The larch wood pasture: structure and dynamics of a cultural landscape

Published version:

DOI:10.1007/s10342-010-0437-5

(Article begins on next page)

The larch wood pasture: structure and dynamics of a cultural landscape

Matteo GARBARINO*

Dept. AGROSELVITER, University of Torino, Via L. da Vinci 44, I-10095 Grugliasco, TO, Italy

*Corresponding author - E-mail: matteo.garbarino@unito.it , phone: 011-670-5535, fax: 011-670-5556.

Emanuele LINGUA

Dept. TESAF, University of Padova, Agripolis, Viale dell'Università 16, I-35020, Legnaro, PD, Italy.

Marta Subirà MARTINEZ

Dept. AGROSELVITER, University of Torino, Via L. da Vinci 44, I-10095 Grugliasco, TO, Italy

Renzo MOTTA

Dept. AGROSELVITER, University of Torino, Via L. da Vinci 44, I-10095 Grugliasco, TO, Italy

Abstract

As a consequence of land abandonment and marginalization, open areas and traditionally managed wood pastures are disappearing from many alpine valleys. Landscape and stand scale dynamics were analyzed in two neighboring inner valleys of central Italian Alps (Valmalenco, SO) dominated by larch (*Larix decidua* Mill.) forests and experiencing different historical land use intensities. Land cover mapping obtained from object-oriented analysis of aerial photographs was used to quantify land cover changes between 1961 and 2003. Spatial statistics were used to quantify landscape patterns, and intensive sampling in permanent plots was employed to perform point pattern analysis at the stand scale. Expansion of forested area at the expense of wood pastures was the main land cover transition observed. Differences in land use intensities were responsible for different patterns at the landscape scale: 1) heavier grazing and human pressure created a more diverse and fragmented mosaic of meadows, open woodlands, forests and wood pastures, 2) lower human impact favored a more homogeneous and stable system. A decline in grazing pressure in the late 70s favored the establishment of larch and spruce in a clustered pattern, typical of the subalpine belt. Subalpine wood pastures, likewise many other semi-natural environments, are in danger of disappearing and lose their productive and cultural characteristics, because they are developing into more closed and dense stands.

Keywords

Wood pasture, Larix decidua, subalpine belt, land abandonment, landscape structure, spatial pattern.

Abbreviations

LCC: land cover class; LU: livestock units

1. Introduction

Landscapes are the expression of the dynamic interaction between natural and anthropogenic forces in the environment (Antrop 2005; Naveh 1995) and land use change is a critical link between anthropic activities and natural changes. Human activities show great heterogeneity in size, intensity, longevity and pattern as observed for natural disturbances (Turner and Dale 1998). Anthropogenic disturbances are widely considered to have negative influence on environmental conservation and heterogeneity (Grossmann and Mladenoff 2007). On the other hand, traditional and extensive land uses may increase heterogeneity and diversity of a landscape mosaic (Dullinger et al. 2003), creating new semi-natural habitats (Naveh 1995). Historical knowledge should be considered an important issue in the analysis of human managed systems, that are strongly influenced by traditional activities (Bürgi 1999; Swetnam et al. 1999). Thus, it is important to collect historical quantitative data with spatial and temporal reference (e.g. sequence of aerial photography) and other documentary records, combining them with natural records (Axelsson and Östlund 2001; Swetnam et al. 1999; Tasser et al. 2007).

Wood pasture is a type of human-dominated landscape, a semi-natural environment, maintained through traditional range and forest management. Wood pastures are grazable forestlands where thinning is used by humans to preserve an open canopy cover suitable for grazing of large herbivores (Mountford and Peterken 2003; Rackham 1998). Till the second world war silvopastoralism was a traditional form of land management in many European countries, characterized by particular cultural and conservation features (Mayer et al. 2005; Mountford and Peterken 2003; Peterken 1977). These silvo-pastoral systems combined timber and forage production and were usually subjected to communal use for grazing (Vera 2000). Some excellent examples of large remnants of ancient wooded pastures can be found in England at Denny Wood - New Forest (Mountford and Peterken 2003), in the Iberian peninsula with “dehesas” in Spain and “montados” in Portugal (Marañón 1988; Pinto-Correia 1993; Piussi and Farrell 2000; Plieninger 2003) and in the Swiss Jura mountains. Some analogies with Europe can be found in eastern United States where grazing by cattle and bison (before 1850) contributed to create park-like forest landscapes with grasslands (see Vera (2000) for a complete review).

In many larch (*Larix decidua* Mill.) forests in the Alps, human intervention devoted to maintain a sparse overstorey and an abundant ground cover for grazing created also a unique silvo-pastoral landscape. Subalpine wood pastures are heterogeneous areas where wooded, half-open and open areas constitute a rich feeding source for large herbivores. In the past these forests were managed as open woodlands, with sparse (< 300 trees/ha) larch trees on grasslands that were generally over-used for grazing or mowing and secondary forest products, such as tar, litter and fire wood (Albert et al. 2008; Bürgi and Gimmi 2007; Didier 2001; Gimmi et al. 2008; Schulze et al. 2007). Larch was favored by humans for livestock herding, because its light canopy permits the growth of suitable foraging ground cover (Motta and Lingua 2005). Positive selection of larch was carried out by cutting down competing species and protecting established larches with small fences.

The transformation and reduction of these semi-natural environments in the Alps is a consequence of marginalization and subsequent rural depopulation of the region in relation to the urbanization (Bätzing et al. 1996). Marginal land abandonment in Europe has been observed since the second half of the 20th century, and caused a drastic decline of the livestock population that resulted in undergrazing in many Mediterranean countries (Papanastasis 1997). As a consequence of grazing reduction and lack of management, land cover types such as forests, woodlands and shrublands expanded. This contributed to reduce open habitats like grasslands (Cousins et al. 2003; Dullinger et al. 2003; Grace 1999) and wood pastures.

The Valmalenco was chosen as study area because it is an example of currently grazed alpine valley with meadows and wood pastures. In particular, two neighboring watersheds representing different historical land use intensities were selected (Garbarino et al. 2009) in order to assess how subalpine wood pasture cover has changed through time. Specifically, we tested the following hypotheses: 1. The anthropogenic disturbance regime affects the pattern of land use/land cover change observed in Valmalenco. 2. The decline of traditional land use practices led to a significant reduction of open and semi-open forest landscapes. 3. Human impact on wood pasture is manifest at both landscape and stand scale. Finally, we discuss potential management strategies for restoration and conservation of subalpine wood pastures.

2. Methods

2.1. Study area

Landscape structure has been analyzed in two watersheds of the upper Valmalenco (Fig. 1), a lateral valley of Valtellina (Central Alps, Italy). The Musella watershed occupies 1150 ha in the eastern Malenco valley (46º 19’ N; 9º 54’ E), and the Ventina study area occupies 1124 ha in the western Valmalenco (46º 18’ N; 9º 46’ E). Musella has 470 ha of forested area ranging from 1650 to 2360 m a.s.l., Ventina has 170 ha of forested area ranging from 1650 to 2255 m a.s.l. Moraines and glaciers cover a majority of the Ventina watershed, which is steeper than Musella. The bedrock is silicate and serpentine is the predominant rock. Both study areas follow a north-south direction and are inner valleys of the “endalpic district” (Del Favero 2002) characterized by a continental climate. Annual precipitation from 1921 to 1990 has varied from 668 mm to 1551 mm, averaging 974.9 mm (Lanzada, 1000 m a.s.l.). In both catchments European larch is the dominant tree species with Norway spruce (*Picea abies* (L.) H. Karst), Swiss stone pine (*Pinus cembra* L.) and mountain pine (*Pinus mugo* subsp. *uncinata* Mill.) as co-dominant species throughout the subalpine zone. Two common subalpine shrub species are locally abundant: dwarf mountain pine (*Pinus mugo* subsp. *mugo* Turra) and green alder (*Alnus viridis* (Chaix) D.C.).

