Land-use history and topographic gradients as driving factors of subalpine Larix decidua forests

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Abstract

European larch (*Larix decidua* Mill.) forests in the are a cultural landscape that has been shaped by humans for centuries through traditional management. Biological and historical data sources were employed, and a multi-scale approach was adopted to capture the influence of factors affecting the structure of these forests. Landscape and stand scale dynamics were analyzed in 4 watersheds (c. 13000 ha) of the western and central Italian Alps that have experienced different land-use intensities. Observed landscape changes were generalized using path analyses developed from a common conceptual model. Stand structure and a range of environmental variables were sampled in 203 circular plots, and land use and anthropogenic variables were derived from thematic maps and aerial photographs. We used multivariate statistical analyses (ordination and SEM models) to relate forest structure, anthropogenic influences, land uses, and topography. The most commonly observed land cover transition was an expansion of forests at the expense of open areas. All studied watersheds were dominated by larch forests, but their structure and spatial pattern differed greatly. Anthropogenic variables were less important at Ventina, the least accessible site, but emerged as fundamental to explain stand structure in the other study sites. Complexity of topography and proximity to roads had influenced past human activities mainly in the most accessible sites. Regeneration density was higher at lower elevations and closer to human settlements. Quantification of the role played by forest harvesting and cattle grazing in past centuries is critical for understanding how global change factors may influence future dynamics of mountain forests in the European Alps and similar cultural landscapes worldwide.

Key words

Landscape pattern; land-use change; legacy effects; historical ecology; stand structure; *Larix decidua*; forest grazing; SEMs; Italian Alps

Abbreviations

MUS – Musella; VEN – Ventina; VEG – Veglia; DEV – Devero;

Introduction

Land-use history and its consequences are considered as major components of global change (Foster et al. 1998) and the temporal effects of land-use legacies can persist long after the abandonment of human activities (Bellemare et al. 2002; Gimmi et al. 2008). In regions of the world where human impacts have been pervasive and dominant for centuries, the ecosystem effects of climate change can be altered and overwhelmed by landscape modifications induced by land-use change (Clavero et al. 2011; Foster et al. 1998). A historical understanding of land-use change as a fundamental ecological process is necessary to predict future landscape change scenarios in cultural landscapes and better inform policy decisions on landscape management and conservation (Chauchard et al. 2007; Foster et al. 1998; Foster et al. 2003).

The regime of land use or anthropogenic disturbance regime (Gimmi et al. 2008) is determined by previous agricultural land use type (e.g. mowing, thinning, grazing), intensity (e.g. traditional or delayed mowing, density of grazing animals), extent, and duration of land use (e.g. timing of agricultural abandonment). Despite the importance of land-use change for landscape ecological investigations (Bolliger et al. 2007; Wu and Hobbs 2002) little is known regarding the anthropogenic disturbance regime and its long-term effects on the structure and distribution of vegetation in mountain forest regions such as the European Alps (Tasser et al. 2007). Due to several centuries of intense land use and subsequent natural reforestation (Sitzia et al. 2010) land use is the most important factor for landscape change in the Alps (Gehrig-Fasel et al. 2007) and human influence on forest landscapes is also manifest through the anthropogenic alteration of disturbance regimes such as fire, avalanches, and debris flows (Kulakowski et al. 2011).

European mountain economies were largely based on traditional non-timber forest uses, such as wood pasture and forest litter collecting (Burgi 1999; Gimmi et al. 2008; Peterken

1999). Forest grazing was the most important non-timber forest use in the mountain regions and was often more important than timber harvesting, particularly at higher elevations. Long-term influences of former grazing activities have been documented throughout the entire European Alps ({Albert, 2008 #2711} Chauchard et al. 2007; Motta et al. 2006; Tasser et al. 2007). Modified landscapes where extensive livestock grazing is the dominant land use can be defined as variegated landscapes (Fischer and Lindenmayer 2007). These landscapes are characterized by gradual boundaries between native vegetation (forest patches) and surrounding modified land (pastures). The importance of grazing activities in the Italian Alps during the early 1950s was much higher than today. Range and permanent pastures occupied about 53% of the mountain area and all pastures had already been grazed for hundreds of years (White 1950). Cattle grazing in un-fenced pastures was the dominant use, but lesser numbers of sheep and goats also grazed mountain pastures.

In European alpine settings, livestock grazing remains an important component of land use that is strongly influenced by natural, socio-economical, and political environments (Neumann et al. 2009). The anthropogenic disturbance regime is generally strongly influenced by socio-economical changes leading to land-use intensification or else abandonment (Wu 2006). An example of this can be found in the European Alps where the abandonment of traditional practices such as grazing is a consequence of depopulation and marginalization of mountainous areas (Baldock et al. 1996; Bätzing et al. 1996; MacDonald et al. 2000). Land use change in developed countries is often strictly linked to abandonment of traditional agricultural practices on less productive and less accessible lands (Kulakowski et al. 2011). This is particularly true for southern Europe, where the twentieth century was characterized by land use intensification in the plains, valley bottomlands, and coastal areas (Falcucci et al. 2007). Conversely, marginal and less productive areas, usually located in the mountains, were abandoned (Chauchard et al. 2007).

