-635.

7. Tables

Table 1: List of plant species: (a) which are good *Nardion* indicator species; and (b) unfavourable species in *Nardion* grasslands defined by Eggenberg *et al*. (2001). Good *Nardion* indicator species are specialized, acidophilic and oligotrophic species. Eutrophic species represent the biggest part of unfavourable species (U). These species are adapted to eutrophic soil condition and are not regarded as typical *Nardion* grassland species and therefore their present is unfavourable within these grasslands. Only species which occurred at least once in the vegetation surveys are listed here from the species defined by Eggenberg et *al*. (2001).

a) *Nardion* indicator species	**b) Unfavourable species (U)**		
	Eutrophic species		**Other unfavourable species**
Antennaria dioica	*Anthriscus sylvestris*	*Taraxacum officinale*	*Briza media*
Arnica montana	*Arrhenatherum elatius*	*Trifolium repens/thalii*	*Centaurea scabiosa*
Astrantia minor	*Carum carvi*	*Trisetum flavescens*	*Helictotrichon pubescens*
Campanula barbata	*Cynosurus cristatus*	*Veronica chamaedrys*	*Leucanthemum vulgare*
Crepis conyzifolia	*Dactylis glomerata*	*Agrostis capillaris*	*Fragaria vesca*
Gentiana punctata	*Festuca arundinacea*	*Bellis perennis*	*Luzula sylvatica*
Geum montanum	*Festuca pratensis*	*Festuca rubra aggr.*	*Trifolium medium*
Hieracium lactucella	*Galium album*	*Alchemilla vulgaris*	*Vicia sepium*
Hypochaeris uniflora	*Heracleum sphondylium*	*Chaerophyllum villarsii*	
Leontodon helveticus	*Holcus lanatus*	*Crepis aurea*	
Meum athamanticum	*Knautia arvensis*	*Geranium sylvaticum*	
Nigritella rhellicani	*Lolium multiflorum*	*Phleum alpinum aggr.*	
Potentilla aurea	*Phleum pratense*	*Poa alpina*	
Pseudorchis albida	*Pimpinella major*	*Polygonum bistorta*	
Ranunculus villarsii	*Poa pratensis*	*Ranunculus tuberosus*	
Sempervivum montanum	*Poa trivialis*	*Silene dioica*	
Trifolium alpinum	*Ranunculus acris*	*Trollius europaeus*	
Viola lutea	*Rumex acetosa*		

Table 2: Description of all explanatory variables used for the first step of the data analysis of pastures and meadows. Variables are categorized into three separate groups according to their properties: a) environment; a) management; and c) soil. The three response variables and random factor used for the linear mixed-effect models in the first step are listed at the end of the table. In brackets after the variable name, it is indicated if a variable was only used for the analysis of pastures or meadows and if a variable was highly correlated (Spearman correlation coefficient |rs| > 0.6) with another variable and therefore removed for further analyses. The column type shows if a variable was continuous or categorical, the column source indicates how the information was obtained and the description gives further information on the definition and unit of the respective variable.

Variable	Type	Source	Description
a) Environment			
Elevation	Continuous	ArcGIS	[m]
Slope	Continuous	In the field	Slope of the grassland where the vegetation survey was done [°]
Area	Continuous	ArcGIS	Area protected by the Bernese government [m^2]
Exposition	Continuous	In the field	Exposition recorded with a compass [degree] and cosine-transformed to disentangle the north and south exposition [-1:1]
b) Management			
Time of first grazing (pastures)	Continuous	Interview	Ordinal date at which livestock is put on the grassland the first time [0 : 365]
Days of grazing (pastures)	Continuous	Interview	Sum of days the livestock is grazing over all grazing periods
GVE per area (pastures)	Continuous	Interview/ ArcGIS	Livestock unit per total area grazed [ha] (the area of the whole pastures not only the area of the *Nardion* grassland) * Days of grazing / 100 (to account for the fact that the pastures are only used in summer)
No grazing periods (pastures)	Categorical	Interview	Is the livestock put once or more than once on the grassland [1/2+]
Travel time	Continuous	Interview	Time the farmer needs to reach the grassland [minutes].
Fertilization	Categorical	Interview	Is there any type of fertilizer currently applied on the grassland [no/yes]
Time of cut (meadows)	Continuous	Interview	Date at which the meadow is cut
c) SOIL			
pH	Continuous	Dissolved in $CaCl_2$	Acidity of the soil (acid: [1-6], neutral: [7] and alkaline: [8-14])
P (removed due to high correlation with pH)	Continuous	Olsen method	Phosphate content in the soil [mg/l]

C (removed due to high correlation with N)	Continuous	CNS-analysis	Carbon concentration in the soil [% of weight].
N	Continuous	CNS-analysis	Total nitrogen concentration in the soil [% of weight]
S (removed due to high correlation with N)	Continuous	CNS-analysis	Sulphur concentration in the soil [% of weight]
C/N ratio	Continuous	CNS-analysis	Ratio of carbon/nitrogen in the soil
d) OTHER VARIALBES			
Cover of *N. stricta*	Continuous	Relative cover estimates from the vegetation survey	The relative cover of *N. stricta* in a plot of 28 m^2 [%]
Cover of eutrophic species	Continuous	Relative cover estimates from the vegetation survey	The sum of the relative covers of all eutrophic species (Table 2) in a plot of 28 m^2 [%]
Nardion grassland quality index	Continuous	Calculated values based on relative cover estimates	Integral measure: sums up the Shannon index of the total vegetation survey, the Shannon index *Nardion* indicator species and subtract the *N. stricta* cover and the cover of other unfavourable species (Definition of plant species see Table 4)
Region (random factor)	Categorical	-	All grasslands belong to a defined region: Diemtigtal, Kandertal, Tschingel, Lenk, Niesen and Zweisimmen

Table 3: Results of the second step of the model selection (pastures only): output of the function 'dredge' from the MuMIn package (Barton 2016) for the three response variables a) *N. stricta,* b) eutrophic species and c) *Nardion* grassland quality index. All competitive models within ΔAICc of 2 are listed and their goodness-of-fit is indicated by the marginal and conditional R^2 calculated with the function 'sem.model.fits' from the piecewiseSEM R-package (Lefcheck 2015). Abbreviations for explanatory variables: A = Area; CN = soil Carbon/N ratio; E = Elevation; FG = Time of first grazing; GP = Number of grazing periods; GD = Number of grazing days; N = total nitrogen concentration; EX = Exposition; PH = soil pH; LVA= livestock unit per area grazed.

