



# Spatial Distribution of Highland Cattle in *Alnus viridis* Encroached Subalpine Pastures

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## OPEN ACCESS

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### Specialty section:

This article was submitted to  
Conservation and Restoration  
Ecology,  
a section of the journal  
Frontiers in Ecology and Evolution

**Received:** 06 November 2020

**Accepted:** 18 January 2021

**Published:** 19 February 2021

### Citation:

Svensk M, Pittarello M, Nota G,  
Schneider MK, Allan E, Mariotte P  
and Probo M (2021) Spatial  
Distribution of Highland Cattle in  
*Alnus viridis* Encroached Subalpine  
Pastures. *Front. Ecol. Evol.* 9:626599.  
doi: 10.3389/fevo.2021.626599

Green alder (*Alnus viridis*) is a shrub species that has expanded over former pastures in Central Europe due to land abandonment, leading to negative agri-environmental impacts, such as a reduction in forage yield and quality and an increase in nitrate leaching. Robust livestock breeds such as Highland cattle could be used to control *A. viridis* encroachment. The objectives of this study were to investigate the impact of *A. viridis* encroachment on plant community composition and diversity and to map the spatial distribution of Highland cattle in *A. viridis*-encroached pastures. During the summer of 2019, three different Highland cattle herds were placed along an *A. viridis* encroachment gradient. A total of 58 botanical surveys were carried out before grazing to assess plant community composition, pastoral value, and ecological indicator values. The spatial distribution of cattle was studied during the whole grazing period by monitoring six to eight cows equipped with GPS collars in each herd. Plant species associated with higher pastoral values of the vegetation were found in areas with lower *A. viridis* cover, while highly encroached areas were dominated by a few nitrophilous and shade-tolerant broad-leaved species and by ferns. Cattle spent more time in areas with higher pastoral value but did not avoid areas with high cover of *A. viridis*, on steep slopes or far from water. These results show that Highland cattle are able to tolerate harsh environmental conditions and that they can exploit *A. viridis*-encroached pastures. This suggests that they have a high potential to reduce *A. viridis* encroachment in the long-term.

**Keywords:** biodiversity, GPS tracking, grassland, robust livestock, INLA, Alps, green alder, grazing

## INTRODUCTION

Throughout the last decades, socioeconomic changes have led to a reduction in agro-pastoral activities in European mountain areas, triggering profound landscape modifications, and widespread natural reforestation and shrub encroachment in former pastures (Estel et al., 2015). For instance, from 1985 to 2013, shrublands and forests have increased by 10.6% across Switzerland, with the largest increases in the Alps (Abegg et al., 2020). Shrublands now cover an area of 679 km<sup>2</sup> in Switzerland, with about

70% of them dominated by pure stands of green alder [*Alnus viridis* (Chaix.) D. C.], which is the most rapidly expanding shrub species in Central Europe (Anthelme et al., 2007). *A. viridis* is a pioneer species, which lives in symbiosis with the N<sub>2</sub>-fixing actinomycete *Frankia alni* (Huss-Daniel, 1997), and its presence is determined by land use intensity (Caviezel et al., 2017). Encroachment by *A. viridis* can have several negative agri-environmental impacts: in particular, *A. viridis*-dominated shrublands have lower plant and animal diversity and forage quality than open grazed areas (Anthelme et al., 2001). A recent study showed that *A. viridis* encroachment resulted in a rapid decline in plant species richness, with dense *A. viridis* patches hosting 62% less species than adjacent open pastures (Zehnder et al., 2020). Moreover, there is high nitrate and dissolved organic carbon leaching from *A. viridis* shrublands, which results in water pollution, soil acidification, hydrological drawbacks, and gaseous nitrogen losses (Bühlmann et al., 2016; van den Bergh et al., 2018). It is therefore important to find methods that control *A. viridis* encroachment in order to reverse biodiversity losses and to protect key ecosystem services.