One of the most evident consequences of land abandonment is the reforestation of formerly open lands (Bolliger et al. 2007) with a subsequent loss of biodiversity, cultural heritage, and landscape attractiveness (Dullinger et al. 2003; Hunziker and Kienast 1999). Land abandonment in Mediterranean mountains has led to the expansion of shrubs and forests at the expense of many semi-natural open habitats (species-rich grasslands, hay meadows, wood pastures, and grazed wetlands), which were previously maintained by traditional practices (Chauchard et al. 2007). Natural reforestation is a site-dependent process influenced by several natural factors: topography, climate, soil, vegetation, snow gliding, avalanches, and seed dispersal strategies. The type and intensity of former land use, such as pasturing and mowing additionally play a decisive role (Wickham et al. 1999).

This study investigated the anthropogenic disturbance regime of subalpine forests of the Italian Alps to inform management strategies for subalpine landscapes including former agricultural areas. Subalpine forests of western and central Alps are dominated by European larch (*Larix decidua* Mill.) and are heterogeneous landscapes where dense and sparse stands coexist together with open areas and wood pastures (Garbarino et al. 2011). The traditional silvo-pastoral management of this cultural landscape favored a sparse cover of larch trees, resulting in open woodlands that were used for grazing or production of natural hay meadows for livestock fodder (Albert et al. 2008; Motta and Lingua 2005; Schulze et al. 2007). As a consequence of reduced grazing pressure and lack of management a dramatic reduction of grasslands and subalpine wood pastures has been documented (Cousins et al. 2003; Dullinger et al. 2003).

Aerial photography is a powerful tool to study land cover and land use changes (LUCC) of small mountain watersheds because it allows for high spatial and radiometric resolution (Morgan et al. 2010). This study combined landscape reconstruction and mapping, using aerial photography and historical records, with field sampling to estimate the impact of historical land use on the structure of modern-day European larch forests of the Italian Alps at both stand and landscape scales. Specifically, we tested the following hypotheses: a) the historical land use intensity affects the landscape structure, composition, and dynamics of central Italian Alpine valleys; b) topography and the anthropogenic disturbance regime are strong drivers of stand structure of larch forests; c) statistical causal models can provide a synthetic tool to highlight the underlying gradients that commonly affect the structure of subalpine *Larix decidua* forests. Finally we discuss the importance of historical data sources for ecosystem modeling.

Methods

Study area

The analysis units for this study were four inner valleys of the western and central Italian Alps (Fig. 1). Two of these watersheds (Veglia and Devero) were located in the western Lepontine Alps, Piedmont region. The others (Musella and Ventina) were two watersheds of the Valtellina, in the western Retiche Alps, Lombardy region. The Veglia (VEG) watershed occupies 4117 ha in the upper Cairasca valley (46°16’ N; 8°08’ E), the Devero (DEV) watershed occupies 6674 ha in the Devero valley (46°19’ N; 8°15’ E), the Musella (MUS) watershed occupies 1150 ha in the eastern Valmalenco (46°19’ N; 9°54’ E), and the Ventina (VEN) watershed occupies 1124 ha in the western Valmalenco (46°18’ N; 9°46’ E). Rock outcroppings, bare soil and glaciers dominate above tree line in all four valleys, but slopes are steeper at VEN (Table 1). The bedrock is silicate and serpentine is a common rock to all the sites, but at VEG and DEV the Augen gneiss is also present. MUS and VEN follow a north-south orientation, whereas VEG and DEV are oriented from northeast to southwest. All study areas are inner valleys of the “endalpic district” (Del Favero 2004) characterized by a temperate continental climate. In all watersheds, European larch is the dominant tree species with Norway spruce (*Picea abies* (L.) H. Karst) as a co-dominant species at lower elevations.

mountain pine (*Pinus uncinata* Mill.) and Swiss stone pine (*Pinus cembra* L.) are more abundant at VEN. Locally abundant shrub species include alpenrose (*Rhododendron ferrugineum* L.) and green alder (*Alnus viridis* (Chaix) D.C.).

#Figure 1 and Table 1 approximately here#

The traditional economic system of these alpine valleys in medieval times was based on frequent movements of people and domestic animals due to the seasonal fluctuations in availability of natural resources. Charcoal production and pitch extraction from the bark of larch trees were common practices and the cultivation of rye was active during the 1300s at DEV, but only at lower elevations. However, the most important historical land use was grazing in the subalpine pastures and larch forests between June and August. Mowing was practiced at DEV only, but stone removal, burning of shrub fields, and thinning were activities common to all the studied watersheds, and were used to improve and maintain the quality and quantity of pastures (Crosa Lenz and Frangioni 2005). Cattle grazing has occurred in these areas since approximately 1300 (Bergomi 2006; Streifeneder et al. 2006), and was restricted and managed by the local authorities, but goats grazed freely as long they did not damage pastures.

