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Research paper

Plant diversity and pastoral value in alpine pastures are maximized at different nutrient indicator values

Marco Pittarello*, Michele Lonati, Alessandra Gorlier, Elisa Perotti, Massimiliano Probo, Giampiero Lombardi

Department of Agricultural, Forest and Food Sciences, University of Torino, Largo Braccini 2, Grugliasco, I 10095, Italy

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A B S T R A C T

In alpine environments, very low and very high amounts of soil nutrients are generally associated to the lowest plant diversity and forage quality levels. Both soil nutrient content and forage quality and productivity of a site can be inferred from plant species lists, by attributing each species a nutrient indicator value (N value) and a quality value, and computing respectively average N Value and Pastoral Value (PV) at site scale. We used a wide dataset of vegetation surveys carried out in the pastures of Western Italian Alps to 1) evaluate if N values, PV, and plant diversity (species richness and Shannon diversity index) change along an elevation gradient, from montane/sub-alpine pastures (i.e. the ones located below treeline) to alpine pastures (above treeline), 2) analyze the relationships between N value and plant diversity indexes and between N value and PV, and 3) evaluate whether the N values associated to the highest plant diversity and PV differ.

Plant diversity, PV, and N values were higher in the pastures located at lower elevation. Plant diversity and PV showed a unimodal relation with N values, both in the montane/sub-alpine and alpine belts. Plant diversity indexes peaked at intermediate N indicator values, confirming the Intermediate Disturbance Hypothesis, while PV peaked at higher N values, where higher nutrient availability in the soil increased plant species productivity, growth rate, leaf turnover and nutrient concentration, digestibility, and palatability. The overall shape of the curves as well as the N values at which plant diversity and PV values peaked did not considerably change from montane/sub-alpine to alpine pastures. These results suggest that an extensive pastoral management is recommended when plant diversity conservation is the main goal. Conversely, a more intensive management can produce an overall enhancement of forage quality/productivity of alpine pastures, but only if restricted under certain critical N values.

1. Introduction

Pastoral management is one of the most important drivers of soil and plant nutrient concentration in alpine pastures, due to the removal and accumulation of nutrients that livestock exert by grazing and deposing dung and urine, respectively (Jewell et al., 2007; Lonati et al., 2015). The concentration of soil nutrients, mainly nitrogen and phosphorous, affects plant diversity and forage yield and quality as well (Güsewell et al., 2012; Gardarin et al., 2014). In alpine environments, very low and very high amounts of soil nutrients are generally associated to the lowest plant diversity and forage quality levels; low amounts of nutrients favor the dominance of few oligotrophic plant species in the sward, whereas very high amounts promote the dominance by a few nitrophilous plants. In both cases, these plant species are generally characterized by low nutritive value or high levels of toxic compounds (Aerts and Chapin, 1999; Iussig et al., 2015; Orlandi et al., 2016). For these reasons, identifying and maintaining adequate levels of nutrient concentration in the soil is a major management goal when targeting plant diversity conservation and forage yield and quality.

Soil nutrient content can be measured directly by chemical analyses or through vegetation-derived ecological indicators, such as nutrient (N) indicator values, which have the advantage to be cost-effective, since they are calculated from plant species lists (Hintermann et al., 2000). The N indicator values were originally proposed by Ellenberg (1974) for Central Europe and by Landolt (1977) for Swiss flora. Recently, they have been updated and extended to whole alpine flora by Landolt et al. (2010), so that they are now available for each plant species growing in the Alps. Such indicator values rely on the knowledge and extensive field experience of botanists and ecologists, so to correctly characterize the condition of a site by means of ecological

Abbreviations: PV, Pastoral Value; N Landolt, Landolt indicator value for soil nutrient content (N); H', Shannon diversity Index

* Corresponding author.
E-mail address: marco.pittarello@unito.it (M. Pittarello).

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indicator values, a consideration of as many as possible plant species growing at that site is recommended (Landolt et al., 2010). The N indicator values can properly characterize an area (Tölgyesi et al., 2014) and they are well correlated to the supply of several nutrients (e.g. nitrogen, phosphorous, and potassium) and to the potential biomass production of the site (Diekmann, 2003). For these reasons, their application has strongly increased in the literature since year 2000 (Wildi, 2016).

Another synthetic index derived from vegetation surveys is the Pastoral Value (PV), which summarizes forage yield, quality, and palatability for livestock (Daget and Poissonet, 1969). Since it is calculated from sward botanical composition, the PV is more constant and less influenced by temporal fluctuations than other forage parameters, such as aboveground biomass, organic matter digestibility, or crude protein content (Daget and Poissonet, 1969). Therefore, especially in pastures characterized by a high cover of perennial species, it can provide a reliable estimate of the grassland carrying capacity, which has been defined by Allen et al. (2011) as the maximum livestock stocking rate achieving a target level of animal performance, in a specified grazing system, that can be applied over a defined time without deterioration of the grazing land. The average annual carrying capacity of a particular alpine grassland can thus be calculated by multiplying its grazable area with PV and with altitudinal and slope coefficients, as defined by Cavallero et al. (2007). Moreover, the PV is directly related to forage energy and alpha-linolenic acid content (Daget and Poissonet, 1969; Ravetto Enri et al., 2017). Because of its reliability and simplicity of computation, PV has been widely used, e.g. in south-western Alps, (Probo et al., 2014, 2016; Pittarello et al., 2016a), in the Apennines (Cervasio et al., 2016), in Sardinia (Bagella et al., 2013; Bagella et al., 2017), in southern Italy (Fracchiolla et al., 2017), in central and eastern Pyrenees (Sebastià et al., 2008), in Romania (Sărăţeanu and Alexandru, 2011), and in central Chile (Ovalle et al., 1999).