2.2. Historic land use

Grazing activities are documented for the area already since 1447, when the authorities decided to assign a limited area for each shepherd’s hut “malga” due to previous problems caused by overgrazing. Cattle grazing was commonly limited by stockyards within the alpine pastures, while goats grazed freely as long as they did not damage pastures (Bergomi 2006). Grazing data from the beginning of the twentieth century (Società Agraria di Lombardia 1901) revealed that grazing pressure was much higher at Musella than Ventina (190.5 and 33.6 livestock units (LU) respectively). Grazing pressure declined to 49 LU at Musella and 27 LU at Ventina in the late 70s and recently (2000) disappeared at Ventina (Della Marianna et al. 2004). A substantial increase of livestock units (91 LU) in 2006 was observed at Musella, likely as a consequence of a recent restoration policy applied to mountain pastures throughout the Lombardy region.

2.3. Landscape analysis

Different sources were used to perform the study. Grazing pressure data for each "malga" were taken from documents supplied by historical archives (livestock censuses, statistical data, chronicles). Demographic data on residents and farm employees were used, together with forest management plans and information on stocking rate. The landscape analysis was performed on four (2 watersheds, 2 periods) raster-based maps (1-m resolution) derived from historical (1961) and recent (2003) aerial photos. Historical aerial photos were scanned and orthorectified at 1-m resolution using PCI Geomatica 10.2 (PCI Geomatics Enterpises Inc., Richmond Hill, ON). An object-oriented image analysis was implemented in eCognition 4.0 (Definiens Imaging, München, D) to obtain a segmentation and semi-automatic classification of the aerial orthoimages (Weisberg et al. 2007). Six land cover classes (LCC) were detected for each map (dense forest, sparse forest, wood pasture, shrubland, meadow, rock). The object-based classification was integrated through on-screen digitization and ground control points in order to better differentiate sparse forest from wood pasture polygons according to a threshold based on canopy cover (10-30 % for wood pasture and 30-80 % for sparse forest). Each resulting raster map was then enhanced by using a 3 x 3 pixels moving window majority filter using ArcGIS 8 (ESRI, Redlands, CA) in order to reduce the effect of different input image quality (Neel et al. 2004) and achieve a minimum mapping unit (MMU) of 9 m^2. An accuracy assessment was performed on each map resulting in the K statistic ranging from 0.63 (69% overall accuracy) for Ventina 1961 to 0.75 (80% overall accuracy) for Musella 1961. The K statistic obtained for Ventina 2003 was K=0.71 (77% overall accuracy) and for Musella 2003 was K=0.66 (72% overall accuracy).

Landscape structure was measured using the spatial analysis program Fragstats 3.3 (McGarigal and Marks 1995) on land cover raster-based (1-m resolution) maps for each date using a 8-cell neighborhood definition. Since many metrics on landscape-level are closely related, if not perfectly redundant, and describe similar aspects of landscape structure (Cain et al. 1997; Neel et al. 2004; Riitters et al. 1995), 9 metrics on landscape-level (Table 1) were selected excluding the highly correlated ($r > 0.8$) ones (Tischendorf 2001). Core-area metrics were computed using a 50 m edge depth that is considered a conservative estimate of the depth of the coniferous forest edge environment (Chen et al. 1992; Tinker et al. 1998).

On class-level, 14 metrics were computed for the six land cover classes of the two sites and for the two periods. Principal component analysis (PCA) was used to group metrics into uncorrelated components that explained most of the variation in the original data (McCune and Grace 2002; Tinker et al. 1998), and are linear combinations of the original variables (Griffith et al. 2000). Moreover PCA allowed us to compare classes from all periods from both study areas. Each dataset used in the PCA was transformed by the standard deviation in order to put variables, that were measured in different units, on an equal footing (McCune and Grace 2002).

A transition matrix was used to summarize the state of the landscape in each time period and the transitions through time with respect to each of the 6 LCC.

2.4. Stand structure

In order to study the spatial pattern and dynamics of wood pasture also at the stand scale, two 1-ha permanent plots were established in 2007 within a wood pasture at Musella and within a dense forest at Ventina. These plots were localized using the 2003 land cover maps and the forest structure maps and data obtained in a previous study in the same catchments (Garbarino et al. 2009). An intensive sampling was adopted to reduce the subjectivity that might affect a spatial pattern analysis in a smaller-scale study area and to capture the spatial dimensions of the processes of interest (Motta et al. 2002; Motta and Lingua 2005). All trees (DBH ≥4 cm), stumps, snags (standing dead trees with DBH ≥4 cm) and logs (lying dead trees with base diameter ≥10 cm) were identified, tagged and mapped. Saplings (DBH <4 cm and height >10 cm) were identified and mapped in a 0.2 ha transect (20x100 m) located in the middle of the permanent plot and perpendicular to the slope direction. The following parameters were measured for all trees and saplings: diameter at 50 cm and 1.30 m height, total height, crown length, and vertical crown projection (4 radii) along the two directions marked by the plot axes. A combination of structural diversity indices and classical stand structure measures provided a synthetic description of stand structure. Structural diversity measures included species richness, diameter standard deviation, and Vertical Evenness index, a measure of vertical structure complexity (Neumann and Starlinger 2000). For the stumps we measured the height, the diameter at the top and at the ground level.

Mapped locations of saplings, stumps, stems and canopies were then generated and analyzed in a GIS environment. In order to evaluate if the distributions of trees, species, saplings, and woody debris were random, regular or clumped, the univariate Ripley's $K(t)$ function was computed (Ripley 1977). To investigate the relationships between classes (i.e. living vs. dead trees, and saplings) we examined bivariate spatial interactions using Ripley's $K_{12}(t)$ (Lotwick and Silverman 1982). See Lingua et al. (2008) for details concerning the formulations and the square root transformations of such metrics ($L(t)$ and $L_{12}(t)$).

The spatial pattern analyses were carried out only for classes having more than 20 elements, and applying a 1 m lag distance starting from 1 m up to the half of the shortest side of the permanent plot, in order to limit the influence of edge effects (Haase 1995).

Different null models were chosen for the different analyses to avoid misinterpretation of the results (Goreaud and Pélissier 2003). Complete spatial randomness was adopted as a null model for the univariate analyses. For the living vs. dead (snags and stumps) pattern, we choose the null hypothesis of random mortality, since mortality agents can only work within the limits set by the distribution of living trees prior to the occurrence of disturbance events (Aakala et al. 2007). For the relative pattern of size classes (i.e. big trees DBH≥30 cm, small trees DBH<20 cm, and saplings) we selected the antecedent condition null model in order to randomize the location of the smaller classes only, whose establishment happened when the bigger (older) class was already present in the stand. 10000 Monte Carlo simulation runs were used to assess the significance of deviation from the null model assumptions, providing 99% confidence envelopes.