Image analysis

Aerial photographs for the years 1954, 2000 (Piedmont sites), 1961, and 2003 (Lombardy sites) were available for ca 13000 ha of forested landscape. Historical aerial photographs were scanned and orthorectified at 1-m resolution using PCI Geomatica 10.2 (PCI Geomatics Enterprises Inc., Richmond Hill, ON). Automated segmentation (scale parameter = 10) with manual correction was used to delineate polygons (Definiens 2004) that were classified into six categories of land cover (dense forests: >80% crown cover, sparse forests: 30-80% crown cover, grazed forests: 10-30% crown cover, shrubland, meadow, rock). The eight resulting raster maps (i.e. 4 landscapes x 2 time periods) were then enhanced in a GIS environment in order to reduce the effect of different input image quality and achieve a minimum mapping unit (MMU) of 9 m^2 (Garbarino et al. 2011). The landscape pattern analysis was limited to the vegetated part of the 4 valleys in order to reduce the weight of the rocks category. Thus, each raster map was clipped using an altitudinal cutoff of 2400 m a.s.l. representing the potential treeline for the central Italian Alps (Caccianiga et al. 2008; Lingua et al. 2008). An accuracy assessment was performed on each map resulting in the K statistic ranging from 0.63 (69% overall accuracy) for VEN 1961 to 0.87 (93% overall accuracy) for VEG 1954 (Table 2).

#Table 2 approximately here#

Landscape analysis

To analyze changes in landscape pattern, we used Fragstats software (McGarigal and Marks 1995) to calculate several key landscape metrics for the studied period, applying an 8-cell neighborhood definition. We selected representative metrics for landscape configuration and composition, including patch size and density, edge, contagion, connectivity, and diversity (Cushman et al. 2008). Since many metrics are closely related at the landscape level and describe similar aspects of landscape structure (Cain et al. 1997; Neel et al. 2004; Riitters et al. 1995), nine landscape-level metrics were selected excluding those that were highly correlated ($r > 0.8$) (Tischendorf 2001).

Landscape structure was also analyzed at the class level by computing 14 metrics for the 6 land cover classes of the four sites for the two time periods. Indirect ordination analysis (PCA) was used to reduce the redundancy of landscape metrics into uncorrelated components (McCune and Grace 2002), allowing comparison of land cover classes from all time periods and watersheds (Tinker et al. 1998).

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

Historical data on grazing activities in the four watersheds were obtained from regional inventory dataset of Piedmont (Pastorino et al. 1980) and Lombardy (Della Marianna et al. 2004; Società Agraria di Lombardia 1901), historical archives (Bergomi 2006) and grazing management plans (Scalabrini et al. 2004). Grazing data at the watershed scale were only available for the 1901-2010 period and were used as proxy variable of human pressure on the studied landscapes.

Stand structure and data analysis

Stand structure data were collected in the field in 203 circular plots (56 for VEG, 79 for DEV, 28 for MUS, and 40 for VEN). Sampling plots for the VEG and DEV watersheds were located on a 300 x 300 m wide regular grid, whereas at MUS and VEN a stratified random sampling design was applied (Garbarino et al. 2009). Plots of 12-m radius were used for the tree (diameter at 1.30 m, DBH $\geq$5 cm) layer survey, and subplots with a radius of 6 m were established within each plot for the sapling (DBH <5 cm and height >10 cm) layers. For all trees we measured DBH and total height. The three larch trees with the greatest diameter were cored upslope at a height of 50 cm in order to estimate stand age. For regeneration only density, composition and height were collected. From these data the following stand descriptors were used in the analyses: relative dominance of larch trees, maximum age of trees, density of trees, tree height, basal area, canopy cover, average DBH, standard deviation of DBH, relative dominance of larch regeneration, regeneration density and richness. The topographic variables (elevation, slope, aspect) were derived from a 10-m digital elevation model and the anthropogenic variables (proximity to buildings and roads) were derived from thematic maps (see Garbarino et. al 2009 for details).

Redundancy analysis (RDA), a constrained ordination method (Rao 1964; ter Braak and Prentice 1988) was used to investigate the proportion of variability explained by predictor variables relating to environment, anthropogenic influences and historical land cover, and their correlation with stand structure variation. Historical land cover classes were derived from the land cover maps previously obtained and were treated in the analysis as nominal variables. All ordination analyses (PCA and RDA) were performed using Canoco® software (ter Braak and Smilauer 1998), and their statistical significance tested by the Monte Carlo permutation method based on 10000 runs with randomized data.

Relationships among independent (topographic and anthropogenic) variables and the response variable (stand structure) were analyzed by means of path analysis in the Mx software that utilizes covariance matrices as input data and a maximum likelihood (ML) fit function (Neale 1994). Path analysis is a specialized version of Structural Equation Models (Shipley 2000) that permits testing an *a priori* model including cause-and-effect relationships between the studied variables. Our *a priori* or conceptual model (Fig. 2) was based on the interactions between topographic and anthropogenic variables in shaping forest structure. A PCA was used to extract a smaller subset of stand structure descriptors (first two principal components) for use in the path models. Alternative models were compared using a combination of Akaike's Information Criterion (AIC) statistic and the Root Mean Square Error of Approximation (RMSEA). The latter is a goodness-of-fit index that is relatively independent of sample size. A model with RMSEA < 0.06 was considered a good fit (Hu and Bentler 1999). All such models were computed and the models with the smallest AIC statistics were selected as the most parsimonious models (Hu and Bentler 1999).

