



Use of Molasses-Based Blocks to Modify Grazing Patterns and Increase Highland Cattle Impacts on *Alnus viridis*-Encroached Pastures

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Alnus viridis is a pioneer species that has expanded in Central Europe in the last decades, causing a series of negative agro-environmental impacts. Robust livestock grazing could be used as a targeted tool to reduce its encroachment, but more information is needed to find the best approach to achieve this goal. In this study, we assessed the potential of molasses-based blocks (MB) to lure Highland cattle into *A. viridis*-encroached areas and monitored impacts on the vegetation after grazing. In 2019 and 2020, two Highland cattle herds equipped with GPS collars were placed in three paddocks in the Swiss and Italian Alps, differing in the degree of *A. viridis* encroachment. In 2020, MB were added to highly encroached areas within each paddock to attract the herds to feed on *A. viridis*. Botanical surveys were carried out before and after grazing, around MB and control areas. Highland cattle grazed significantly more around MB (up to 50 m from the MB) compared to the previous year (i.e., same area without MB) and compared to control areas. The increased targeted grazing around MB led to a significant decrease in herbaceous cover and an increase in bare soil compared to control areas. Livestock grazing and trampling significantly reduced the cover of ferns, tall herbs, medium and small herbs, and woody species around MB compared to control areas. *A. viridis* leaves and branches were significantly removed and damaged up to 10 m from the MB, due to the more intense livestock grazing. Such results highlight the potential of this management regime to effectively reduce *A. viridis* encroachment in montane grasslands.

Keywords: GPS-tracking, green alder, montane grassland, robust livestock, targeted grazing

INTRODUCTION

During the last century, socio-economic transformations have led to a large-scale decrease in agro-pastoral activities across the mountain areas of Europe, resulting in many challenges for grassland management and biodiversity conservation (MacDonald et al., 2000; Valkó et al., 2018). For instance, in Switzerland, the last 30 years have witnessed a significant decrease in grassland area in alpine regions (Strebel and Bühler, 2015; Zehnder et al., 2016). The reduction of livestock farming

has caused profound landscape modification and widespread shrub and tree encroachment in former meadows and pastures (Estel et al., 2015). For example, from 1985 to 2013, shrublands and forests increased by 10.6% across Switzerland, with the largest increases in the Alps (Abegg et al., 2020). Encroachment of montane grasslands by woody species has been even more pronounced in the Italian Alps (Orlandi et al., 2016). Shrublands now cover an area of 679 km² in Switzerland (Abegg et al., 2020), with about 70% of them composed by green alder [*Alnus viridis* (Chaix.) D. C.], which is among the most rapidly expanding shrub species in Central Europe (Anthelme et al., 2007). *Alnus viridis* is a pioneer shrub species that lives in symbiosis with the N₂-fixing actinomycete *Frankia alni* (Huss-Daniel, 1997). It is found mostly in steep, north and west-facing slopes, but it can easily expand into other habitats in montane environments, thanks to its efficient colonization ability and substantial seed production (Farmer et al., 1985; Caviezel et al., 2017). Its presence is strongly affected by land-use intensity, as land-abandonment is a key driver of its spread (Caviezel et al., 2017).

Encroachment by *A. viridis* can have several negative agro-environmental impacts on montane grasslands, which in turn reduce the provision of key ecosystem services for society. For instance, *A. viridis* encroachment prevents forest succession, and causes nitrogen enrichment in soils leading to increased nitrate leaching and higher risk of dissolved organic carbon leaching (Bühlmann et al., 2016; Hunziker et al., 2017). This can result in soil acidification, water pollution and gaseous nitrogen losses (Caviezel et al., 2014; Bühlmann et al., 2017). van den Bergh et al. (2018) also showed that *A. viridis*-encroachment increases the evaporative water loss. Moreover, *A. viridis*-dominated shrublands are characterized by a lower forage quality and host lower animal and plant diversity than adjacent grasslands (Anthelme et al., 2001; Bühlmann et al., 2014; Svensk et al., 2021). A recent study by Zehnder et al. (2020) showed that *A. viridis* encroachment resulted in a rapid reduction in plant species richness and grassland specialist species, with dense *A. viridis* patches hosting 62% less species than nearby open pastures. This decrease in biodiversity is linked to reduced light levels in highly encroached areas, as well as to soil nitrogen enrichment. Indeed, only a few tall and shade-tolerant plants with broad leaves, such as *Adenostyles alliariae* (Gouan) A. Kern and *Cicerbita alpina* L. (Wallr.), together with a few fern species, are able to adapt to these ecological conditions and dominate the understory vegetation of *A. viridis* shrublands (Svensk et al., 2021). Furthermore, in contrast to coniferous forests, *A. viridis* stands do not provide protection against erosion and avalanches on steep slopes, mostly due to the elasticity of their branches that easily bend under snow pressure (Caviezel et al., 2014). Their resistance to this environmental pressure provides an advantage for *A. viridis* in these areas, compared to other shrubs or trees that can easily break under such disturbance. Finally, the encroachment by *A. viridis* can also adversely impact landscape quality in montane areas, resulting in reduced attractiveness for tourists.

