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Control of purple moor-grass (*Molinia caerulea*) and the plant diversity on Randbøl Hede

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Abstract

The traditional management (burning, cutting and grazing) of heathlands are being abandoned and at the same the heathlands are being exposed to increasing amount of nutrients coming from atmospheric deposition. These changes have led to a decrease in species diversity and the encroachment of the problem species *M. caerulea*. *M. caerulea* are outcompeting the dwarf shrubs, which originally dominated the heathlands.

This study investigated managements' effectiveness on increasing the number of species, control of *M. caerulea* and restoring the dwarf shrub species, *C. vulgaris*, *E. tetralix* and *E. nigrum* at Randbøl Hede, a heathland in Denmark. The effectiveness was studied by comparing the effect on number of species, cover of *M. caerulea* and the cover of dwarf shrubs for managed areas to areas without management. The effect was studied in both short- and long-term. The managements investigated in the study were, burning, burning combined with clearing, burning combined with cutting, burning combined with cutting and grazing, burning combined with grazing, clearing, cutting and grazing.

Most of the management showed to have no effect. Except for grazing and burning. Grazing gave a higher number of species both in the short and long-term. Comparing the long-term effects grazing also gave a lower cover of *M. caerulea*. The long-term effect of burning decreased the cover of *M. caerulea* the first year but the cover increased afterwards, which indicated the need for follow-up management. There was no cover of *C. vulgaris* the first year with burning, but the cover increased to be higher compared no management.

Resumé

Før i tiden blev afbrænding, slåning og græsning praktiseret på heder, men disse aktiviteter er faldende og samtidig er heder udsat for stigende næringsindhold fra atmosfærisk deposition. Dette har ført til faldende artsdiversitet og stigning af problemarten *M. caerulea*. *M. caerulea* udkonkurrere dværgbuskearterne som oprindeligt dominerede hederne.

Studiet undersøger forskellige forvaltningsaktiviteters effekt på øgning af antallet af arter, kontrol af M. caerulea, og bevarelse af dværgbuske arterne; *C. vulgaris*, *E. tetralix* and *E. nigrum*, på Randbøl Hede i Danmark. Effekten blev undersøgt ved at sammenligne effekten på antallet af arter, dækningsgraden af *M. caerulea* og dækningsgraden af dværgbuskene, mellem forvaltede og ikke forvaltede områder. Både den kortsigtet og langsigtet effekt blev undersøgt. Forvaltningsaktiviteterne som blev undersøgt var, afbrænding, afbrænding kombineret med rydning, afbrænding kombineret med slåning, afbrænding kombineret med slåning og græsning, afbrænding kombineret med græsning, rydning, slåning og græsning.

De fleste af forvaltningsaktiviteterne viste ikke nogen effekt. Udover græsning og afbrænding. Græsning gav at højere antal arter både på kortsigtet og langsigtet effekt. Den langsigtede effekt af græsning gav også en lavere dækningsgrad af *M. caerulea*. Den langsigtede virkning af afbrænding reducerede dækningsgraden af *M. caerulea* det første år, og efterfølgende steg dækningsgraden. Dette indikere at der er brug for forvaltning til at følge op efter afbrænding. Der var ingen dækning af *C. vulgaris* det første år med afbrænding, men dækningsgraden steg til at være højere end for områder uden forvaltning.

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Introduction

Semi-natural grasslands

Semi-natural grassland is a term for areas developed by human influence, mainly through grazing and cutting for more than thousands of years (Van Dijk 1991, Hopkins 2009). Humans clearing woodland and draining marshland for pastoral farming have led to semi-natural grassland. These areas still have a predominance of native species despite human intervention. Therefore, the areas remain "unimproved" in agricultural terms (Hopkins 2009). The vegetation found in semi-natural grasslands consist of different type of grasses, herbs, sedges, rushes and mosses (Bullock et al. 2011). Nutrient poor-soil and management with cutting and grazing have led to the high diversity of species connected to semi-natural grasslands (Hansson and Fogelfors 2000, Bullock and Pakeman 1997). Over time, semi-natural grasslands have become depleted of nutrients by the constant removal of plant material by cutting (Hansson and Fogelfors 2000). Besides increasing the diversity of plants, grazing affect the composition of the vegetation and increase the cover of bare ground (Bullock and Pakeman 1997).

Semi-natural grasslands in Europe have high biological diversity, and a great part of the most threatened bird species, vascular plants, and insects in Europe are linked to the semi-natural grasslands. In contrast to other nature types, e.g. forests, semi-natural have to be managed and preserved to ensure that the area continues to meet these species' requirements (Emanuelsson 2008). If nothing is done to keep the vegetation on a grassland level it will eventually evolve into a forest (Bullock et al. 2011, Webb 1998). The recreational value of semi-natural grassland is often high, and more studies have shown that people have a high preference for "pastoral landscape" for recreational activities. In many European countries, semi-natural grassland is also a part of the cultural heritage. Semi-natural grassland also provides an opportunity to produce meat and dairy products with no or minimal negative effect on the landscape, and in way which are highly acceptable from an animal ethics perspective (Emanuelsson 2008).

Abandonment of semi-natural grasslands leads to changes in the area's ecosystem services. In general, managed semi-natural grasslands have higher nutrient cycling, forage quality, regional climate regulation, aesthetics, and species than semi-natural grassland abandoned (Johansen et al. 2019).

The status of semi-natural grassland in Europe

The intensification of agriculture has led to a decline of semi-natural grasslands since the 1940s. Semi-natural grasslands produce less than half of the production from improved grasslands. Up to the decline of semi-natural grassland, grassland agriculture in Europe was of low intensity. It made it possible for habitat diversity to co-exist with food production (Hopkins 2009).

For a long time, semi-natural grasslands were not something the European nature conservation was particularly concerned about. The focus was more on forests, mountain areas, and wetlands. Many grasslands in Europe were regarded as a product of degenerating hypothetical mighty forests, and with influence from the USA, grasslands were seen as areas possible for restoring disappeared forests. However, more countries in Europe got to focus on their natural grasslands and started a conservation program (Emanuelsson 2008). Nature and landscape conservation has been incorporated within EU farm policy due to negative consequences of habitat loss and other environmental damage. Outside the EU, some states have made similar changes in their policy. During the Convention on Biological Diversity in 1992, several countries added the protection of biodiversity within agricultural habitats as a commitment under the terms of the convention (Hopkins 2009).

Even though the decline of semi-natural grasslands has led to policy support through agri-environment schemes, intensification of agriculture and poor management or abandonment continue to threaten the remaining semi-natural grasslands areas (Hopkins 2009. There has only been more obvious attention on semi-natural grasslands at a European level for the last twenty years. In 2004 through EEA (the European Environmental Agency in Copenhagen), the EU started to invest more in evaluating the semi-natural grassland. However, there are difficulties in rating the value of the area from a conservation perspective and defining semi-natural grassland, e.g. the acceptable level of fertilization for an area to count as a semi-natural grassland (Emanuelsson 2008). The semi-natural grasslands are decreasing in western Europe because the grazing system needed for maintaining the nature type is insufficient. In eastern and central Europe, it is a more mixed situation. In Romania, the semi-natural grasslands are some of the most well managed in Europe (Emanuelsson 2008). However, in the rest of this part of Europe a great part of the semi-natural grasslands are unmanaged due to uncertainty about land ownership and contractions in the agricultural sector. The situation is mixed in Mediterranean Europe as well. There are still many semi-natural grasslands areas left, but the status and number of areas have deteriorated. The semi-natural grassland has started getting more attention in this part of Europe (Emanuelsson 2008).

Heaths/Heathland

Heathlands are of the semi-natural grassland nature type. Heathlands have nutrient-poor soil and are dominated by dwarf shrubs species from the Ericacecae family, which include heather (*Calluna vulgaris*), cross-leaved heather (*Erica tetralix*) and crowberry (*Empetrum nigrum*) (Sprecht 1997, Fagúndez 2013, Gimmingham 1992).

Humans started creating heathlands around 4000 years ago, when they cleared forests for agricultural use, thereby preventing land from regenerating to forest again. The traditional land use of heathlands consisted of grazing stock, cutting turf, cutting vegetation for fuel, burning, and harvesting (Gimingham 1972, Webb 1986). This way of using the land has led to heathland ecosystems with a low nutrient status and an arrested plant succession.

Nowadays, the traditional forms of land use are only performed in a few areas. Therefore, the heathlands are decreasing and changing. Heathlands are considered to have a high potential for nature conservation in Europe due to their importance in biodiversity and cultural value (Webb 1998). Besides the abandonment of the traditional land use, heathlands in Europe are shifting from being nutrient poor to nutrient rich due to the increasing amount of nutrients coming from atmospheric deposition (Naturstyrelsen 2016a). In the last 100 years, the emission of nitrogen has been rising, leading to both increasing contents of nutrients and acidification of the soil (Vogel et al. 2015). Species fitted for a nutritious environment, e.g. *M. caerulea*, dominate the heaths instead of the dwarf shrubs, which dominate under nutrient-poor conditions (Vogel et al. 2013). *Molinia caerulea* is a problem for heaths and their shrub species. For areas, now dominated by *M. caerulea* it is typically, impossible for heaths shrubs species to dominate the areas again (Buttenschøn et al. 2005, Naturstyrelsen 2015). The increasing prevalence of *M. caerulea* is also a result of lacking or insufficient management of the heaths (Aerts 1993).

Overgrowth with woody plants is a natural threat for heaths if the areas are no longer managed with grazing or cutting as they were in older days. Overgrowing is a threat to the “original” plants and animals associated with the heaths. If the heathland is divided into smaller areas, the overgrowing will occur faster. The drainage of wet heath bogs also accelerates the overgrowing process for this type of area. If the heathland has a tight cover of shrubs or grass, it will prevent the overgrowth of woody plants (Naturstyrelsen 2016a).

Since 1800, the heathlands in Denmark have been decreasing because of agricultural practices and conifer plantations (Nielsen 1953). The heathland accounted for 40% of Jutland in 1850, this has reduced to 3.4% in 1965 (Levin and Normander 2008). Heaths with an area size of five ha or bigger were protected under “Naturfredningsloven”(the Nature Conservation Act) in 1984, and in 1992 it was extended to include heaths down to ¼ ha (Buttenschøn and Schmidt 2015).

Management methods

Management is necessary if we want to preserve our heathlands. There are different management methods to restore the heathland and counteract the threats. The management methods have different aims; some reduce the nutrient content, prevent overgrowth or reduce the cover of unwanted or invasive species.

