A comprehensive insight into the geography of forest cover in Italy: Exploring the importance of socioeconomic local contexts

Abstract

Forest cover is intended as a key attribute of local socioeconomic systems influencing the spatial organization of any given region. Changes in forest cover are affected by joint biophysical and anthropogenic factors associated to urban-rural, coastal-inland and elevation gradients. This study investigates the relationship between socioeconomic structure and selected indicators of change over time in forest cover (2000-2012) on a fine-grained resolution scale in Italy. We assess the importance of socio-spatial structures and economic polarization in the geography of forest expansion and decline considering 145 indicators that evaluate jointly the economic, social and environmental sustainability of local contexts. Agriculture, income, education and labour market indicators discriminate contexts with high forest area and only low changes in forest cover from those with low forest area and moderate changes in forest cover. High forest cover in rural districts is spatially associated with depopulation, land abandonment, soil erosion, subsidence agriculture, unemployment and low educational levels. The highest rate of change in forest cover was observed in economically-dynamic and accessible local contexts with specific social and demographic profiles. Integrated environmental and socioeconomic policies for sustainable development are required to incorporate forest cover as a pivotal target variable and benefit from the understanding of the role of rural communities in forest management.

Keywords: Forest cover, Land-use change, Socioeconomic profile, Indicator, Municipality, Italy.

1. Introduction

Ecological disturbance caused by human-driven landscape transformations is the main cause of biodiversity loss, habitat fragmentation and land degradation (Zipperer, 2002; Foley et al., 2005; Blondel et al., 2010; Sirami et al., 2010). Therefore, assessing landscape characteristics and environmental quality plays a crucial role in natural resource planning and biodiversity conservation. Interest to landscape issues is common to geo-physical disciplines and social sciences. High-quality natural environments (e.g. forests, shrubland, pastures, wetlands) require renewed monitoring approaches based on their joint socioeconomic and landscape value. Approaches that concentrate on the role of local socioeconomic contexts are particularly needed to ascertain the dynamic patterns underlying complex socio-ecological systems (Safriel and Adeel, 2008; Raymond et al., 2009; Conrad and Cassar, 2014). Rural communities reflect the long-term interplay between humans and natural resources as a result of joint demographic, cultural, political and economic processes (Salvati and Carlucci, 2011). The role of feedbacks, thresholds, and synergies in complex socio-environmental systems is also a relatively well known issue with examples drawn from climate change, land-use, habitat fragmentation, desertification, soil and water pollution, among others.

The characteristics of local contexts and rural communities are important factors shaping forest landscape, from the stand level to compartment and landscape level (Konijnendijk et al., 2006; Zhang et al., 2010). Understanding the human-forest relations requires considering "economic behaviour in relation to social structures and processes as well as a necessary focus on the context-bounded and culturally rooted human actors' behaviour" (Schlüter and von Detten, 2011). Regional disparities, economic marginality, rural poverty and increased anthropogenic pressure on fragile land have been hypothesized to be decisive in the depletion of the forest resource base in both affluent and emerging countries (Blaikie and Brookfield, 1987; Boyce, 1994; Boardman et al. 2003; Iosifides and Politidis, 2005). However, although being an essential component in the analysis of drivers of change, only in few cases (Kelly et al. 2015) the spatial distribution of forest cover and the socioeconomic profile of local communities have jointly been studied using a truly holistic approach .

Forest Transition (FT) theory describes a process with divergent trends in forest cover (from decline to expansion of forest areas and vice versa) depending on place-specific socio-environmental conditions (Mather, 1992, 2004, 2007; Mather et al., 1998; Rudel et al., 2002; Klooster, 2003; Bray and Klepeis, 2005; Hecht et al., 2006; Meyfroidt and Lambin, 2008; Rudel, 2009; DeFries and Pandey, 2010; Yackulic et al., 2011; Redo et al., 2012; Gutiérrez Rodríguez and Ruiz Perez, 2013; He et al., 2014). Changes from net deforestation to net reforestation reflect the impact of economic factors at the regional scale, such as urbanization, population growth, crop intensification, learning and education level, governance quality and the level of environmental awareness (de Jong, 2009; Mather et al. 1998; Barbier et al. 2009; Pagnutti et al. 2013). The FT theory contributes to the understanding of long-term land-use changes *e.g.* in terms of land abandonment or biodiversity conservation, and informs policies that promote a sustainable management of forest land (Bajocco et al., 2012; Salvati et al., 2013; Ferrara et al., 2014; Otero et al., 2015).

