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Unsustainable cattle load in alpine pastures alters the diversity and the composition of lichen functional groups for nitrogen requirement

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Abstract

Despite their considerable relevance as biodiversity hotspots, alpine ecosystems are presently threatened by several anthropogenic disturbances. Among these, pasture-derived nitrogen deposition is expected to significantly alter community composition and diversity of many sensitive organisms, such as lichens. We analysed patterns of γ-diversity components in epilithic lichen communities of pasturelands in the Maritime Alps (north-west Italy). Our aims were: 1) to estimate the shift in functional groups for nitrogen tolerance along a gradient of increasing cattle load; 2) to establish the cattle critical load. High cattle load reduced the species replacement and significantly increased the similarity in the oligotrophic component of the lichen communities. The oligotrophic component was the most sensitive functional group to nitrogen. Based on the relative abundance of oligotrophs we set the cattle critical load of the area at 0.12 grazing animals per hectare.

Alpine regions represent one of the largest biodiversity hotspots in Europe, based on favourable climatic conditions, habitat heterogeneity, dynamic processes and historical land use (Casazza et al., 2008). However, many alpine ecosystems are threatened by human activity, resulting in the potential loss of distribution range and habitat suitability for many species over the near future (Casazza et al., 2008). This loss is a consequence of climate change, increasing urbanisation and atmospheric nitrogen deposition (Giordani et al., 2014). In threatened ecosystems, changes in land use affects the biodiversity with vegetation communities largely controlled by pastoral practices and other agricultural activities. In combination with fire, grazing is the main disturbance of vegetation and biomass loss with domestic cattle grazing as major driver of global vegetation dynamics (Diaz et al., 2007). In addition to grazing damage, intensive browsing and trampling, pasture is a significant source of nitrogen deposition in alpine environments. Pastoral activities often occur in protected areas, even though their negative effect on biodiversity is known.

In alpine pasturelands, lichens represent a relevant component of the ecosystem where lichens colonize bare soil and rock outcrops. In alpine regions, characterised by highly stressful environmental conditions for many organisms, lichens are among the dominate organisms. Lichens have a high freezing tolerance including the ability to be photosynthetically activated by water vapour uptake from snow at temperatures ca. −20°C (Kappen, 2000). Field studies have demonstrated that alpine lichens are metabolically active at air temperatures between −0.7 and 12.8°C (Reiter et al., 2008). Conversely, lichen communities are sensitive to several disturbances, including nitrogen depositions from cattle. Nitrogen deposition is thought to cause shifts in species composition in lichen communities, altering the relative abundance of several functional groups with different nitrogen requirements, i.e. nitrophytic vs. oligotrophic species (Pinho et al., 2011). Basing on these properties, epiphytic lichen functional groups related to nitrogen supply have been used to set critical loads and levels for nitrogen compounds in forest or agricultural ecosystems (Giordani et al., 2014). Even though in saxicolous vs. epiphytic communities the distribution of lichens is more associated to incident solar radiation and geochemistry, mineralogy and the physical properties of substrates (e.g. Spitale and Nascimbene, 2012), possible common driving factors, such as eutrophication can be hypothesized.

This study investigated the novel idea of evaluating the effects of pastoral grazing on the composition and diversity of epilithic lichen communities in alpine areas. In particular, we estimated the shift in lichen communities along a gradient of increased cattle load, with particular reference to the relative abundance of functional groups for nitrogen tolerance. To achieving this aim, we analysed patterns of γ-diversity components (species replacement, R; richness difference, D; and similarity, S) using the conceptual and methodological framework provided by Podani and Schmera (2011). We aimed to establish the cattle critical load in the study area, based on the variation of the relative frequency of functional groups.

Lichen sampling was conducted in seasonally grazed pastures at high altitude (1400 to 2000 m a.s.l.) in the Alpi Marittime Regional Park (south-western Italian Alps). To highlight possible critical thresholds in the ecosystem, twenty-one sampling plots were randomly selected in 7 non-adjacent pasture patches along a gradient of impact based on the declared number of grazing animals per pasture (i.e., Adult Cattle Unit, ACU), which is considered a proxy variable for the nitrogen load affecting a pastoral area. In the studied pastures the ACU ranged from 90 to 250. The overall pasture area was 4565 ha, the patches ranging from 90 ha to 981 ha.

The surveys were carried out during the summer of 2011, on acid migmatitic gneiss rocks with a max inclination of 30°. Under undisturbed conditions, this substrate mainly hosts oligotrophic lichen communities. The surveys used a North oriented square grid (50 × 50 cm) divided into 25 quadrats. The frequency of each species was calculated as the sum of each lichen species per quadrat within the grid. To calculate the diversity of functional groups, species were grouped according to nitrogen-tolerance using an *a priori* classification (Nimis and Martellos, 2008). This classification uses a 5-class ordinal scale, where the value 1 is given to strictly oligotrophic species, while a 5 corresponds to species tolerating a very high eutrophication. Specifically, species classified as 1 and 2 were considered oligotrophic, species with a maximum value equal to 4 or 5 were N-tolerant and species with a minimum value equal to 4 or 5 were considered as strictly nitrophytic. Mesophytic species (with a maximum value equal to 3) were escluded from the analysis (cfr. Supplementary Material).