Controlling shrub encroachment is challenging because mechanical removal is extremely difficult and expensive in harsh and marginal mountain conditions due to steep slopes and a lower density of road network. Moreover, many shrub species are not palatable to grazing animals, since their foliage has low digestibility, mostly due to high tannin concentrations (Waghorn, 2008). However, some robust livestock species and breeds can forage on shrubs and digest their leaves, thanks to ruminal bacterial populations, which can degrade lignified material and which have high resistance to tannins (Manousidis et al., 2016). Highland cattle are a robust breed that are increasingly being reared in different European alpine countries due to their ability to forage on poor quality and shrub-encroached pastures (Pauler et al., 2020a,b). As a consequence, the particular grazing behavior of Highland cattle can also result in distinct pasture botanical composition, with reduced woody plant species cover in the long term (Pauler et al., 2019). However, the impact of robust livestock on shrub encroachment may depend on environmental and management conditions, such as slope, pastoral value of the vegetation, and distance to water sources and attractive supplements for livestock (Probo et al., 2014; Homburger et al., 2015; Pittarello et al., 2016). It is therefore important to evaluate the conditions under which robust livestock breeds are able to effectively reduce shrub encroachment in alpine pasture.

However, to the best of our knowledge, no study has assessed in detail the drivers related to plant community composition and diversity in *A. viridis*-encroached pastures nor the potential of Highland cattle to reduce *A. viridis* encroachment. For this reason, in the present study, we aimed (i) to disentangle the topographic and ecological drivers of plant community composition and diversity in *A. viridis*-encroached pastures, from Northern to Southern Alps and (ii) to measure the spatial distribution of Highland cattle in *A. viridis*-encroached pastures to determine whether they are attracted to or avoid *A. viridis* patches. Here, we hypothesized that spatial distribution of Highland cows would vary depending on *A. viridis* cover and

other factors such as distance to water, slope, and the pastoral value of the vegetation. More specifically, we expected cows to spend more time in areas around water sources and in more valuable pasture and to avoid steep slopes.

## METHODS

To investigate vegetation features and cattle spatial distribution, three Highland cattle herds were placed in four different *A. viridis*-encroached paddocks in the Swiss and Italian Alps in the summer of 2019. Three paddocks were located in Switzerland: Bovonne 1 and Bovonne 2 (in the canton of Vaud) and Champlong (in the canton of Valais). Bovonne 1 and Bovonne 2 were adjacent paddocks, grazed one after the other by the same herd. The fourth paddock was located in Val Vogna (in the province of Vercelli) in the Italian Alps (**Table 1**). Highland cattle grazed each paddock for approximately 1 month: in July (Bovonne 1), from mid-July to late-August (Champlong), and in August (Bovonne 2 and Val Vogna). All the herds included suckler cows, heifers, and calves, varying in age from 6 months to 17 years. The paddocks had similar environmental conditions in terms of elevation and slope, were grazed at comparable livestock stocking rates, and were representative of a gradient of *A. viridis* encroachment, i.e., with *A. viridis* cover values ranging from 20 to 70% (**Table 1**). A water trough was installed in each of the two paddocks in Bovonne, while many natural streams were present both in Val Vogna and Champlong paddocks.

In order to characterize the drivers of plant community composition and diversity within each paddock, the botanical composition was determined along 12.5-m transects. Transects were placed in patches ( $1.08 \pm 0.22$  ha, **Table 1**) with homogeneous botanical composition and vegetation structure, and the vertical point-quadrat method was used to record plant species (Daget and Poissonet, 1971). At 50-cm intervals along each transect, the plant species touching a steel needle were identified and recorded (i.e., 25 points per transect). Since rare species are often missed by this method, all other species within a 1-m buffer area around the transect were also recorded (Kohler et al., 2004). A total of 58 vegetation transects were surveyed in the four paddocks (**Table 1**). Plant species nomenclature followed Aeschimann et al. (2004). The relative abundance of each plant species was computed by dividing species frequency of occurrence by the sum of frequency of occurrence values for all species in the transect and multiplying it by 100. A species relative abundance value of 0.3% was assigned to all the species found only in the buffer zone and not in the main transect, following Pittarello et al. (2016). We then calculated the pastoral value (PV) of the vegetation, based on the species composition. The PV is a synthetic index summarizing forage yield, quality, and palatability for livestock (Pittarello et al., 2018). To estimate PV, we attributed each species an index of specific quality (Cavallero et al., 2007). The index of specific quality depends on the preference, morphology, structure, and productivity of the plant species, and it ranges from 0 (low) to 5 (high). The