The intimate connection between demographic transitions and forest transitions, particularly well studied in developing regions of the world, is relevant also in developed countries since it involves multiple dimensions that should be considered as synergic drivers of change. In wealthier regions, demographic changes impact forest management schemes influencing the provision of ecosystem services. Changes in the use of forest resources from productive aims to non-economic landscape or environmental functions (e.g. aesthetic, recreational, conservative) can be adapted to the local context only in a sufficiently long time interval based on a sustainable forest management and planning that takes into account the evolution of rural communities and land-use models as well as their understanding of forest management general context (Hajjar et al., 2014).

The decline in forest area is associated with a broad spectrum of social processes driven by industrialization and agricultural intensification (Meyfroidt and Lambin, 2011). By contrast, variable patterns have been associated with the increase in forest cover. Wealthier countries have generally shown turning points from decline to expansion of forest land in a time period encompassing the two World Wars and coinciding with rapid demographic changes (Rudel et al., 2002; Bray and Klepeis, 2005; Klooster, 2003; Baudelle and Olivier, 2006). These results confirm the intimate relationship between socio-demographic changes and forest transition in affluent countries.

Extensive land-use transformations impacting on natural ecosystems were observed during the last century in Europe (European Environment Agency, 2006; Hill et al., 2008; Xiao et al., 2013; Zhang et al., 2013; Lazarus, 2014; Santos et al., 2014) with multiple environmental and socioeconomic factors being implicated in this process. On the one hand, land-use changes determined the fragmentation, simplification and deterioration of natural landscapes, rather than deforestation *tout court* (Vince et al., 2005). On the other hand, urban expansion in metropolitan regions has determined a polarization in high and low-density areas, relegating large portions of the national territory to economic marginality, with unbalanced demographic structures and a stagnant economy. Natural forest expansion was observed in such districts since the 1980s (Mancino et al. 2014). Although the (natural or human-driven) increase in forest cover is generally considered a signal of improvements in environmental quality at large, this process requires carefully land planning especially in peri-urban areas and rural landscapes with medium population density and high accessibility. Knowledge of the socioeconomic factors most associated to forest dynamics is also strategic to identify correct policy interventions and economically-viable solutions for the sustainable management of forests in marginal contexts vulnerable to depopulation, land abandonment and soil erosion (Canadas and Novais, 2014).

Forest landscape in southern Europe is the result of multiple factors that interact over different spatial scales, exercing a dominant influence on the use of neighbouring land (Scarascia Mugnozza et al., 2000). Empirical studies confirm the importance of multiple source of data to understand changes in spatial structures and characteristics of forests heavily impacted by human activities (Motta and Edouard, 2005). Forest cover has influenced the socio-spatial profile of rural communities shaping the localization of agriculture and settlements (Antrop, 2005; Galeotti, 2007; European Environment Agency, 2010). Forest cover has been long influenced at the same time by human activities determining social disparities and economic polarization along the elevation gradient (Corbelle-Rico et al., 2012; Niedertscheider and Erb, 2014; Zitti et al., 2015). This complicates the assessment of forest expansion in rapidly evolving socio-ecological systems.

Ecological and anthropogenic processes were increasingly studied together to identify (apparent or latent) factors causing transformations in the Mediterranean forest landscape (Shiliang et al., 2014). Increasing attention is given to the role of forests at the urban-rural interface and along the elevation gradient, especially in coastal areas where human pressure is greater (Theobald, 2004; Galiana-Martin et al., 2011; Barbati et al., 2013). For example, forests in flat areas constitute an invaluable landscape, preserving biodiversity and forming a green infrastructure which contains urban expansion and mitigates the negative externalities of industrial and agricultural activities (Salvati and Sabbi, 2011).