In mountain ecosystems a general decrease in plant diversity, N indicator, and forage values occur with increasing elevation, due to differences in growing season, temperature, precipitation, bedrock type, soil, nutrient contents, deposition, and mineralization rates (Körner, 2003; Güsewell et al.,2012). In this study we used a wide dataset of vegetation surveys carried out in the pastures of the Western Italian Alps to:1) evaluate if N indicator, PV, and plant diversity indexes (species richness and Shannon diversity) change along an elevation gradient, from montane/sub-alpine pastures (i.e. the ones located below treeline) to alpine pastures (i.e. the ones located above treeline), 2) analyze the relationships between N value and plant diversity indexes and N value and PV, and 3) evaluate whether the N values associated to the highest plant diversity and PV differ.

2. Materials and methods

2.1. Study area and vegetation surveys

Data were collected across the Western Italian Alps of Piedmont Region during the period 2001–2007. In that period, 3839 surveys were carried out to characterize the vegetation composition of alpine pastures, which are mainly grazed by domestic livestock during summertime (Cavallero et al., 2007) (Fig. 1).

Elevation ranged from 491 to 2901 m a.s.l. Vegetation surveys were carried out within vegetation communities developed over a wide spectrum of soil nutrient content conditions as described in Cavallero et al. (2007), from oligotrophic (e.g. pastures dominated by *Carex sempervirens* Vill., *Nardus stricta* L., *Trifolium alpinum* L. and *Carex sempervirens, Festuca paniculata* (L.) Sch. et Th., and *Festuca ovina* s.l.) to nitrophilous vegetation communities (e.g. pastures dominated by *Chenopodium bonus-henricus* L, *Rumex alpinus* L., and *Urtica dioica* L.), through mesotrophic (e.g. pastures dominated by *Festuca rubra* s.l. and *Agrostis tenuis* Sbith. and *Festuca violacea* s.l.) and eutrophic (e.g. pastures dominated by *Alchemilla vulgaris* s.l., *Dactylis glomerata* L., and *Trisetum flavescens* (L.) Beauv.) vegetation communities.

Each survey was conducted along a 25-m linear transect in which botanical composition was determined using the vertical point-quadrat method (Daget and Poissonet, 1971). At every 50-cm interval along the transect, plant species touching a steel needle were identified and recorded (i.e. a total of 50 measurements). Since occasional species are often missed by this method, a complete list of all other plant species included within a 1-m buffer area around the transect line (vegetation plot) was also recorded (Pittarello et al., 2016b). Plant nomenclature followed Pignatti (1982).

The N Landolt indicator value (hereafter 'N Landolt'; Landolt et al., 2010) was attributed to each plant species recorded in vegetation surveys and to all occasional plant species within vegetation plots. An average N Landolt was calculated afterwards for each survey using species presence/absence data.

For each plant species recorded in the vegetation surveys, the frequency of occurrence (f_i = number of occurrences/50 points), which is an estimate of species canopy cover (Probo et al., 2013), was calculated. Species Relative Abundance (SRA_i) was computed at each transect and used to detect the proportion of different species according to the equation of Daget and Poissonet (1971):

$$SRA_i = \frac{f_i}{\sum_{i=1}^{n} f_i} \cdot 100(\%)$$

A SRA value = 0.3 was attributed to all occasional plant species found within vegetation plot but not along linear transects (Vacchiano et al., 2016). To estimate PV, we attributed each species an Index of specific quality (ISQ) (Daget and Poissonet, 1971; Cavallero et al., 2007). The ISQ depends on the preference, morphology, structure, and productivity of the plant species and it ranges from 0 (low) to 5 (high) (Daget and Poissonet, 1971). The PV, which ranges from 0 to 100, was calculated as follows (Daget and Poissonet, 1971):

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

where ISQ_i is the ISQ value for the species *i* (Cavallero et al., 2007).

Plant diversity was expressed in terms of species richness and Shannon diversity index (H'). Shannon diversity index (H') was calculated for each vegetation transect according to the following equation:

$$H' = -\sum_{i=1}^{i=n} \left\{ \frac{SRA_i}{100} \times \log_2\left(\frac{SRA_i}{100}\right) \right\}$$

The elevation of each vegetation survey was calculated from a Digital Terrain Model (50-m resolution) (CSI Piemonte 2005). Since the altitudinal limit between montane/sub-alpine and alpine belt can vary linearly with the latitude (Ozenda, 1985), the treeline limit was linearly interpolated from the southern zone (2300 m a.s.l. − 43.5° latitude) up to the northern zone (2000 m a.s.l. − 46.5° latitude) of Piedmont. Elevational and latitudinal limits were set according to Ozenda (1985). Vegetation surveys were attributed to the montane/sub-alpine or alpine belt depending on whether their elevation was lower or higher than the interpolated treeline limit computed for the latitude at which the survey was conducted. According to this method, 2196 vegetation surveys were located below the treeline and 1643 above it (Fig. 1).

2.2. Data analysis

Mann-Whitney *U* tests (Sokal and Rohlf, 1995) were used to assess whether N Landolt, PV, species richness, and H' differed between montane/sub-alpine and alpine pastures.

Generalized Linear Models (GLMs) and Generalized Additive Models (GAMs) were performed to analyze the relationships between N Landolt and PV, species richness, and H'. The models were performed separately for the vegetation surveys located in the montane/sub-alpine and alpine belts. The GLMs (Zuur et al., 2009) were fitted by using both the linear

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