Burning

Burning gives better terms for heath plant species that thrive under nutrient poor conditions e.g. *C. vulgaris*. After treatment, the vegetation will grow again and is not reset. Burning resets the lifecycle for *C. vulgaris* (Naturstyrelsen 2016a, Lindholm 2019). Therefore this method is used to rejuvenate the *C. vulgaris* in areas where the species is old and dying or to reduce the cover of problematic species e.g. *M. caerulea* and trees. However, only conifers below 1-1.5 meters are removed for good with burning, other trees will sprout again after burning, so it is necessary to clear for trees afterward (Naturstyrelsen 2016a). Burning is not helpful for the dwarf shrub *E. nigrum*. The species does not survive burning, and therefore areas with this species have to be protected from burning (Naturstyrelsen 2016a).

Burning can reduce the nutrient content in the treated area if the peat layer is burnt. A lot of nitrogen is removed by burning and only a small amount of phosphor. However, burning the litter layer and lower can damage the roodstock buds and reduce the vegetative regeneration (Barker et al. 2004). Burning the peat layer reduces the nutrient and *M. caerulea* cover, but not the way to restore *C. vulgaris* (Naturstyrelsen 2016a).

M. caerulea can easily survive one burning due to its compact tussocks and well protected grow points. Therefore, it is necessary to burn an area multiple times if the goal is to reduce the cover of *M. caerulea* (Naturstyrelsen 2016a). A study by Brys et al. found that fire had a positive effect on the abundance of *M. caerulea*. The study showed tha*t M. caerulea* in burned areas had higher biomass above ground and increased seed set and germination. The seedling densities were around six times greater in burned than unburned heathland two years after the fire (Brys et al. 2005). However, grazing or cutting can be added after burning to reduce the bloom of *M. caerulea* (Naturstyrelsen 2016a).

Cutting

Cutting can reduce the amount of nutrients if the cut material is removed from the heath. *Erica* species are rejuvenated by cutting. The cover of *M. caerulea* is reduced by cutting and thereby gives better chances for *Erica*- and other heath species to spread (Naturstyrelsen 2016a). On the negative side, cutting Erica species will create less variation in vegetation, and the species' age will be more the same. However, this problem can be solved by cutting smaller areas over different years (Naturstyrelsen 2016a). If *C. vulgaris* is cut at ground level, the cutting can damage the root system and thereby lower the vegetative regeneration. On the other hand, cutting at a higher level can give a vigorous vegetative regeneration (Barker et al. 2004).

Grazing

In general, grazing gives a higher diversity of species by preventing one species from covering the whole area, if all species are grazed equally (Naturstyrelsen 2016a). Animals will trample plants and create more space for new vegetation (Naturstyrelsen 2016a). Grazing also affects composition of the vegetation, and will increase the cover of grasses shifting to a grassy heath instead of a shrub dominated heath (Bullock and Pakeman, Newton et al. 2009). Grazing can improve the heath by preventing overgrowning with trees and reduce the cover of *M. caerulea* and destroying the tussocks of M. caerulea (Naturstyrelsen 2016a). *C. vulgaris* and other dwarf shrubs are positively affected by grazing because it rejuvenates them (Naturstyrelsen 2016a). Over-grazing can decrease the cover of dwarf shrubs and lead to an increase in the cover of herbaceous plants (Hulme et al. 2002, Garcia et al. 2009, Celaya et al. 2010). Therefore overgrazing are potentially a threat to heathland because it affect the dwarf shrubs negatively. Grazing only removes a small amount of nutrients from the area. Grazing leads to a redistribution of nutrients, the dispersion depends on where the animals manure (Naturstyrelsen 2016). The effect of grazing depends on the type of animals, stocking rate and grazing periodicity (Naturstyrelsen 2016a, Olff and Ritchie 1998).

Cattle cannot choose the specific plants they want to eat, and the vegetation has to be more than 6 cm before they can eat it. They would rather eat grass and grass-like (halvgræs) species compared to herbs and do not eat plants that taste bitter (Buttenschøn 2007, Naturstyrelsen 2016a). They prefer areas dominated by grass over areas dominated by dwarf shrubs (Pratt et al. 1986). Cattle can be hard on woody plants but does not graze them effectively enough to avoid overgrowth of the heath (Naturstyrelsen 2016a). Cattle are heavy, can cause damage to C. vulgaris by trampling and are able to create bare ground (Gimingham 1972, Lindholm 2019).

Sheep are able to eat vegetation close to the ground and choose specific plants to eat (Lake et al. 2001, Naturstyrelsen 2016a). They eat vegetation that taste bitter and have more varied diet than cattle (Naturstyrelsen 2016a, Grant et al. 1985, Grant et al. 1987). They can survive in areas with a low level of nutrients because of their ability to choose specific plants. They prefer grasses in the summer, and outside the growing season they have a preference for *C. vulgaris* (Grant et al. 1987). Most species of sheep will eat woody plants, and some eat conifers, too. Sheep prefer to graze on dry areas (Naturstyrelsen 2016a). Sheep are not heavy enough to cause bare ground creation or damage to *C. vulgaris* by trampling (Lindholm 2019).

Goats prefer grazing vegetation at their shoulder height and can reach vegetation up to a meter in height. Goats are not bothered by thorns, and their strong teeth make it possible for them to bite over branches. Due to this, goats are an excellent animal to use for areas overgrown with bushes.

Like sheep, goats can also select specific plants, and goats prefer the most nutrient rich part of the plants (Naturstyrelsen 2016a). Goats rather eat tall herbs than grass (Buttenschøn, 2010). An experiment comparing sheep and goats grazing heathland showed that goats are grazing a greater part of *C. vulgaris* than sheep (Naturstyrelsen 2016a).

Horses can select specific plants and can grass herbs and grasses very close. Horses are not ruminants. Instead, they consume a greater amount of food, passing through their digestive system at a higher rate. Therefore, horses can also manage in areas dominated by more rough grass like *M. caerulea* and *D. flexuosa*. Normally horses do not eat woody plants, but it is possible to make them, to prevent the growth of new trees (Naturstyrelsen 2016a). Horses are more flexible in using the different vegetation in the area compared to cattle (Pratt et al. 1986).

Wild red deer can also affect the heath's vegetation. If the population is large enough, wild red deer can give a high grazing pressure in winter and low grazing pressure in summer (Naturstyrelsen 2016a).

All the animals have their benefits and disadvantages. Therefore, grazing with more than one type of animal can help reduce the disadvantages. This can be done with co-grazing or switching between the animals used. Grazing can be used as a follow-up after an area has been e.g. burned or cut to avoid the area being overgrown with unwanted species. If *M. caerulea* has dominated a burnt area before burning, adding grazing will reduce the bloom of *M. caerulea* there to come after burning (Naturstyrelsen 2016a).

Clearing

The goal of clearing is to prevent heathland areas from being overgrown with woody plants and keep the light-open heathland areas. Clearing reduces the amount of nutrients by removing unwanted plants. The method is also used for reducing invasive species and removing their seed sources. For dry heathland Prunus serotina and *Cytisus scoparius* (non-native subspecies from southern Europe) are invasive species, but also non-native conifer species spreading from old plantations is a threat to this kind of heathland. For wet heathland, birch and willow trees are a problem (Naturstyrelsen 2016a). Even though trees can be a problem, removing all of them from the heath area is not ideal. Many of the heathland's animals somehow depend on the trees, e.g. trees provide shelter for wild red deer, thereby making the area more attractive for them. Wild red deer will help keep the heathland light-open if they are in a great enough number (Naturstyrelsen 2016a).

Hypothesis

This study investigates how the different types of management affect the vegetation in a heathland, both on short-term and long-term. This is investigated by testing how burning, clearing, cutting, and grazing affect the number of species and cover of *M. caerulea* and the *Erica* species; *C. vulgaris*, *E. tetralix* and *E. nigrum*. This study also wants to determine if there is a difference between using cattle or sheep for grazing as management by comparing the Shannon-Wiener-index number of species and cover of *M. caerulea* and *C. vulgaris*. Due to sheep's preference for dry areas, I tested if there were differences between the Shannon-Wiener-index number of species and cover of *M. caerulea* and *C. vulgaris* between high and low-lying areas grazed by sheep.

Method

Study site

This study focuses on Randbøl Hede, a protected heathland area on Jutland in Denmark. Randbøl Hede has been protected at national level since 1932 and covers about 750 ha. The government owns around 650 ha (Naturstyrelsen 2022). Randbøl Hede and the neighboring area Frederikshåb Plantage are designated as a Natura 2000 area due to the habitat types and bird species found at the areas (Naturstyrelsen 2017, Naturstyrelsen 2016b). Like many other heathland areas, Randbøl Hede is threatened by an increased level of nutrients which are causing problematic species e.g. *M. caerulea* to outcompete *C. vulgaris* and other heather species. The eastern part of the government owned area consists mainly of dunes and acid pasture. The heath consists of more varied nature types distributed in a mosaic structure. Some of these nature types are dry heath, wet/moist heath, occasionally wet meadow, and inland dune with *E. nigrum* (Naturstyrelsen 2012).

LIFE RAHID project

Randbøl hede has been a part of the Naturstyrelsen's LIFE RAHID (Restoration of Atlantic heaths and inland dunes in Denmark) project carried out from 2010 to 2016. Randbøl Hede was chosen for this project due to the low cover of shrubs (*Erica* species). In 2012, 80% of the area was grass heath or pasture, whereas shrubs dominated accounted for 15% (Naturstyrelsen 2012). The goal of this project was to restore the conservation status of Randbøl Hede and restore the *Erica* species by carrying out different types of management (Oddershede, 2017). This project only took place in the government owned part of the heath. Randbøl Hede has been managed with several types of management; burning, clearing, cutting, grazing with cattle, and grazing with sheep.

The LIFE RAHID project has experimented with repeated burning of areas dominated by *M. caerulea*. The goal of the repeated burning of *M. caerulea* is to give a bigger advantage to the *Erica* species by creating more bare mineral soil (Naturstyrelsen 2016a). The project has used both cattle and sheep for grazing. Permanent grazing with cattle for larger and more varied heathland areas. The area grazed by cattle is a permanent enclosure. For other areas, *M. caerulea* has been controlled with intensive grazing with sheep for a shorter period (Naturstyrelsen 2016a). For areas grazed by sheep, the sheep have been rotated around in the areas. Burning, grazing with cattle, and grazing with sheep are the most performed management types on Randbøl Hede.

Data collection

In context with Naturstyrelsen's LIFE RAHID (Restoration of Atlantic heaths and inland dunes in Denmark) project, 135 plots were placed in transect on the heath, all plots have associated coordinates. Prior to this study, data on the vegetation was collected in 2012, 2014, and 2016 as a part of the LIFE RAHID project. In 2012, data was collected in the spring, and for 2014 and 2016, it was collected in the autumn. The number of plots were data was samples differed between the years in 2012 it was 131, 2014 it was 73 plots and in 2016 it was 132 plots.