In the light of the increasing concern about forest resources in Mediterranean Europe (European Environment Agency, 2010), attempts have been made over the last decades to classify forest landscapes according to the characteristics of local communities and the surrounding biophysical environment. In this sense, two approaches can be followed: (i) the assessment of the latent spatial relationship between forest indicators and a wide set of territorial indicators representing the local context in regions with long-established human-landscape interactions and (ii) the classification of local-scale spatial domains into homogeneous clusters based on forest indicators and socioeconomic profiling.

Based on these premises, the present study contributes to the assessment of population and land-use factors dealing with socio-demographic, economic and forest transitions in affluent countries. We explore the local-scale spatial complexity of the socio-environmental systems in Italy focusing on the long-term nexus between rural communities and forests. A multivariate analysis of contextual indicators profiling rural communities in six research dimensions (population, labour market, economy, quality of life, agriculture, environment) allowed us to investigate the changing local context at the base of complex socio-environmental systems undergoing socio-demographic and forest transitions.

We considered rural communities as an element shaping forest structure and short-term changes in forest cover (Iosifides and Politidis, 2005). Forest cover is thus regarded as the results of the long-term interplay between nature and humans and the recent landscape transformations are dependent on the (more or less rapid) evolution of local contexts. Complexity in the spatial distribution of forest cover in Italy and the peculiar relationship with agriculture and human settlements at the local scale make Italy an interesting case for investigating complex socio-environmental systems which reflect the millenary interaction between natural landscapes, cropping systems and rural communities (Antrop, 2005; Costantini et al., 2009; Zitti et al., 2015). Wood resources have been traditionally utilized since millennia and forests have been managed for a long-term in Italy, the country with the largest surface area of coppiced forests in Europe.

We implemented a data mining approach with the aim to identify the socioeconomic traits that discriminate Italian local communities in relation to a set of indicators assessing selected characteristics of forest landscapes in Italy. We have applied the forest monitoring approach proposed by Hansen et al. (2013) which provides indicators assessing forest cover and short-term forest loss and gain. The approach was based on the multidimensional analysis of 19 forest indicators and 145 context (biophysical and socioeconomic) indicators at the municipal scale. Administrative spatial domains allow for a comprehensive socioeconomic profile of local communities (Salvati and Carlucci, 2011).

2. Methodology

2.1. Study area

Italy covers 301,330 km^2 classified as 23% lowlands, 42% uplands and 35% mountainous land. Italy is characterized by disparities in environmental conditions (climate, vegetation, soils, agricultural systems) and socioeconomic variables (income, labour market, demography and socio-spatial structures). The 8101 Italian municipalities are the spatial domain considered in the present study as referring to the 2001 administrative asset. This choice allows for the effective matching with a number of indicators derived from official statistics at the local scale (Istat, 2006). The local governance system changed only moderately in 2014 with 8,094 municipalities administering the Italian territory. The use of municipalities and local districts as the elementary spatial domain in the analysis of land quality and socioeconomic profile of rural communities is proposed and discussed in Salvati and Zitti (2011). Despite criticisms concerning the use of administrative boundaries for assessing biophysical variables, these spatial units show appreciable features that fill the need for data integration in environmental, socio-demographic and economic fields (Salvati and Carlucci, 2011). Indeed, municipalities (i) address the local dimension of the social, demographic and economic processes, (ii) exploit data at an enough detailed spatial scale when analysing the impact of land quality on socio-spatial and production structures and (iii) allow identifying the most relevant geographical gradients supposed to have a role in the spatial organization of a given region.

2.2. Forest data

The primary data source we used is the forest map and related geo-referenced datasets produced by Hansen et al. (2013). Tree cover and forest loss and gain surface area for the time interval between 2000 and 2012 were mapped at a spatial resolution of 30 m considering vegetation > 5 m in height (Hansen et al. 2014). Forest gain (or loss) were respectively defined as the establishment of tree canopy from a non-forest state (or the removal of tree canopy from a forest state). Loss and gain were reported as a twelve-years total (2000-2012). Forest cover raster file (2000) represents the degree of tree cover ranging from 0% to 100% in 30 x 30 m spatial resolution.