Because *A. viridis* predominantly establishes on steep slopes and marginal locations, with few roads, the mechanical removal of this shrub species can be technically difficult, expensive and time consuming. One alternative and sustainable nature-based

solution to counteract shrub encroachment could be the use of targeted grazing (Elias and Tischew, 2016; Elias et al., 2018; Pauler et al., 2022). Meisser et al. (2014) monitored the grazing behavior of Hérens cows in *A. viridis* dominated pastures and showed that they did spend time in half or more encroached areas, despite their usual preference for open areas. However, many shrub species like *A. viridis* are not palatable for production-oriented livestock due to their low foliage digestibility. Stević et al. (2010) found that *A. viridis* leaves contained an average of 4.4% of tannins, which could eventually cause an astringent taste and reduce palatability (Kumar and Vaithiyanathan, 1990). Nevertheless, some robust livestock species and breeds have higher resistance to tannins, with ruminal bacterial populations that can better degrade lignified material, allowing them to feed on shrubs and digest their leaves (Berry et al., 2002; Marques et al., 2017). For instance, previous studies have shown that sheep and goats can efficiently feed on woody plants and significantly reduce their cover (Iussig et al., 2015; Álvarez-Martínez et al., 2016; Pauler et al., 2022). Some cattle breeds can also feed on shrub species (Zehnder et al., 2016; Pauler et al., 2019). For example, Highland cattle, a robust breed originating from Scotland, are able to graze on low quality shrub foliage (Pauler et al., 2020a) due to their low maintenance energy requirements and their more efficient use of nutrients from the vegetation (Berry et al., 2002). This has recently led, together with the low costs of their maintenance and care, to an increased rearing of this livestock breed in alpine regions (Pauler et al., 2020b). Previous studies have demonstrated their capacity to reduce woody plant species cover over time, with a turnover in plant diversity (Pauler et al., 2019, 2020a). In addition to the direct grazing of the leaves, Highland cattle are also able to damage shrub branches and trunks thanks to their long horns (Svensk et al., 2021), even if they do not directly debark trees as some robust goat or sheep breeds do (Pauler et al., 2022). Recently, Svensk et al. (2021) showed that Highland cattle can graze on steep montane pastures characterized by high *A. viridis* cover and associated low forage quality vegetation in the understory. Therefore, Highland cattle grazing could be an efficient and sustainable tool to reduce *A. viridis* encroachment and restore encroached pastures in the long-term.

Together with cattle feeding behavior, livestock management techniques are also key elements to increase livestock impacts on targeted shrub-encroached vegetation. For instance, livestock supplements could be used to attract them to underused and shrub-encroached locations (Probo et al., 2013, 2016). Different types of dietary supplementation exist, mainly composed of salt (i.e., mineral mix supplements) or sugar (i.e., molasses-based blocks, MB). Previous studies have already demonstrated the efficacy of mineral supplements in attracting beef cattle herds within steep montane shrub-encroached areas (Probo et al., 2013; Pittarello et al., 2016). For example, in a 5-year study, Probo et al. (2016) highlighted a significant reduction in shrub cover, together with the establishment of typical pasture species with higher forage quality, thanks to the effects produced by grazing, trampling, seed and dung translocation at mineral supplement locations. Dehydrated MB were also proven to be efficient in influencing cattle grazing patterns in unfavorable field conditions

(i.e., steep slopes, far from water sources and usually undergrazed zones) and across large areas in the North American steppes (Bailey and Welling, 1999; Bailey et al., 2001). However, they have never been tested in montane shrub-encroached areas, despite their lower cost and labor compared to fencing and herding. The MB for cattle grazing management provides different advantages, such as an enrichment of cattle diets through mineral supplementation, that can also reduce the risks of foot pathology and mycotoxicosis, and an enhancement of the intake of forage with low palatability, thanks to their appetizing role (Mordenti et al., 2021). However, more information is needed on the efficiency of molasses-based supplements in changing livestock spatial distribution and increasing the cover of target plant species of functional groups, in montane environments. Indeed, previous studies (e.g., Tocco et al., 2013), showed that the analysis of functional group cover in the short-term can be essential to assess the effectiveness of targeted grazing techniques in a longer term.

In the present study, we placed MB on *A. viridis*-encroached pastures to attract Highland cattle herds and increase their effects on shrub vegetation. Specifically, we aimed to investigate: (i) the effect of strategically placed MB on Highland cattle spatial distribution and (ii) the impacts of targeted grazing by livestock around MB on *A. viridis* shrubs, understory plant functional groups and soil cover. We hypothesized that (i) Highland cattle would significantly use more the areas around MB, and (ii) their targeted grazing and trampling pressure would have a higher impact on *A. viridis* shrubs around MB, with an increased removal of leaves and damage on trunks and branches compared to control areas. Simultaneously, we expected (iii) the understory vegetation to be more affected around MB, with an increase in bare soil due to livestock grazing and trampling, which could lead to a potential recolonization of those areas by typical pasture species in the long-term.

MATERIALS AND METHODS

Study Areas and Grazing Management

During the summer seasons of 2019 and 2020, two Highland cattle herds were placed in three *A. viridis*-encroached paddocks in the Swiss and Italian Alps. The first one (paddock 1, 17.88 ha) was located in Val Vogna, in the province of Vercelli (Italy). The other two paddocks (paddock 2, 8.26 ha and paddock 3, 7.67 ha) were located in Bovonne, in the canton of Vaud (Switzerland) and were grazed by the same herd. All paddocks were grazed at a comparable stocking rate between years (Table 1) and had similar topographical conditions, with an elevation of $1,861 \pm 45$ m a.s.l (mean \pm s.e.) and slope of $23 \pm 8^\circ$ (mean \pm s.e.). The three paddocks were representative of an *A. viridis* cover gradient, with an average cover of 20, 61, and 71%, respectively, in paddock 1, 2, and 3. The herds grazed in the summer pastures from the middle of June to the beginning of September (Table 1). All the herds included cow/calf pairs and heifers, varying in age from 6 months to 17 years (with an average of 5 years for paddock 1 and 4 years for paddock 2 and 3) and about 70% of the animals

were present in both years at the same site. A water trough was installed in paddocks 2 and 3, while natural streams were present in paddock 1. In each herd and during both years, six to ten cows (Table 1) were equipped with GPS collars (Followit AB, Tellus GPS System collars, Sweden) that recorded their position every 10 min during the whole grazing period, with an accuracy of 2–5 m.