A circle with a 5 meter radius was marked up at each plot. Inside this plot, all plant species were identified. Lichens and mosses were not identified at species level. The species coverage was assessed visually for dwarf shrub and tree species. In the present project, I used the coverage data for the species *Calluna vulgaris*, *Empetrum nigrum*, *Erica tetralix* and *Molinia caerulea.*

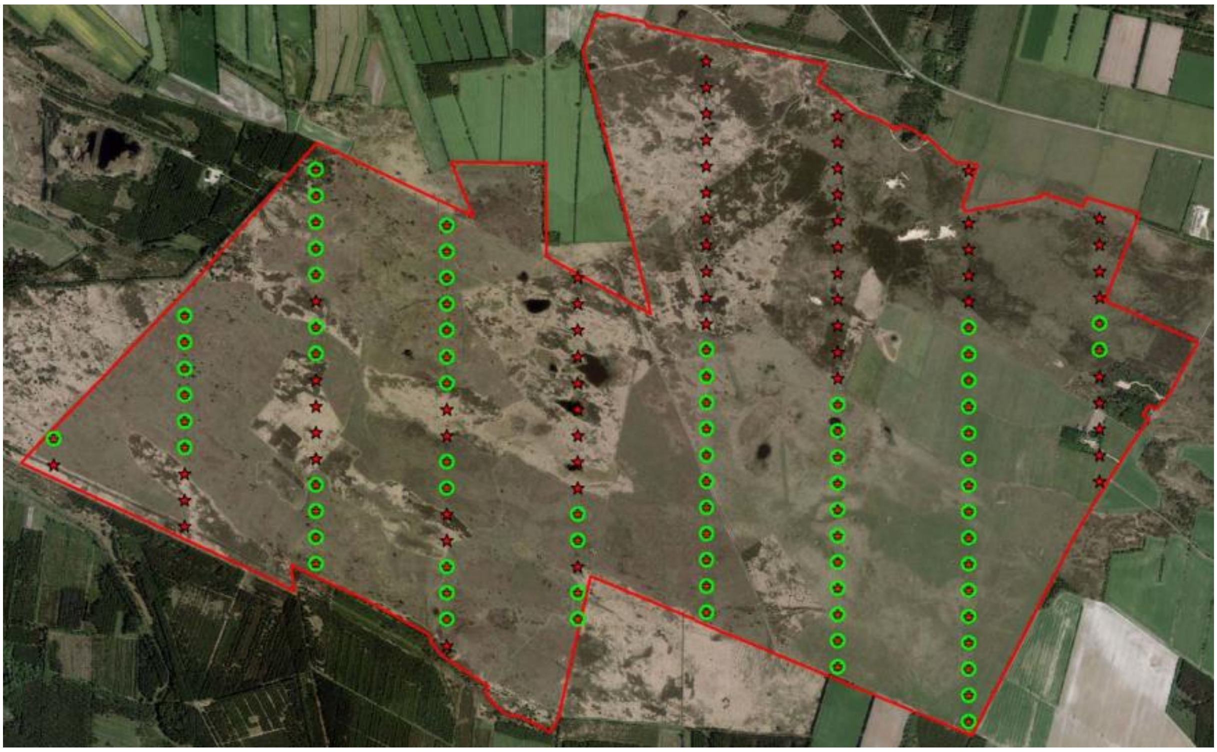

Figure 1. Map of Randbøl Hede. The red line indicates the area of the heath owned by the Government/Naturstyrelsen. The red stars are the sample points. (Picture from Naturstyrelsen)

Study species

I chose to focus on the species *M. caerulea*, *C. vulgaris,* and *Erica* species combined (*C. vulgaris*, *E. tetralix*, *E. nigrum*), to study the effect of the management. According to the species score used for evaluation of the Danish heaths in the LIFE-RAHID project, *C. vulgaris*, *E. tetralix*, *and E. nigrum* are sensitive to cultural influence (e.g. adding of nutrients, overgrowing), whereas M. caerulea is defined as a problem species for the heathland area and outcompete the dwarf shrubs (Oddershede 2017, Miljøstyrelsen 2022). The *Erica* species was originally dominating the heaths, but due to the increasing amount of nutrient and lack of management, *M. caerulea* is dominating the heaths (Vogel et al. 2013, Aerts 1993).

Molinia caerulea commonly known as purple moor grass, is a perennial tussock grass. The species form dense tussocks, which can be 8 to 20 cm in diameter. The leaves are upright and are 20 to 40 cm high and the stalks with the inflorescences can be up to 75 cm high (Jefferies 1915). M. caerulea has been observed to grow on a varied range of soil types (Pigott 1956, Perrin 1961, Birse and Robertson 1976). The species have a high abundance on both soils that are highly acidic (pH < 4.0) and calcareous (pH > 7.0) (Grime et al. 1988). The species blooms in June and July (Frederiksen et al. 2019). The growth of *M. caerulea* start in early spring and grows rapidly. In the end of spring, the seedlings of *C. vulgaris* have been outcompeted by *M. caerulea* for light and space (Lunt et al. 2021). *M. caerulea* is adapted to a higher nutrient level compared to dwarf shrubs (Naturstyrelsen 2016a).

Calluna vulgaris also known by its common name heather. *C. vulgaris* is an evergreen dwarf shrub and usually does not grow taller than 60 cm. It is multiple-stemmed and branched. It can be found in heathland, pasture, raised bog and forest. The species blooms in August and September (Frederiksen et al. 2019). It has four development phases; 1) pioneer (up to 10 years), 2) building (to 15 years), 3) mature (to 25 years) and 4) degeneration (aged to 30-40 years) (Watt 1955, Gimingham 1972, Gimingham 1975, Webb 1986). The biomass production is highest up to the mature phase (Gimingham 1975). In older phases the species can be rejuvenated, its younger phase were it has a higher production, by burning, cutting and grazing (Naturstyrelsen 2016a). The species is central in determination the conservation status of European dry heaths because it is a key species for the nature type (Schellenberg and Bergmeier 2022, European Commission 2013). *C. vulgaris* is monitored for assessing the habitat quality and to guide the management of heathland habitats in temperate Europe (Schellenberg and Bergmeier 2022).

Erica tetralix (cross-leaved heath) is an evergreen dwarf shrub and is between 10 and 25 cm in height, which makes it shorter than *C. vulgaris*. *E. tetralix* blooms in July and August and are found in heathland, raised bog and lakeshores (Frederiksen et al. 2019).

Empetrum nigrum, known by the common name crowberry. Like *C. vulgaris* and *E. tetralix* it is as evergreen dwarf shrub, and about the same size (10 to 30 cm) in height as *E. tetralix*. E. nigrum can be found in heathland, dune and peat bog. The species blooms in March and April (Frederiksen et al. 2019).

Management methods

All management methods that had been performed no longer than five years from data collection was noted to have been performed on the plot at the time of data collection. For some of the plots there have been performed more than one type of management five years prior to data collection. Each combination has been accounted as a management type (Table 1). Figure 2 shows examples of the different managed plots, there is no examples of clearing and cutting because none of plots have been managed with those in 2021 or five years prior. The order or of the management or repetition of management has not been taken into account, because it was not possible to investigate the effect of this due to a low number of samples.

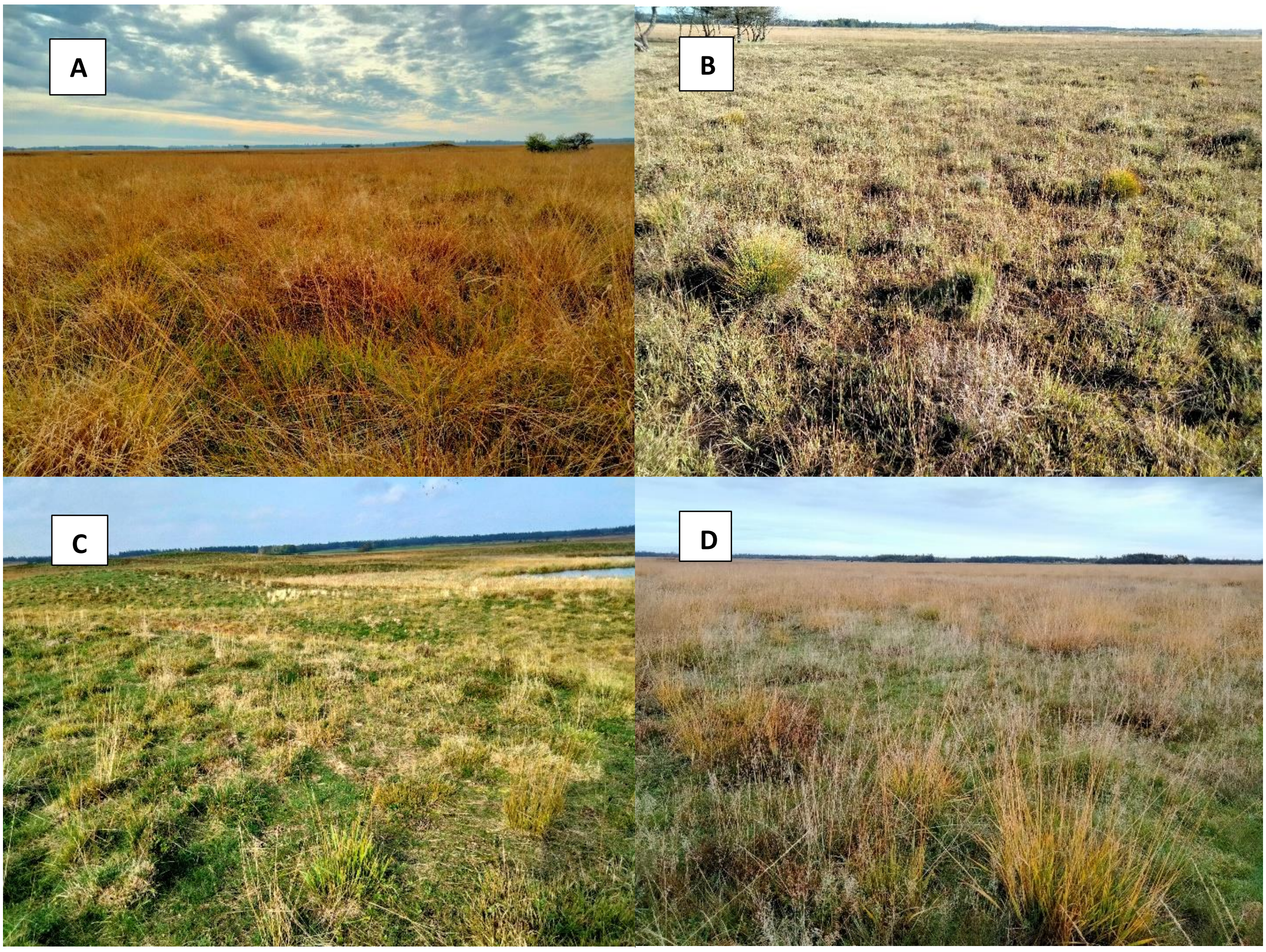

Figure 2. Different management areas. A) none, B) burning, C) grazing with sheep and D) grazing with cattle. The images were taken in autumn 2021.