The analysis was performed using Google Earth Engine which contains a nearly complete set of imagery from the Landsat 4, 5, 7 and 8 satellites made available from the USGS Earth Resources Observation and Science archive referring to the growing season. Automated Landsat pre-processing steps were developed to create a per-pixel set of cloud-free image observations which in turn was employed to calculate time-series spectral metrics facilitating regional-scale mapping. Training data to relate to the Landsat metrics have been derived from on-screen image interpretation with the aim to '*delineate change and no change training data for forest cover loss and gain'*. See Hansen et al. (2013) for further technical information and field validation. To verify the spatial coherence of Hansen and coworkers' map in our study area, a field survey based on 2000 random observation points has been carried out with the objective to check forest cover, loss and gain data using Corine Land Cover maps and interviews with local experts.

A total of 19 indicators were derived from the information included in the forest map described above and referring to the 2000 forest cover and the 2000-2012 forest gain/loss dynamics (SM. Table 1). The percent forest cover in the total municipal surface area is considered the most relevant indicator (For_Cov) in the collected dataset and was complemented with a standardized indicator assessing the size of each municipality (Sup_mun). Ten indicators were developed with the aim to assess the extent of defined classes of forest cover (1-10%, 11-20%, ..., 91-100%) in the municipal surface area (f1_10, ... f91_100). Forest cover intensity (For_int) was further calculated as the weighted average of the surface area of each forest class in every municipality. Diversity (Div) and evenness (Eve) in the spatial distribution of forest cover were calculated using Shannon (H') and Pielou (J) indexes at the municipal scale. Gain and loss in forest cover were finally calculated in each municipality as the percent area with forest gain or forest loss in both (i) the total forest area and (ii) the total municipal area, obtaining four indicators (gain_for, loss_for, gain_mun, loss_mun). A gain-to-loss indicator was finally calculated and mapped subtracting the surface area of forest loss to the surface area of forest gain in each municipality. Indicators were derived from the overlapping of the forest raster map with the shapefile representing the boundaries of the Italian municipalities (disseminated by ISTAT) on the basis of the 'zonal statistics' tool provided with the ArcGIS package (ESRI Inc, Redwoods, USA) which computes a surface-weighted average of each variable's values belonging to the *i*-th spatial domain.

2.3. Contextual indicators

The variables considered in the present study (SM. Table 2) were made available from official statistics (mainly from the Italian National Statistical Institute, Istat) and refer to 2000 or 2001. These years represent the most recent point in time with an enough large availability of socioeconomic indicators on a municipal scale in Italy (Istat, 2006). The limited availability of some variables in the most recent census wave, modifications in census techniques, and late dissemination for some other variables have prevented collecting a comparable dataset referring to the most recent time interval. At the same time, working with 2000/2001 data allows a direct match with soil data mainly collected along the 1990s and forming the primary informative base for the land quality indicators (Salvati et al. 2011). For each Italian municipality a total of 145 indicators have been computed from the collected variables and classified into six research dimensions (Population: 24 indicators, Labour market: 20, Economy: 23, Quality of life: 18, Agriculture: 34, Environment: 30) and 17 themes (settlement characteristics, population dynamics and structure, job market, education, economic structure, tourism, income, wealth, crime, land tenure, agricultural landscape, innovation and quality in agriculture, human capital in agriculture, water use and management, land resources and territory, soil quality and degradation). Indicators have been selected according to Sabbi and Salvati (2014).

2.4. Statistical analysis

An exploratory data analysis framework was developed in the present paper incorporating Principal Component Analysis (PCA), non-parametric correlations, non-hierarchical clustering and discriminant analysis. PCA was run separately on the data matrices composed respectively by 18 Forest (F) indicators (the percent forest cover is taken as supplementary variable) and 145 Context (C) indicators both collected for the 8101 municipalities in Italy. The former PCA is aimed at summarizing few dimensions based on a restricted number of forest dynamic indicators (cover, composition, structure, loss and gain). The latter PCA is aimed at summarizing a small number of axes with key indicators profiling local communities from the socioeconomic and territorial point of view. Based on the number of input variables, components with eigenvalue > 2 and > 4 were selected respectively in the PCA run on F and C matrices. Component loading and score plots have been produced to illustrate the main results of the analysis. The scores of the principal components run on the matrices 'F' and 'C' were correlated pair-wise using Spearman non-parametric coefficients and testing for significant correlations at $p < 0.05$ after Bonferroni's correction for multiple comparisons.