In 2020, five dehydrated MB (with 2–3% of residual moisture) of 22.5 kg each were added to each paddock as attractive points. They were provided within small boxes of $40 \times 28 \times 20$ cm. They were mostly composed of sugar (40%), which has an appetizing effect and fosters the intake of low forage quality vegetation (Mordenti et al., 2021), and contained mineral supplements which are often lacking in natural montane environments (Schlegel and Kessler, 2001), thus complementing cattle feeding (detailed composition available in Supplementary Table 1). The number of blocks was defined based on the average consumption by cattle given by the producer (i.e., 35–50 g/calf \times day, 100 g/heifer \times day, and 150–200 g/cow \times day). The consumption of MB was monitored in each paddock every 2 days to check that enough molasses was available during the grazing period. At the end of the grazing period, the MB were weighed and the average consumption per animal was estimated by dividing the total amount consumed by the number of animals and grazing days. The MB were placed at five points along a 40-m line, lying along a contour line, and separated by 10 m from each other (Supplementary Figure 1), in highly *A. viridis*-encroached areas (i.e., areas with more than 2/3 of *A. viridis* cover). A control line was also established in each paddock in areas with comparable *A. viridis* cover, slope, botanical composition and distance to water sources. These two similar zones (190 ± 72 m apart) were identified in each paddock and assigned randomly to either control or MB areas before the grazing season of 2020. Moreover, to avoid any pre-existing effect of the area on cattle distribution, we also checked that the MB and control locations were similarly exploited by livestock in 2019, before the MB were established in 2020. Around control and MB lines, buffer areas with a radius of 10 and 50 m were created in a GIS environment, and the number of GPS positions was calculated for each cow within each buffer (using QGIS 3.6 software). As one GPS location was recorded every 10 min, we calculated the average number of minutes a cow spent per day in every buffer area. The 10-m buffer was used to assess the attractive effect in a small area, in which livestock were likely present to actively consume MB, while the 50-m buffer was used to estimate the attractive effect on a larger scale, i.e., including areas where livestock grazed and walked around MB locations.

Vegetation Surveys

Around both MB and control points, botanical surveys were carried out in 2020 both before grazing (June–July) and after grazing (August), in cross-shaped vegetation transects of 10 meters (see Supplementary Figure 1), using the vertical point-quadrat method (Daget and Poissonet, 1971). At 50 cm intervals along each transect, the vascular plant species touching a steel needle up to a grazable height (i.e., 1.8 m) were identified and

TABLE 1 | Grazing periods, grazable area, livestock stocking rates and number of GPS collars in the study areas in 2019 and 2020.

Year	Paddock	Grazing period	Number of grazing days	Livestock units (LU ^a)	Grazable area (ha)	Stocking rate (LU/ha * year)	Number of GPS collars
2019	Paddock 1	July 19th to September 3rd	44	45.4	17.88	0.31	6
	Paddock 2	July 2nd to 19th	17	29.8	8.26	0.17	8
	Paddock 3	July 30th to August 17th	19	29.8	7.67	0.19	8
2020	Paddock 1	July 20th to August 18th	29	70.4	17.88	0.31	8
	Paddock 2	June 15th to July 2nd	17	29.6	8.26	0.17	10
	Paddock 3	July 2nd to 20th	18	29.6	7.67	0.19	10

^aLU, Livestock Unit. One livestock unit = 1 animal of 500 kg.

recorded. To account for rare species around the transect, all other species within a one meter buffer around the transect were also recorded (Kohler et al., 2004). Each line of MB and control points in all three paddocks was made up of 16 transects (i.e., 48 vegetation transects in control areas and 48 in MB areas in total). The percentages of herbaceous cover and bare soil were visually assessed before and after grazing within a one-meter buffer around each transect, to assess the changes in vegetation cover produced by livestock targeted grazing and trampling. Plant species nomenclature followed Aeschmann et al. (2004).

Along the vegetation transect, the percentage species cover (%SC) was calculated by converting the recorded frequency of occurrence of each plant species to 100 measurements. A %SC of 0.3% was assigned to the species found only in the 1-m buffer zone and not along the transect, following Pittarello et al. (2016). Species were grouped in three main functional groups (see **Supplementary Table 2**) that were common among all paddocks and typical of the understory of *A. viridis*-encroached pastures (Svensk et al., 2021): (1) Ferns and tall herbs, i.e., all ferns and tall broad-leaved forbs having a leaf diameter greater than 10 cm and taller than 40 cm, following Pignatti (1982); (2) medium and small herbs, i.e., other non-graminoid species that were not classified as tall herbs; and (3) woody, i.e., all woody species (including *A. viridis*). Graminoids were not taken into account as they were a minor component of the understory vegetation, representing only $5.9 \pm 3.1\%$ on average (mean \pm SE) of the vegetation cover in each paddock (with a maximum of 11.5% in paddock 1).

Along each transect three *A. viridis* shrubs were selected every 3–4 m and marked. We did not include the central transect in this selection as the central transects had two MBs close to them. One branch from each tree was selected to assess the number of living leaves before and after grazing, and thus estimate the removal of *A. viridis* leaves by Highland cattle, and the damage done to the observed branch. Whenever the branch was totally broken and untraceable after grazing, the number of remaining living leaves was considered equal to zero. The damage made on *A. viridis* branches through grazing, scratching or trampling was also visually assessed with the following scale: 0 (no damage), 1 (moderate damage), 2 (intense damage) and 3 (branch totally damaged or broken). The maximum height at which damage was observed on each branch was also recorded.