**TABLE 1** | Topographical, management, and vegetation characteristics of the four *A. viridis*-encroached paddocks.

	Bovonne 1	Bovonne 2	Champlong	Val Vogna
Coordinates	N46°16'9.857" E7°6'44.252"	N46°16'12.118 E7°6'58.814"	N45°56'2.306" E7°12'14/333"	N45°46'18.815" E7°54'9.198"
Average elevation (m a.s.l.)	1,745 ± 46	1,789 ± 32	2,012 ± 36	1,897 ± 67
Average slope (°)	23 ± 8	21 ± 10	22 ± 8	21 ± 6
Average distance to water (m)	116 ± 44	156 ± 3	18 ± 19	107 ± 75
Grazable area (ha)	8.26	7.67	5.99	17.88
Grazing days	28	24	40	28
Number of livestock units	23.5	23.5	11.3	71.2
Stocking rate (livestock units ha <sup>-1</sup> year <sup>-1</sup> )	0.22	0.20	0.21	0.30
Number of GPS-equipped cows	8	8	7	6
Cover of <i>Alnus viridis</i> (%)	61 ± 32	71 ± 28	44 ± 30	20 ± 34
Number of vegetation transects	11	11	12	24
Average vegetation patch size (ha)	0.69 ± 0.12	0.59 ± 0.08	0.50 ± 0.09	1.87 ± 0.53
Pastoral value (PV)	6.5 ± 6.1	5.6 ± 6.5	10.4 ± 6.3	18.3 ± 11.9
Species richness of the paddocks	71	96	123	157

Cover of *Alnus viridis*, distance to water, elevation, slope, and pastoral value of the vegetation are mean values (+SD) measured at a 10-m × 10-m cell scale over the whole paddock area. One livestock unit = 1 animal of 500 kg.

PV, which ranges from 0 to 100, was calculated as follows (Daget and Poissonet, 1971):

$$PV = \sum_{i=1}^n (SRA_i \times ISQ_i) \times 0.2$$

where  $SRA_i$  is the species relative abundance, and  $ISQ_i$  is the index of specific quality value of the species  $i$ .