A non hierarchical clustering (using the *k*-means computation strategy) was run on the forest indicators matrix (by including the percent forest cover as active indicator) with the aim to classify Italian municipalities into homogeneous partitions. Following the parsimony criterion, the analysis was carried out for a set of solutions (cluster numbers) ranging from 2 to 10 (the highest number of cluster partitions considered appropriate for illustrating the characteristics of forests in the study area). The most efficient cluster partition was identified by using pseudo F statistic and the Cubic Clustering Criterion as diagnostic statistics (Salvati and Zitti, 2009). Based on cluster membership, each k-means group of municipalities was profiled using the average values of the 145 contextual indicators. To allow comparison among different research dimensions, indicators were standardized using (z) scores indicating (positive or negative) deviations from each indicator average. A Discriminant Function Analysis (DFA) was finally run to identify the contextual indicators with the highest contribution in discriminating among the selected clusters. Six models were estimated separately using forward stepwise linear DFAs based on the six research dimensions described in the paragraph 2.3 (population, labour market, economy, quality of life, agriculture, environment). Standardized indicators entered each model according to the results of a F test with $p < 0.01$.

3. Results

3.1. Descriptive statistics

Figure 1 represents the spatial distribution of percent forest cover and gain-loss index in Italy. Forest cover follows the elevation gradient being higher along the Alps and Apennines and in restricted portions of Sicily and Sardinia. Areas with < 10% forest cover in the total municipal area are concentrated in the Po valley (northern Italy), along the Adriatic coast (central Italy) and in flat or coastal areas of southern Sicily and Sardinia. The spatial distribution of the gain-loss index between 2000 and 2012 is more heterogeneous with highly positive values (gain-loss > 1% in the municipal surface) observed in sparse municipalities especially in central and southern Italy. Moderately positive values of the gain-loss index (0% - 1%) are observed primarily in the eastern side of the Po plain (northern Italy), along the Apennines (central and southern Italy) and in internal areas of Sicily and Sardinia. The relationship between percent forest cover and gain-loss index is negative and linear (Spearman $r_s = -0.27$, Pearson $r = -0.26$, both comparisons: $p < 0.001$ and $n = 8101$). Forest gains are more frequently observed in areas with low forest cover and the reverse applies for forest losses.

3.2. Principal Component Analysis

The PCA run on forest indicators extracted three axes with 70% cumulative variance (Table 1: PCA loadings and Figure 2: PCA scores). PCA discriminates forest structural indicators (Component 1 and 2) from indicators assessing short-term changes in forest cover (Component 3). Component 1 (PC1, 43%) is formed by indicators assessing intensity (for_int) and diversity (Div and Eve) in forest cover (from f1_10 to f91_100). Scores of PC1 well illustrate the elevation gradient in Italy (positive scores associated to mountain municipalities with high forest cover). Component 2 (PC2, 16%) illustrates the divergent spatial localization of low-density forest classes (from 1% to 40% cover) and high-density classes (from 81% to 100%). Positive scores were associated to rural areas with moderate-low forest cover (< 40%), discontinuous forest patches and high fragmentation of natural landscape concentrated in southern Italy (eastern Sardinia, eastern Sicily, Apulia and part of Calabria). Negative scores are found in northern and central Italy mountain areas with high forest cover (> 80%) and homogeneous natural landscape (northern Apennines, Lombardy and Trentino-Alto Adige Alps, southern Apennines). Percent forest cover is correlated positively to PC1 and negatively to PC2. Component 3 (PC3, 11%) attributes positive and high loadings to the four indicators of changes (2000-2012) in forest cover (loss_mun, gain_mun, loss_for, gain_for). Positive scores highlight municipalities with high short-term gains (or losses) in forest cover which are sparse across Italy in both mountain and flat districts.