For the analyses of soil and functional group cover as well as leaf removal, a response ratio (RR) was computed for all the assessed variables according to the following formula:

$$RR = \frac{Value_{Post} - Value_{Pre}}{Value_{Pre}}$$

where “Value_{Post}” is the value measured after grazing and “Value_{Pre}” the value measured before grazing. This formula provides an indication of the effect size, which is not biased by the initial (before grazing) differences among replicates. A negative RR indicates that the value decreased after grazing, while a positive RR indicates that the value increased after grazing.

Statistical Analysis

All statistical analyses were performed using R version 3.4.4 (R Core Team, 2017). The effects of treatment (control vs. MB), the year (2019, 2020) and their interactions on the spatial distribution of cows were tested separately for the 10- and 50-m buffers by using a linear mixed-effect model (lme, package “nlme”), with “paddock” as a random factor. Spatial distribution of cows was measured as the average time spent by a cow at the herd level within the buffer (minutes day⁻¹ cow⁻¹, obtained from GPS location counts), i.e., the sum of the minutes spent by all GPS-equipped cows in the considered buffer, divided by the number of GPS-equipped cows. The effects of treatment (control vs. MB) on 2020 soil cover (RRs of herbaceous cover and bare soil) and on functional group cover (RRs of ferns and tall herbs, medium and small herbs, and woody species cover) were tested using generalized least square models (GLS), with treatment (control vs. MB) as fixed factors and coordinates of the transects, nested in paddock, as random effects. This random effect structure takes into account the nested structure of the data and accounts for any residual spatial autocorrelation among neighboring transects. The effects of MB, distance of shrubs along the transect, and their interactions, on the RR of *A. viridis* leaves were tested using the same type of GLS model, again with the coordinates of the transects nested in paddock. Although the GLS analysis takes into account the potential spatial autocorrelation and pseudoreplication, we carried out an additional, conservative analysis in which we analyzed only the average RR in each area of the paddocks (i.e., 3 control points vs. 3 MB, one control and one MB from each paddock: 6 data points in total), using ANOVA. The ANOVA has much lower power than the GLS model but is completely free from any spatial autocorrelation

or pseudoreplication issues. *Post hoc* tests were performed for the models when significant effects were detected (Tukey's test, $P < 0.05$), and additional Student's test (*t*-test) were performed to assess the difference of RRs from zero.

RESULTS

Effects of Molasses-Based Blocks Placement on Livestock Spatial Distribution

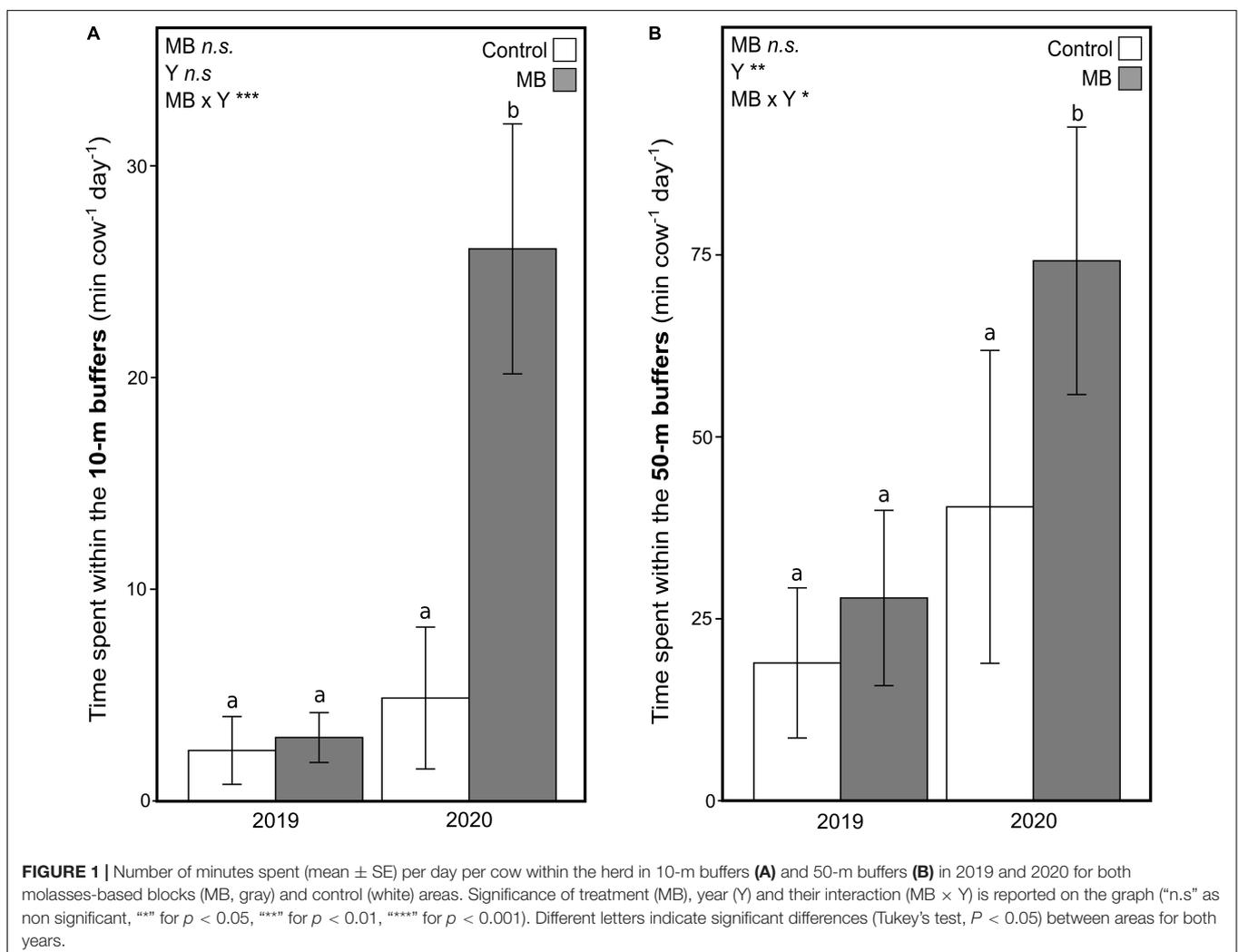
Based on the remaining molasses after grazing, we calculated that each animal consumed 134 g of molasses per day on average. All MB (except two placed in paddock 3) were completely consumed at the end of each grazing period.