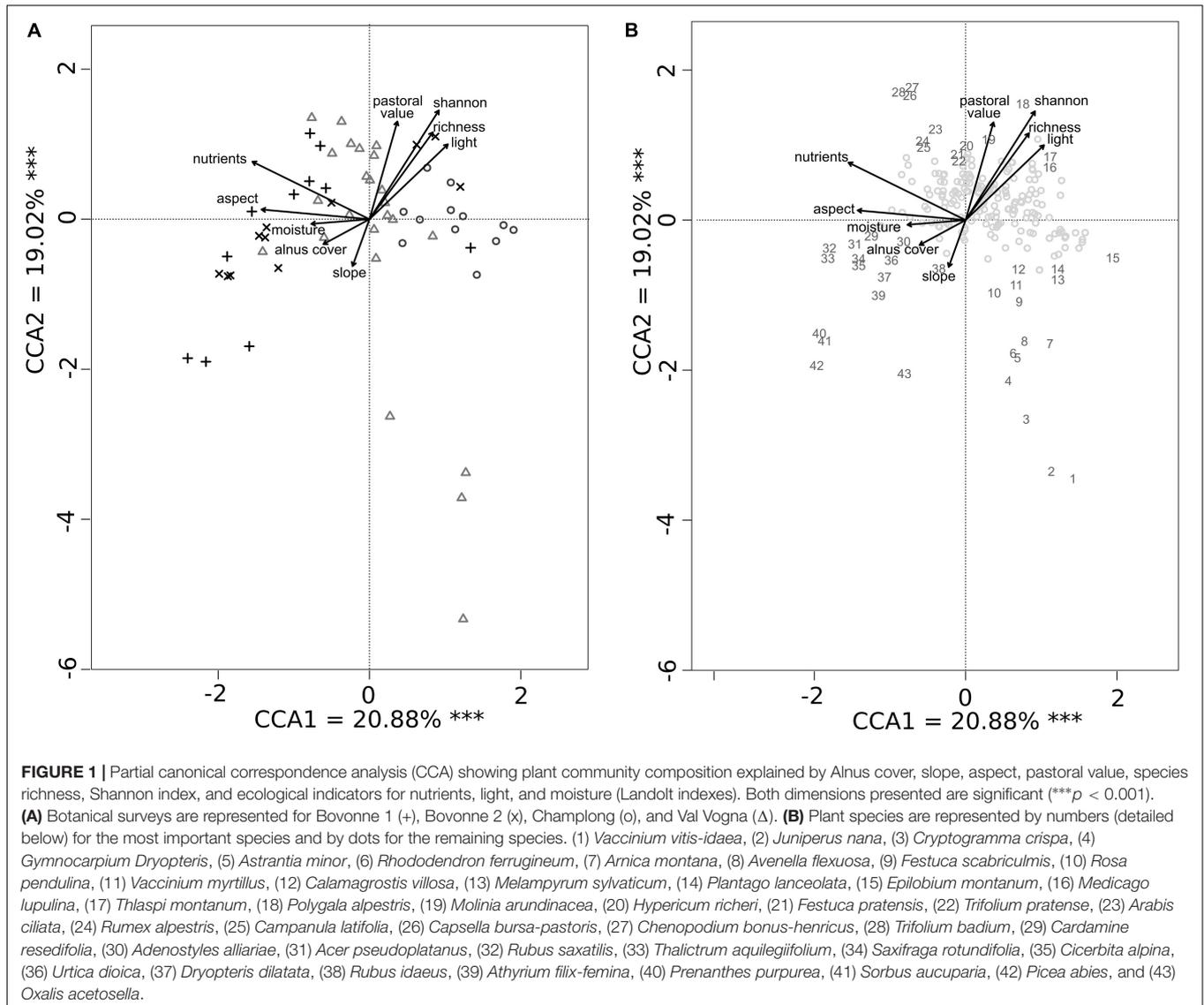
Moreover, we used the indicator values of Landolt et al. (2010) for each plant species. These indicate the environmental conditions in the habitats in which the given species occurs and are a measure of its environmental preferences. We used the light (L), soil moisture (F), and nutrient value (N) (nitrogen) indicators. We then determined the mean ecological conditions of each vegetation patch, as the mean Landolt value for L, F, and N by multiplying each species indicator value by its relative abundance. For each vegetation transect, two plant diversity indexes were computed: species richness and Shannon diversity index  $H'$  (Magurran, 1998). *A. viridis* canopy cover (%) was visually estimated within each vegetation patch.

Each paddock was subdivided into 10- × 10-m grid cells, and the distance to water sources (i.e., streams and water troughs), the aspect, elevation, and slope were calculated for the centroid of each cell using (QGIS/ArcView/SAGA/R). Moreover, *A. viridis* cover and PV were calculated for each grid cell using the values of the corresponding vegetation patch. If a cell covered more than one vegetation patch, the patch accounting for most of the cell area was considered. To avoid issues with circular variables (where high and low values are close together), aspect was transformed into southness ( $180 - |\text{aspect} - 180|$ ) (Chang et al., 2004). In each herd, six to eight cows were equipped with GPS collars (Followit<sup>†</sup> Tellus GPS collars) that recorded their position every 10 min during the whole grazing period, with an average accuracy of 2–5 m (Table 1). The number of GPS fixes was calculated for each grid cell.

All statistical analyses were performed using R version 3.4.4. A partial canonical correspondence analysis (CCA, vegan package), taking into account the spatial distance between botanical surveys, was performed to describe how PV, biodiversity indices, ecological indicators (i.e., Landolt indexes), and topography (i.e., slope and aspect) were related to plant community composition (after Hellinger transformation). Moreover, relationships between *A. viridis* cover and diversity indexes and PV were analyzed with generalized linear mixed models with Poisson (species richness and PV) and quasi-Poisson (Shannon diversity index  $H'$ ) distributions, with paddock considered as a random factor (lme4 package). The spatial distribution of cattle calculated from GPS data (i.e., the number of GPS fixes counted in each grid cell) was investigated separately for three distinct periods within each paddock, i.e., the beginning (P1), middle (P2), and end (P3) of the grazing period. These periods had equal lengths within each paddock and varied between 1 and 2 weeks depending on the length of the grazing period (Table 1). The impacts of slope, *A. viridis* cover, distance to water, and PV on the number of GPS fixes were assessed using linear regression models with zero-inflated negative binomial likelihood, as this error distribution accounted for overdispersion in the response variable (tested using the AER package). Homburger et al. (2015) found this likelihood structure to be appropriate for GPS counts in zones incompletely exploited by cattle. In order to account for the spatial autocorrelation of data, a spatial structure error term (using a two-dimensional random walk of second order) was included, and the model was fitted by Integrated Nested Laplace Approximation (INLA).