For investigating the short-term effect there was samples enough for testing the effect of the following managements; none (n = 90), burning (n = 128), burning combined with clearing (n = 8), burning combined with cutting (n = 26), burning combined with cutting and grazing (n = 10), burning combined with grazing (n = 15), clearing (n = 9), cutting (n = 8) and grazing (n = 165).

Table 1. The number of plots with the management performed no longer, than 5 years prior to collection of vegetation data, for the years 2012, 2014, 2016, and 2021.

Year	None	Burning	Burning_Clearing	Burning_Cutting	Burning_Cutting_Grazing	Burning_Grazing	Clearing	Cutting	Grazing
2012	47	35	0	3	0	0	5	4	37
2014	0	18	3	12	4	4	1	0	31
2016	14	33	5	11	7	8	3	6	42
2021	29	42	0	0	0	3	0	0	55

For studying, the long-term effect there was not enough plots where management had stopped after the first management had been performed. Instead, the long-term effect was studied by looking at the "short-term" effect over the years. The plots had to have the same type of management performed during the time of study, from data collection in 2012 to data collection in 2021, where the management has been performed no longer than five from data collection. There was enough samples to study the long-term effects for no management (n = 9) and burning (n = 9) and grazing (n = 30).

For the comparison between areas grazed by cattle and sheep, the plots could also have been managed with other types of management in combination with grazing. Only data collected in 2021 was used for the grazing comparison. For 2021, 45 plots have been managed with cattle grazing and 13 plots with sheep grazing.

Vegetation sampling

I collected new data for this study in the autumn of 2021 and did it for 129. For the remaining six plots it was either impossible because they were placed in ponds or were at the Nature center, and therefore were no longer heathland area. To draw the circles I used a stick with four measuring strings attached. Each measuring string had a length of 5 m, equal to the radius of the circle. The measuring strings was attached to the vegetation or ground using clothespins (depending on the height of the area, must equal to height of the stick). For identifying the plants, I used the "Dansk flora" (book), looked at the list of species from the previous years, and used the only community at "naturbasen.dk". The cover was measured for all species and was assessed visually. The circle was divided into four parts to make the covering assessment more precise. For species with a low cover, the measured down to 0.05% for ¼ of the circle.

For the plots grazed by sheep at the time, I was collecting data. The circle was not as precise compared to the other plots. I had to measure the 2.5 m radius with my steps because the activity of sheep in the area made it impossible to use the measuring strings.

For plots placed in areas grazed by sheep. I noted (only for the year 2021) whether they were high- or low-lying compared to the overall terrain of the heathland. Six new extra plots were added due to a low number of high-lying samples. The plots were chosen by comparing a map from the "SDFE kortviser" (https://sdfekort.dk/spatialmap) with a google maps satellite map. The "SDFE kortviser" map showed 0.5 m elevation curves and a 50% transparency shadow map. I used the lakes/ponds in the area to help place the maps on top of each other. I placed the new plots on the highest points in the area grazed by sheep. After the addition of plots, there were 8 high- and 6 low-lying plots.

Data analysis

The software R was used for all the statistical analyses. I only analyzed data for management types that had more than five samples. Differences were significant if the p-value < 0.05.

Short-term effect

The number of species and cover of *M. caerulea*, *C. vulgaris,* and *Erica* species (*Calluna vulgaris*, *Empetrum nigrum*, *Erica tetralix*) was used as response variables for determine the difference in short-term effect between managements. The data for the cover of *C. vulgaris* and *Erica* species had to be log transformed using "Log(cover+1)" to homogenize and reduce the skew of the relationships. For determine if the short-term effect of the management methods differed from no management. An ANOVA model was fitted to test the overall effect of the management for each response variable. T-tests was used for determine which management methods differed in the response variables from no managements. The managements that were significantly different from no management were compared to each other using t-tests.

Long-term effect

The long-term effect was assessed for no management, burning, and grazing over the years 2012, 2014, 2016, and 2018. However, for no management, there was no data for 2014 because none of the plots was assessed that year. To reduce the skew of the relationships and homogenize the data for the cover of *C. vulgaris* and *Erica* species was log transformed using "Log(cover+1)". The response variables for determine the differences in the long-term effect was the number of species and cover of *M. caerulea*, *C. vulgaris,* and *Erica species*. The response variables were compared between the years for each management method by fitting an ANOVA model to test the overall effect. Afterwards t-test was used for each management method to determine which years differed from “2012”. Years that differed from “2012” were compared with t-tests.

The same approach were used for comparing the long-term effect between the management methods. The mean of the response variable from 2012 to 2021 were compared by first fitting an ANOVA model and afterwards determine the difference using t-tests. The management methods were also compared by determine how the response for each year differed between the management methods.

Grazing comparison

The difference between cattle and sheep was compared using Shannon-Wiener-index, number of species, and the cover of M. caerulea and C. vulgaris as response variable. The Shannon-Wiener-index was calculated using the cover of the species instead of the number for individuals for the species. For the grazing comparison, I only used data collected in 2021. Since it was the only year with the cover assessed for all species. The difference between areas grazed by cattle and sheep was determined using Welch’s two-sample t-test. The same approach was used for determine the difference between high- and low-lying areas grazed by sheep.

Results

Short term effect

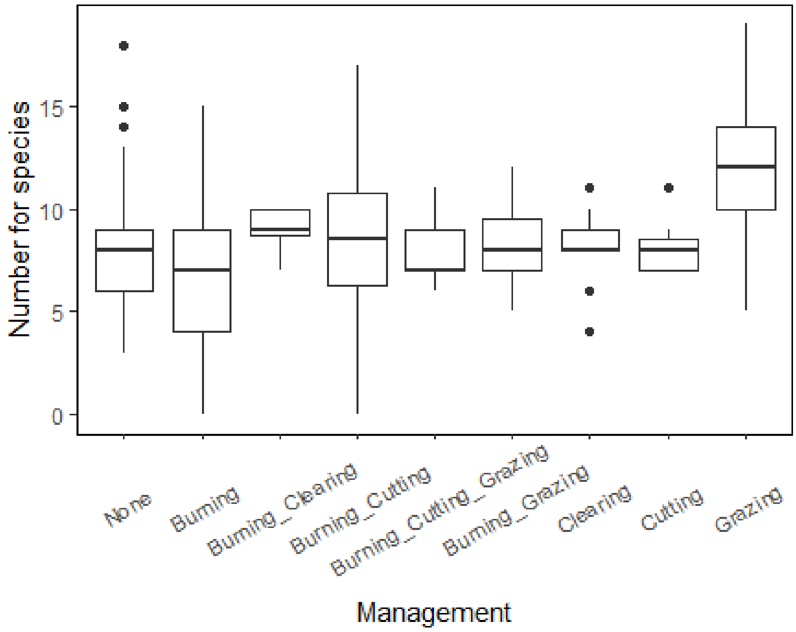

Figure 3. Number of species for different types of management (performed no later than five years from data collection). Data from the years 2012, 2014, 2016, and 2021.

Areas with grazing had the highest number of species, and areas managed with burning performed within 5 years had lowest numbers (fig. 3). Compared to no manangement (n = 90) the number of species was significantly higher (ANOVA: F = 23.378, d.f. = 10 and 454) for grazing (n = 165, t = 9.788, p < 0.0001) and significantly lower for burning (n = 128, t = -2.997, p = 0.0029). The no significance in the number of species for no manangement compared to burning combined with clearing (n = 8), burning combined with cutting and grazing (n = 10), burning combined with grazing (n = 15), clearing (n = 9) and cutting (n = 8). The number of species was significantly higher for grazing than for burning (Welch's t-test: t = 12.711, d.f. = 242,09, p < 0.0001)

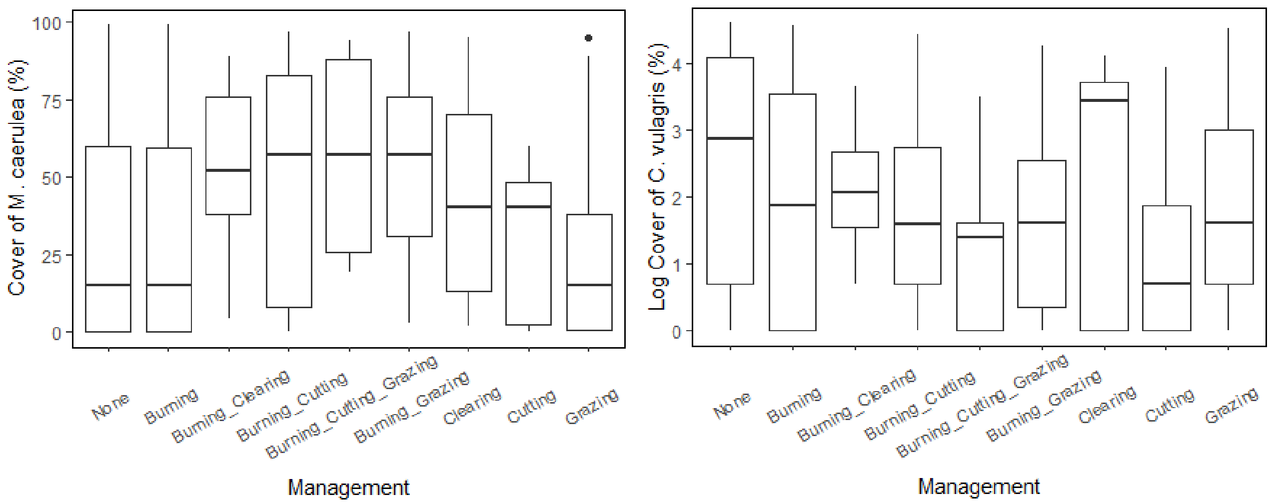

Figure 4. Effects of different management types (performed no later than five years from data collection) on *M. caerulea* cover (left) and *C. vulgaris* cover (right). Data from the years 2012, 2014, 2016, and 2021.

The cover *of M. caerulea* was significantly lower (ANOVA: F = 4.5895, d.f. = 10 and 454) for no management (n = 90) compared to burning combined with grazing (n = 15, t = 2.382, p = 0.0177), burning combined with grazing and cutting (n = 10, t = 2.172, p = 0.0303), burning combined with cutting (n = 26, t = 2.541, p = 0.0114). However, none management had a significantly higher cover of *M. caerulea* compared to grazing (n = 165, t = -2.318, p = 0.0209). The cover of *M. caerulea* for burning (n = 128) and clearing (n = 9) was not significant from no management. The cover of *M. caerulea* was significantly lower for grazing compared to burning combined with grazing (t = 3.589, p = 0.00037), burning combined with cutting and grazing (t = 3.156, t = 0.0017).