#Figure 2 approximately here#

Results

Land use history and landscape configuration

Historical data on grazing activities (Table 3) suggested a declining trend through time that was common to all the studied valleys. Cattle were more abundant than sheep and goats at VEG and DEV, but the proportion of species animals was more evenly distributed in the Lombardy sites (MUS and VEN). VEN emerged as the least utilized watershed and is the only currently ungrazed.

#Table 3 approximately here#

The increase of edge density and shape index mean was common to all the study sites, indicating a general increase in polygon shape irregularity from 1954 to the present (Table 4). Patch density, area mean and landscape shape index increased in all the study sites, except for VEN that proved to be the only study site to remain relatively stable in terms of its landscape configuration. Landscape diversity (SDI) ranged from 0.5 at VEN to 0.8 at MUS in 1961and remained fairly stable in all the studied watersheds.

#Table 4 approximately here#

Land cover change

The total area of forest cover ('Dense' plus 'Sparse') increased in all study sites (Table 5) with the increase being particularly strong at DEV (+88%) and VEG (+58%). Conversely a consistent reduction of the wood pastures or 'Grazed Forests' was observed, with the greatest decline (-95%) at VEN. The 'Meadows' class decreased in all study sites ranging from -39% at VEN to -20% at DEV. The land cover changes in the four study sites were similar, but MUS and VEN emerged as the most and the least dynamic landscapes, respectively.

#Table 5 approximately here#

Principal component analysis provided a graphical depiction of changes in landscape metrics associated with the different land-cover classes. The first component accounted for 40.3% of the total variation and reflected a gradient of patch density, edge density and contiguity (Table 6). The second component explained an additional 23.7% of the total variation and was negatively correlated with patch size and aggregation. The ordination revealed that open and semi-open land cover classes ('Meadows' and 'Grazed Forests') were strongly fragmented as a consequence of a reduction of their surface area and number of patches (Fig. 3). An increase of fragmentation was also experienced by ‘Sparse Forests’ class as reflected in an increase of patch density. Conversely the ‘Dense Forests’ class showed an increase of aggregation and mean patch size.

#Figure 3 and Table 6 approximately here#

Stand structure and its driving factors

European larch dominated in all the studied landscapes, but VEN emerged as having the highest species richness both in the trees and the regeneration layers (Table 7). VEG had a strong dominance of larch (96%) and among the older (217 years) and bigger (c.a. 24 cm) trees. Closed and dense stands were abundant at MUS where the presence of Norway spruce and small trees was more common.

Table 7 approximately here#

The relationships between stand structure variables, environmental variables and anthropogenic factors were assessed through RDA (Fig. 4). The first and second axes accounted for 9.4 and 2.8% of the total variation, respectively and the species-environment correlation for the first RDA axis was 58.6%. Higher regeneration density (R-De) was associated with former pastures (‘Meadows’) and wood pastures (‘Grazed Forests’). These sites were located in close proximity to human settlements and shepherds’ huts (Bu), at lower elevations (El), and gentle slopes (Sl). All tree size (e.g. Dbh and He) and stand density (e.g. BA and CC) descriptors were positively associated with former ‘Dense Forests’. At higher elevations, corresponding to the former ‘Sparse Forests’, the dominance of larch both in the tree (T-Do) and the regeneration (R-Do) layers was strong.

#Figure 4 approximately here#

Starting from a conceptual model (Fig. 2), we tested alternative path models combining data from all four watersheds (n = 203 plots). The focus dependent variables were two synthetic descriptors of stand structure derived from a PCA: tree size (PC 1) and stand age (PC

2). Only one of the tested models was statistically significant (Fig. 5). The model included tree size as dependent variable and the positive interaction between anthropogenic influences (Proximity to buildings) and topographic factors (aspect; β = 0.11). Elevation was the most important predictor and was negatively associated with tree size (β = -0.34). A weak negative effect on the dependent variable was also observed for proximity to buildings (β = -0.13). A direct negative effect (β = -0.12) of aspect on tree size was slightly enhanced by indirect effects mediated by proximity to buildings (total effect β = -0.13).

#Figure 5 approximately here#

Discussion

Results of this study provide strong evidence that the anthropogenic disturbance regime in the central Alps remains an overriding factor for shaping the actual structure and composition at landscape and stand scales. The studied alpine valleys have a long history of human land use expressed mainly by grazing on mountain pastures and forests. The decline of these traditional practices has directly affected the present landscape pattern. In less accessible valleys the human impact was less intense and less frequent resulting in a landscape less prone to land cover changes.

The anthropogenic disturbance regime of our study sites was dominated by cattle grazing that was active every summer mainly in open pastures and secondarily within wood pastures. However, the intensity of historical human impact has differed among our study sites. VEG, DEV and MUS experienced a very intense land-use probably due to their more favorable topography, whereas VEN, which occupies a more marginal and less accessible valley, was less disturbed by human activities. These topographic differences are clearly reflected in our results for land cover change. Since 1954, all the studied landscapes have been characterized by increased forest cover and decreased open and semi-open habitats. VEN experienced a lower magnitude of this natural reforestation process, as well as less intense changes to landscape configuration overall.