Univariate and bivariate indices were calculated with the software SPPA 2.0 (Haase 2001).

3. Results

3.1. Landscape analysis

The two watersheds had similar total area, but differed considerably in the initial landscape structure. Musella watershed showed a larger amount of patches and edges (Patch Density and Edge Density) than Ventina, resulting in a lower aggregation (Contagion and Connectance) and mean patch size (AREA_MN). On the contrary Ventina revealed a less diverse (SIDI) and hence more homogeneous and aggregated landscape mosaic (Table 1). This high level of homogeneity observed at Ventina was also confirmed by the high portion of total landscape area occupied by the largest patch (LPI > 80%). Differences between the two study areas were evident also in landscape composition changes. A fairly stable situation with small variation of metrics on landscape-level in the period 1961-2003 was observed at Ventina, while Musella showed a decrease of patch size and thus of aggregation (Fig. 1, Table 1). The aggregation of patches (Landscape Shape Index) remained almost similar at Ventina, but a significant decrease was evidenced by Musella. A higher overall shape complexity (Shape Mean) was measured for Musella, the increase in shape complexity observed at Ventina between 1961 and 2003 was small.

The main land cover change observed at class level was a consistent surface increment of dense forests in both areas (55% at Ventina, 160% at Musella), while sparse forests showed a small increment only at Musella (Tables 2, 3). Wood pasture and meadow classes were greatly affected by tree and shrub encroachment. In particular, meadows and wood pastures reduced their extension at Musella by 62% and 63%, respectively.

Principal component analysis was used as data reduction technique and provide an ordination scatter plot of LCC's. The first principal component accounted for 39.3% of the total variation and reflected variations of patch density, complexity and aggregation (Table 4). The second component explained an additional 28.8 % of the total variation and was correlated to patch size, core area and cohesion. The scatter plot of LCC's revealed that Ventina was confined in the right part of the graph indicating higher aggregation and homogeneity (Fig. 2). A more intense landscape change was observed at Musella, where forest classes (Fd and Fs) became less aggregated and increased in patch size. Wood pasture was the only class that showed a substantial change at Ventina, while an increase of fragmentation was experienced by both watersheds.

3.2. Stand structure

European larch was the dominant species in both permanent plots (Table 5). Larch was highly dominant in both the tree (85% at Musella and 96% at Ventina) and the sapling (92% and 90% respectively) layers. Musella had 502 trees$\cdot$ha^{-1} and 383 saplings$\cdot$ha^{-1}, and the basal area was 9.6 m$^{2}\cdot$ha^{-1}. A higher density of trees (776$\cdot$ha^{-1}) and basal area (13.4 m$^{2}\cdot$ha^{-1}) and a lower number of saplings (135$\cdot$ha^{-1}) were found at Ventina permanent plot. Vertical evenness index and standard deviation of DBH suggested a more layered and diversified structure at Musella, but Ventina had more tree species (7 vs. 4). The number of standing dead trees (snags) in the two permanent plots was similar (16 vs. 15), but Ventina had a higher dead wood volume (9.97 m$^{3}\cdot$ha^{-1}) mainly represented by dead trees laying on the ground (logs, 4.76 $m^3 \cdot ha^{-1}$). At Musella the deadwood volume was 3.11 $m^3 \cdot ha^{-1}$ mainly composed of stumps (2.56 $m^3 \cdot ha^{-1}$).

Trees were found to be clumped in both permanent plots (Table 6) with some differences between species: larch was found to be clumped at all spatial scales, while spruce at Musella and stone pine at Ventina had grouped distributions only up to a distance of 7 and 8 m respectively. Big trees were randomly distributed at Musella, while were found to be clumped up to 14 m at Ventina, exhibiting little differences between big diameters and heights. Standing dead trees and stumps were randomly distributed in both study areas, while larch saplings were significantly clumped ($p < 0.001$) at all distances up to 10 m.

Positive spatial association (attraction) was found between saplings of larch and saplings of other species at all spatial scales up to 17 m (Table 7). Saplings showed negative spatial association (repulsion) with big trees up to distances of about 10 m at Musella, while attraction was found between small trees and saplings in both study sites. Saplings were associated to stumps between 6 and 10 m at Ventina, but repulsion between 2 and 9 m was found at Musella.

4. Discussion and conclusion

4.1. Land use history and landscape change

The historic anthropogenic disturbance and grazing pressure emerged as a key factor for shaping landscape structure of Valmalenco. The Musella watershed was affected by a higher grazing pressure and showed a more diverse and fragmented mosaic of meadows, open woodlands, forests and wood pastures. Landscape indices (e.g. Patch Density and Largest Patch Index) provided the evidence that Musella was and actually is a heterogeneous and diverse (Simpson’s Diversity

Index) landscape with a high density (15-26/100 ha) of small patches. The high intensity of human pressure experienced by this landscape contributed to create a disaggregated mosaic (Landscape Shape Index). It is likely that this anthropogenic disturbance regime affected the temporal dynamics as well. In fact forest fragmentation and the following abandonment favored secondary successions within this watershed. Ventina was not concerned by abrupt changes, probably due to its relatively homogeneous and connected landscape. In contrast, the abundance of open areas, together with the changes in grazing pressure, favored a larger amount of transitions at Musella. Forty years of reduced and unmanaged human pressure lead to a more fragmented landscape with less core areas (Core Area and Disjunct Core Area indexes) and more complex patches (Shape Index). In the 1961 – 2003 time span, the extent of forest land cover classes increased at the expense of wood pastures and meadows that, mainly at Ventina, were represented by a smaller number of patches. Differences emerged between meadow and wood pasture classes: the “wood pasture to forest” transition was a stronger change compared to the “meadow to forest” transition, probably due to the fact that wood pastures were located in more marginal areas. The decline of some traditional practices and the abandonment of marginal lands led to concentrate the grazing activities close to human settlements (Lasanta-Martinez et al. 2005). This process is related to different forms of abandonment and has been noted in many other sub-Mediterranean-Alpine and Mediterranean land use systems (Pinto-Correia and Mascarenhas 1999). Extensification is often connected with intensification on the most productive lands, subsequently causing an increase of contrasts between productive and abandoned lands (Baudry 1991). Some areas of Valmalenco, like many others mountainous regions, experienced a strong development of some activities (e.g. sky resorts) that attracted many people and favored the extensification of the neighboring watersheds.

4.2. Forest structure and grazing pressure

The stand scale analysis confirmed the hypothesis that Ventina was less disturbed by human activities, while Musella was intensively modified by traditional practices like thinning and forest grazing (Garbarino et al. 2009). Although the study plots had similar elevation and overstorey species composition, they differed in density of trees, saplings, stumps and spatial pattern. The past and current human use of the stand at Musella lead to a high amount of stumps and a very low density of dead downed logs (Lingua et al. 2008). The strong human influence on this stand was confirmed by a low basal area and, above all, the absence of the typical subalpine clustered pattern. The past and actual use of this stand as wood pasture, created and maintained through selective cutting, had led to a random distribution of larch tree stems (Motta and Lingua 2005). As a consequence of reduced grazing pressure on the forest in the late 70s, regeneration of larch and spruce established according to a typical subalpine clustered pattern (Schonenberger 2001). Musella permanent plot can be considered a portion of subalpine wood pasture, but a different pattern was observed at Ventina study site. The relatively high amount of dead wood on the ground (logs) together with the high density and the clustered distribution of trees and saplings of every size were considered signs of low human impact on the forest.