No management had the highest mean cover of *C. vulgaris* and burning combined with cutting and grazing had the lowest. No management (n = 90) had a significantly higher cover of *C. vulgaris* (ANOVA: F = 4.2045, d.f. = 8 and 450) compared to burning (n = 128, t = -2.386, p = 0.0175), burning combined with cutting (n = 26, t = -1.952, p = 0.0516), burning combined with cutting and grazing (n = 10, t = -2.324, p = 0.0206), cutting (n = 8, t = -1.980, p = 0.0483) and grazing (n = 165, t = -2.738, p = 0.0064). Clearing (n = 9) and burning combined with clearing (n = 26) was not significant from none management. There was no significance between the areas with management performed no later than 5 years.

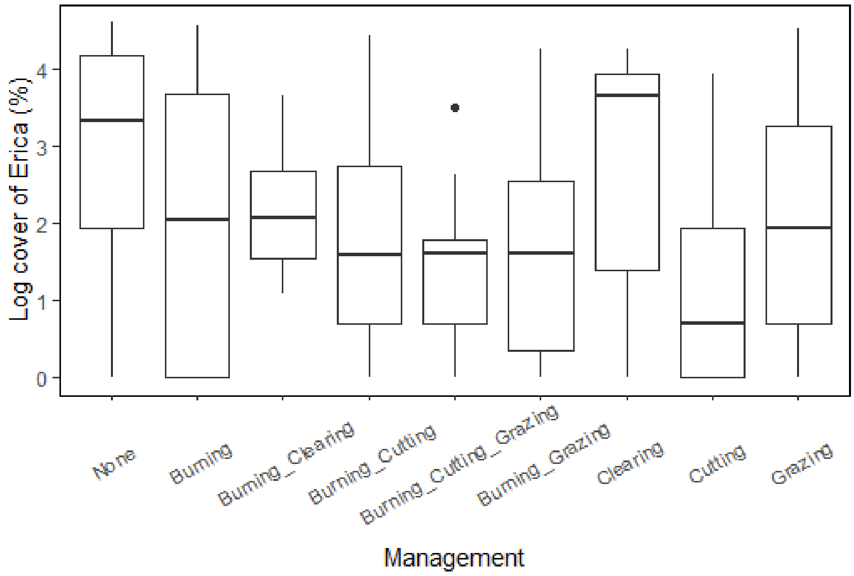

Figure 5. Effects of different management types (performed no later than five years from data collection) on *Erica* species (*C. vulgaris*, *E. tetralix,* and *E. nigrum*) cover. Data from the years 2012, 2014, 2016, and 2021.

Areas without management (n = 90) had the highest cover of *Erica* species (fig. 5). The cover of Erica species was significantly higher for none management (ANOVA: F = 3.5834, d.f. = 8 and 450) compared to, burning (n = 128, t = -3.855, p = 0.0001), burning combined with cutting (n = 26, t = -3.211, p = 0.0014), burning combined with cutting and grazing (n = 10, t = - 2.895, p = 0.004), burning combined with grazing (n = 15, t = -2.664, p = 0.008), cutting (n = 8, t = -2.706, p = 0.0071) and grazing (n = 165, t = -3.969, p < 0.0001). There was no significance between no management and clearing (n = 9) and burning combined with clearing (n = 8). There was no significantly difference in the cover of Erica species for areas with management.

Table 2. The means and SEM for number of species, and cover of *M. caerulea*, *C. vulgaris* and *Erica* species(*C. vulgaris*, *E. tetralix,* and *E. nigrum*) for the different managements. The p-values are for the comparison to none.

Management	Mean number of species	p-value	Mean cover of M. caerulea	p-value	Mean log cover of C. vulgaris	p-value	Mean log cover of Erica species	p-value
None	7.88 ± 0.26	-	32.2 ± 3.75	-	2.41 ± 0.18	-	2.83 ± 0.17	-
Burning	6.59 ± 0.34	**0.0029**	31.3 ± 3.01	0.8430	1.90 ± 0.15	**0.0175**	2.03 ± 0.15	**0.0001**
Burning Clearing	9.0 ± 0.38	0.3322	53.1 ± 9.64	**0.0710**	2.11 ± 0.33	0.6081	2.16 ± 0.30	0.2334
Burning Cutting	8.42 ± 0.69	0.4349	49.9 ± 7.23	**0.0114**	1.73 ± 0.28	**0.0516**	1.75 ± 0.28	**0.0014**
Burning Cutting Grazing	7.9 ± 0.46	0.9830	54.9 ± 9.74	**0.0303**	1.25 ± 0.35	**0.0206**	1.43 ± 0.33	**0.0040**

Burning Grazing	8.33 ± 0.49	0.6024	53.0 ± 8.29	**0.0177**	1.69 ± 0.39	0.0995	1.70 ± 0.39	**0.0080**
Clearing	8.11 ± 0.70	0.8314	44.4 ± 11.10	0.2637	2.22 ± 0.61	0.7355	2.54 ± 0.59	0.5802
Cutting	7.75 ± 0.55	0.9120	37.5 ± 9.86	0.6449	1.19 ± 0.56	**0.0483**	1.22 ± 0.56	**0.0071**
Grazing	11.9 ± 0.24	**< 0.0001**	22.6 ± 1.99	**0.0209**	1.85 ± 0.11	**0.0064**	2.04 ± 0.11	**< 0.0001**

Long-term effect

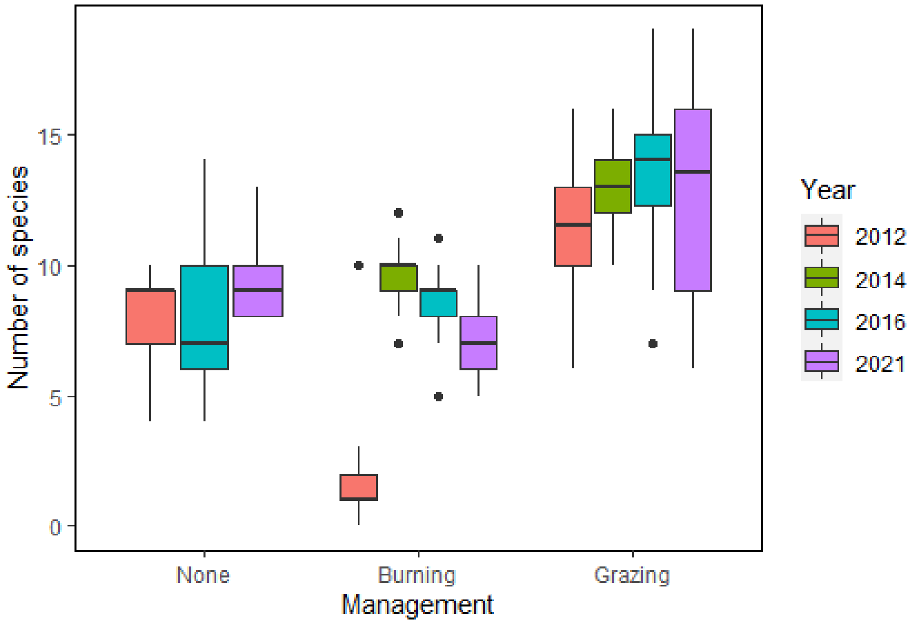

Figure 6. Effects of different management types (performed no later than five years from data collection) over the years on the number of species.

Grazing had the highest mean number of species. Burning and none were in the same range as the number of species, except for the first year of burning (2012), which was much lower than the others (fig. 6). There was no significant difference between the years with none management (n = 9, ANOVA: F = 1.4137, d.f. = 2 and 24).

For areas with only burning, the number of species rose from 2012 to 2014 and then decreased the rest of the years (fig. 6). The mean number of specieswas significantly higher than for 2014 (ANOVA: F = 21.642, d.f. = 3 and 32, t = 0.9663, p < 0.0001), 2016 (t = 0.9663, p < 0.0001) and 2021 (t = 0.9663, p < 0.0001) compared to 2012. There was significance between 2014 and 2021 (t = -2.645, p = 0.0126).

The number of species was increasing from 2012 to 2016 for areas with grazing (fig. 6). The mean number of species for 2016 was significantly lower than for 2012 (ANOVA: F = 2.5647, d.f. = 3 and

116, t = 2.725, p = 0.0074). 2014 (t = 1.785, p = 0.0768) and 2021 (t = 1.644, = 0.1028) were not significantly different from 2012.

The number of species in 2012 for burning (ANOVA: F = 60.441, d.f. = 2 and 45, t = -5.214, p < 0.0001) was significantly lower compared to none (t = 4.359, p < 0.0001). Grazing had a significantly higher number of species compared to none. Grazing compared to burning (t = 10.827, p < 0.0001) showed grazing had a significantly higher number of species. For 2014, there was no data on the number of species for no management. The number of species was significantly higher for grazing (ANOVA: F = 24.505, d.f. = 1 and 37, t = 4.95, p < 0.0001) compared to burning in 2014. In the 2016, there was no significant difference in the number of species between none and burning (ANOVA: F = 25.001, d.f. = 2 and 45, t = 0.545, p = 0.589). Grazing (t = 5.868, p < 0.0001) had a significantly higher number of species compared to none in 2016. The number of species for burning in 2021 was no significantly different from no management (ANOVA: F = 11.986, d.f. = 2 and 45, t = -1.567, p = 0.1241). The number of species in 2021 was significantly higher for grazing (t = 2.667, p = 0.0106) compared no management.

The mean number of species over the period 2012 to 2021 varied between the managements (ANOVA: F = 70.57, d.f. = 2 and 180). The mean was 8.37 (SEM = 0.46) for no management, 6.83 (SEM = 0.57) for burning and 12.70 (SEM = 0.26) for burning. Burning (t = -2.099, p = 0.0382) was the number of species was significantly lower and grazing (t = 7.108, p < 0.0001) had significantly higher number of species compared to no management. The burning-grazing comparison also showed significant difference (t = 10.779, p < 0.0001).