Response variables	Models with ΔAICc ≤ 2	Df	AICc	ΔAICc	Weight	Marginal R^2	Conditional R^2
a) *N. stricta*	GP + FG + FG ^{2}+ EX	7	102.6	0.00	0.473	0.472	0.477
	GP + EX	5	103.9	1.34	0.242	0.292	0.372
b) Eutrophic species	A + CN	5	104.5	0.00	0.123	0.335	0.337
	A + GP + PH +PH^2	7	105.0	0.45	0.098	0.439	0.439
	A + PH + PH^2	6	105.4	0.84	0.081	0.393	0.393
	A + CN + N	6	105.5	0.93	0.077	0.390	0.419
	A + CN + GP	6	105.5	0.99	0.075	0.361	0.361
	A	4	105.7	1.15	0.069	0.238	0.238
	A + GP	5	105.8	1.26	0.065	0.286	0.286
	CN + N	5	106.2	1.68	0.053	0.306	0.458
	A + CN + GP + N	7	106.3	1.75	0.051	0.416	0.426
c) *Nardion* grassland quality index	E	4	123.5	0	0.348	0.213	0.213
	E + A	5	124.7	1.2	0.19	0.257	0.257
	E + GD	5	125	1.51	0.163	0.249	0.249
	E + LUA	5	125.4	1.85	0.138	0.244	0.244

Table 4: Averaged models from of the second step of the pastures analysis. All competitive models within ΔAICc ≤ 2 from the dredge function are average with the 'model.avg' function of the 'MuMIn' R-package (Barton 2016) for the three response variables a) *N. stricta*; b) eutrophic species; and c) *Nardion* grassland quality are listed: estimates, unconditional standard errors (SE), confidence interval for the estimates and relative importance. In bold are variables with a confidence interval for the estimate not including zero (key variables which influence the respective response variable). The relative importance is indicating the importance of the variable relative to the other explanatory variables within the competitive models.

Variables	Estimate	Unconditional SE	Confidence interval	Relative importance
a) *N. stricta*				
(Intercept)	0.380	0.206	(-0.041, 0.801)	
N° grazing periods	-0.759	0.263	**(-1.298, -0.219)**	1.00
Time of first grazing (linear)	-0.159	0.155	(-0.506, 0.025)	0.66
Time of first grazing (quadratic)	0.238	0.198	**(0.100, 0.617)**	0.66
Exposition (linear)	0.397	0.132	**(0.127, 0.667)**	1.00
b) Eutrophic speices				
(Intercept)	-0.089	0.214	(-0.521, 0.342)	
Area (linear)	-0.397	0.189	**(-0.743, -0.119)**	0.92
C/N ratio (linear)	-0.193	0.215	**(-0.684, -0.043)**	0.53
N° grazing periods	0.188	0.287	(-0.140, 1.025)	0.43
pH (linear)	0.001	0.082	(-0.311, 0.318)	0.29
pH (quadratic)	-0.117	0.198	**(-0.679, -0.141)**	0.29
N	-0.073	0.144	(-0.578, 0.016)	0.26
(C) *Nardion* grassland quality index				
(Intercept)	3.054	0.185	**(2.675, 3.433)**	
Elevation	0.587	0.193	**(0.193, 0.981)**	1.00
Days of grazing	-0.286	0.188	(-0.670, 0.097)	0.23
Area	0.271	0.194	(-0.126, 0.667)	0.19
Livestock unit per area grazed	-0.242	0.188	(-0.627, 0.142)	0.16

Table 5: All explanatory variables with a *P* < 0.1 in the linear mixed-effect models of the meadow analysis. In bold are variables with a *P* < 0.05 for at least one of the response variables.

	***N. stricta* cover**				**Eutrophic species cover**				***Nardion* grassland quality index**			
	Estimate	SE	*P*	R^2	Estimate	SE	*P*	R^2	Estimate	SE	P	R^2
a) Environmental												
Elevation	**0.622**	**0.261**	**0.049**	**0.387**	-	-	-	-	-	-	-	-
Slope	**0.685**	**0.243**	**0.026**	**0.469**	-	-	-	-	-	-	-	-
b) Management												
Travel time	**0.697**	**0.230**	**0.019**	**0.5644**	-	-	-	-	-	-	-	-
c) Soil												
pH	-0.612	0.264	0.054	0.3740	**0.823**	**0.199**	**0.004**	0.773	-	-	-	-

8. Figures

Figure 1: Typical *Nardus stricta* turf early in the season when its nutrient level is still high.

Figure 2: Typical *Nardion* grassland species found in the Bernese Prealps (left to right: *Campanula barbata, Gentiana purpurea, Arnica montana, Geum montanum, Nigritella nigra*).

Figure 3. Definition of the federal criteria for the assessment of species-rich and degraded *Nardion* grasslands. (Eggenberg *et al.* 2001). The assessment is divided into two steps: first the grassland must fulfil both aspects of the main criteria (for meadows only one aspect must be fulfilled). Second, one aspect of the subcriteria must be fulfilled and if both, main- and subcirteria are fulfilled, the grassland is classified as species-rich *Nardion* grassland. The definition of unfavourable species and *Nardion* indicator species is shown in Table 1.