The processes observed within the Musella permanent plot evidenced that the establishment of larch and spruce regeneration in a subalpine wood pasture is permitted if grazing pressure is maintained low. Mayer et al. (2006) suggested to hold down a grazing pressure threshold of 1 $LUha^{-1}$ or to provide time intervals without grazing (Van Uytvanck et al. 2008). Heavy grazing pressure followed by periods of moderate grazing is often associated to the onset of tree regeneration in many sites (Mast et al. 1997). In fact, moderate livestock grazing may facilitate tree establishment since few seedlings are trampled, bare mineral soil is exposed and competition from grasses is reduced. Moreover is demonstrated that, at least in short term, deciduous species like European larch are less affected by low intensity livestock grazing than the evergreen ones (Vandemberghe et al. 2007). Juniper (*Juniperus nana* L.) thickets may act as safe sites (Smit et al. 2005) for tree establishment at Musella permanent plot. Other studies performed in different environments revealed that unpalatable shrub thickets play as shelters protecting woody species from browsing (Smit et al. 2009; Van Uytvanck et al. 2008; Vera 2000). However, the encroachment of juniper thickets may reduce the area where larch recruits more effectively and grows faster than late-successional species. The study indicates the anthropogenic disturbance regime and the decline of traditional practices as the main factors affecting the landscape change pattern in Valmalenco. A significant reduction of open forests mainly due to grazing decline, was observed at both landscape and stand scale.

4.3. Wood pasture conservation issue

At the landscape scale, agricultural land use can have either a positive or a negative effect on biodiversity and associated goods and services (Bolliger et al. 2007). Regarding diversity in our study sites, both the landscape and stand scale analyses revealed that Musella was more diverse than Ventina. The vertical structure of the stand was multi-layered and the diameter distribution revealed a higher heterogeneity at Musella. Moreover, the watershed analysis showed a complex mosaic at Musella and a more homogeneous and stable situation at Ventina.

This study gives the evidence of a transforming landscape, where wood pasture can be considered an 'endangered' traditional land use. Subalpine wood pastures, like many other semi-natural environments, run the risk to disappear and lose their productive and cultural characteristics, because they are developing into closed stands (Mountford and Peterken 2003). The needs for conservation of such environments has been outlined by several European and American authors (Grossmann and Mladenoff 2007; Manning et al. 2006; Piussi 2000) as having paramount importance in order to prevent the disappearance of their diversity and cultural aspects. Open areas should be maintained by the processes that created them (Albert et al. 2008). The balance between trees and herbivores is a fundamental issue in wood pasture management and grazing must be controlled as to limit damage to trees (Adams 1975). Livestock grazing only affects grasses and forbs, instead wildlife and goats browsing directly influences shrubs and trees regeneration growth. Thus, cattle grazing can be considered less dangerous than wild ungulates browsing (Mayer et al. 2006) because only a high cattle stocking rate may increase the risk of unintentional trampling on trees. For these reasons, landscape management should find a balance between the conservation of open areas and wood pastures and natural encroachment of trees. In this context it is probably anachronistic to go back to a traditional management of subalpine valleys, but diversity at landscape scale can be maintained through traditional extensive mowing and grazing. Conservation through thinning and subsequent grazing is suggested in places like Musella where tourism and livestock grazing are still present. In such valleys a portion of wood pastures, located near the active pastures, could be maintained by eliminating the shrubs cover and coarse woody debris. In this way the cultural aspect of these landscapes can be perpetuated for touristic purposes. Unlike wood pastures, maintenance of meadows might need a greater grazing pressure to avoid recruitment of trees. In order to do so, it is important to maintain the restoration policy applied by Lombardy region in order to improve economic conditions of these marginal lands and prevent further abandonment of the active huts.

Acknowledgements

We thank Tiziana Stangoni and Floriano Lenatti for the logistical support and the Sondrio Province, and Istituto Geografico Militare for providing aerial images and geographic material. We also thank the Lombardy Region and the Sondrio Province for funding this research through the “Programma regionale di ricerca in campo agricolo 2004-2006” program and two anonymous referees for the valuable comments and contributions.

References

Aakala T, Kuuluvainen T, De Grandpré L, Gauthier S (2007) Trees dying standing in the northeastern boreal old-growth forests of Quebec: spatial patterns, rates, and temporal variation. Can J For Res 37:50-61

Adams SN (1975) Sheep and cattle grazing in forests: a review. J Appl Ecol 12, 143-152

Albert CH, Thuiller W, Lavorel S, Davies ID, Garbolino E (2008) Land-use change and subalpine tree dynamics: colonization of Larix decidua in French subalpine grasslands. J Appl Ecol 45:659-669

Antrop M (2005) Why landscapes of the past are important for the future. Landscape Urban Plan 70:21-34

Axelsson AL, Östlund L (2001) Retrospective gap analysis in a Swedish boreal forest landscape using historical data. Forest Ecol Manag 147:109-122

Bätzing W, Perlik M, Dekleva M (1996) Urbanization and depopulation in the Alps: an analysis of current social–economic structural changes. Mt Res Dev 16:335-350

Baudry J, (1991) Ecological consequences of grazing extensification and land abandonment: role of interactions between environment, society and techniques. Options Méditerranéennes 15:13-19

Bergomi M (2006) Politica e Amministrazione in Valmalenco nell'Età Moderna. Società Storica Valtellinese, Sondrio