The PCA run on context indicators extracted six axes explaining 37% of the total variance. A total of 52 indicators out of 145 (35.9%) are correlated with at least one principal component (population: 8 indicators (33%), labour market: 11 indicators (11%), economy: 6 indicators (26%), quality of life: 9 indicators (50%), agriculture: 9 indicators (27%), environment: 9 indicators (30%)). Component 1 (13%) is correlated with 25 indicators mainly from the labour market and quality of life dimensions and illustrates the opposition between areas with high participation to the job market and districts with high unemployment rate. The former areas are characterized by population growth, high per-capita income and a moderately-high sustainable development index and are concentrated in northern Italy (Lombardy, Emilia Romagna, Veneto) and in scattered districts of central Italy (Tuscany, Marche, Rome metropolitan region).

The latter districts are characterized by population aging, youth unemployment and high proportion of workers in the public sector and are situated mainly in southern Italy (Figure 2).

Component 2 (10%) is correlated with 18 indicators assessing primarily population, agriculture and environment dimensions. The component well illustrates the elevation gradient in Italy with positive scores associated to flat municipalities with higher land quality, crop intensity, a dynamic population (families with > 3 components) and high crime intensity, among others. Mountain municipalities received negative scores and are characterized by population aging and higher proportion of vacation houses, hotels and restaurants, water reservoirs, soil organic carbon content and pastures/meadows in the natural landscape. Flat areas are more sensitive to land degradation risk while mountain areas are more vulnerable to landslide risk. Component 3 (5%) is correlated with 2 indicators (dwelling size and average value of bank deposits per capita) and illustrates the urban-to-rural gradient in Italy. Positive scores are associated to urban municipalities with compact settlements (low dwelling size) and wealthier population (high value of bank deposits). higher land quality, crop intensity, a dynamic population (families with > 3 components). Component 4 (4%) illustrates a more subtle division between economically-dynamic rural areas (characterized by negative scores and higher loadings to the population with secondary education and families with children) and economically-marginal rural areas (characterized by positive scores and higher loadings to elderly indexes). Component 5 (3%) identifies agricultural districts specialized in tree crop, especially vineyard, with high-quality productions and small farms (as indicated by the index of farm marginalization). Component 6 (2%) indicates municipalities with a high proportion of utilized agricultural area in the total municipal area.

3.3. Correlation analysis

A non-parametric Spearman analysis was run to identify significant pair-wise correlations between forest and context principal component scores (Table 3). Forest component 1 indicating high forest cover was correlated negatively with context component 1 (wealth gradient) and component 2 (elevation gradient) and positively with context components 3 (urban-rural gradient) and 5 (high-quality agricultural productions, mainly wine). Forest component 2 (low and discontinuous forest cover) was positively correlated with context components 2 and 4 (disadvantaged rural districts). Forest component 3 (gain/loss dynamic) was positively correlated with context components 4 and 6 (agricultural districts). Taken together, these results indicate that municipalities with continuous high forest cover are situated (i) in mountain districts with an economic structure dominated by tourism, a demographic structure moving towards aging, medium-high unemployment rate, land abandonment, natural non-forest landscapes dominated by pastures and meadows and in (ii) upland areas with high-quality cropping systems dominated by tree crop. Municipalities with low and discontinuous forest cover are mainly situated in flat, coastal and peri-urban areas, characterized by population growth and a dynamic economic structure. Municipalities with high forest gains or losses (2000-2012) are situated in rural districts with high proportion of utilized agricultural area.

3.4. K-means clustering

Non hierarchical clustering classified Italian municipalities in four homogeneous groups (Table 4) with variable size (from 1378 municipalities in cluster 1 to 3067 municipalities in cluster 4) forming a gradient of forest cover from cluster 1 (on average 81%) to cluster 4 (9%). Cluster 1 municipalities are concentrated along the mountain chains of Alps and Apennines (Figure 3). Cluster 4 municipalities are mainly situated in flat areas along the Po valley, the Adriatic coast from Marche to Apulia and in southern Sicily. Clusters with intermediate forest cover (cluster 2: 60% and cluster 3: 36%) show a more heterogeneous spatial distribution and concentrate in central Italy (Tuscany, Umbria) and southern Italy (Campania, Basilicata), representing rural districts with mixed natural landscapes and high-quality crop mosaics. Areas with forest loss are higher than areas with forest gains in clusters 1, 2 and 3 and the reverse pattern was observed for cluster 4.