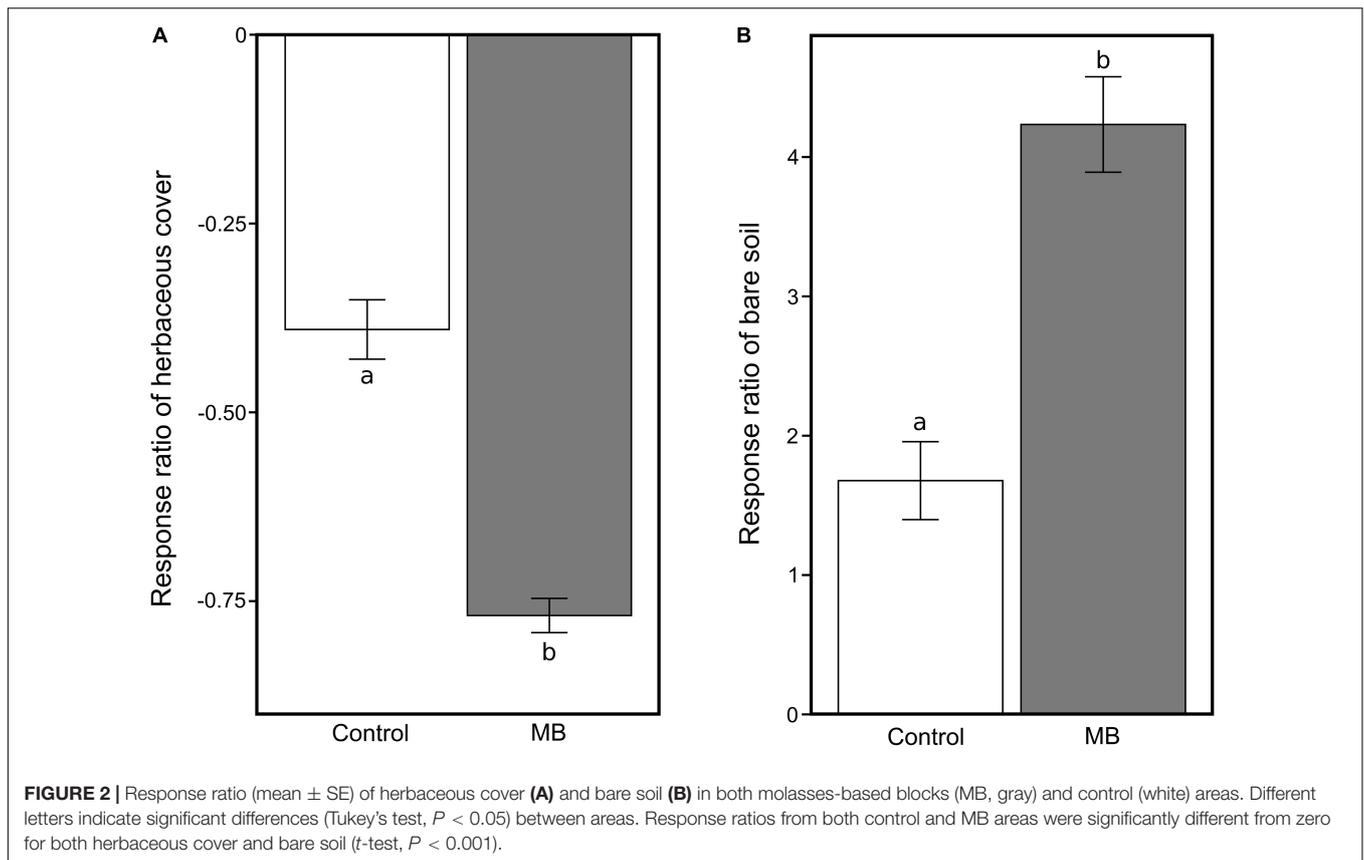
There were no significant differences in the average number of minutes spent by cows between control and MB areas in 2019, in both 10- and 50-m buffers ($P = 0.99$ and $P = 0.78$, respectively; **Figure 1** and **Supplementary Table 3**), indicating that the locations chosen were equally attractive to livestock,

before the MB were placed in 2020. There was a significant increase of livestock use in MB areas in 2020 compared to 2019 for both 10-m (MB \times Y, $P < 0.001$, + 771% on average; **Figure 1A**) and 50-m (MB \times Y, $P < 0.05$, + 166% on average; **Figure 1B**) buffers.

Effects of Livestock on Soil Cover

The percentage of bare soil was highly impacted by livestock targeted grazing and trampling. There was a significant decrease in herbaceous cover and a significant increase in bare soil after grazing, in both control and MB areas, with response ratios always significantly different from zero ($P < 0.001$, **Figure 2** and **Supplementary Table 3**). The impacts of livestock around the MB always had a significant effect on both herbaceous cover and bare soil ($P < 0.001$, **Figure 2**), with a higher impact on bare soil around MB compared to control areas. The herbaceous cover had an average RR of -0.77 around MBs, and decreased from 73.5% before grazing to 16.2% after grazing. In control areas, herbaceous cover had an average RR of -0.39 and decreased from 61.9% before grazing to 35.5% after grazing. On the other hand, the percentage of bare





soil had an average RR of 4.23 around MB, and represented 17.1% before grazing and 76.2% after grazing. In control areas, bare soil had an average RR of 1.68, and represented 29.2% before grazing and 56.7% after grazing. The ANOVA analysis performed on the average RR cover per paddock provided the same results, except for percentage of bare soil for which the effect of MB was marginally significant (see **Supplementary Table 4**).