Bolliger J, Kienast F, Soliva R, Rutherford GN (2007) Spatial sensitivity of species habitat distribution patterns to scenarios of land-use change (Switzerland). Landscape Ecol 22:773-789
Bürgi M (1999) A case study of forest change in the Swiss lowlands. Landscape Ecol 14:567-575
Bürgi M, Gimmi U (2007) Three objectives of historical ecology: the case of litter collecting in Central European forests. Landscape Ecol 22:77-87
Cain D, Riitters K, Orvis K (1997) A multi-scale analysis of landscape statistics. Landscape Ecol 12:199-212
Chen J, Franklin J, Spies T (1992) Vegetation responses to edge environments in old-growth Douglas-fir forests. Ecol Appl 2:387-396
Cousins SAO, Lavorel S, Davies I (2003) Modeling the effects of landscape pattern and grazing regimes on the persistence of plant species with high conservation value in grasslands in south-eastern Sweden. Landscape Ecol 18:315-332
Del Favero R (2002) I tipi forestali nella Regione Lombardia. Cierre edizioni, Milano
Della Marianna G, Gusmeroli F, Puccio C (2004) Gli alpeggi della Comunità Montana Valtellina di Sondrio. Fondazione Fojanini, Sondrio
Didier L (2001) Invasion patterns of European larch and Swiss stone pine in subalpine pastures in the French Alps. Forest Ecol Manag 145:67-77.
Dullinger S, Dirnböck T, Greimler J, Grabherr G (2003) A resampling approach for evaluating effects of pasture abandonment on subalpine plant species diversity. J Veg Sci 14:243-252
Garbarino M, Weisberg PJ, Motta R (2009) Interacting effects of physical environment and anthropogenic disturbances on the structure of European larch (Larix decidua Mill.) forests. Forest Ecol Manag 257:1794-1802
Gimmi U, Bürgi M, Stuber M (2008) Reconstructing anthropogenic disturbance regimes in forest ecosystems: a case study from the Swiss Rhone valley. Ecosystems 11:113–124
Goreaud F, Pélissier R (2003) Avoiding misinterpretation of biotic interactions with the intertype K_{12}-function: population independence vs. random labelling hypotheses. J Veg Sci 14:681-692
Grace JB (1999) The factors controlling species density in herbaceous plant communities: an assessment. Perspect Plant Ecol Evol Syst 2:1-28
Griffith J, Martinko E, Price K (2000) Landscape structure analysis of Kansas at three scales. Landscape Urban Plan 52:45-61
Grossmann EB, Mladenoff DJ (2007) Open woodland and savanna decline in a mixed-disturbance landscape (1938 to 1998) in the Northwest Wisconsin (USA) Sand Plain. Landscape Ecol 22:43-55
Haase P (1995) Spatial pattern analysis in ecology based on Ripley's K-function: Introduction and methods of edge correction. J Veg Sci 6:575-582
Haase P (2001) Can isotropy vs. anisotropy in the spatial association of plant species reveal physical vs. biotic facilitation? J Veg Sci:12 127-136
Lasanta-Martinez T, Vicente-Serrano SM, Cuadrat-Prats JM (2005) Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: a study of the Spanish Central Pyrenees. Appl Geogr 25:47-65

Lingua E, Cherubini P, Motta R, Nola P (2008) Spatial structure along an altitudinal gradient in the Italian central Alps suggests competition and facilitation among coniferous species. J Veg Sci 19:425-436

Lotwick HW, Silverman BW (1982) Methods for analysing spatial processes of several types of points. J Roy Stat SocB Met 44:406-413

Manning AD, Fischer J, Lindenmayer DB (2006) Scattered trees are keystone structures - Implications for conservation. Biol Conserv 132:311-321

Marañón T (1988) Agro-sylvo-pastoral systems in the Iberian peninsula: Dehesas and montados. Rangelands 10:255-258

Mast JN, Veblen TT, Hodgson ME (1997) Tree invasion within a pine/grassland ecotone: an approach with historic aerial photography and GIS modeling. Forest Ecol Manag 93:181-194

Mayer AC, Estermann BL, Stockli V, Kreuzer M (2005) Experimental determination of the effects of cattle stocking density and grazing period on forest regeneration on a subalpine wood pasture. Animal Res 54:153-171

Mayer AC, Stockli V, Konold W, Kreuzer M (2006) Influence of cattle stocking rate on browsing of Norway spruce in subalpine wood pastures. Agroforest Syst 66:143-149

McCune B, Grace JB (2002) Analysis of ecological communities. MjM Software Design, Gleneden Beach, OR

McGarigal K, Marks BJ (1995) Fragstats: spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351. USDA Forest Service, Pacific Northwest Research Station, Portland, OR

Motta R, Lingua E (2005) Human impact on size, age, and spatial structure in a mixed European larch and Swiss stone pine forest in the Western Italian Alps. Can J For Res 35:1809-1820

Motta R, Nola P, Piussi P (2002) Long-term investigations in a strict forest reserve in the eastern Italian Alps: spatio-temporal origin and development in two multi-layered subalpine stands. J Ecol 90:495-507

Mountford EP, Peterken GF (2003) Log-term change and implications for the management of wood-pastures: experience over 40 years from Denny Wood, New Forest. Forestry 76:19-43

Naveh Z (1995) Interactions of landscapes and cultures. Landscape Urban Plan 32:43-54

Neel M, McGarigal K, Cushman S (2004) Behavior of class-level landscape metrics across gradients of class aggregation and area. Landscape Ecol 19:435-455

Neumann M, Starlinger F (2000) The significance of different indices for stand structure and diversity in forests. Forest Ecol Manag 145:91-106

Papanastasis VP (1997) Livestock grazing in Mediterranean ecosystems: an historical and policy perspective. In: Papanastasis VP, Peter D (eds), Ecological basis of livestock grazing in mediterranean ecosystems. European Commission, Brussels, pp 5-9

Peterken GF (1977) Habitat conservation priorities in British and European woodlands. Biol Conserv 11:223-236

Pinto-Correia T (1993) Threatened landscape in Alentejo, Portugal: the ‘montado’ and other ‘agro-silvo-pastoral’ systems. Landscape Urban Plan 24:43-48

Pinto-Correia T, Mascarenhas J (1999) Contribution to the extensification/intensification debate: new trends in the Portuguese montado. Landscape Urban Plan 46:125-131
Piussi P (2000) Expansion of European mountain forests. In: Price MF, Butt N (eds), Forest in sustainable mountain development: a state of knowledge report for 2000. CABI Publishing, Wallingford, pp 19-25
Piussi P, Farrell EP (2000) Interactions between society and forest ecosystems: challenges for the near future. Forest Ecol Manag 132:21-28
Plieninger T (2003) Effects of land-use history on size structure of holm oak stands in Spanish dehesas: implications for conservation and restoration. Environ Conserv 30:61-70
Rackham O (1998) Savanna in Europe. In: Kirby JK, Watkins C (eds), The Ecological history of European Forests. CABI, Wallingford, pp 1-24
Riitters K, O'Neill R, Hunsaker C, Wickham J, Yankee D, Timmins S, Jones K, Jackson B (1995) A factor analysis of landscape pattern and structure metrics. Landscape Ecol 10:23-39
Ripley BD (1977) Modeling spatial patterns (with discussion). J Roy Stat SocB Met 39:172-212.
Società Agraria di Lombardia (1901) Atti della commissione d'inchiesta sui pascoli alpini. Società Agraria di Lombardia, Milano
Schonenberger W (2001) Cluster afforestation for creating diverse mountain forest structures - a review. Forest Ecol Manag 145:121-128
Schulze E-D, Mischì G, Asche G, Börner A (2007) Land-use history and succession of Larix decidua in the Southern Alps of Italy - An essay based on a cultural history study of Roswitha Asche. Flora 202:705-713
Smit C, Béguin D, Buttler A, Müller-Schärer H (2005) Safe sites for tree regeneration: a case of associational resistance? Journal of Vegetation Science 16:209-214
Smit C, Pohl M, Buttler A, Freléchoux F (2009) Does the strength of facilitation by nurse shrubs depend on grazing resistance of tree saplings? Basic and Applied Ecology 10:427-436
Swetnam TW, Allen CD, Betancourt JL (1999) Applied historical ecology: using the past to manage for the future. Ecol Appl 9:1189-1206
Tasser E, Walde J, Tappeiner U, Teutsch A, Noggler W (2007) Land-use changes and natural reforestation in the Eastern Central Alps. Agriculture, Ecosystems and Environment 118:115–129
Tinker D, Resor C, Beauvais G, Kipfmueller K, Fernandes C, Baker W (1998) Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest. Landscape Ecol 13:149-165
Tischendorf L (2001) Can landscape indices predict ecological processes consistently? Landscape Ecology 16:235-254
Turner MG, Dale VH (1998) Comparing large, infrequent disturbances: what have we learned? Ecosystems 1:493–496
Van Uytvanck J, Maes D, Vandenhaute D, Hoffmann M (2008) Restoration of wood pasture on former agricultural land: The importance of safe sites and time gaps before grazing for tree seedlings. Biol Conserv 141:78-88
Vandenberghe C, Freléchoux F, Moravie M, Gadallah F, Buttler A (2007) Short-term effects of cattle browsing on tree sapling growth in mountain wooded pastures. Plant Ecology 188:253-264
Vera FWM (2000) Grazing ecology and forest history. CABI, Wallingford

Weisberg PJ, Lingua E, Pillai RB (2007) Spatial patterns of pinyon–juniper woodland expansion in central Nevada. Rangeland Ecol Manag 60:115-124

Tables

Table 1. Metrics on landscape-level (McGarigal and Marks, 1995) computed for the two sites at two periods (4 land cover maps).