A comprehensive profile of the four clusters based on context indicators is provided in Figure 4 using standardized scores for each indicator by research dimension. Demographic, economic, agricultural and environmental indicators clearly highlight the spatial divergence between clusters 1 and 4, outlining the intermediate position of both clusters 2 and 3 at the same time. Taken together, labour market and quality of life indicators are less discriminant among clusters, apart from single indicators (e.g. unemployment rate, crime rate). The contribution of individual indicators in the overall discrimination among clusters is studied through a linear discriminant analysis.

3.5. Discriminant analysis

Results of the step-wise discriminant analysis run on k-means clusters as a-priori groups are reported in Table 5 separately for the six research dimensions. Among population variables, the indicators with the highest discriminant power among clusters are the proportion of non-occupied houses, dwelling size, the percentage of people working and residing in the same municipality, population density, the percentage of recent dwellings, population residing in compact settlements and in urban nuclei and the percentage of families with children. Among labour market variables, the indicators with the highest discriminant power among clusters are the proportion of employees in total workers, participation rate, and the percentages of literate/illiterate population and of population with tertiary and primary education.

Among economic variables, the indicators with the highest discriminant power among clusters are the ratio of resident population to stores, the density of workers, and the percentages of workers in manufacturing, commerce, informatics, renting and real estate sectors, financial, insurance and banking sectors, and in the primary sector. Among quality of life variables, the indicators with the highest discriminant power among clusters are crime intensity, work accidents, per capita consumption rate and the subscriptions to TV channels.

Among agricultural variables, the indicators with the highest discriminant power are those assessing rural development, socio-spatial attributes of local communities and traditional agronomic practices/cropping systems (the percentages of agricultural utilized area and of arable and perennial crop, agricultural landscape diversity, irrigated land, the proportion of farmholders and employees in the primary sector, crop with designation of local origin, family farms, intensive/extensive farms and farm size distribution). Among environmental variables, the indicators with the highest discriminant power are those assessing the vulnerability of land to defined soil/land degradation processes (such as landslides, desertification, erosion, compaction, wildland fires) or those evaluating soil attributes and quality (soil organic carbon content, soil pH, land suitability to cropping). Elevation and latitude are also important variables discriminating among clusters.

4. Discussion

Monitoring the expansion (or decline) of forest land using remote sensing is an important tool to identify natural forest dynamics and to inform environmental policies aimed at conserving high-quality landscapes (Minchella et al. 2009; Vacchiano et al. 2012; Borrelli et al. 2014; Mancino et al. 2014; Nolè et al. 2013). Quantitative frameworks have been also proposed to monitor forests using landscape metrics and to assess environmental quality of a given area through field (or remotely sensed) vegetation data and land-use maps (e.g. Grignetti et al. 1997; Minchella et al. 2009; Borrelli et al. 2014). The use of such data to compile indicators useful for evaluating structure and composition of forest cover is widely accepted in the fields of nature conservation and land-use planning (Mancino et al. 2014). However, integrating landscape analysis with land management and socioeconomic variables contributes to decision- making (Munafò et al. 2010). It is widely recognized that the global knowledge of forest dynamics may benefit from the integration of ecological, political, cultural and socioeconomic issues operating at different spatial scales, from regional to local (Rudel et al. 2005).