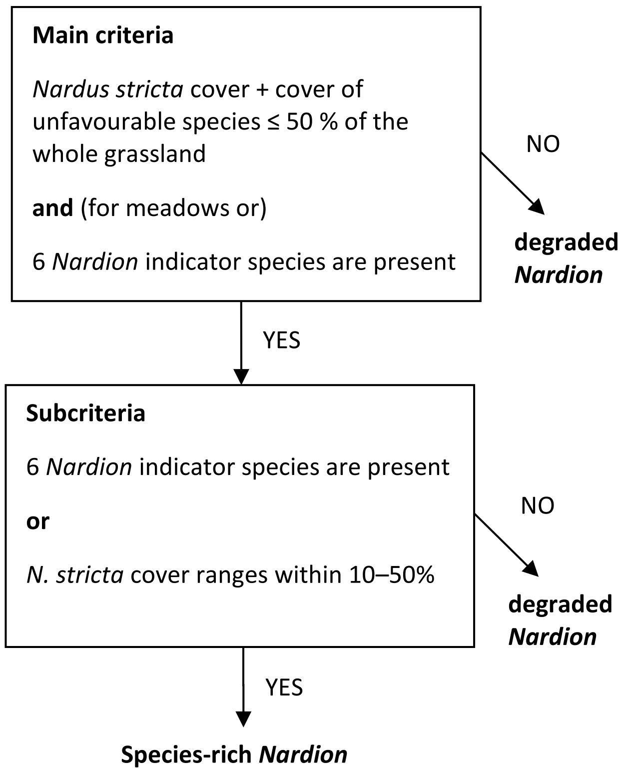


Figure 4: Degraded *Nardion* grasslands driven either by a strong dominance of *N. stricta* (left) or of eutrophic species (right).

Figure 5: The study sites in the northern Prealps of the canton Berne were arranged into the six regions/valleys: Zweisimmen; Diemtigtal; Lenk; Niesen; Kandertal and Tschingel. Species-rich grasslands are indicated in green, degraded grasslands are coloured in blue or red depending on their degradation reason (blue= eutrophic species dominated; red =N. stricta dominated grasslands). Sources: World Topographic Map (ESRI) and https://www.weltkarte.com.

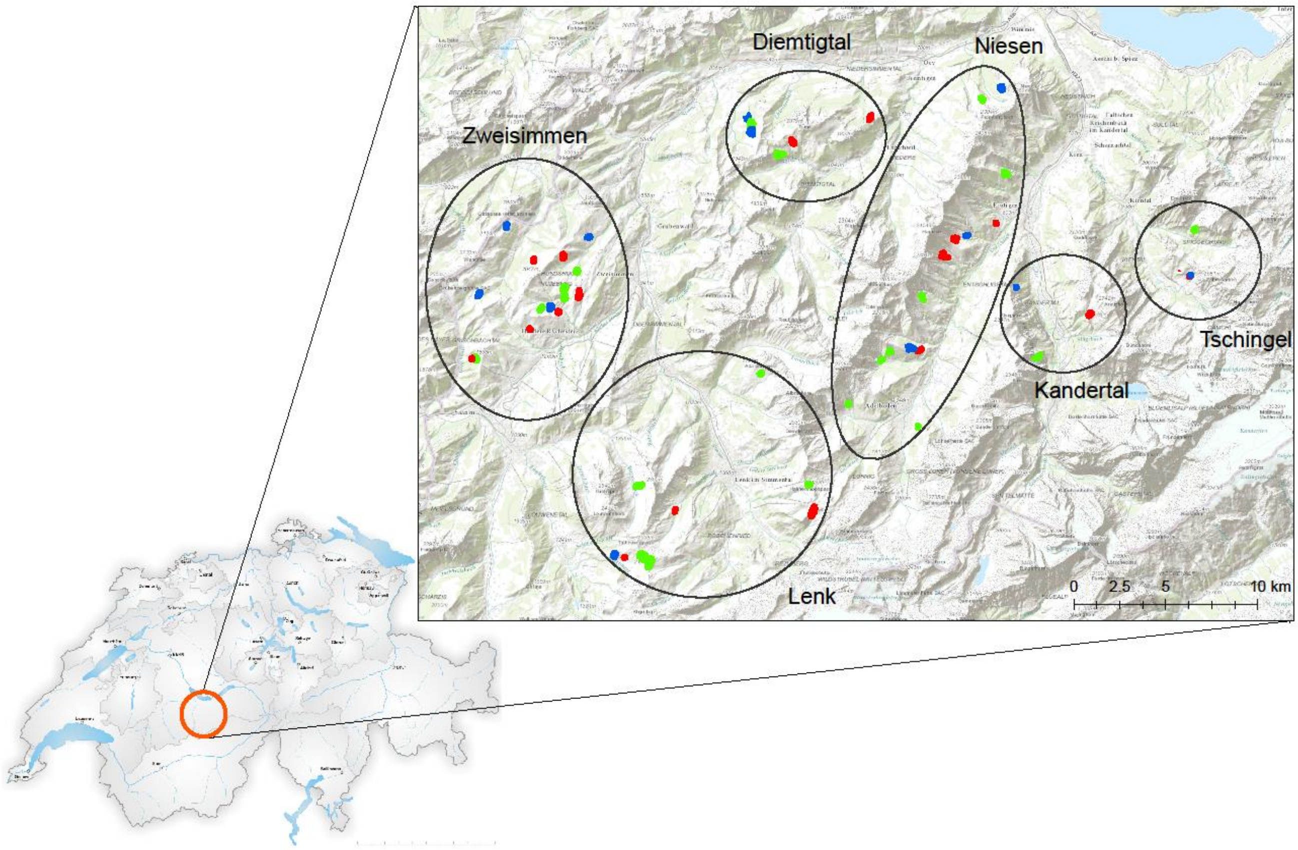


Figure 6: Cantonal assessment of grasslands into species-rich and degraded *Nardion* grasslands according to the federal classification criteria (Eggenberg *et al.* 2001) is shown in dark grey and the assessment based on the vegetation survey of the present study following the same criteria is indicated in bright grey. Degraded grasslands are either *N. stricta* dominated (*N. stricta* dom.) or eutrophic species dominated (eutrophic dom.).

