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Land-use modifications and ecological implications over the past 160 years in the central Apennine mountains

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Abstract

Today's Mediterranean landscapes result from the interaction between ecosystems and anthropogenic activities. This study aims to assess how the land-use changes between the mid-nineteenth and end of the twentieth century influenced the temporal continuity of the ecosystems in central Apennines (central Italy). Information was acquired from Gregorian cadaster maps, orthophotos and aerial photos (1850, 1954, 1980 and 2010), digitized and georeferenced using QGIS 3.10.1 software. Marked changes in land-use types were found. From 1850 to 1954, grasslands were widely transformed into arable lands, but in the next 60 years changed again into new grasslands and forests. Forests underwent a slow but continuous expansion from 1850 to 2010. Only a small percentage of the forest and grassland patches (14 and 16 percent, respectively) have seen ecological continuity. These considerations call attention to temporal continuity of ecosystems, together with the historical dynamism of landscapes, in defining land management and nature conservation policies.

Keywords

Past land-use, historical legacy, ecosystem stability, Mediterranean landscapes, biodiversity, natural vegetation modification

1. Introduction

Biotic responses to disturbance are time- and space-dependent (Vegas-Vilarrúbia et al., 2011) and the effects of natural and human disturbances on ecosystems may appear after a long time (Rajendra et al., 2014). Growing attention is dedicated to historical human impact on nature (Lewis & Maslin, 2015), including the interferences with ecosystem dynamics (Mercuri et al., 2015). From this point of view, Mediterranean landscapes are the result of the complex interaction between ecosystems and very old, multifaceted, anthropogenic activities (Thompson, 2005; Munteanu et al., 2015). They are characterized by a fine-scale mosaic resulting from topographic and climatic variability (Cowling et al., 1996), causing complex spatial and temporal heterogeneity of resources (e.g. water availability, soil fertility). Such heterogeneity drives the type and intensities of anthropogenic disturbances (e.g. agriculture, grazing and forestry - Naveh, 1994) forming a “cultural landscape” (*sensu* Antrop, 2005), crucial in making these ecosystems one of the world’s biodiversity hotspots (Myers et al., 2000).

Only a small portion of the Mediterranean regions have not been manipulated or “redesigned” by humans over the last ten millennia (Agnoletti et al., 2013; Mercuri, 2014). Anthropogenic processes resulted in the superimposition of a series of land-use practices on the landscape, reflecting the socio-political fluctuations through time (Dupouey et al., 2002). Even if reorganization of new plant communities may be rapid, the legacy of the ecosystem managements adopted by earlier societies continue to influence ecosystem services for long periods (Mensing et al., 2018).

Knowledge of previous land-uses is fundamental for the interpretation of today's ecological features of landscapes (Moreno, 2001; Nordén et al., 2014). In fact, literature aimed at assessing the variation of land-use in the last century has been broadly developed (Plieninger et al., 2016). However, when planning for biodiversity conservation, information concerning the effects of past management on the natural biotas and ecosystems’ properties is also needed (Marignani et al., 2017). Such information might represent a critical element in understanding biodiversity patterns (Keitt, 2009) and in defining management directions and conservation policies (Pressey, 2007). However, studies aimed at investigating the spatial and temporal continuity of ecosystems are inexplicably not common (Nordén et al., 2014).

With reference to the central Apennines, several hints indicate that the plant communities observed today are the result of a strong dynamism of the landscape. Therefore, we hypothesised that only a small portion of land-use types observed today showed temporal continuity.

To test this hypothesis, we assessed the land-use variations which occurred in the last 160 years in a portion of the mountain belt of the central Apennines (central Italy). The objective was to determine whether such variations occurred in a linear way (e.g. from cultivated land to abandoned landscapes) or in a more complex way. Furthermore, we wanted to quantify how much land-use cover over time remained stable.

The historical context

In the Umbria-Marche Apennines (central Italy), research not yet published (see http1) demonstrated the presence of hunter-gatherer populations 11,000 years ago. The first stable settlements date back 7,000-5,000 years ago (Boccanera, 1976) causing the first modifications of the landscape through slash and burn practices, and creating small, not permanent, open areas within the forest (Vannière et al., 2008; Küster, 2019).

Transhumance (*sensu* Lietchi & Biber, 2016) dates to the first millennium B.C. (Brown et al., 2013) after the Osco-Umbrian populations (composite ethnic group originating from Eastern Europe, predecessors of the Piceni, Umbri, Sabelli, and originators of the non-Latin language of central Italy) entered the Italian peninsula and settled along the central Apennine ridge (Villar, 1997). Transhumance has seen intensification over time, with the progressive expansion of open areas and roads, to facilitate the movements of herds across the mountains (Fiecconi et al., 1996). Notwithstanding such alterations, during the expansion of the Umbri and Piceni cultures at first (500-100 B.C.), and later of the Roman civilization, the mountain ecosystem matrix remained substantially dominated by wide forests (Marignani et al., 2017).