Effects of Livestock on *Alnus viridis* Shrubs

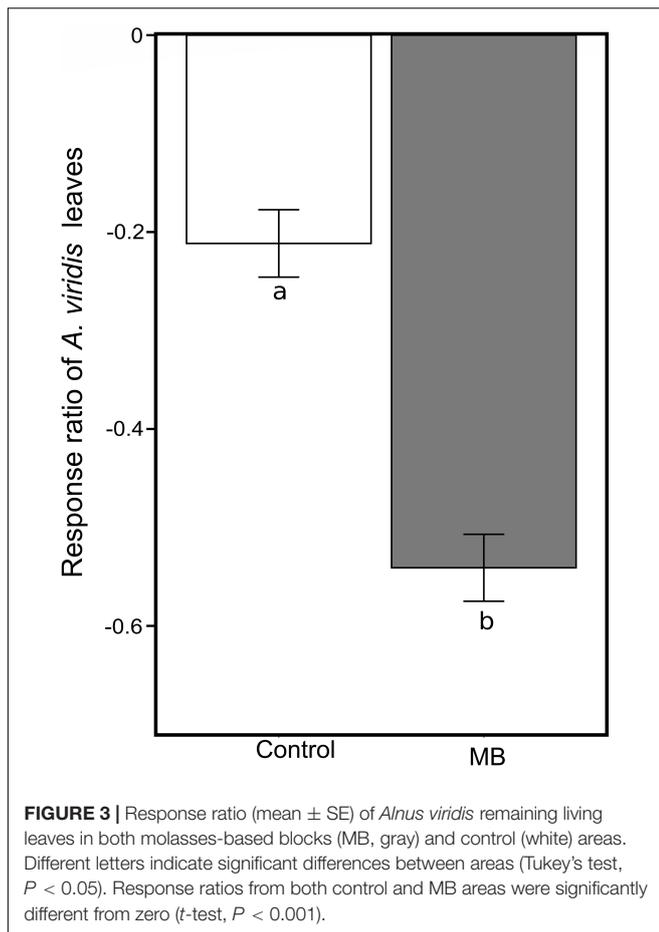
The *A. viridis* shrubs were highly damaged by Highland cattle targeted grazing. There was a significant decrease in the number of *A. viridis* leaves after grazing in both control and MB areas, with a higher decrease around MB and negative response ratios significantly different from zero ($P < 0.001$, **Figure 3** and **Supplementary Table 3**). The interaction between MB and distance was significant ($P < 0.05$), with the removal being higher on shrubs closer to the MB compared to further shrubs, while in control areas the effect was the same independent of the distance. In addition to leaf removal, damage on *A. viridis* branches was assessed at MB locations at an average height of 1.48 ± 0.53 m (mean \pm SE), with 68% of branches having damage scores between 1 and 2 (moderate to intense damages) and 10% with damage scores of 3 (very severe damage or broken branches). Reducing our dataset to 6 data points and analyzing the average

RR of number of *A. viridis* leaves showed that the effect of MB was also significant (see **Supplementary Table 4**).

Effects of Livestock on Understory Plant Functional Group Cover

A total of 149 plant species were recorded during the botanical surveys in all paddocks (the species list and their corresponding functional group are available in **Supplementary Table 2**). Ferns and tall herbs included 37 species and had the highest % SC (44.4%), with *Adenostyles alliariae* (14.1%), *Athyrium filix-femina* (L.) Roth (10.4%) and *Dryopteris dilatata* (Hoffm.) A. Gray (4.3%) being the most dominant species. Most species (78) were medium and small herbs (23.5%), with *Ranunculus aconitifolius* L. (8.7%) *Stellaria nemorum* L. (2.7%) and *Viola biflora* L. (2.2%) being the most dominant. Woody species (26.1%) comprised 14 species, including *Alnus viridis* (18.5%), *Vaccinium myrtillus* L. (2.0%) and *Rhododendron ferrugineum* L. (1.5%). Graminoids were not abundant in the botanical surveys (20 species and 5.9%).

The increased targeted grazing and trampling around MB had a significant impact on understory plant functional groups. There was a significant decrease in fern and tall herb cover and in medium and small herb cover after grazing in both control and MB areas, with negative response ratios always significantly different from zero ($P < 0.001$, **Figures 4A,B** and **Supplementary Table 3**). The presence of MB always had a significant effect on both groups, leading to a higher