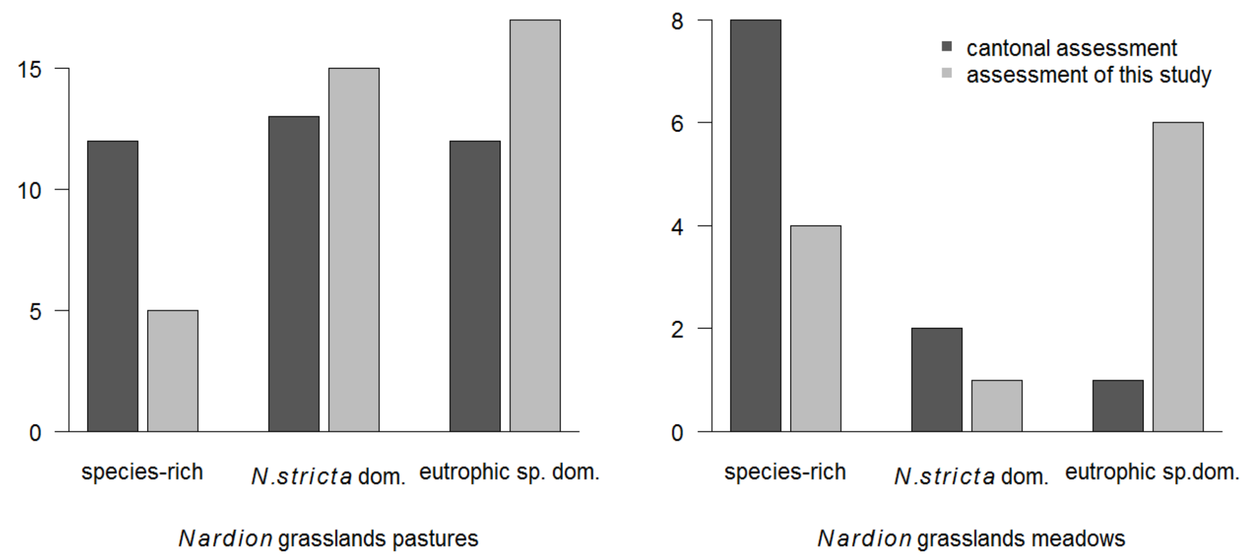


Figure 7: Significant relationships (based on univariate linear mixed effect models, alpha rejection level of 0.05) between *N. stricta* cover and a) exposition (1 = northern and -1 = southern exposition) and b) time of first grazing. *N. stricta* is increasing with elevation and lowest cover were observed in pastures grazed the first time in year around the 28th of June (=180). Circles indicate species-rich and triangles degraded *Nardion* grasslands.

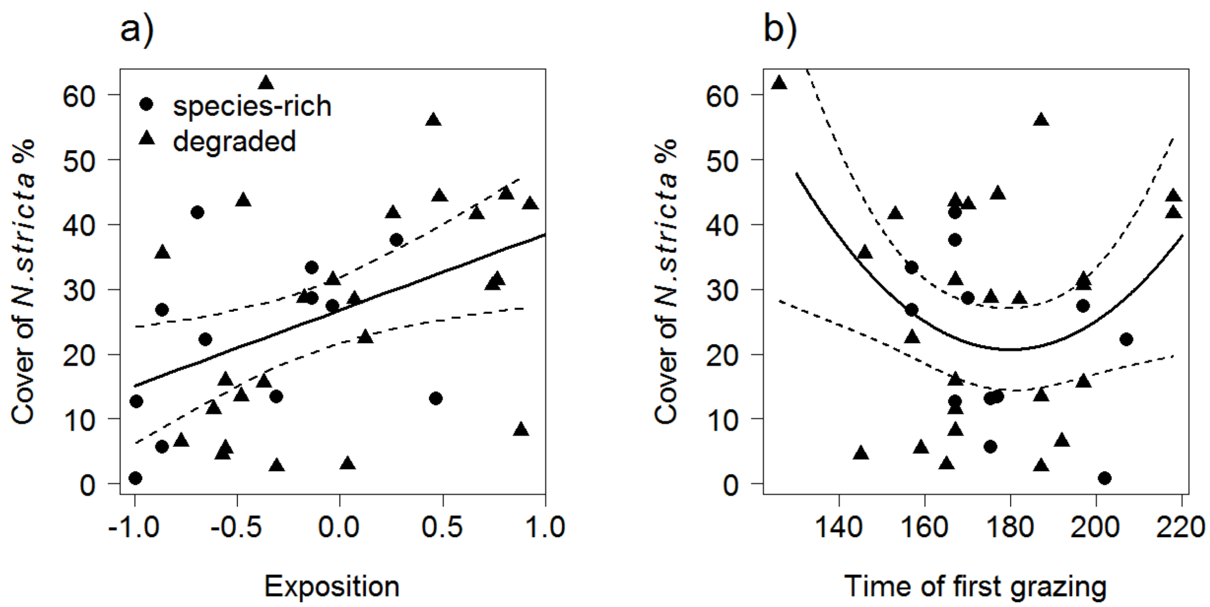


Figure 8: *N. stricta* cover with respect to a) Number of grazing periods and b) the relation of the number of grazing periods to days of grazing (median: bold line; mean: cross; first and third quartiles: box borders; interquartile distance multiplied by 1.5: whiskers, n = number of replicates per category). The star indicates significant differences between the number of grazing periods based on the univariate linear mixed effect models at an alpha rejection level of 0.05. Higher *N. stricta* cover was observed in pastures with only one grazing period than in pastures with two or more grazing periods. Pastures with one grazing period had significantly more grazing days (sum of grazing days over all grazing periods) than those with two or more grazing periods.