Our findings on the expansion of forest cover in the subalpine belt are consistent with other recent studies on the Alps (Didier 2001; Dullinger et al. 2003; Gellrich et al. 2007; Tasser et al. 2007) where a decrease of heterogeneity was observed. However, landscape heterogeneity or diversity increased in our study sites, where new patches of trees expanded over abandoned pastures, balancing the opposing trend of canopy closure experienced by wood pastures. The observed small increase of landscape heterogeneity can also be explained by the fact that grazing is still active in at least three of our study sites (MUS, VEG and DEV), limiting the aggregation of existing forests. The general increase of complexity of the landscape mosaic can be explained by the reduction of large patches of former meadows and wood pastures and the establishment of new patches of forest.

Historical records such as population and livestock archival data are valuable sources of information for understanding reforestation patterns on abandoned land (Chauchard et al. 2007; Motta and Lingua 2005). These kinds of data were incomplete for our study sites; however a clear trend of grazing decline over the last 100 years was common to all watersheds. Tree recruitment and thus regeneration appears to be influenced by grazing pressure in that when the pressure is high regeneration is lacking and vice versa (Chauchard et al. 2007). Notwithstanding the damages caused by goats to tree regeneration, non-selective grazing by cattle is more destructive for tree regeneration than selective grazing by sheep and goats (Hester et al. 1996, Tasser et al. 2007). However, trampling by heavy animals like cattle can have a positive selective effect for certain tree species like larch that require exposed mineral soil for germination (Tasser et al. 2007). Extensive grazing is often necessary to maintain tree regeneration within subalpine wood pastures (Mayer et al. 2003; Schulze et al. 2007).

Previous studies on pre-industrial land use have shown that traditional practices such as grazing, tree felling and fire, singly or in combination, may have a great impact on current forest ecosystems when carried out for long time periods {Conedera, 2010 #3670} (Josefsson et al. 2010). Wood pasture and grazing land uses have strong species-specific consequences in that larch trees are less damaged than other species such as broadleaved trees. In addition, there are other traditional human practices (e.g. seedling removal, thinning, burning) that favored larch at the expense of other less desirable tree species such as stone pine (Motta and Lingua 2005; Motta et al. 2006). The forests of our study sites are almost pure larch forests with stone pine occasionally appearing in the regeneration layer, a clear consequence of the long and pervasive human impact on the species composition of these forests. An analysis of pollen data at VEG revealed that the colonization by larches and birches started ca. 7300 yr BP followed by the establishment of a mixed and open conifer forest with stone pine, mountain pine, Norway spruce and larch (Paganelli and Borgato 2000). Circa 2000 yr BP all evergreen conifers were removed, directly or as a consequence of fire and land use to favor a pure and sparse larch forest associated with extensive pastures {Carcaillet, 2009 #3078}.

Topographic variables and spatial proxies for the strength of anthropogenic influence were important predictors for stand structure. The highest regeneration densities were found at lower elevations and closer to shepherds' huts, where the former land use was pasture or wood pasture. Historical cattle grazing was commonly more intense on gentle slopes close to human settlements. Anthropogenic pressure on low elevation, accessible, and productive forests is generally strong (Castagneri et al. 2010). Denser stands with bigger trees were associated with formerly dense forests meaning that the portion of the landscape that covered by forests has remained almost the same. Elevation has been shown to be a key variable for forest increase elsewhere in the Alps (Kulakowski et al. 2011) where the greatest changes in forest structure have been observed close to the tree-line (Gehrig-Fasel et al. 2007). Kulakowski and others

(2011) indicated a hierarchical importance of multiple interacting factors: 1) the most important variable was elevation, 2) followed by land use expressed by abandonment, 3) then by suppression of natural avalanche disturbance, 4) and climate warming. Our findings generally confirmed this hierarchical classification of underlying gradients of forest changes in the Alps. In fact, our path models for all four study sites indicated elevation as the most important variable and human impact, expressed by proximity to buildings, as the second most important variable. The path model developed within the present research proved to be valid for our four alpine valleys, and may be broadly generalizable to large areas of the Italian Alps.

Our findings indicate that the anthropogenic disturbance regime and its alteration due to land abandonment are key factors for shaping forest and landscape structure. Structural changes in landscapes are ultimately determined by changes in anthropogenic disturbance regimes (Kulakowski et al. 2011), although the physical template and the socio-economic environment act as local constraints. The dramatic reduction of cultural landscapes in the Alps is important to consider from the point of view of sustainable management. Pastures and wood pastures can be maintained through the regulation of cattle densities only in those valleys (e.g. MUS, VEG, DEV) where these practices are still active (Garbarino et al. 2011). More remote and marginal valleys (e.g. VEN) can be considered as monitoring units that should be studied in order to predict future landscape change scenarios in a climate change context. ?? develop naturally towards mixed-multilayered forests?

The present structure and composition of larch forests must be considered in light of their historical context in order to accurately plan future management strategies. The understanding of past land use should be integrated into ecological models used to advise the management of biological reserves (Eberhardt et al. 2003; Gimmi et al. 2008). Reliable quantitative estimates of biomass output due to traditional forest uses provides the potential to incorporate these practices into ecological models and assess the impact on biogeochemical cycles and vegetation changes (Gimmi et al. 2008). Historical ecology can serve as a source of quantitative data on human pressure to inform ecosystem models for prediction of future scenarios of landscape change and species compositional shifts (Robinson et al. 2009; Tappeiner et al. 1998).