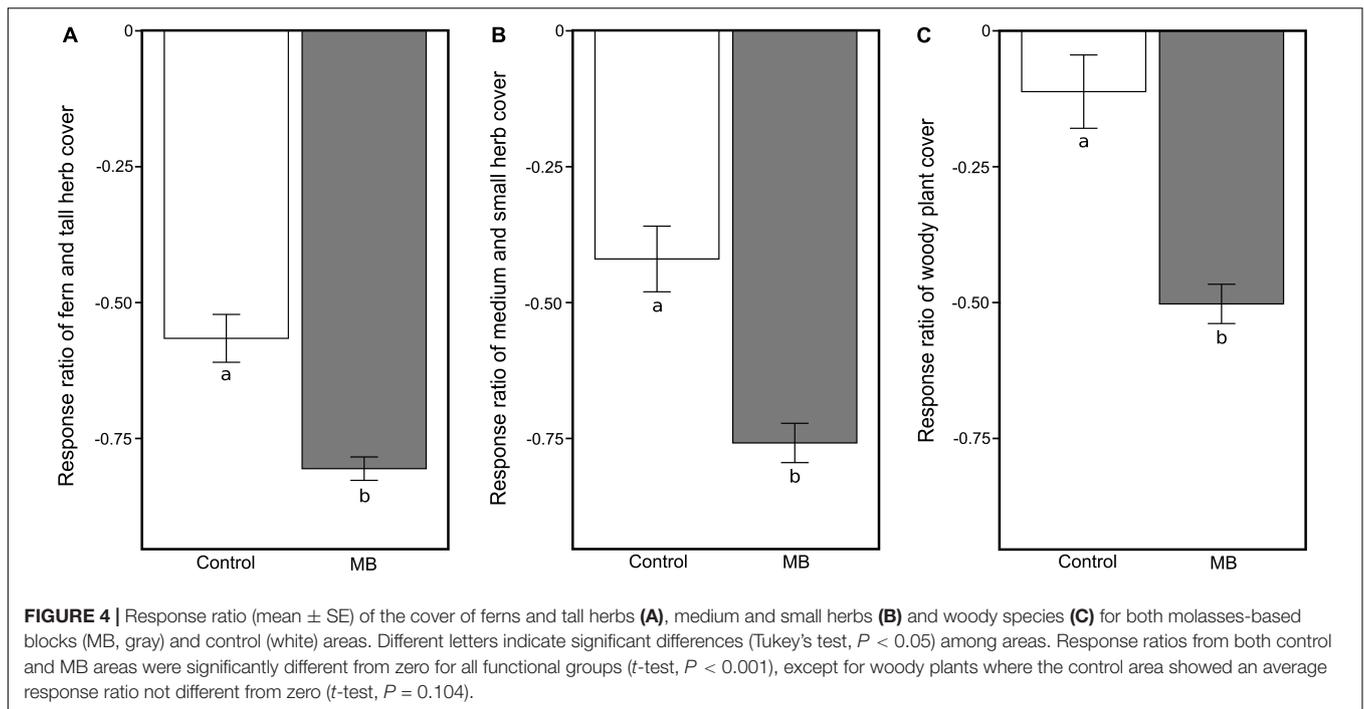
decrease compared to control areas ($P < 0.001$, **Figures 4A,B**). Woody species decreased significantly more around MB than in control areas ($P < 0.001$; **Figure 4C**), in which they were not significantly damaged, with response ratios not different from zero (-0.11 ± 0.07 , $P = 0.10$). Reducing our dataset to only 6 data points and analyzing the average RR of functional groups showed the same results, except for fern and tall herb cover for which the effect of MB was not significant (see **Supplementary Table 4**).

DISCUSSION

Overall, the strategic placement of MB significantly altered Highland cattle spatial distribution, and increased livestock use of areas around MB locations, compared to the previous year and to control areas. This result confirmed our first hypothesis that Highland cattle were attracted to MB and that they were able to use steep and highly encroached *A. viridis* areas, as recently pointed out by Svensk et al. (2021). The results on the effectiveness of MB are thus consistent with those found by Bailey and Welling (1999), who showed that they could attract herds into underused rangelands with poor quality forage. Those authors assessed the efficiency of dehydrated blocks in un-encroached zones with gentle to moderate slopes, while our study showed that such strategic placements can attract herds

even in areas with steeper slopes and high levels of woody species encroachment, where grazing conditions could be more challenging. When analyzing the attractive effect at different spatial scales, a significant increase in the use of areas up to 50-m from MB locations, compared to control areas, was detected. This 50 m-scale effect of MB underlines the potential of such management techniques to increase livestock use over large *A. viridis* encroached patches. The effect of MB within 10-m buffers was even more significant, with substantially increased livestock use at a close range near the molasses-based blocks. Such measurements at different spatial scales highlight the influence of MB on Highland cattle spatial distribution, with this type of management enabling cattle to increase their visits to the surrounding encroached zones once they are attracted by the molasses. Other studies have also shown high potential for different strategic placements to reduce shrub-encroachment at different scales, and to attract herds into under-grazed areas (Bailey and Welling, 2007; Bailey and Jensen, 2008; Pittarello et al., 2016). In particular, Pittarello et al. (2016) found a significant attractive effect at 10- and 50-m around supplement blocks in dwarf-shrub encroached montane pastures, using a different supplement type (mineral mix supplements) for another cattle breed (Piedmontese breed). In our study, under comparable mountain topographic conditions, livestock use and supplement consumption were much higher, with 134 g of molasses consumed per animal per day, corresponding to ca. 80 g of minerals without taking into account the 40% of sugar from molasses content (see **Supplementary Table 1**) compared to 13.7 g of mineral mix supplement in Pittarello et al. (2016), suggesting a higher attractiveness and efficiency of molasses-based than mineral mix blocks in modifying livestock spatial distribution. Indeed, the average time spent around MB (i.e., 74 min cow⁻¹ day⁻¹) was much higher than the 18 min cow⁻¹ day⁻¹ around mineral mix supplements in a 50-m buffer found by Pittarello et al. (2016). Furthermore, the familiarity of the cattle with the paddock characteristics might be an important factor to consider when implementing such management in the long term, as the exploration behavior could increase over time and have an enhanced effect on vegetation.