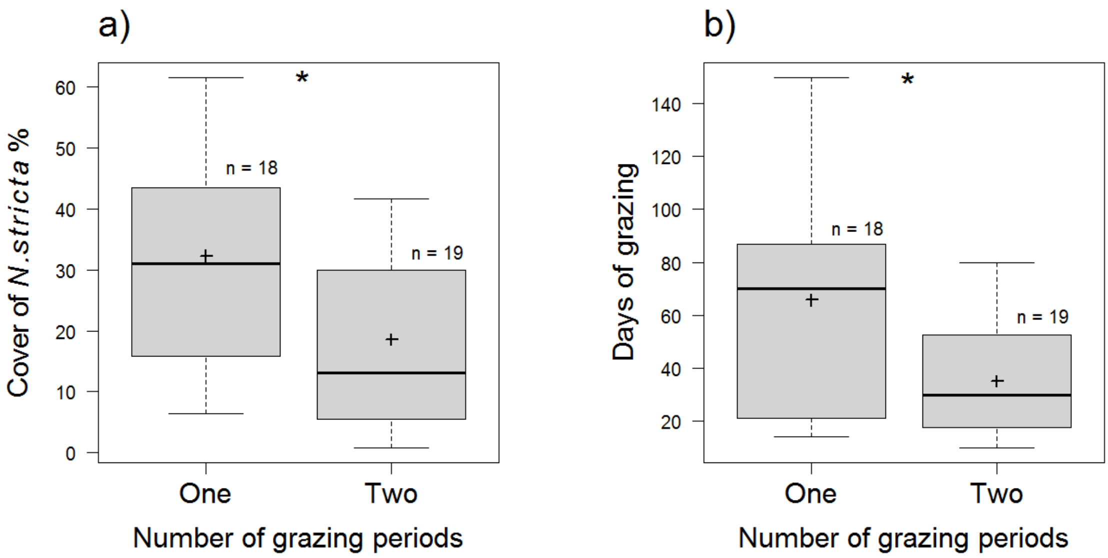


Figure 9: Significant relationships (based on univariate linear mixed effect models, alpha rejection level of 0.05) between eutrophic species and a) soil C/N ratio, b) soil pH and c) area. Eutrophic species had lower cover with an increase of soil C/N ratio, where most abundant at intermediate soil pH of 4.4 and are increasing with size of the *Nardion* grassland. Circles indicate species-rich and triangles degraded *Nardion* grasslan