Metrics (abbreviation)	Component measured	Units	Musella (1151 ha)		Ventina (1123 ha)	
			1961	2003	1961	2003
Patch Density (PD)	Density	n/100ha	15.3	25.8	3.2	3.4
Largest Patch Index (LPI)	Area	%	46.2	39.7	84.2	83.1
Patch Area Mean (AREA_MN)	Area	ha	6.5	3.9	31.2	29.6
Edge Density (ED)	Edge	m/ha	133.7	202.1	50.1	51.0
Landscape Shape Index (LSI)	Edge	-	11.3	17.1	4.2	4.3
Shape Index Mean (SHAPE_MN)	Shape	-	2.4	2.6	2.1	2.2
Contagion Index (CONTAG)	Contagion	%	64.5	65.2	84.2	84.2
Connectance Index (CONNECT)	Connectivity	%	5.4	3.5	16.9	12.2
Simpson's Diversity Index (SIDI)	Diversity	-	0.6	0.7	0.3	0.3

Table 2. Transition matrix showing land cover changes (ha) from 1961 to 2003 at Musella watershed. Values are expressed in hectares and in percent (in parentheses) relative to the total area of the class in 1961.

Land cover classes in 1961	Land cover classes in 2003						Total area
	Dense Forest	Sparse forest	Wood pasture	Shrubland	Meadow	Bare soil	
Dense Forest	104.49	6.34	2.19	0.73	0.24	0.92	114.91
	(91%)	(6%)	(2%)	(1%)	(<1%)	(1%)	(10%)
Sparse forest	85.00	74.97	2.20	2.32	4.24	11.45	180.18
	(47%)	(42%)	(1%)	(1%)	(2%)	(6%)	(16%)
Wood pasture	61.65	6.07	13.79	0.04	1.37	1.80	84.72
	(73%)	(7%)	(16%)	(<1%)	(2%)	(2%)	(7%)
Shrubland	4.67	13.70	0.11	19.69	0.00	1.86	40.03
	(12%)	(34%)	(<1%)	(49%)	(<1%)	(5%)	(3%)
Meadow	14.95	12.80	9.93	0.21	21.39	20.96	80.24
	(19%)	(16%)	(12%)	(<1%)	(27%)	(26%)	(7%)
Bare soil	28.98	89.42	2.78	4.62	3.07	521.82	650.69
	(4%)	(14%)	(<1%)	(1%)	(<1%)	(80%)	(57%)
Total area	299.73	203.31	31.00	27.60	30.31	558.82	1150.78
	(26%)	(18%)	(3%)	(2%)	(3%)	(49%)	(100%)

Table 3. Transition matrix showing land cover changes (ha) from 1961 to 2003 at Ventina watershed. Values are expressed in hectares and in percent (in parentheses) relative to the total area of the class in 1961.

Land cover classes in 1961	Land cover classes in 2003						Total area
	Dense Forest	Sparse forest	Wood pasture	Shrubland	Meadow	Bare soil	
Dense Forest	46.98 (81%)	9.45 (16%)	0.07 (<1%)	0.00 (<1%)	0.00 (<1%)	1.24 (2%)	57.74 (5%)
Sparse forest	15.26 (19%)	37.86 (47%)	0.00 (<1%)	6.86 (8%)	0.37 (<1%)	20.50 (25%)	80.85 (7%)
Wood pasture	16.85 (92%)	0.44 (2%)	0.84 (5%)	0.00 (<1%)	0.00 (<1%)	0.12 (1%)	18.25 (2%)
Shrubland	2.02 (27%)	0.82 (11%)	0.00 (<1%)	2.97 (40%)	0.00 (<1%)	1.64 (22%)	7.45 (1%)
Meadow	0.02 (<1%)	1.08 (27%)	0.00 (<1%)	0.73 (18%)	1.86 (46%)	0.34 (8%)	4.03 (<1%)
Bare soil	8.56 (1%)	25.72 (3%)	0.00 (<1%)	1.14 (<1%)	0.38 (<1%)	919.37 (96%)	955.18 (85%)
Total area	89.70 (8%)	75.37 (7%)	0.91 (<1%)	11.69 (1%)	2.61 (<1%)	943.21 (84%)	1123.50 (100%)

Table 4. Principal component loadings for the metrics on class-level (LCC) (McGarigal and Marks, 1995). Bold indicates the highest values for each metric.

Metrics (abbreviation)	PC1	PC2	PC3	PC4
Landscape Shape Index (LSI)	**-0.398**	-0.137	0.066	0.112
Clumpiness Index (CLUMPY)	**0.356**	-0.082	**0.358**	-0.173
Patch Density (PD)	**-0.344**	-0.213	0.166	-0.069
Contiguity Index Mean (CONTIG_MN)	**0.330**	0.182	0.080	0.068
Aggregation Index (AI)	**0.324**	-0.188	**0.345**	-0.215
Total class Area (CA)	0.100	**-0.446**	-0.167	-0.211
Landscape Division Index (DIVISION)	-0.185	**0.391**	0.312	0.138
Cohesion (COHESION)	-0.010	**-0.388**	0.267	0.177
Area mean (AREA_MN)	0.209	**-0.356**	-0.313	-0.043
Disjunct Core Area (DCAD)	-0.226	-0.188	**0.450**	0.025
Shape Index Dist. Mean (SHAPE_MN)	-0.191	-0.192	**-0.383**	**0.380**
Connectance (CONNECT)	0.179	-0.031	0.192	**0.719**
Core Area Index Mean (CAI_MN)	0.294	-0.254	0.029	**0.364**
Edge Density (ED)	-0.298	-0.306	0.183	-0.102
Eigenvalue	5.508	4.032	1.516	1.262
% of variance	39.3	28. 8	10.8	9.0

Table 5. Stand characteristics of Musella and Ventina permanent plots.