Habitat suitability models can be used to simulate or predict potential impacts of landscape changes on species habitats (Bolliger et al. 2007). For example, it would be interesting to use a species distribution modeling approach (Guisan and Zimmermann 2000; Hirzel and Le Lay 2008) for a species such as Swiss stone pine to compare potential habitat with current distribution, and so isolate the effects of historical land-use practices on current species distribution. Ultimately, this type of understanding is needed to model climate change response of tree species in the context of changing land-use practices in mountain forests and for the planning of the expected forest ecosystem services {Lindner, 2010 #3671}.

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Tables

Table 1 Summary statistics and characteristics of the four watersheds analyzed in this study. Total area is the total watershed surface, analyzed area is the portion (below 2400 m a.s.l.) of the watershed used in the landscape structure analyses, and forested area is the sum of 3 land cover categories (dense, sparse and grazed forests) in 2000 or 2003. The values within parenthesis under the precipitation column are elevations of meteorological stations.

Landscapes	Total Area (ha)	Analyzed Area (ha)	Forested Area (ha)	Elevation Mean (m a.s.l.)	Elevation Range (m a.s.l.)	Slope Mean (°)	Mean Annual precipitation (mm)
Veglia	4117	2505	515	2314	1496-3419	24	1520 (2240 m a.s.l.)
Devero	6674	4843	1092	2227	1412-3175	21	1626 (1840 m a.s.l.)
Musella	1151	787	412	2275	1650-3050	28	975 (1000 m a.s.l.)
Ventina	1123	468	132	2534	1651-3587	32	975 (1000 m a.s.l.)

Table 2 Classification accuracy (OA = Overall Accuracy, K = K statistic) obtained through confusion matrices (Lillesand and Kiefer 1994) of eight land cover maps derived from aerial photographs (sources).

Watershed	Year	Sources	Accuracy (OA)	Accuracy (K)
Veglia	1954	IGM G.A.I.	93	0.87
Veglia	2000	IT2000	89	0.82
Devero	1954	IGM G.A.I.	90	0.85
Devero	2000	IT2000	88	0.83
Musella	1961	IGM	80	0.75
Musella	2003	Sondrio P.	72	0.66
Ventina	1961	IGM	69	0.63
Ventina	2003	Sondrio P.	77	0.71

Table 3 Domestic livestock data (number of animals) in the four study areas in the 1901-2010 period. Missing data are expressed with a “-“.

		Veglia			Devero			Musella			Ventina	
Year	Cattle	Sheep	Goats	Cattle	Sheep	Goats	Cattle	Sheep	Goats	Cattle	Sheep	Goats
1901	-	-	-	-	-	-	200	0	150	24	50	30
1921	2299	900	95	802	500	35	-	-	-	-	-	-
1969	583	348	201	-	-	-	-	-	-	-	-	-
1979	798	600	500	-	-	-	47	0	20	29	0	0
1981	1148	1000	500	819	300	64	-	-	-	-	-	-
1982	860	-	-	-	-	-	-	-	-	-	-	-
1983	800	150	100	-	-	-	-	-	-	-	-	-
1986	-	-	-	416	122	51	-	-	-	-	-	-
1988	450	500	400	-	-	-	-	-	-	-	-	-
1989	200	-	-	-	-	-	-	-	-	-	-	-
1990	250	-	-	-	-	-	-	-	-	-	-	-
1991	228	66	-	371	4	89	-	-	-	-	-	-
1992	262	98	-	-	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	40	0	40	0	0	0
2003	229	-	-	333	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	85	0	0	0	0	0
2006	-	-	-	-	-	-	97	0	0	0	0	0
2007	-	-	-	-	-	-	68	0	0	0	0	0
2008	208	127	254	291	0	0	-	-	-	-	-	-
2009	284	138	224	257	0	0	-	-	-	-	-	-
2010	241	156	269	280	0	0	-	-	-	-	-	-

Table 4 Key landscape metrics (McGarigal and Marks, 1995) computed for the 4 watersheds at two periods (8 land cover maps).

Metrics (Units)	Musella (787 ha)		Ventina (468 ha)		Veglia (2505 ha)		Devero (4843 ha)	
	1961	2003	1961	2003	1954	2000	1954	2000
Patch Density (n/100ha)	12.2	20.4	4.6	4.4	10.7	12.4	8.5	9.2
Largest Patch Index (%)	11.1	16.3	36.2	34.6	27.9	23.5	15.9	10.6
Patch Area Mean (ha)	4.4	2.6	12.7	13.4	4.7	4.1	4.3	4.0
Edge Density (m/ha)	91.5	144.3	45.6	46.7	85.0	108.7	70.0	79.4
Landscape Shape Index	9.8	14.8	4.3	4.3	16.0	20.1	21.1	23.8
Shape Index Mean	2.4	2.6	2.1	2.3	2.4	2.9	2.5	2.9
Contagion Index (%)	53.4	56.2	69.1	70.1	62.5	59.2	59.4	56.5
Connectance Index (%)	3.4	2.4	11.4	7.7	1.5	1.7	0.9	0.8
Simpson’s Diversity Index	0.8	0.7	0.5	0.6	0.6	0.7	0.7	0.7

Table 5. Transition matrices showing land cover changes in the 4 study sites. Values are expressed in hectares and in percent (in parentheses) relative to the total area of the class in 1954 or 1961. The category ‘Bare soil and water’ was removed from the transition matrices.