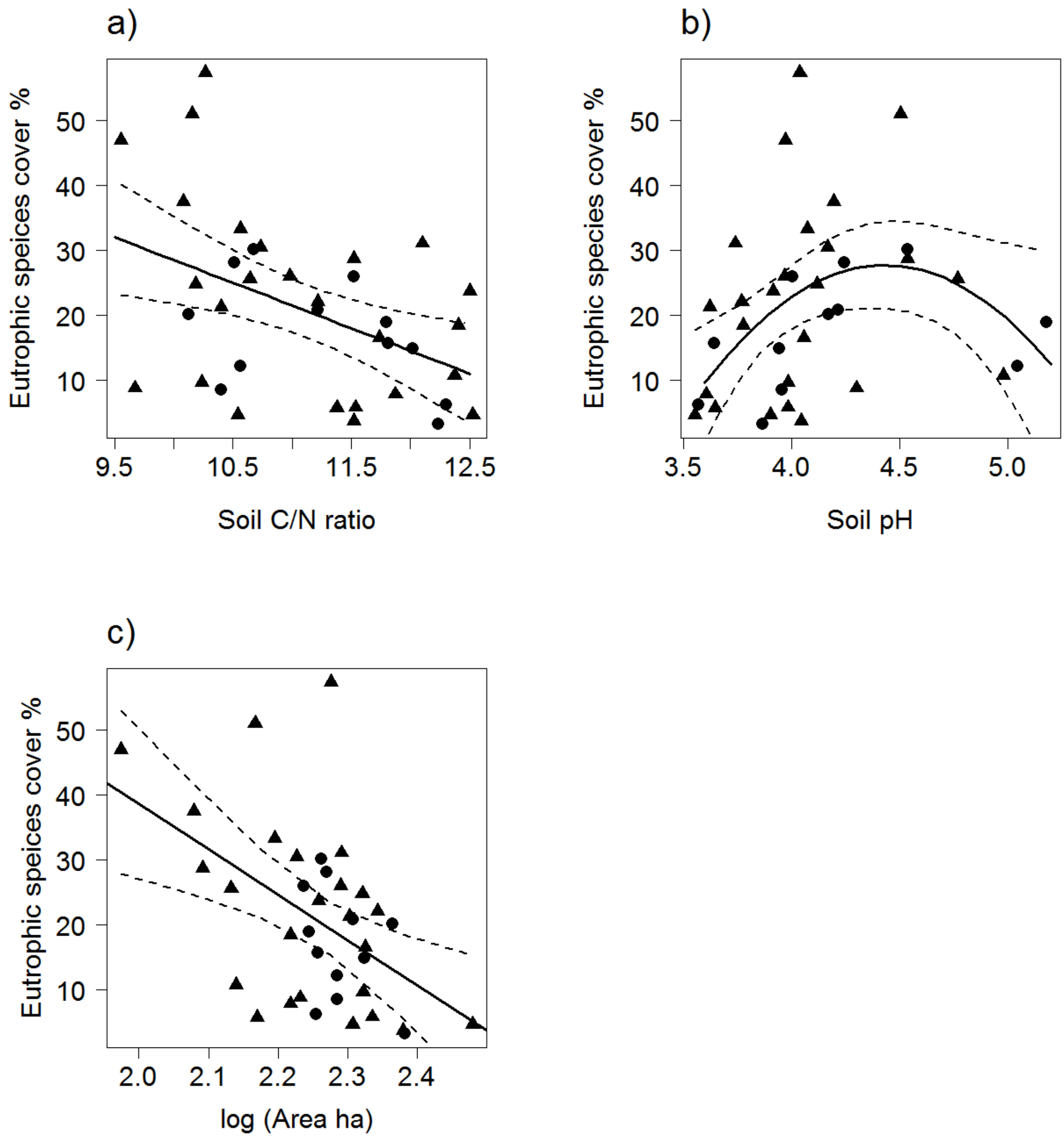


Figure 10: Significant relationship (based on univariate models , alpha rejection level of 0.05) between *Nardion* grassland quality index and elevation. Pastures at higher elevation have higher quality than low elevated pastures. Quality is defined by the *Nardion* grassland quality index which ranges from zero to one, one being the best possible quality and zero the poorest. More specifically, a quality index of one represent a grassland with a high Shannon index of the overall vegetation and of *Nardion* indicator species, a *N. stricta* cover lower or equal to 24.3% and absence of eutrophic species (see Table 10). Circles indicate species-rich and triangles degraded *Nardion* grasslands.

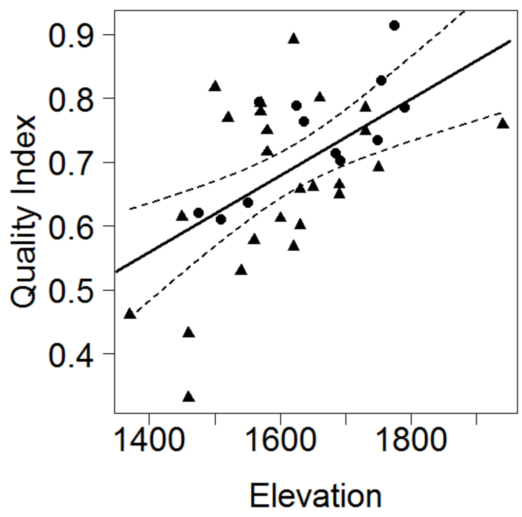


Figure 11: Correlation plot from the function 'corrplot' (Wei & Simko 2016) of all variables of Table 2 for pastures. Indicated are Spearman correlation coefficients and significant correlations based on an alpha rejection level of 0.1 are framed by a blue (positive correlation) or red (negative correlation) square.