		Density				Diversity		Coarse Woody Debris		
		Trees (ha^{-1})	Saplings (ha^{-1})	Trees BA (m^2/ha)	Trees DBH-Sd (cm)	Vertical Evenness	Richness (ha^{-1})	Stumps (ha^{-1})	Snags (ha^{-1})	Logs (ha^{-1})
Musella	L. decidua	427	351	8.51	11.22					
	P. abies	65	29	1.01	9.54					
	Others	10	3	0.05	2.75					
	Total	502	383	9.58	10.91	0.73	4	93	16	3
Ventina	L. decidua	745	122	13.19	8.26					
	P. cembra	25	8	0.20	4.61					
	Others	6	5	0.02	1.17					
	Total	776	135	13.41	8.17	0.58	7	53	15	81

Table 6. Ripley's K(t) for different size classes of larch and spruce and woody debris at Musella and Ventina using 99% confidence envelope with a 1-m step. Random distribution and clumped distributions are reported with R and C respectively.

	Distance (m)																																																	
MUSELLA	1				5					10					15					20					25					30					35					40					45					50
Trees total	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Larch trees	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Spruce trees	C	C	C	C	C	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Stumps	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R	R	C	R	R	C	C	R	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Snags	R	R	R	R	R	R	R	R	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Big trees	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Small trees	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Saplings total	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C																													
Saplings larch	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C																													
Saplings spruce	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R																													
VENTINA																																																		
Trees total	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Larch trees	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Stone pine trees	C	C	C	C	C	C	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Stumps	R	R	R	R	R	R	R	R	R	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Snags	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Big trees	R	R	R	C	C	C	C	C	C	C	C	C	R	R	R	R	R	R	R	R	C	R	C	R	C	C	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Small trees	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Saplings total	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C																																	
Saplings larch	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C																																	
Saplings others	C	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R																																	

Table 7. Ripley's K12(t) for larch versus spruce saplings and trees and woody debris at Musella and Ventina. A plus (+) sign indicates a positive spatial association, a minus sign (-) indicates a negative spatial association, and an empty cell indicates spatial independence.

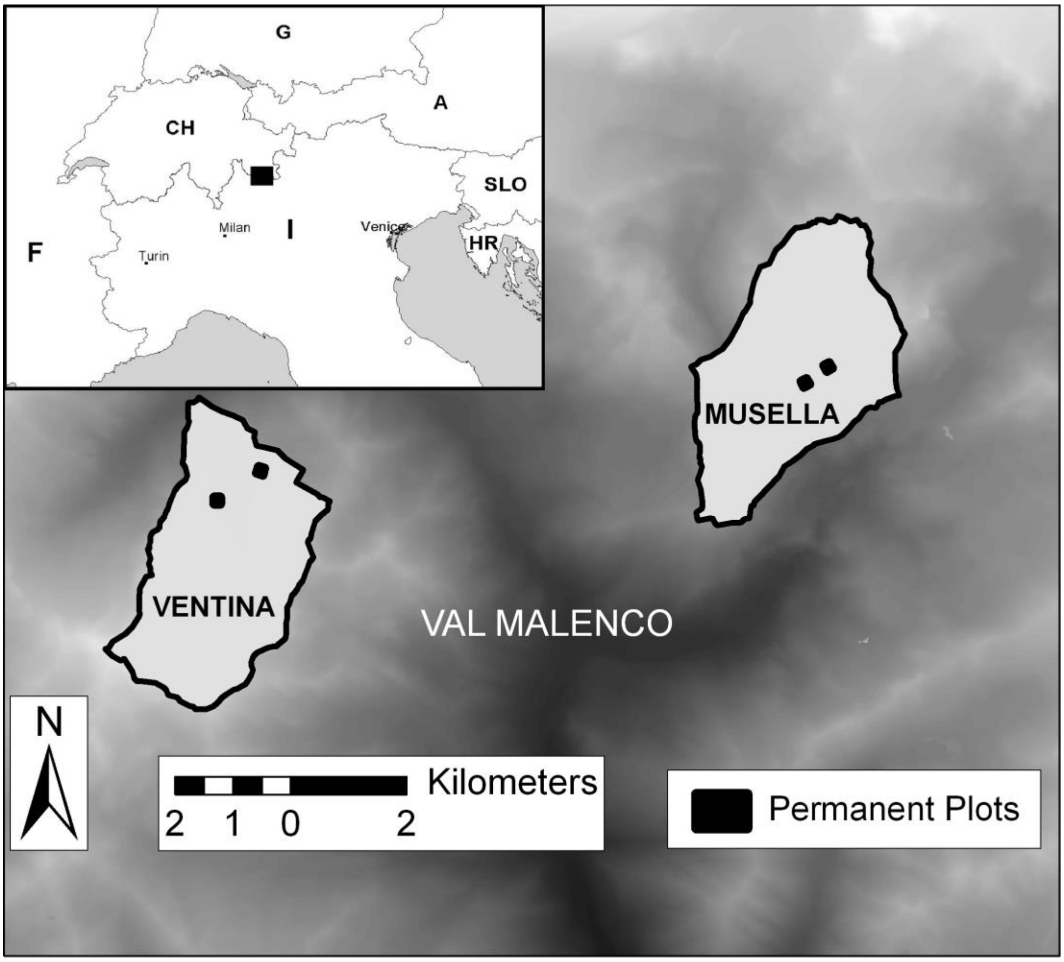
	Distance (m)																																																	
MUSELLA	1				5					10					15					20					25					30					35					40					45					50
Larch – spruce (saplings)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																																
Larch – spruce (trees)																																																		
Big – small trees					-																												+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
Big trees – stumps																																																		
Stumps – small trees		+	+		+	+				+	+	+	+	+	+																																			
Stumps – snags												+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Big trees – saplings		-	-	-	-	-									+	+	+	+	+	+	+																													
Small trees – saplings	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+																													
Stumps – saplings		-	-	-	-	-	-	-	-										+	+	+																													
VENTINA																																																		
Larch – other sp. (saplings)				+	+	+	+	+		+	+	+	+	+	+	+	+																																	
Larch – stone pine (trees)																																+																		
Big – small trees																																			+		+	+	+	+	+	+	+	+	+	+	+	+	+	+
Big trees – stumps																																																		
Stumps – small trees	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+																			+	+	+	+	+			+	+	+	+	+	+
Stumps – snags																																																		
Big trees – saplings				-										+	+	+	+																																	
Small trees – saplings		+				+	+	+	+	+	+	+	+	+	+	+	+																																	
Stumps – saplings							+	+	+	+		+	+	+	+	+	+																																	