## RESULTS

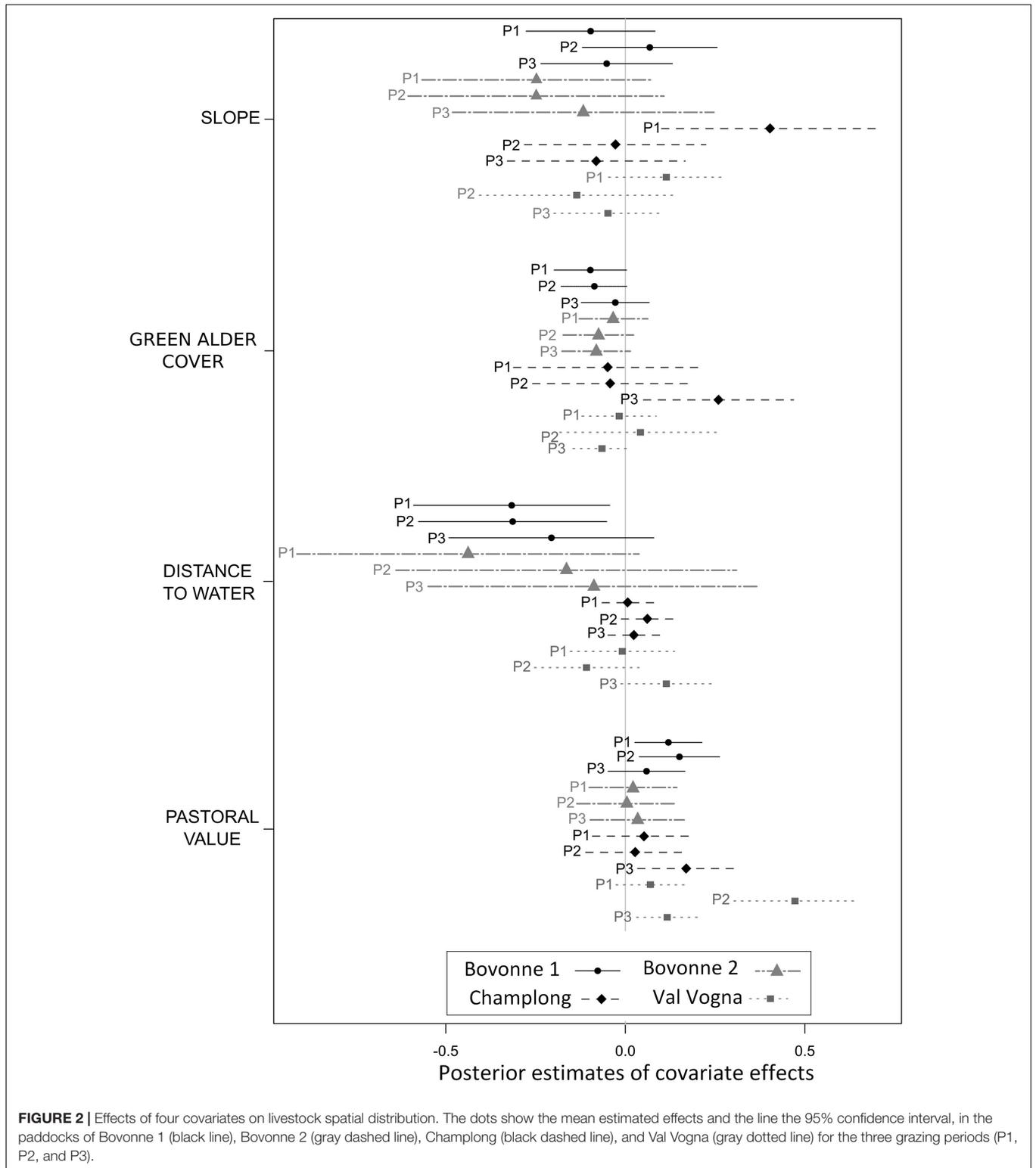
We found a total of 252 plant species in all the paddocks, with the highest species richness detected in Val Vogna (157