We analysed the presence–absence data matrix with SDR Simplex software (Podani, 2001), using The Simplex method (SDR Simplex - Podani and Schmera, 2011). We evaluated the relative importance of components of γ diversity i.e., S, D and R for all pairs of plots.

S was calculated following the Jaccard coefficient of similarity:

$S_{Jac} = a/n$,

where a is the number of species shared by two sites (standard rocks) and n is total number of species.

D was calculated as the ratio of the absolute difference between the species numbers of each site (*b*, *c*) and the total number of species, *n*:

$D = |b - c|/n$

R was calculated as:

$R = 2*\min\{b,c\}/n$.

Following Podani and Schmera (2011), we also calculated a relativized β-diversity as the sum of R+D; a relativized richness agreement, as the sum of R+S and a relativized nestedness, as the sum of S+D.

A total of 44 species were recorded, corresponding to 76.8% of the total number of *taxa* estimated by Jacknife analysis for the study area. The increasing cattle load in the alpine pasturelands caused relevant shifts in the relative compositions in the epilithic lichen communities as a whole and in the functional groups based on nitrogen requirement (Table 1). Using the complete dataset (i.e., all species) there was a very high relativized richness agreement among plots (> 80%). R was the major component of γ-diversity, accounting for ca. 50%, irrespective of the cattle load on the plots. Increasing the cattle load from low to high caused a consistent increase in pair-wise plot similarity, corresponding to a decreased richness difference among plots. Basically, these results suggested that an increasing cattle load lead to a homogenization and an impoverishment of the community.

The analysis of γ-diversity components revealed opposite trends for distinct functional groups, indicating the effects of nitrogen compounds on alpine ecosystems. The relative richness agreement existed in oligotrophic and N-tolerant species, with no clear trend across the cattle load gradient. The pairwise similarity among plots increased from low to high cattle loads in both functional groups, but this similarity showed a relevant increase in N-tolerant compared with oligotrophic species. Conversely, the oligotrophic functional group showed the relative species replacement was the major component of γ-diversity, decreasing according to the cattle load gradient, producing a decrease in β-diversity and an increase in nestedness. Thus, under high cattle load, consistently with a reduced turnover of the species, the set of oligotrophs decreased regularly from the richest to the poorest site.

N-tolerant and strictly nitrophytic species showed different trends for S, D and R, the strictly nitrophytic was the only functional group where increased cattle loads did not caused increased similarity. Additionally, the strictly nitrophytic functional group showed that species replacement amounted to ca. 50% and their relative richness difference in all cattle load categories was higher than compared with the other functional groups. Therefore, contrasting other groups, β-diversity was considerably high (> 80%) and overcame the richness similarity.

In general, oligotrophic species showed a more consistent response compared with other functional groups to the effects of nitrogen and the cattle load gradient. Our findings support other studies (Pinho et al., 2011; Jovan et al., 2012) showing that functional group distributions of lichens are driven by the combined effect of multiple N pollutants. These studies indicated that the oligotrophic functional group is more sensitive to increasing N availability compared with nitrophytic groups.

On the contrary, Wolseley et al. (2006), investigating the lichen epilithic communities of granitic outcrops in Scotland, found that nitrophytes responded better than acidophytes to possible increase of nitrogen due to agriculture.

In our study, the relative frequency of oligotrophs showed a significant (Spearman $r = 0.720$; $p<0.001$) decrease as the total number of adult cattle units (ACU) increased (Figure 1). Oligotrophs in the study area nearly disappeared for ≥ 0.25 ACU/ha, but the interpolation curve showed a sharp decrease of the relative frequency of this functional group for ACU/ha> 0.12, which can be considered as the cattle critical load for pasturelands in the study area.

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Table 1. Percentage contributions from the SDR-simplex analyses of epilithic lichen communities in the study area. Results are presented for the entire dataset including all sampled species and for subsets of functional groups for nitrogen tolerance. Bold numbers emphasize the maximum for each column in each dataset. Arrows indicate monotone trends along gradients of cattle load.

Dataset	Cattle load	Similarity(S)	Relativized species replacement (R)	Relativized richness difference (D)	Relativized beta diversity (R+D)	Relativized richness agreement (R+S)	Relativized nestedness (S+D)
All species	Low	34.4	**49.4**	16.2	65.6	**83.8**	50.6
	Intermediate	40.1	**44.8**	15.1	59.9	**84.9**	55.1
	High	44.2	**50.1**	5.8	55.8	**94.2**	49.9
Oligotrophic	Low	30.4	**54.6**	14.9	69.6	**85.1**	45.3
	Intermediate	33.6	**48.3**	18.1	66.4	**81.9**	51.7
	High	37.9	**46.9**	15.1	62.1	**84.9**	53.1
N-tolerant	Low	**72.0**	15.3	12.7	28.0	**87.3**	84.7
	Intermediate	**72.0**	0.0	28.3	28.3	71.7	**100.0**
	High	**81.0**	10.7	8.3	19.0	**91.7**	89.3
Strictly nitrophytic	Low	19.2	**50.5**	30.3	**80.8**	69.7	46.1
	Intermediate	21.1	**57.8**	21.1	**78.9**	78.9	31.1
	High	16.7	**47.7**	35.7	**83.3**	64.3	35.0

Figure 1. Biplot of the % oligotrophic lichen species as a function of ACU at plot level. The fitted line is a distance weighted least square function with stiffness = 0.2.