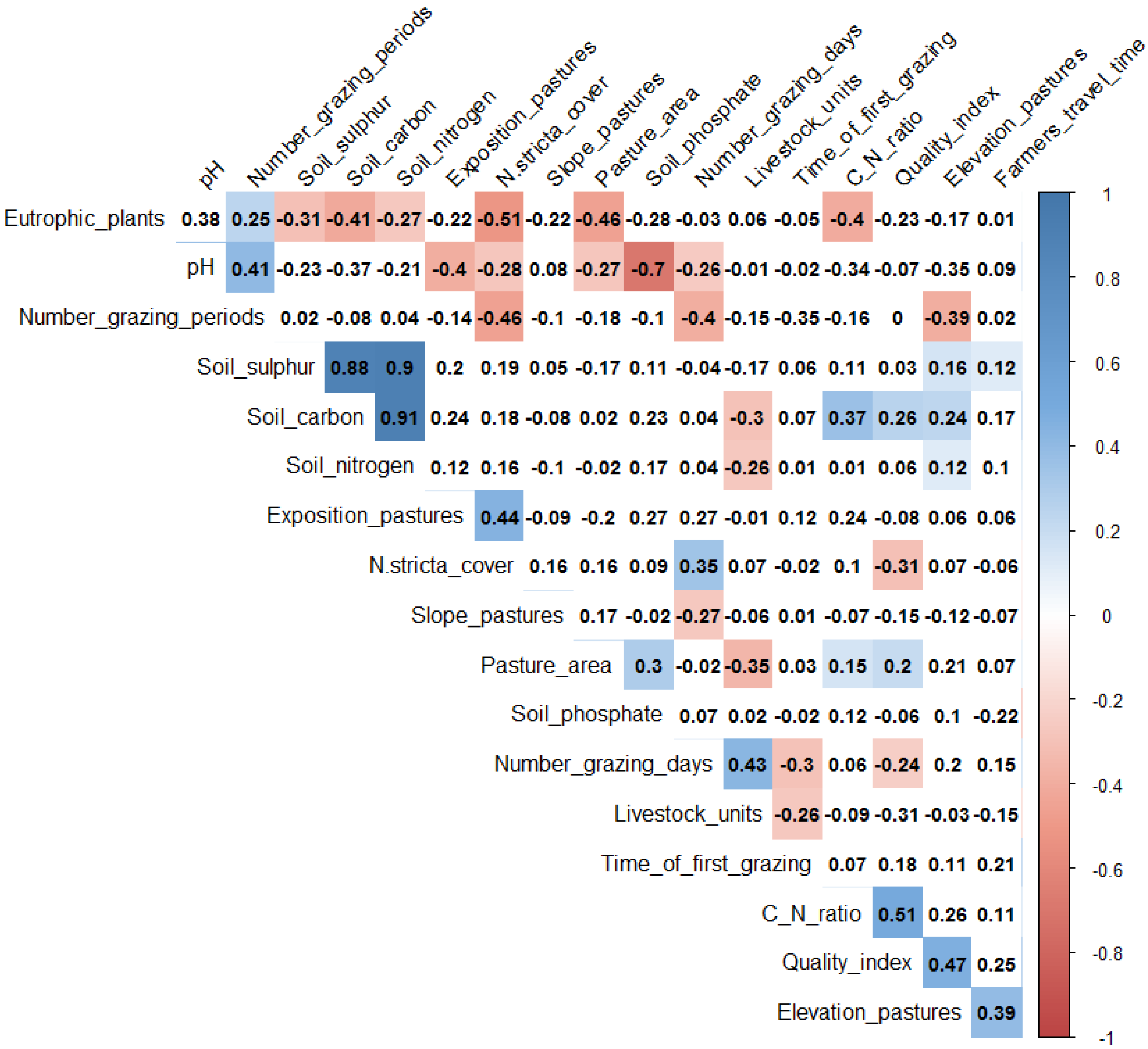
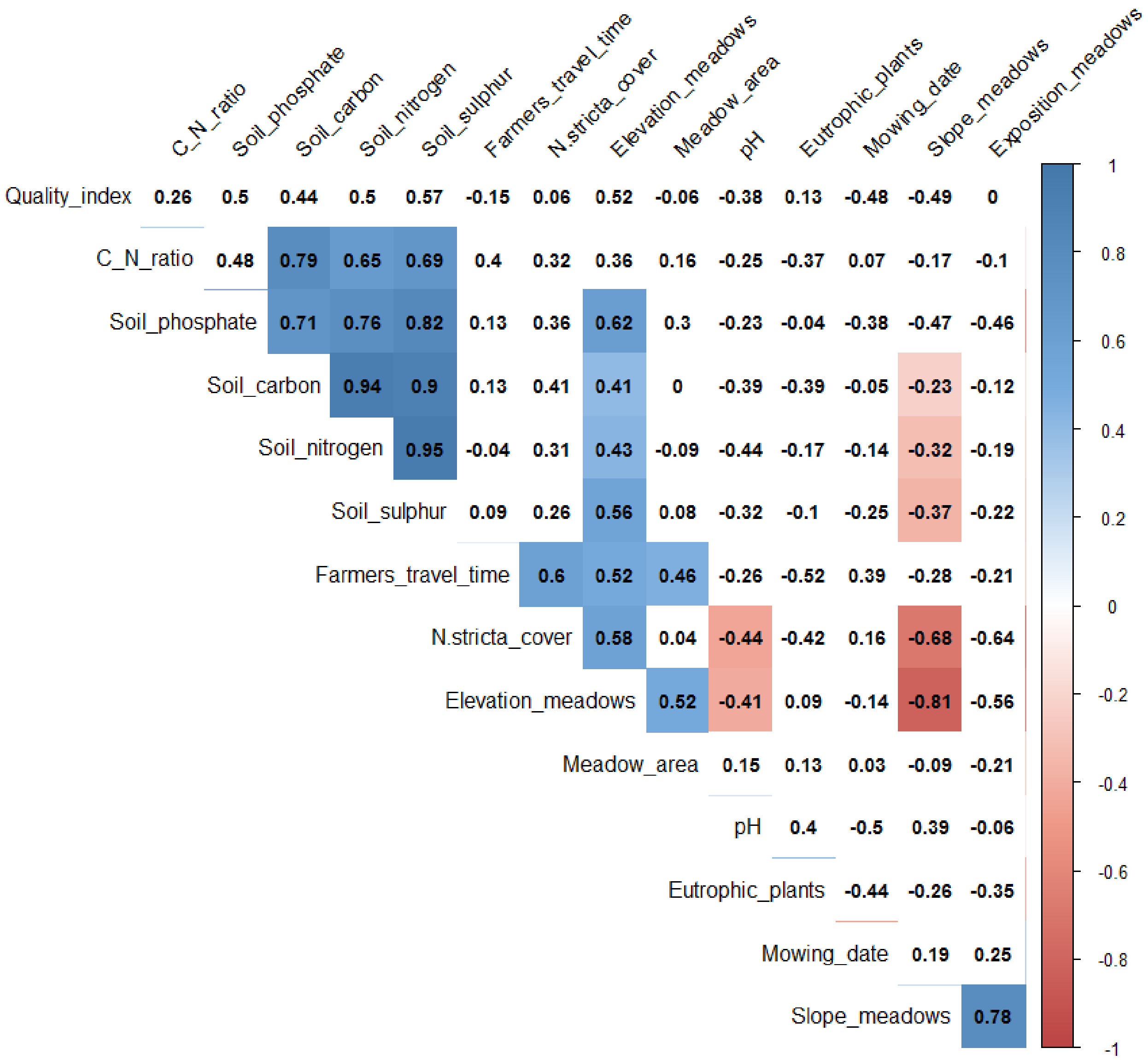


Figure 12: Correlation plot from the function 'corrplot' (Wei & Simko 2016) of all variables of Table 2 for meadows. Indicated are Spearman correlation coefficients and significant correlations based on an alpha rejection level of 0.1 are framed by a blue (positive correlation) or red (negative correlation) square.



Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix A: Description and detailed information of the study sites and on the questionnaire to interview farmers on management practises.

Appendix B: ArcGIS file with detailed information on the location of the study site.

Appendix A

Table A1: Inventory of the canton of Berne for all *Nardion* grasslands sorted by management practise (pastures or meadow) and status (species-rich or degraded) in 2014.

Management practise	**Species-rich *Nardion* grasslands**	**Degraded *Nardion* grasslands**	**Total**
Meadow	60	7	67
Pasture	46	56	102
Total	106	63	169

Table A2: Detailed information on all investigated grasslands. X- and Y-Coordinates are indicted in the Swiss coordinate system CH1903. Identification numbers are given by the cantonal authorities to identify the grasslands. Exposition and slope were measured in the centre of the vegetation survey. After visiting all grassland, five meadows were discarded and the specific reasons are indicated in the last column.