species, **Table 1**). The results of the CCA analysis highlighted different ecological, topographical, and vegetation impacts on plant community composition (**Figure 1**), which significantly explained the variation in community composition across the paddocks (CCA 1 = 20.9%, CCA2 = 19.0%, CCA3 = 12.9%, CCA 4 = 10.9%, and total = 84.6%). Vegetation patches within the two Bovonne paddocks were characterized by higher *A. viridis* cover and nitrogen enrichment (i.e., higher values for N indicator). In contrast, the Champlong paddock had many open pasture patches (with higher light availability), while Val Vogna patches were more heterogeneous. Four patches in Val Vogna were well distinguished and corresponded to vegetation dominated by dwarf shrubs, such as *Vaccinium vitis-idaea*, *Juniperus nana*, and *Rhododendron ferrugineum*, with low PV (**Figure 1B**). *A. viridis* cover had a significant negative effect on plant species richness, Shannon diversity index  $H'$ , and PV ( $p < 0.001$ ). Indeed, plant species associated with higher PV (e.g.,

*Festuca pratensis* and *Trifolium pratense*) were often found in the most open areas, characterized by a lower *A. viridis* cover, as well as typical small sized pasture species (e.g., *Medicago lupulina* and *Polygala alpestris*), which were associated with the highest light availability and biodiversity (both in terms of species richness and Shannon diversity index  $H'$ ). Conversely, areas with high levels of *A. viridis* encroachment and with high indicator values for N were dominated by a few tall broad-leaved species, such as *Adenostyles alliariae* and *Cicerbita alpina*, together with ferns (mainly *Athyrium filix-femina* and *Dryopteris dilatata*).

Estimates of linear regression models showed that livestock spatial distribution was often positively influenced by PV. Cattle spent more time in high PV areas in Bovonne 1 (during periods 1 and 2), Champlong (period 3), and Val Vogna (periods 2 and 3) (**Figure 2**). In Bovonne 2, the PV did not influence cattle spatial distribution. The cover of *A. viridis*, slope, and distance to water



**FIGURE 2 |** Effects of four covariates on livestock spatial distribution. The dots show the mean estimated effects and the line the 95% confidence interval, in the paddocks of Bovonne 1 (black line), Bovonne 2 (gray dashed line), Champlong (black dashed line), and Val Vogna (gray dotted line) for the three grazing periods (P1, P2, and P3).

sources did not generally affect livestock spatial distribution. *A. viridis* cover and slope only had significant effects in the Champlong paddock during the third and the first grazing period, respectively; in both cases, cattle spent more time in areas with

high *A. viridis* cover and on steeper slopes. Distance to water had a negative effect only in periods 1 and 2 in Bovonne 1 paddock, where water sources were less abundant, meaning cattle spent more time close to water.

## DISCUSSION

Overall, plant communities with higher *A. viridis* cover had lower plant diversity and were dominated by a few broad-leaved species, like *A. alliariae* and *C. alpina*, which prefer N-enriched conditions. These results support the findings of Anthelme et al. (2001) and Zehnder et al. (2020), who also showed a decline in alpine plant diversity with *A. viridis* encroachment. The few species that survive in *A. viridis*-dominated areas are able to take advantage of the N-enrichment and increased shading, and they replace many typical pasture species that are highly light demanding. Interestingly, other than broad-leaved species, the understory vegetation of many *A. viridis* patches was dominated by ferns (in particular, *A. filix-femina* and *D. dilatata*). These ferns are also highly shade tolerant, but they typically prefer areas with lower N levels, compared to the broad-leaved species (Landolt et al., 2010). They may therefore be more abundant in areas recently invaded by *A. viridis* where N levels have not increased so much. These results show that encroachment by *A. viridis* threatens the diversity of Alpine pastures and leads to a loss of typical pasture species.