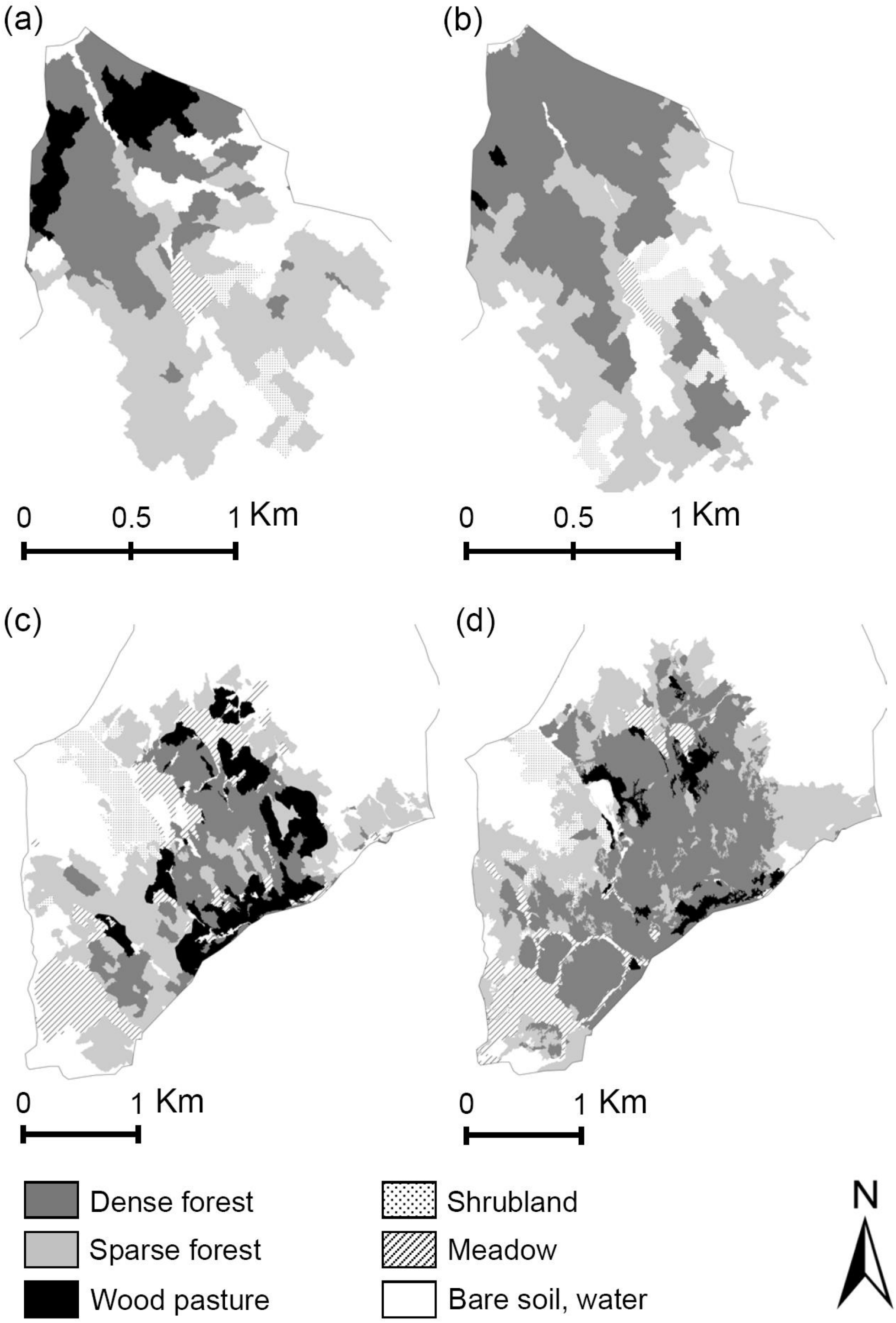
Figure legends

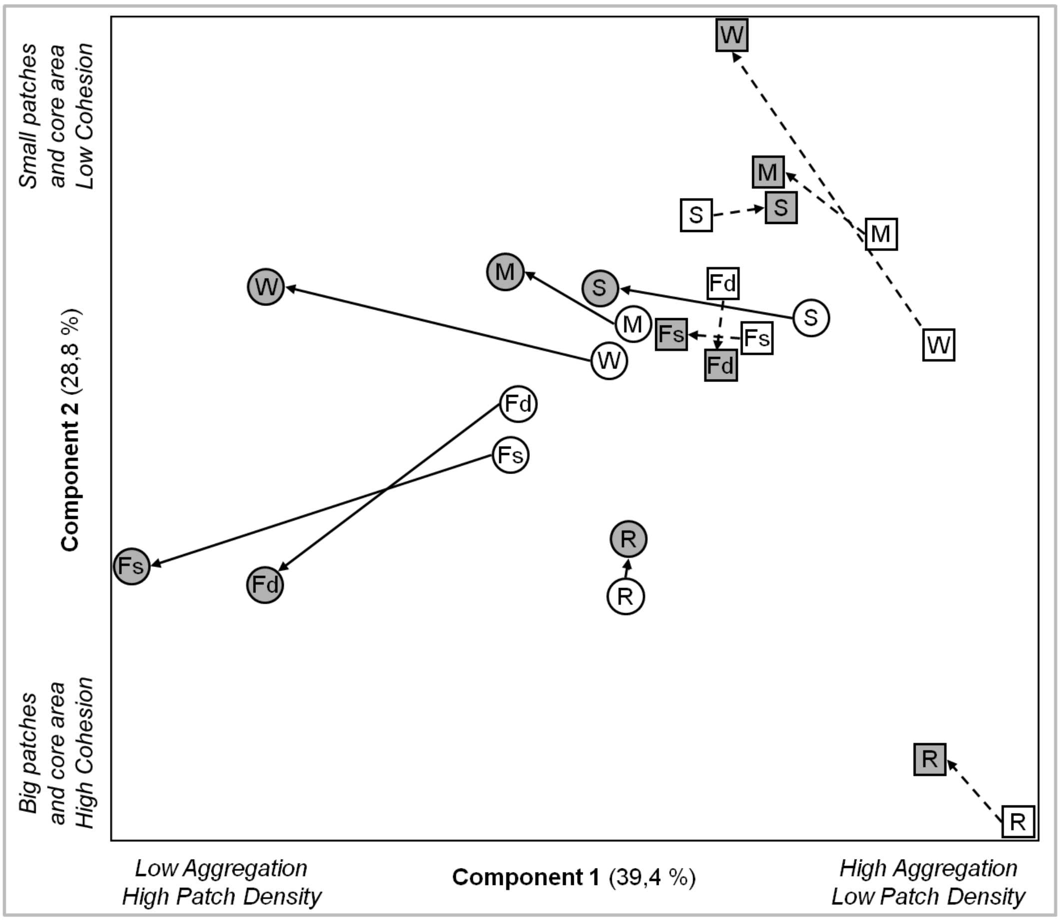
Fig. 1 Location of the Valmalenco study area within the central Italian Alps.

Fig. 2 Land cover maps derived from aerial photographs for the two landscapes at two periods: a) Ventina 1961; b) Ventina 2003; c) Musella 1961 and d) Musella 2003

Fig. 3 Principal component analysis of 6 land cover classes (Fd = dense forest, Fs = sparse forest, W = wood pasture, S = shrubland, M = meadow, R = bare soil, water) for 4 maps (2 landscapes, 2 periods). LCC scores are labeled according to sites (Ventina: square points with dashed lines; Musella: circular points with solid lines), and periods (1961: unfilled points; 2003: filled points)


G
A
CH
SLO
Milan
I
Venice
F
Turin
HR
MUSELLA
VENTINA
VAL MALENCO
N
Kilometers
2 1 0 2
Permanent Plots


(a)
(b)
0
0.5
1 Km
0
0.5
1 Km
(c)
(d)
0
1 Km
0
1 Km
Dense forest
Sparse forest
Wood pasture
Shrubland
Meadow
Bare soil, water
N


Small patches
and core area
Low Cohesion
Component 2 (28,8 %)
Big patches
and core area
High Cohesion
Low Aggregation
High Patch Density
Component 1 (39,4 %)
High Aggregation
Low Patch Density
W
M
S
Fd
Fs
R