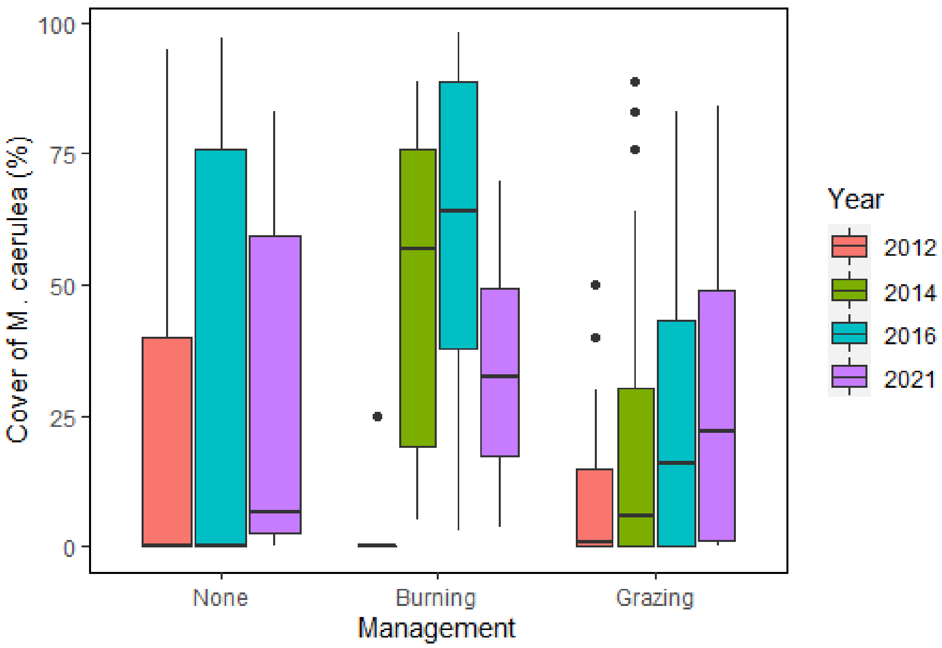

Figure 7. Effects of different management types (performed no later than five years from data collection) over the years on the cover of *M. caerulea*.

For none management, the mean cover of *M. caerulea* was lowest in 2012 and highest in 2016. However, there was significance between the years (ANOVA: F = 0.2573, d.f. = 2 and 24).

Burning had the lowest and highest cover of *M. caerulea* compared to the grazing and none management. For areas only managed with burning of the cover of *M. caerulea* increased from 2012 to 2016 and decreased from 2016 to 2021 (fig. 7). The cover M. caerulea was significantly lower for 2012 (ANOVA: F = 21.624, d.f. = 3 and 32) than for 2014 (t = 7.474, p < 0.0001), 2016 (t = 6.325, p < 0.0001) and 2021 (t = 4.830, p < 0.0001). There was also significance between 2016 and 2021 (t = -2.130, p = 0.0409). 2016 (t = 0.923, p = 0.3629) and 2021 (t = -1.207, p = 0.2362) were not significantly different from 2014.

For grazing the cover of *M. caerulea* increased over the years (fig. 7). The cover of *M. caerulea* for 2016 (ANOVA: F = 3.3035, d.f. = 3 and 116, t = 2.232, p = 0.02752) and 2021 (t = 3.038, p = 0.00294) were significantly higher compared to 2012. 2014 (t = 1.726, p = 0.0275) showed no difference compared to 2012. The comparison of 2016 to 2021 showed no difference (t = 0.806, p = 0.4218).

In 2012 the cover of *M. caerulea* (ANOVA: F = 2.4992, d.f. = 2 and 45, t = -2.181, p = 0.34439) for burning was significantly lower compared to none. For grazing (t = -1.738, p = 0.089086), the comparison to none showed no significance in cover of *M. caerulea*. There was no data for the cover of *M. caerulea* for none in 2014. The comparison of the cover of *M. caerulea* in 2014 between burning and grazing showed grazing (ANOVA: F = 6.6524, d.f. = 1 and 37, t = -2.579, p = 0.014) had a significantly lower cover. The cover of *M. caerulea* in 2016 was not significantly different from none for burning (ANOVA: F = 5.313, d.f. = 2 and 45, t = 1.890, p = 0.06526) and grazing (t = -0.912, p = 0.36673). In 2021 neither burning (ANOVA: F = 0.1217, d.f. = 2 and 45, t = 0.173, p = 0.86363) nor grazing (t = -0.255, p = 0.7996) the cover of *M. caerulea* were significantly difference from none.

For the mean of cover of *M. caerulea* over the period from 2012 to 2014 none had a mean cover of 28.7 (SEM = 6.84), for it was 36.0 (SEM = 5.56) and grazing 20.2 (SEM = 2.23). Burning (ANOVA: F = 4.6553, d.f. = 2 and 180, t = 1.022, p = 0.308) and grazing (t = -1.402, p = 0.163) was not different from no management.

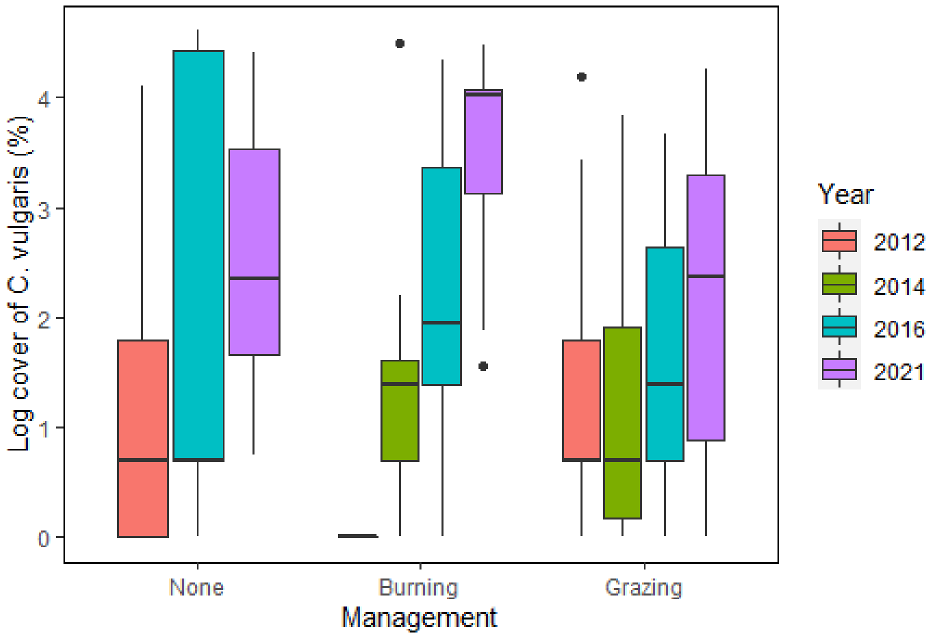

Figure 8. Effects of different management types (performed no later than five years from data collection) over the years on the cover of *C. vulgaris*.

For areas without management, the cover of *C. vulgaris* increased from 2012 to 2021 (fig. 8). There was no significance in the cover of *C. vulgaris* between for the year 2016, and 2021 compared to 2012, for areas without management (ANOVA: F = 1.6068, d.f. = 2 and 24).

The cover of *C. vulgaris* was lowest for areas managed with burning in 2012 compared to the other years and management. The areas only managed with burning had a cover of *C. vulgaris* that was increasing over the years (fig. 8). The cover of *C. vulgaris* was significantly higher for 2014 (ANOVA: F = 14.594, d.f. = 3 and 32, t = 2.775, p = 0.0091), 2016 (t = 4.208, p = 0.00019) and 2021 (t = 6.499, p < 0.0001) compared to 2012. There was significance between 2014 and 2021 (t = 3.673, p = 0.0009), and 2016 and 2021 (t = 2.240, p = 0.0322). The difference between 2014 and 2016 was not significant (t = 1.422, p = 0.1615).

For grazing, the cover of *C. vulgaris* was similar in 2012 and 2014, and the cover increased in the following years (fig. 8). The cover of *C. vulgaris* in 2021 (ANOVA: F = 4.3446, d.f. = 3 and 116) was significantly different from 2012(t = 2.964, p = 0.00368). There was no significance between 2012 and the rest of the years.

For 2012, burning had a significantly lower cover of *C. vulgaris* compared to none (ANOVA: F = 4.045, d.f. = 2 and 45, t = -2.231, p = 0.0307). The cover of *C. vulgaris* for grazing was not significantly different from none in 2012 (t = 0.000, p = 0.9996). In 2014, there was no data for no management. The comparison of *C. vulgaris* cover in 2014 between burning and grazing, was not significant (ANOVA: F = 0.7614, d.f. = 1 and 37, t = -0.873, p = 0.3885). The cover of *C. vulgaris* in 2016 for burning showed no difference from none (ANOVA: F = 1.0766, d.f. = 2 and 45, t = 0.126, p = 0.900). For grazing the cover of *C. vulgaris* in 2016 was also showed no difference from none (t =

-1.069, p = 0.291). In 2021 both burning ((ANOVA: F = 3.5695, d.f. = 2 and 45, t = 1.561, p = 0.125) and grazing (t = -0.733, p = 0.468) was not significantly different from no management.

The mean of the log cover of *C. vulgaris* over the period 2012 to 2021 was 1.95 (SEM = 0.31) for none, 1.80 (SEM = 0.28) for burning and 1.51 (SEM = 0.11) for grazing. There was no significant different between none and burning (ANOVA: F = 1.4022, d.f. = 2 and 180, t = -0.426, p = 0.671). The comparison of none and grazing (t = -1.474, p = 0.142) was not significant either.

Table 3. The means and SEM for number of species, and cover of *M. caerulea* and *C. vulgaris* for the different managements. There is two p-values for each mean, the p-values refer to the mean in the column before. The p-values (2012) are for the comparison to 2012 within the management type. The p-values (none) are for the comparison to none for the same year, except for 2014 where burning and grazing were compared.

Management	Year	Mean number of species	p-value (2012)	p-value (none)	Mean cover of *M. caerulea*	p-value (2012)	p-value (none)	Mean log cover of *C. vulgaris*	p-value (2012)	p-value (none)
None	2012	7.89 ± 0.61	**-**	-	21.7 ± 11.0	-	-	1.20 ± 0.48	**-**	**-**
	2016	7.78 ± 1.06	0.921	-	33.4 ± 14.0	0.5012	-	2.17 ± 0.66	0.2030	-
	2021	9.44 ± 0.58	0.173	-	30.8 ± 11.5	0.5997	-	2.48 ± 0.41	0.0992	-
Burning	2012	2.33 ± 1	**-**	**< 0.0001**	2.78 ± 2.78	**-**	**0.0344**	0 ± 0	-	0.0307
	2014	9.56 ± 0.50	**< 0.0001**	-	48.2 ± 11.5	**< 0.0001**	-	1.49 ± 0.45	**0.0091**	**-**
	2016	8.44 ± 0.58	**< 0.0001**	0.589	59.8 ± 10.8	**< 0.0001**	0.0652	2.25 ± 0.50	**0.0002**	0.900
	2021	7 ± 0.53	**< 0.0001**	0.1242	33.1 ± 7.54	**< 0.0001**	0.8636	3.45 ± 0.35	**< 0.0001**	0.125
Grazing	2012	11.6 ± 0.39	**-**	**< 0.0001**	9.53 ± 2.62	**-**	0.0891	1.20 ± 0.22	**-**	0.9996
	2014	12.9 ± 0.34	0.0768	**< 0.0001**	20.1 ± 4.90	0.0870	**0.014**	1.13 ± 0.18	0.8167	0.3885
	2016	13.6 ± 0.48	**0.0074**	**< 0.0001**	23.2 ± 4.41	**0.0275**	0.3667	1.62 ± 0.20	0.1706	0.291
	2021	12.8 ± 0.72	0.1038	**0.0106**	28.1 ± 4.96	**0.0029**	0.7996	2.11 ± 0.26	**0.0037**	0.468