After the dissolution of the Roman Empire, and the Gothic Wars (535-554 B.C.), medieval writers recount a period of reforestation along with the abandonment of settlements (Hemphill, 1988).

During the Middle Ages and Renaissance, utilization of natural resources started to undergo fluctuations, mainly related to the climatic, historical, and demographic characteristics of each period and area. For example, the Lombards placed a greater value on the production of livestock promoting the expansion of oak trees (La Rocca, 2002; Wickham, 1994), which was also favoured by the occurrence of a warm and dry period (Mensing et al., 2018). During these periods, the re-conversion from open area to forest was quite rapid (Mensing et al., 2018). Depopulation and changes in socio-economic characteristics also affected animal breeding, decreasing shepherding activities and the grazing pressure on pastures (Di Stefano, 1984, 1988).

Starting from the late Renaissance period, the land-use of the central Apennines was based on small villages functioning as closed organizations of permanent residents. These areas were characterized by collective agricultural fields, multi-functional forests and grasslands systems all around the village, serving as a public asset (Gobbi, 2003). This organization is likely to have produced a low environmental impact on the natural resources, which had to be preserved as much as possible, since this type of economy was without substantial external commercial exchanges (Gobbi, 2003).

During the second half of the nineteenth century and the first half of the twentieth century, the population of Italy increased from 22,000,000 to 47,000,000 inhabitants (Del Panta & Detti, 2019). The result was the reduction of forests and destruction of pastures, both replaced by arable lands (Sansa, 2003). In the mountain areas, because of the strong population increase, the loss of soil was so intense that several croplands were used as "*maggese*" (Bocchi, 2015), that is the

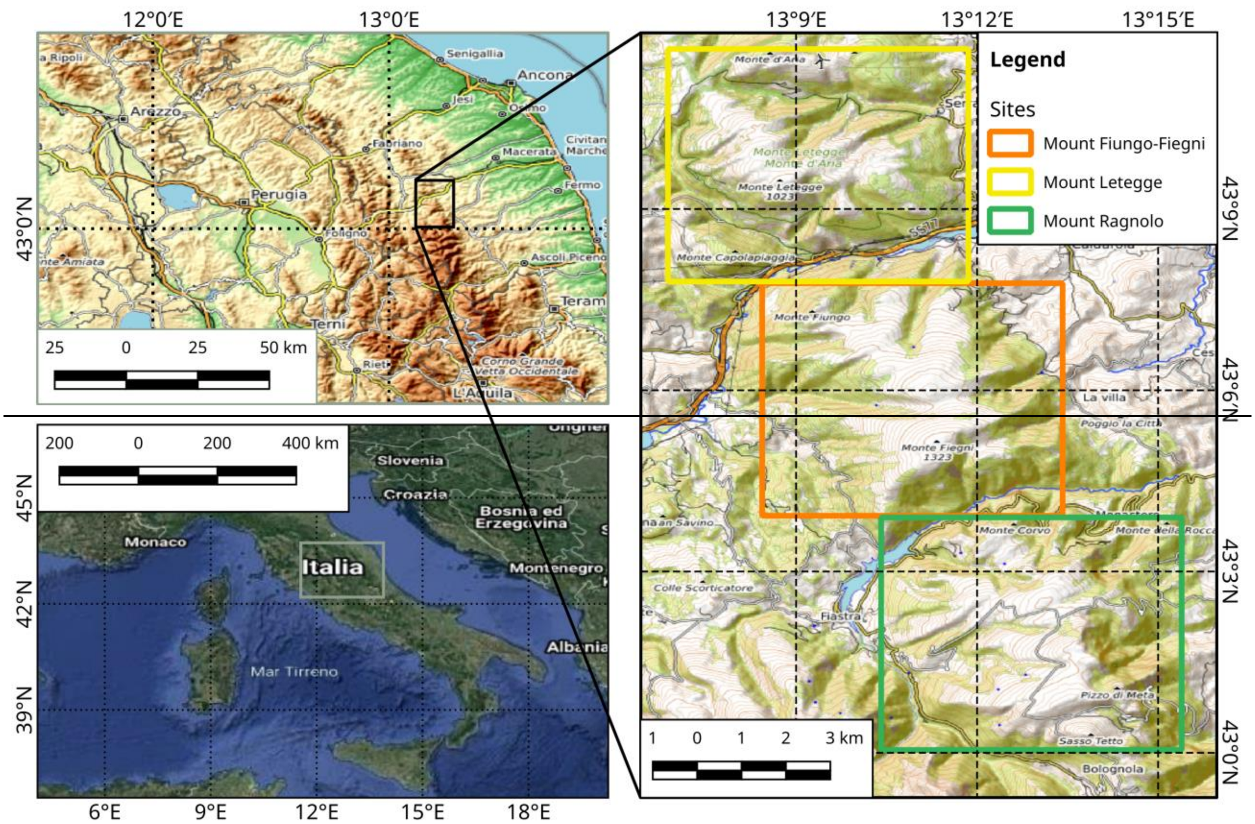
alternating one or two years with ploughing and sowing followed by four or five years of abandonment and used as pastures.
Finally, the socio-economic changes following World War II produced a new drastic depopulation of the Mediterranean mountains (Catsadorakis, 2007), with the migration of young families to new industrial centres and large metropolitan areas. As a result, open areas were abandoned and started to follow secondary succession finally leading to forest expansion (MacDonald et al., 2000; Bracchetti et al., 2012).