Veglia 1954 to 2000	1	2	3	4	5	Total area
1 Dense Forest	62.55 (79%)	11.47 (15%)	0.00 (<1%)	1.63 (3%)	4.19 (6%)	79.82 (8%)
2 Sparse forest	28.87 (15%)	138.11 (68%)	8.75 (5%)	10.03 (5%)	18.94 (10%)	204.68 (21%)
3 Wood pasture	8.88 (8%)	48.94 (40%)	38.97 (32%)	3.47 (3%)	23.53 (20%)	123.78 (13%)
4 Shrubland	1.46 (2%)	47.95 (33%)	0.34 (<1%)	68.37 (48%)	27.28 (19%)	145.39 (15%)
5 Meadow	10.69 (3%)	90.93 (20%)	17.18 (4%)	52.40 (12%)	283.79 (63%)	454.97 (46%)
Total area	112.43 (12%)	337.38 (34%)	65.23 (7%)	135.89 (14%)	357.71 (36%)	1008.62 (100%)
Devero 1954 to 2000						
1 Dense Forest	114.06 (88%)	14.08 (11%)	0.76 (1%)	0.03 (<1%)	1.81 (2%)	130.72 (6%)
2 Sparse forest	68.89 (19%)	232.36 (64%)	18.64 (6%)	13.40 (4%)	32.03 (9%)	365.30 (16%)
3 Wood pasture	36.71 (13%)	125.55 (44%)	92.71 (32%)	9.89 (4%)	26.29 (10%)	291.12 (13%)
4 Shrubland	3.56 (1%)	101.38 (28%)	5.23 (2%)	175.13 (48%)	87.16 (24%)	372.44 (16%)
5 Meadow	29.13 (3%)	208.19 (17%)	40.68 (4%)	118.52 (10%)	838.21 (68%)	1234.71 (52%)
Total area	252.33 (11%)	681.54 (29%)	157.99 (7%)	316.94 (14%)	985.49 (42%)	2394.27 (100%)
Musella 1961 to 2003						
1 Dense Forest	104.48 (92%)	6.35 (6%)	2.20 (2%)	0.73 (<1%)	1.02 (<1%)	114.75 (24%)
2 Sparse forest	84.97 (49%)	74.94 (43%)	2.20 (2%)	2.32 (2%)	10.25 (6%)	174.66 (36%)
3 Wood pasture	61.64 (74%)	6.07 (8%)	13.8 (17%)	0.05 (<1%)	2.72 (4%)	84.27 (18%)
4 Shrubland	4.67 (13%)	13.71 (36%)	0.12 (<1%)	19.69 (52%)	0.00 (<1%)	38.17 (8%)
5 Meadow	14.33 (19%)	12.81 (17%)	9.93 (13%)	0.22 (<1%)	39.72 (52%)	76.99 (16%)
Total area	270.07 (56%)	113.85 (24%)	28.23 (6%)	22.99 (5%)	53.7 (11%)	488.82 (100%)
Ventina 1961 to 2003						
1 Dense Forest	46.91 (84%)	9.45 (17%)	0.07 (<1%)	0.00 (<1%)	0.00 (<1%)	56.42 (40%)
2 Sparse forest	15.27 (26%)	37.86 (63%)	0.00 (<1%)	6.86 (12%)	0.37 (<1%)	60.35 (42%)
3 Wood pasture	16.85 (93%)	0.44 (3%)	0.84 (5%)	0.00 (<1%)	0.00 (<1%)	18.12 (13%)
4 Shrubland	2.03 (35%)	0.82 (15%)	0.00 (<1%)	2.97 (52%)	0.00 (<1%)	5.81 (5%)
5 Meadow	0.02 (<1%)	1.09 (30%)	0.00 (<1%)	0.73 (20%)	1.87 (51%)	3.70 (3%)

Total area	81.06 (57%)	49.65 (35%)	0.9 (<1%)	10.56 (8%)	2.24 (2%)	144.39 (100%)

Table 6 Principal component loadings for the metrics on class level (McGarigal and Marks 1995). Bold font indicates the highest value for each metric.