Difference between Cattle and Sheep

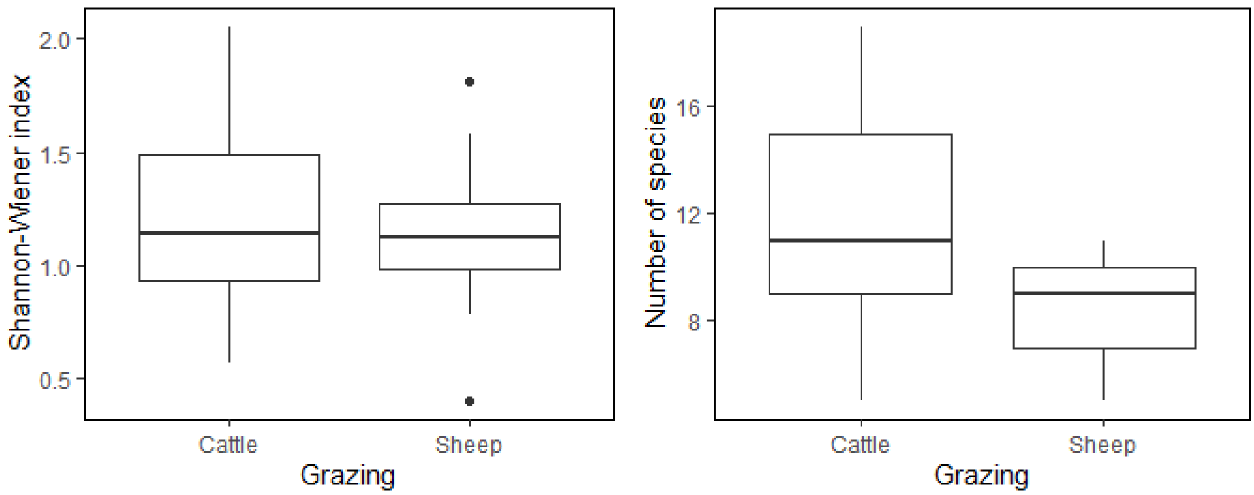

Figure 9. Effect of grazing with cattle or sheep on Shannon-Wiener index (left) and the number of species (right). Data from the year 2021.

There was no significant difference in the Shannon-Wiener i between cattle (n = 45) and sheep (n = 13) grazing (Welch's t-test: t = 0,56479, d.f. = 19.071, p = 0.579) (fig. 9 left), eventhough the mean index for grazing with cattle was slightly higher (1.204 compared to 1.140). For figure 9 (right), grazing with cattle had a higher number of species than grazing with sheep (11.6 compared to 8.62), and this was significantly higher (Welch's t-test: t= 3.7038, d.f. = 39.062, p= 0.000)

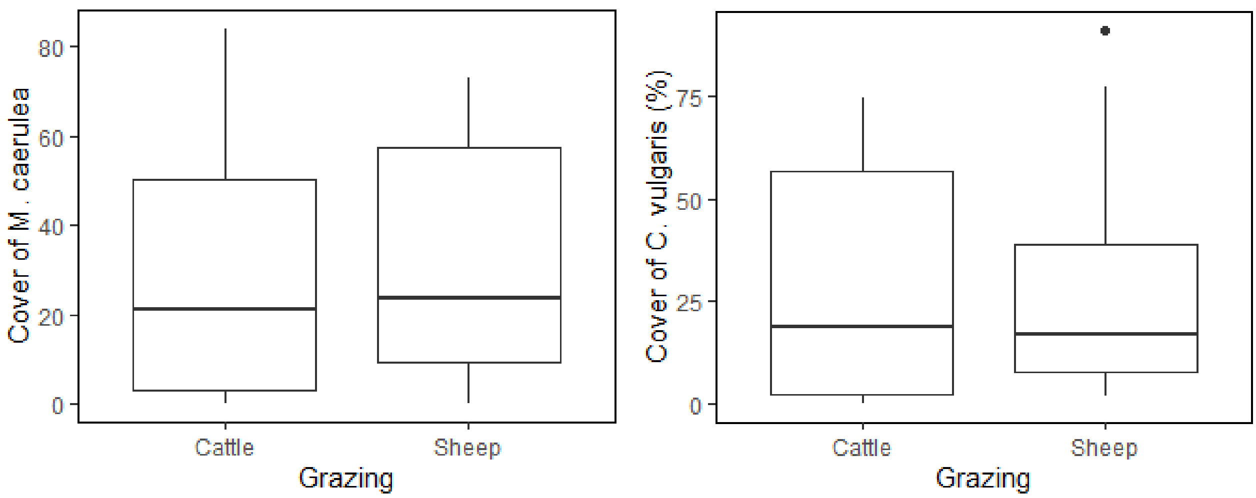

Figure 10. Effect of grazing with cattle or sheep on the cover of *M. caerulea* (left) and *C. vulgaris* (right). Data from the year 2021.

The mean cover of *M. caerulea* was 28.12 % for areas grazed by cattle (n = 45) and 31.35 % for areas grazed by sheep (n= 13) (fig. 10 left). However, this was not significantly different (Welch's t-test: t = -0.39695, d.f. = 19.993, p = 0.696). The cover of *C. vulgaris* was a little higher for grazing with sheep than cow (27.599 compared to 26.895) (fig. 10 right), but the difference was not significant (Welch's t-test: t = -0,078652, d.f = 18.263, p = 0.938).

Table 4. The means and SEM for the Shannon-Wiener index, number of species, and cover of *M. caerulea* and *C. vulgaris* for cattle and sheep grazing.

Grazing	Mean Shannon-Wiener index	Mean number of species	Mean cover of M. caerulea	Mean cover of C. vulgaris
Cattle	11.6 ± 0.05	11.60 ± 0.58	28.12 ± 3.94	26.90 ± 3.96
Sheep	8.62 ± 0.10	8.62 ± 0.56	31.35 ± 7.10	27.60 ± 8.02

Difference between low and high areas grazed by sheep

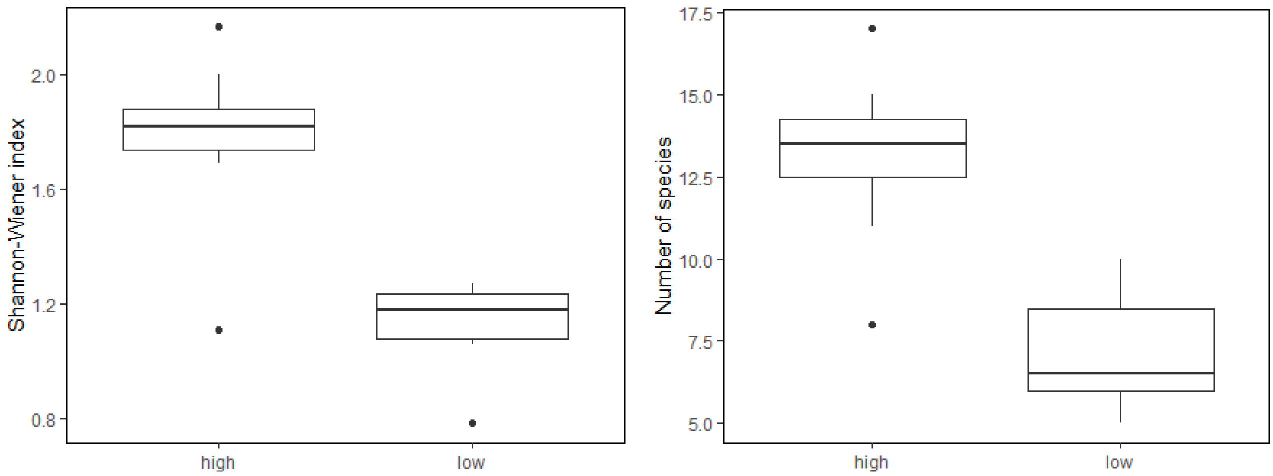

Figure 11. Difference between high- and low-lying areas grazed by sheep on Shannon-Wiener index (left) and the number of species (right). Data from the year 2021.

For figure 11, the Shannon-Wiener index (1.77 compared to 1.12) and the number of species (13.13 compared to 7.17) was higher for high-lying areas (n = 8) than it was for low-lying areas (n = 6). The difference was significant for both the Shannon-Wiener index (Welch's t-test: t = 4.9797, d.f. = 11.558, p = 0.000) and for the number of species (Welch's t-test: t = 4.8072, d.f. = 11.997, p = 0.000).

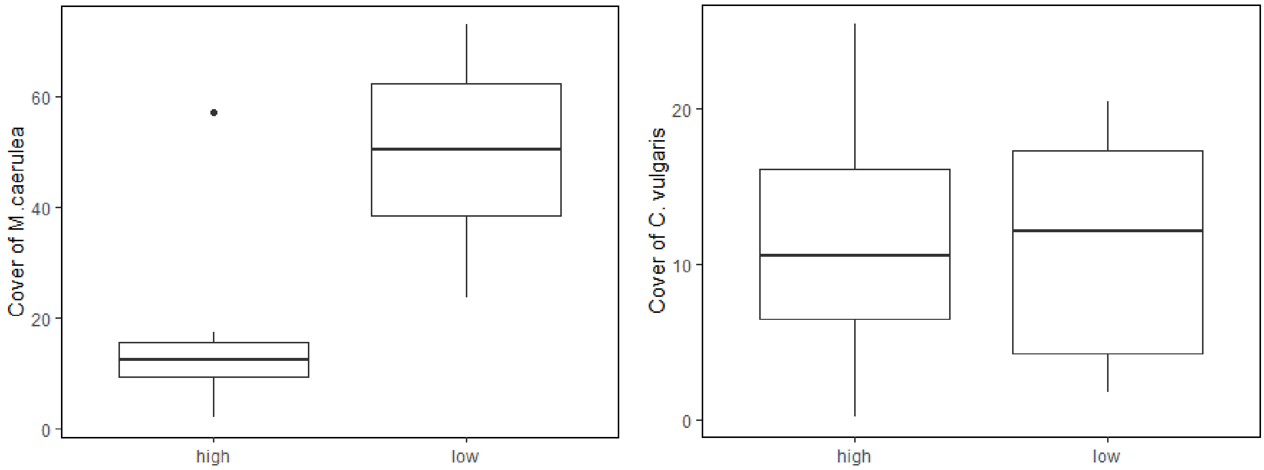

Figure 12. Difference between high- and low-lying areas grazed by sheep on the cover of *M. caerulea* (left) and *C. vulgaris* (right). Data from the year 2021.

For the lower lying areas (n = 6) the cover of *M.caerulea* was significantly higher than for the high-lying (n = 8) areas (Welch's t-test: t = -3.4234, d.f. = 10.407, p = 0.006). There was no significanctly difference between the cover for *C. vulgaris* for high- and low-lying areas (Welch's t-test: t = 0.11541, d.f. = 11.49, p = 0.910).