The Highland cattle did not avoid patches with a high density of *A. viridis*. In fact, they were able to graze in most *A. viridis*-covered areas, therefore indicating that they could be valuable in grazing and reducing *A. viridis* patches. In contrast to many other breeds (e.g., Homburger et al., 2015), Highland cattle were also capable of grazing on the steepest slopes and were able to spend time in areas further from water sources, as they were not significantly influenced by these harsh conditions. This is in line with the observations of Pauler et al. (2020a) who found that Highland cattle used space more evenly and avoid steep slopes less than other breeds. Moreover, cattle even preferred *A. viridis* patches and steep slopes in Champlong, during certain grazing periods, which shows that cattle are able to move to areas with the most unfavorable conditions and can stay there for relatively long periods (approximately 2 weeks). Cattle also responded differently to the various factors during the time they were on the paddocks. This indicates that the herds may explore the paddock intensively at the beginning of the grazing period before selecting particular areas later on. However, despite the fact that Highland cattle graze less selectively on plants compared to other breeds (Pauler et al., 2020b), they were still mostly attracted to valuable pastures. Thus, providing a mosaic of open pasture areas with higher quality forage in *A. viridis*-encroached paddocks may be a good solution to respect grazing preferences while increasing grazing pressure on *A. viridis*-encroached patches. Moreover, this type of setting would enhance the potential for seed translocation through endo- and epi-zoochory by Highland cattle (Mouissie, 2004; Cosyns et al., 2005). Indeed, in the study of Pauler et al. (2019), plant species relying on epizoochory were significantly more frequent in pastures grazed by Highland cattle than in paddocks grazed by other breeds, probably because the long fur of this breed is ideal for transporting seeds. Animal movements might thus provide additional seed translocation fluxes from pastures to encroached areas to facilitate the restoration of typical pasture vegetation in the long-term (Pittarello et al., 2016). However, future research is needed to assess the simultaneous

effects of cattle grazing, trampling, and seed transportation on the restoration of pasture vegetation in *A. viridis*-encroached areas. We observed considerable impact of the cattle on vegetation within the encroached areas (data not shown), including intense defoliation of *A. viridis* shrubs and a reduction of their canopy cover, due to browsing, as well as damage to branches due to cattle movement and scratching. Moreover, an increase in bare soil due to livestock trampling and a considerable number of dung pats was observed within *A. viridis*-encroached areas. If repeated for several years, these effects of the cattle could provide favorable conditions for the recolonization of typical pasture vegetation in formerly encroached areas. The repetition of the botanical surveys along the fixed vegetation transects installed during this study could allow us to assess the medium- and long-term impacts produced by Highland cattle on vegetation. In addition, testing improved techniques to attract livestock to the most encroached areas, such as the placement of specific attractive points (Pittarello et al., 2016; Bailey et al., 2019), might be relevant to further increase the grazing pressure and thus livestock impacts on *A. viridis*-encroached subalpine pastures. In conclusion, our results show that Highland cattle can graze in harsh environmental conditions and exploit *A. viridis*-encroached pastures. This suggests that they have a high potential to reduce *A. viridis* encroachment in the long-term.

## 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: <http://doi.org/10.5281/zenodo.4420882>.

## ETHICS STATEMENT

The animal study was reviewed and approved by Direction générale de l'agriculture, de la viticulture et des affaires vétérinaires du canton de Vaud. Written informed consent was obtained from the owners for the participation of their animals in this study.

## AUTHOR CONTRIBUTIONS

MS: data collection, formal analysis, and writing. MPi and GN: methodology, data collection, formal analysis, and writing. MKS: methodology, formal analysis, and writing. EA: supervision and writing. PM: supervision, methodology, data collection, 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.

## FUNDING

This study is part of the RobustAlps project funded by the Swiss National Science Foundation (SNF), grant no. 184925.

## ACKNOWLEDGMENTS

We are grateful to the Société d'économie alpestre de Bex, and Millasson, Dorsaz, Reggiani, and Puttalaz families for the

provision of cattle and their precious help and collaboration. We would also like to thank Elisa Perotti and Davide Barberis for the help on botanical surveys and Luc Stévenin and Marin Tromme for setting up and monitoring the paddocks fencing.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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