Evidence collected in the present study outline the complex relationship between representative socioeconomic indicators characterizing local communities and the environmental features of Italian land (Salvati et al. 2013; Kelly et al. 2015). Changes in the socioeconomic context influenced the spatial distribution of low- and high- cover forest classes and the gain-loss ratio in forest cover (2000-2012). Elevation and latitude were identified as the biophysical gradients most associated to the spatial distribution of forest cover in Italy. K-means clustering indicates distinct forest structures irrespective of species composition: continuous high forest stands with percent cover above 70% indicating high tree density and low patch fragmentation and more sparse woodlands with percent cover below 30% embedded in natural matrices (e.g. pastures, meadows, wetlands), crop mosaics or the urban-rural interface and sometimes utilized for agro-forestry purposes. Forest gain and loss rates are found not dependent from forest cover. Forest loss is moderately high in peri-urban districts and flat agricultural areas with intensive cropping systems and high human pressure. The highest forest gains are mainly observed in mountain municipalities or in economically-marginal areas in central/southern Italy. High gain rates are also observed in restricted lowland areas in northern Italy possibly due to the expansion of agro-forestry crop along the Po valley. However, the significant relationship observed at the urban-rural interface in central Italy and indicating that percent forest loss increases more than proportionally with the percent forest cover is not confirmed at the country scale (Salvati et al. 2015). The relationship between 2000-2012 percent gain in forest area and 2000 percent forest cover confirms this preliminary result. Dense forest classes (71%-100%) have experienced the highest loss and gain rates. The lowest loss and gain rates were observed for sparse woodland (1%-30% tree cover). Losses overpassed gains especially for moderately dense classes (31%-70%) possibly indicating forest landscapes exposed to higher disturbances. Taken together, these results indicate short-term forest dynamics with more evident gains in forest districts or rural districts with isolated but well conserved woods than in peri-urban districts with high human pressure and isolated tree patches. This directly reflects the management options adopted in specific areas. Local management plans requires an improved knowledge of the local socioeconomic context with the objective to develop multi-scale and top-down forest planning schemes (e.g. from municipal to regional plans), considering place-specific socioeconomic factors in forest land management at wider levels. The spatial variability in the gain-to-loss ratio may indicate the role of socioeconomic factors of forest expansion (or degradation) at the local scale.

Both regional socioeconomic structures and local communities depend on the interplay of environmental, cultural and political attributes (Antrop, 2005). Although development studies have evaluated the importance of forest land as a production factor, there is further scope for exploring the influence the socio-spatial structure of a given region has on forest distribution and structure using comparative and spatially disaggregated approaches (Forino et al. 2015).

The framework proposed in this study is suitable to assess the multifaceted spatial relationships between socioeconomic factors and biophysical conditions underlying forest cover in Italy. While correlation does not necessarily imply causation, multivariate and non-parametric statistical techniques contribute to identify non-linear, latent relationships reflecting the complexity of socio-environmental local systems (Zitti et al. 2015). The novelty of this study lies in the use of a homogeneous indicators' set at the country scale investigating complex dynamics at a disaggregated geographical level. The indicators selected have provided a quite comprehensive profile of the socioeconomic, cultural, political and territorial structure of Italian municipalities and may be considered as the information base of geographical systems supporting integrated policy decisions (Boardman et al. 2003; Zuindeau, 2007; Imeson, 2012).

Results of this study also provide information to design more effective responses to protect high-quality forests and priority natural landscapes (Briassoulis, 2011). While protecting forests and the surrounding natural habitats is a priority target for sustainable land management, specific spatial planning measures are needed to preserve and re-connect woodland, pastures and wetlands embedded in crop mosaics. Single-target measures aimed at preserving high-quality forests should be better integrated into a spatial planning 'vision' aimed at designing more effective strategies for the 'natural landscape' where forests are an important - but not unique - component. The notion of 'polycentric forests' protection, intended as a set of measures preserving habitat connectivity and promoting green corridors formed by crop mosaics and semi-natural areas, is relevant in this perspective. High forests may represent the less disturbed patches forming the core areas of a given polycentric network of forest-natural patches. A strategy (i) improving the ecosystem functionality of pristine stands, (ii) maintaining the aesthetic and recreational value of most accessible stands and, finally, (iii) preserving isolated wood fragments, may complement the actions previously described. Finally, measures controlling the unwanted expansion of forest land at the expense of abandoned cropland are considered important to preserve the traditional diversity of agro-forest mosaics.

5. Conclusions

The present study proposes an exploratory data analysis of a wide set of forest and contextual indicators with the objective of identifying the main characteristics of local communities more associated to specific profiles of forest cover and structure. A multidimensional approach proved to be suited to grasp the interconnection between the different components of socio-environmental systems. Our results outline the spatial pattern in selected local contexts and the latent relationship with indicators assessing forest distribution, structure and expansion, highlighting the importance of integrated assessment for sustainable management of forest land. A thorough environmental monitoring integrated with a diachronic socioeconomic analysis provides the necessary information to support specific policy and management options for preserving high-quality forest landscapes in ecologically-sensitive areas.

6. References

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