Table 5. The means and SEM for the Shannon-Wiener index, number of species, and cover of *M. caerulea* and *C. vulgaris* for high and low-lying areas.

	Mean Shannon-Wiener index	Mean number of species	Mean cover of M. caerulea	Mean cover of C. vulgaris
High	1.77 ± 0.11	13.13 ± 0.95	16.75 ± 6.02	11.74 ± 3.17
Low	1.12 ± 0.07	7.17 ± 0.79	49.75 ± 7.53	11.21 ± 3.31

Discussion

The effect of the managements

In general, the areas without management had the best status for the short term. Not many of the other management types had a significantly higher number of species, and the cover of *M. caerulea* was higher for most of the management types. The cover of *C. vulgaris* and *Erica* species was also lower for the other management types compared to no management. However, when looking at the long-term effect, grazing had the best status when looking at the number of species and cover of *M. caerulea* compared to burning and no management.

Burning

The areas with burning within the last five years from data collection had the lowest number of species and a wide variation in the number of species and cover of species, especially for the short-term effect. The wide variation of the data for areas with burning can be due to the difference in the time the areas had been burned. If an area has been burned close to data collection, the number and cover of the species will be lower than for an area that had been burned earlier and where the vegetation has had more time to grow back. For the long-term effect, the variation in data was equal for all the management types.

When looking at the effect in the short term, burning alone had a lower cover of *M. caerulea* than the areas with burning combined with other management. This reason could be that for the areas only treated with burning, the burning had been performed closer to the data collection than for the areas with burning combined with other types of management. However, this does not fit with what was expected. Burning increases the spread of *M. caerulea* by increasing its sexual production (Jacquemyn et al. 2005, Brys et al. 2005). Therefore, it is recommended to add grazing or cutting to an area after the fire to reduce the bloom of *M. caerulea* (Naturstyrelsen 2016a). The areas in this study where cutting and grazing was combined with burning had a larger cover of *M. caerulea*. Due to a low number of samples, it was not possible to take the order of the management into account. This could be why these areas have a larger cover of *M. caerulea* because grazing and cutting could have happened before the burning of the area.

When looking at the long-term effect, which only focuses on areas with just burning, the repeated burning, which has been tested at Randbøl Hede (Naturstyrelsen 2016a), did not seem to have a clear effect on M*. caerulea*. Burning gave a low cover of *M. caerulea* the first years, but the cover increased afterwards. The cover was greater than for no management except for the first year (2012). The increasing of *M. caerulea* could be reduced using follow-up management e.g. grazing or cutting after burning (Naturstyrelsen 2016a). On the other side, burning gave a higher cover of *C. vulgaris* than no management. The cover of *C. vulgaris* was also increasing, which again supports that repeated burning benefits the heath. Another study has found that burning reduced the dominance and frequency of *C. vulgaris* (Ross et al. 2003), which fits with the short-term effect seen in this study. The short-term effect showed a lower cover of *C. vulgaris* for areas with burning (and combined with other managements) than those without management. This is despite of burning should have a positive effect on *C. vulgaris* because it rejuvenates the species. However, this management is only an advantage when the species is old and dying (Naturstyrelsen 2016a). This could be why burning seems to have a negative effect on *C. vulgaris* on the short-term, because the *C. vulgaris* was not old and dying. However, the positive effect of burning on *C. vulgaris* was seen on the long-term effect, except for the first years. Therefore, the reason for negative effect on *C. vulgaris* for burning on short-term can be that it takes more time to see the positive effect on *C. vulgaris*.

Clearing

The areas managed with clearing did not differ from areas without management when looking at the short-term effect of the management. The goal of clearing is to remove woody plants from overgrowing the heathland, so looking at the short-term effect is not ideal for testing the effect of clearing. Instead, it would have been more interesting to see the cover of shrubs and woody plants over the years and see what effect removing woody plants has on the shrub cover and how long the effect lasts.

Cutting

When comparing cutting to no management, it was not seen to positively affect the vegetation since the cover of *C. vulgaris* and *Erica* species was lower. The goal of cutting was to reduce the cover of *M. caerulea* and rejuvenate the *Erica* species (Naturstyrelsen 2016a), which in this study was not achieved. Another study has found that cutting had a consistent effect on increasing the species diversity and reducing the cover of *M. caerulea* (Milligan et al. 2004). The findings of this study could suggest that the impact of cutting would be easier to see if the effect was compared over a longer period. It is likely that more time is needed to see the effect of cutting or that the data has to be compared over the years to get a picture of the effect. However, it was not possible to study the long-term effect of cutting, which could have shown something else, like the study by Milligan et al. 2014.

Cutting should help reduce the amount of nutrients if the cut material is removed afterward (Naturstyrelsen 2016a), but according to a study by Haerdtle et al. (2006), the removal of nitrogen by cutting and burning was equal to five years of atmospheric emission. So cutting alone will not be enough to lower nutrient content, making heathland less desirable for *M. caerulea*. If the goal of cutting is to reduce the amount of nutrients in the area, Sod-cutting is a better solution. Sod-cutting has been observed to remove 89 years' worth of atmospheric nitrogen input. It can also remove an amount of total nutrients equal to between 37 and 176 years of atmospheric input (Haerdtle et al. 2006). Cutting at ground level or lower can damage the root system of *C. vulgaris* and lower the vegetation regeneration (Barker et al. 2004). Therefore the goal of the cutting and to be taken into account when choosing the cutting level. This also makes it possible to match the management more to the area's needs.

Grazing

As expected, grazing gave a higher number of species in both short- and long-term, which was greater than for areas without management. Grazing also showed a lower cover of *M. caerulea*.

There was observed no big difference between areas grazed by cattle and sheep. The number of species was significant higher for areas grazed by cattle. However, the opposite was expected because sheep have a more varied diet than cows (Grant et al. 1985, Grant et al. 1987). Therefore, sheep should graze the species more equally than cows because sheep are grazing more of them. The more equal grazing would create less variation species cover of the areas, and thereby giving more species opportunity to cover the area. Otherwise, there was no difference between to two.

The sheep have been observed to spend more time on the higher areas than the lower areas. They prefer to graze on a dry area and at Randbøl Hede the more elevated areas were more dry compared to the lower areas which were more wet (Naturstyrelsen 2016a). The Shannon-wiener index and number of species were greater for the high areas, which also had a lower cover of *M. caerulea*. This indicates that the sheep spend are grazing more at the higher-lying areas and that this creates a difference between high and low areas. Low-lying areas will not get as effective management service as the high-lying areas because the sheep prefer them. So if one wants to use sheep for grazing *M. caerulea* in an area with a big difference in the terrain, it might be necessary to divide the area into smaller ones to force the sheep to graze the lower parts of the area as well. Thereby preventing *M. caerulea* from overgrowing the lower parts.

Future study

On the control of *M. caerulea* there might be more effect methods for reducing the species than those used in the study. Other studies also mention that the traditional methods; burning, cutting and grazing are not always sufficient in reducing *M. caerulea* (Naturstyrelsen 2015). A study by Marrs et al. used the herbicide glyphosate for control of *M. caerulea* and found it were consistent compared to burning and grazing. Application of the herbicide in combination with removal of Molinia litter and application of *C. vulgaris* seed gave a higher density of *C. vulgaris* seedlings. However, this would need follow-management afterwards since *M. caerulea* was recovering over time and reducing C. vulgaris (Marss et al. 2004). Both application of herbicide and *C. vulgaris* seedlings is other methods that could be used in future studies and in new combinations with other management methods than in the study by Marss et al.

Besides testing “new” management methods that has not been practiced at Randbøl Hede, variations of the methods already could also be focus for a future study. Examples of this could be experimenting with cutting both under and above ground level, or using other types of animals for grazing.

For a future project, it could be interesting to study the managements and their effect on the vegetation in more detail. The goal of performing the management types in the LIFE RAHID seems to have been restoring the heathland rather than testing the effectiveness and differences between the management types. If the goal were to restore Randbøl Hede, adding more detail would also make it easier to identify the most effective combination of management. More details could be added by increasing the sample size, which would make it possible to study the effect of the managements where the sample size were too small. A bigger sample size could also have been it possible to study the order and repetition of managements.

The limitation on samples could be changed by adding more sample plots or simplifying the structure/planning of the managements, thereby creating more sample plots with the same conditions. Especially since this study found no effect for most of the managements, which might imply that the management of Randbøl Hede needs to change. The sample plots from the LIFE RAHID project do not cover all of the management performed on Randbøl Hede, soil-removal has been performed on the heath, but there is no data on it. The project is also from 2016, so if future projects want to follow up on this project, the sample plots will need an update to better include the management happening now.

Although it was possible to test the effect of combining management, it would have been interesting to investigate if the order of the management types had an influence on the effect. This is especially because it is suggests combinations of specific management types for a more effective result. It is recommend adding grazing or cutting to an area after burning, to reduce the bloom of *M. caerulea* that is caused by the burning (Naturstyrelsen 2016a). It would also have been interesting to study if repeating the management would change the effect seen on the vegetation. Other studies have found different effects depending on management's combination, order, and repetition. Milligan et al. 2014 found that over four years, cutting three times was more effective at reducing the cover of *M. caerulea* and increasing the species than cutting once, twice, and no cutting. Therefore, the number of repetitions can influence the effective of the management method.

It would also have been interesting to see have consistent the effect of the managements were, by having plots where management have stopped after the first action and follow the vegetation afterwards.

A more detailed study of management methods would benefit restoring heathlands like Randbøl Hede, but also semi-natural grasslands in general, by implementing the a more detailed knowledge of management methods into the planning of semi-natural grasslands.

Conclusion

In general, the managements methods investigated in this study did not affect the vegetation. The managements were not effective in increasing the number of species, controlling the cover of *M. caerulea* or increasing the cover of the dwarf shrub species (*C. vulgaris*, *E. tetralix* and *E. nigrum*) comparing to no management. Therefore the managements where insufficient in restoring the heathland Randbøl Hede. The most effective of the methods were grazing, which increased the number of species and reduced *M. caerulea*.

The lack of effect from the managements investigated in this study, shows that the management has to change for restoring the heathland. The increasing cover of *M. caerulea* is on the expense of a decreasing cover of the dwarf shrubs species. The dwarf shrubs species cannot re-dominate the heathland without management. Therefore, management effective in reducing the *M. caerulea* is needed for increasing the cover of *C. vulgaris* and restoring the heathland. For restoring Randbøl Hede either a more detailed study of the management or adding new management methods to the area could be the way to a more effective management of the heathland.

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Appendix

The attached files,

“AnneGrarup - R script”

The R script was used for the data analysis.

“YearComparison”

The data used for the comparisons for the short- and long-term effects.

“CommunityComparison”

The data used for the grazing comparisons.