Metrics (abbreviation)	PC1	PC2	PC3	PC4
Clumpiness Index (CLUMPY)	**0.347**	-0.220	0.150	-0.283
Edge Density (ED)	**-0.326**	-0.298	-0.098	-0.210
Patch Density (PD)	**-0.321**	-0.225	-0.191	-0.202
Core Area Index Mean (CAI_MN)	**0.310**	-0.191	0.183	0.077
Contiguity Index Mean (CONTIG_MN)	**0.306**	0.203	0.229	-0.166
Disjunct Core Area Density (DCAD)	-0.130	**-0.400**	-0.092	-0.133
Cohesion (COHESION)	-0.118	**-0.381**	0.367	0.182
Landscape Division Index (DIVISION)	0.108	**0.372**	0.291	0.065
Area mean (AREA_MN)	0.239	**-0.357**	0.242	0.254
Total class Area (CA)	-0.238	-0.053	**0.509**	-0.221
Landscape Shape Index (LSI)	-0.348	0.035	**0.378**	-0.046
Connectance (CONNECT)	0.117	-0.278	-0.168	**0.623**
Shape Index Mean (SHAPE_MN)	-0.295	0.096	0.337	**0.369**
Aggregation Index (AI)	0.320	-0.271	0.129	**-0.327**
Eigenvalue	*5.643*	*3.314*	*1.656*	*1.061*
% of variance	*40.3*	*23.7*	*11.8*	*7.6*
P (10000 Monte Carlo runs)	*0.0001*	*0.0001*	*ns*	*ns*

Table 7 Mean values and standard deviations (indicated in italics) of the 12 stand structure descriptors (Ri – number of trees/regeneration species, Do – proportion of larch trees/regeneration, De - number of trees/regeneration per hectare, Dbh – mean tree diameter at 130 cm, BA – basal area per hectare, He – mean trees/regeneration height, CC – percent canopy cover, Age – age estimation of the 3 largest-diameter larches) collected in the field in 203 circular plots at VEG, DEV, MUS and VEN sites.

	Descriptors	Landscapes							
		Veglia		Devero		Musella		Ventina	
Trees	Ri (n)	1.23	*0.47*	1.56	*0.73*	1.86	*0.52*	2.13	*0.88*
	Do (%)	0.96	*0.09*	0.85	*0.24*	0.56	*0.35*	0.82	*0.23*
	De (n/ha)	506.12	*270.68*	540.86	*363.80*	525.32	*226.44*	401.46	*289.72*
	Dbh (cm)	23.94	*13.39*	21.01	*12.47*	18.89	*11.25*	19.65	*12.94*
	BA (m^2/ha)	19.02	*13.31*	17.14	*13.91*	21.71	*14.76*	19.88	*20.66*
	He (m)	10.51	*3.42*	11.08	*3.62*	10.09	*4.14*	8.12	*3.49*
	CC (%)	33.57	*12.75*	33.48	*20.09*	48.75	*15.88*	36.80	*21.98*
	Age (yrs)	217.27	*153.82*	211.43	*132.50*	141.46	*53.33*	198.23	*126.15*
Regeneration	Ri (n)	1.02	*0.45*	1.29	*0.70*	1.43	*0.92*	1.83	*1.01*
	Do (%)	0.77	*0.40*	0.57	*0.45*	0.63	*0.41*	0.57	*0.36*
	De (n/ha)	683.77	*665.61*	359.56	*572.73*	361.82	*333.04*	212.35	*248.24*
	He (m)	1.04	*0.60*	1.12	*0.64*	0.97	*0.59*	1.06	*0.59*

Figure captions

Figure 1 Location of the four study areas (VEG = Veglia, DEV = Devero, MUS = Musella, VEN = Ventina) within the Alps and Piemonte and Lombardia regions.

Figure 2 Conceptual model tested for all the 4 study areas separately and as a whole through path analysis. Topographic and anthropogenic variables are included in the full model and associated through positive or negative causal path to "Stand structure" that refers to first and second principal components (PC1 and PC2) interpreted as tree size and absolute density respectively.

Figure 3 Principal component analysis of 4 land cover classes (D – dense forest, S – sparse forest, G – grazable forest, M – meadow) for 8 maps (4 landscapes, 2 periods). Rocks and shrubs classes are not shown to reduce the graphic complexity. Land cover classes are labeled according to sites (VEG: rhombus points; DEV: triangle points; VEN: square points; MUS: circular points) and periods (1954 and 1961: unfilled points; 2000 and 2003: filled points).

Figure 4 Redundancy analysis (RDA of 203 plots) of forest structure in relation to historical land uses (1954 and 1961) and environmental variables. Dashed arrows represent the stand structure variables (T-Do = relative dominance of larch trees; AGE = maximum age of trees; T-De = density of trees; T-He = trees height; BA = basal area; CC = canopy cover; Dbh-Me = average Dbh; Dbh-Sd = standard deviation of Dbh; R-Do = relative dominance of larch seedlings; R-De = regeneration density; R-Ri = regeneration richness). Full line arrows are the "biplot scores of environmental variables" (El = elevation; Sl = slope; As = aspect; Bu = proximity to buildings). Triangular dots are historical land uses classified by aerial photographs. The analysis emerged as significant ($p < 0.0001$, Monte Carlo test) with 10000 permutations under the full model.

Figure 5 Path diagram for the 4 study areas as a whole (203 plots). Continuous lines: positive paths; dotted lines: negative paths; single arrow lines: causal paths; double arrow lines:

covariance paths. Thickness of causal path vectors corresponds to the strength of effect. Only significant path coefficients are presented next to each path. Fit indices of the model are: RMEA (Root Mean Square Error of Approximation) < 0.001; AIC (Akaike's Information Criterion) = -2.365; P = 0.441; degrees of freedom = 2; ML ChiSq = 1.635.

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