Overall, the increased use by Highland cattle of areas with MB led to a significant removal of leaves and damage to the branches of *A. viridis* shrubs. Moreover, it resulted in a decrease in herbaceous cover and an increase in bare soil after grazing, compared to control areas. Further, the cover of medium and small herbs and woody plants was significantly reduced by the increased livestock use of MB areas. These impacts were related both to targeted grazing and to the mechanical damage caused by Highland cattle once attracted to the MB areas. Such damage may result from trampling, scratching and breaking branches while walking (see **Supplementary Figure 2**), as recently observed by Svensk et al. (2021). The significant effect of the interaction between MB and the distance of shrubs suggests a different effect of the distance between control and MB areas. Indeed, large paths created by the animals were observed between MB and the surrounding area, due to grazing activity and movement from MB to water sources. While we could not differentiate between effects of grazing and trampling on the vegetation, Highland



cattle were observed to graze on species with particularly low forage quality, such as ferns (*A. filix-femina*, *D. dilatata*) and tall herbs (*A. alliariae*). This demonstrates the ability of this breed to feed not only on *A. viridis* shrubs but also on other unpalatable understory species, which is consistent with our second and third hypotheses. Previous studies have also shown that Highland cattle tend to be less selective with regard to forage quality compared to other breeds, and are able to feed on woody plants (Pauler et al., 2020a,b). Moreover, they tend to be more adapted to low quality vegetation and lower nutrient intake, as they continue to gain weight under such constraining conditions (Berry et al., 2002). *A. viridis* leaves and the understory vegetation have also proven to be a valuable fodder resource, but only for certain robust cattle breeds, such as Dexter cattle or Hérens cattle (Meisser et al., 2014; Zehnder et al., 2016). Even if only measured in the short-term, the intense impacts exerted on *A. viridis* shrubs and other woody species indicate the potential for Highland cattle to reduce woody species encroachment in the medium- and long-term.

Maintaining Highland cattle grazing and the strategic placement of MB over the long term could enable typical pasture species to colonize areas where vegetation cover was highly impacted and new gaps were created. Indeed, several studies have shown that long-term targeted grazing by goats led to increased light conditions in formerly highly shrub-encroached pastures, with the establishment of light-demanding, low-growing and less competitive grassland species (Elias et al., 2018; Silva et al., 2019; Köhler et al., 2020). Similarly, we can expect cows to alleviate light competition for the understory vegetation cover (thanks to the combination of increased bare soil and removed of *A. viridis* leaves) likely producing a shift in plant functional groups in the long term, and an increase in plant diversity (Hautier et al., 2009). Moreover, to avoid possible risks of localized erosion

linked to excessive livestock trampling, it would be advisable to regularly move MB to different shrub-encroached areas during the grazing season and throughout the years. This would also allow the expansion of the livestock impacts on vegetation to a wider area (Probo et al., 2013). While our paddocks always had comparable stocking rates between years, they did not always have exactly the same stocking densities (e.g., paddock 1, in which in the second year a bigger herd grazed for a shorter period compared to the first year). Therefore, future studies with similar stocking densities among years would be useful to confirm the present findings. The assessment of the potential effect of social interactions within the herd (Stephenson et al., 2016) could also be useful to refine the effect of MB in the herd at an individual level. Moreover, as Highland cattle periodically traveled from open pastures to highly encroached zones (Svensk et al., 2021), the restoration of former pastures could be enhanced by seed translocation through endo- and epi-zoochory. Indeed, a recent study (Pauler et al., 2019) demonstrated that a higher number of epizoochoric plant species were found in pastures grazed by Highland cattle compared to pastures grazed by production-oriented cattle breeds, since the long fur of the Highland cattle resulted in more efficient seed dispersal. The same study also found that the less selective grazing behavior of this breed led to higher plant species richness in pastures, as Highland cattle consumed a larger range of species compared to other breeds. They were thus able to graze on less palatable dominant species and reduce their abundance for the benefit of other herbaceous species. Moreover, a high number of dung droppings was already observed around MB after grazing, which could further promote seed dispersal from adjacent pastures through endozoochory (Cosyns et al., 2005). Indeed, even if other management strategies such as controlled fires or clear-cutting have proven effective

at reducing shrub encroachment in montane environments, targeted grazing seems to be best suited to restore montane pastures, especially considering the enhanced plant dispersion by livestock (Alados et al., 2019). In addition, the mechanical damage caused to *A. viridis* branches by livestock might increase pathogen attacks on this shrub species and therefore reduce its spread. For example, fungi species of the genus *Phytophthora* can spread through water and have the potential to infect bark lesions of a plant, and have been reported to have severe impacts on alder shrubs including *A. viridis*, sometimes leading to mortality (Pisetta et al., 2012; Bregant et al., 2020).

CONCLUSION

In conclusion, our findings demonstrate that the strategic placement of molasses-based blocks was efficient in attracting Highland cattle toward areas highly invaded by *A. viridis*, despite the harsh terrain (steep slopes). Highland cattle successfully fed on, and damaged, *A. viridis* shrubs around the MB, thus significantly altering the understory vegetation through grazing and trampling, in just one grazing season. Highland cattle could thus have the potential to effectively reduce *A. viridis*-encroachment in the long term, and, by increasing light conditions for understory species and translocating seeds, they could promote montane pasture restoration.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://doi.org/10.5281/zenodo.6491171>.

ETHICS STATEMENT

The animal study was reviewed and approved by the Direction générale de l'agriculture, de la viticulture et des affaires vétérinaires (Canton de Vaud).

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AUTHOR CONTRIBUTIONS

MS: methodology, data collection, formal analysis, and writing. GN and MPi: data collection, formal analysis, and writing. PM: supervision, methodology, data collection, formal analysis, and writing. DB and EP: data collection and writing. ML: formal analysis and writing. EA: supervision, formal analysis, and writing. MPr: conceptualization, funding acquisition, project administration, methodology, supervision, data collection, and writing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2022.849809/full#supplementary-material>

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