Land-use	Identification number	Elevation [m. a. s. l]	Area [ha]	Exposition [°]	Slope [°]	X-Coordinate	Y-Coordinate	Reasons for exclusion
Pasture	5591	1370	0.1346	83	21	312986	158004	-
Pasture	621	1450	1.0645	125	20	592362	157899	-
Pasture	3601	1460	1.1093	285	24	608847	151911	-
Pasture	3600	1460	2.6777	249	32	609847	155911	-
Pasture	1522	1475	2.3010	150	40	2614983	1161365	-
Pasture	620	1500	1.9282	112	21	607696	164443	-
Pasture	1676	1509	4.1733	172	23	602633	162331	-
Pasture	792	1520	0.4881	260	31	558990	151332	-
Pasture	266	1540	0.2984	318	38	624442	156076	-
Pasture	8513	1551	1.5868	150	22	591052	154604	-
Pasture	3539	1567	1.2429	186	21	625292	158258	-
Pasture	1838	1570	0.9793	86	30	590685	153866	-
Pasture	1836	1570	1.4231	28	12	590259	154150	-
Pasture	6163	1580	15.2520	320	30	609847	151911	-
Pasture	541	1580	0.4613	236	39	625056	156831	-
Pasture	1563	1600	3.3096	61	30	611691	156167	-
Pasture	8510	1620	3.0682	124	24	591818	154739	-
Pasture	5592	1620	2.2975	63	23	612267	157809	-
Pasture	790	1625	1.4799	298	21	586205	151405	-
Pasture	5860	1630	2.6439	210	19	603452	163033	-
Pasture	8503	1630	0.3287	36	10	619651	153789	-

Pasture	7789	1636	1.3712	74	18	591714	156076	-
Pasture	1835	1650	0.6383	22	30	590243	154008	-
Pasture	8506	1660	4.8706	268	38	601224	163642	-
Pasture	211	1685	4.99	268	21	601215	164056	-
Pasture	4633	1690	0.9732	312	22	589379	156642	-
Pasture	7806	1690	0.7923	141	21	587852	158535	-
Pasture	8229	1691	2.7143	134	38	590967	155053	-
Pasture	4625	1730	1.9568	119	28	590957	156882	-
Pasture	4638	1730	1.6970	108	18	586310	154746	-
Pasture	1834	1748	1.4012	98	20	589476	154032	-
Pasture	8348	1750	2.7753	242	36	614771	165879	-
Pasture	3863	1754	1.8438	98	22	610499	154692	-
Pasture	843	1774	1.8430	131	22	616710	151420	-
Pasture	8371	1790	1.1653	252	20	613745	165261	-
Pasture	837	1940	2.1942	88	32	615596	115175	-
Meadow	3998	1000	0.2858	90	42	614484	158667	No *N. stricta*
Meadow	3592	1475	0.5629	120	43	608254	151249	-
Meadow	2996	1512	0.4097	95	33	610240	147638	-
Meadow	265	1530	0.3419	230	30	625022	155762	-
Meadow	3596	1558	1.6181	80	43	608720	151734	-
Meadow	1826	1560	0.6185	232	32	589190	152913	Pasture, used in pasture analysis
Meadow	132	1580	0.3606	184	38	609931	151926	No meadow
Meadow	3629	1585	0.6809	24	39	606482	148955	-
Meadow	8469	1640	0.4330	92	32	597031	143095	-
Meadow	4587	1660	2.5735	184	22	593752	140732	-
Meadow	2999	1680	0.4036	232	8	594287	140591	-
Meadow	2657	1724	2.6172	252	30	595045	144451	encroachment
Meadow	1263	1885	0.9944	172	10	601777	150581	-

Meadow	1220	1925	1.3498	218	4	604313	144553	-
Meadow	4606	2000	6.1736	144	38	604578	143105	No *N. stricta*
Meadow	1791	2013	17.6061	240	24	595578	140327	-

Table A 3: Questionnaire used to investigate the management practises of pastures and meadows. The objectives are the variables used for the analysis and the questions used to retrieve the information on them are listed. For each question, a defined type of answer was possible which is indicated in the last column.

Objectives	Questions	Possible answers type
Type of livestock (pastures)	What kind of livestock is grazing the respective area?	Categorical (cow, cattle(one year old cows), calf, horses, goats, lamas); multiple answers are possible
Number of livestock units (pastures)	How many animals of each kind are grazing the respective area?	Continuous, sum off the multiplication of the coefficient times the number of the respective livestock divided by 100 (Schweizerischer Bundesrat 2013) Coefficients: cow= 1, cattle = 0,40, calf = 0,33, horse = 0,70, lama=0,17, goat = 0,17
Grazing periods (pastures)	How many grazing periods are applied?	Categorical (one, two or more)
Time of first grazing (pastures)	At what date does the first grazing of the year occur on average?	Continuous (integer number between 1-365)
Travel time	How many minutes does it take the farmer to reach the grassland from your place of residence?	Continuous (minutes)
Incentives for farming	What are your incentives for managing the respective area?	Categorical (traditional reasons, financial subsidies, yield, stop encroachment, others); multiple answers are possible
Application of fertilizer	Is the grassland currently fertilized (2016)?	Categorical (yes, no)
Management intensity before	How was the management intensity before the current management?	Categorical (higher, lower, equal)
Time span the management of 2016 was already applied in the past	Since how many years do you manage the grassland with the management practise applied in 2016?	Continuous (years)
Number of cuts (meadows)	How many times do you cut the meadow within one year?	Continuous
Time of the first cut (meadows)	When do you cut the meadow?	Continuous (integer number between 1-365)

Erklärung

gemäss Art. 28 Abs. 2 RSL 05

Name/Vorname: Rieder Nora

Matrikelnummer: 12-125-704

Studiengang: Master

Titel der Arbeit: „ Conservation and restoration of *Nardion* grasslands in the Swiss northern Prealps “

Leiter der Arbeit: Dr. Jean-Yves Humbert

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe r des Gesetzes vom 5. September 1996 über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist. Ich gewähre hiermit Einsicht in diese Arbeit.

Ort/Datum Unterschrift