2. Methods

2.1. Study area

The study area extends over 7900 ha, altitudes ranging from 500 to 1600 m a.s.l. along the Umbria-Marche Apennine ridge, divided by the Rivers Chienti and Fiastrone. Since our aim was to assess changes of the landscape of the study area (excluding foothills and valley floor areas), we divided the overall area into three sub-areas representative of the whole mountain territory (Fig. 1, WGS84 coordinates: Mount Letegge 13.153° E, 43.160° N; Mount Fiegni 13.187° E, 43.101° N; Mount Ragnolo 13.209° E, 43.030° N).

Figure 1: Sub-study areas in the Umbria-Marche Apennine region (Mount Letegge, Mount Fiegni, Mount Ragnolo; Base source layers obtained through Google Hybrid and OpenTopoMap)



The study area is characterised by calcareous lithotypes (Regione Marche, 1996-2003) and distinguished by steep slopes, cut by deep valleys, and summits with gentle slopes. The soils follow a sequence, called “catena” (Rodolfy & Cremaschi, 1991), characterised by gradual changes distinguished by progressively less evolved and shallow soils across the different morphologies, going from lithic haplustoll/xerorthent soils on steep slopes, lithic/typic haploxeroll/haplustoll soils on gentle slope, and finally fluventic haploxeroll/hapsustoll soils in bottom (Pieruccini, 2007).
This area, located on the border between the Mediterranean and Temperate regions, is characterized by a bioclimatic variant of the Mediterranean climate, where winter-cold stress and summer-drought stress alternate with different intensities (Somot et al., 2008; Martínez, 2007).
The landscape that nowadays characterises the central Apennines is a complex mosaic of ecosystems, composed of several different plant communities (Malavasi et al., 2018). In general, the summits of the mountains are covered by grasslands and meadows with a varying species composition related to altitude, aspect and slope angle (Catorci & Orsomando, 2001). In the intermediate sectors, there are coppiced broad-leaved woods or, over 1,000 m a.s.l., high *Fagus sylvatica*-dominated communities. Both grasslands and woods are frequently interrupted by scrublands. At the foot of the slopes, arable lands to produce forage for livestock or cereals) are still present. These systems are alternated by ancient villages, representing a vanishing landscape caused by the abandonment of rural settlement and farms.

2.2. Data sources and elaboration

For each of the three sub-areas, data was gathered from the following data sources, referred to year 1850, 1954, 1980, and 2010**:**
1850 - the Gregorian cadastral maps of the Papal State were used (preserved in the state archive - Macerata). Topographic references were limited to the peaks of the mountains, rivers, and urban settlements. Photostatic copies of the cadastral maps were made, which were scanned, geo-referenced using the topographic references as ground control points and digitized using QGIS software version 3.10.1 (QGIS Development Team). Around fourteen-thousands parcels from the registry of the Gregorian Cadastre were acquired. See below for details about the digitization process.

1954 - black/white non-rectified aerial photographs preserved by the Italian Aeronautic Group of the Italian Military Geographic Institute (IGMI-GAI) https://www.igmi.org/en/descrizione-prodotti/aerial-photography/black-and-white-or-colour-aerial-photographs.

1980 - Marche Region Technical Maps and regional orthophotos (1:10.000 scale) (rectified coloured aerial photographs in mosaics), produced and owned by Marche Region **-** http://wms.cartografia.marche.it/geoserver/CTR/wms,
http://wms.cartografia.marche.it/geoserver/Ortofoto/wms.

2010 - coloured rectified digital aerial photographs produced and owned by AGEA (Italian Agency for the Provisions in the Agricultural Sector) and made available through Marche Region - https://geodati.gov.it/geoportale/visualizzazione-metadati/scheda-metadati/?uuid=m_amte:299FN3:eda6494c-b619-441a-a2d7-4097f8cde540.

All the geographic data processes described below have been carried out using QGIS software version 3.10.1 (QGIS Development Team), according to the land-use classes described in Table 1. The cadastral maps (1850) were visually interpreted whereas the aerial photographs (1950, 1980, and 2010) were digitalized manually at 1:25,000 scale to produce four separate land-use polygon vectors (one for each period considered in the analysis). Land-use polygons were then converted to rasters with 100 x 100 m pixel dimensions (each pixel representing an area of 1 ha), that were used for the following analyses.

Table 1: Description of land-use types in the study area.

Land-use type	Description
Forest	Forests, also including the riparian vegetation
Scrubland	Scrub formations
Grassland	Pastures, mowed grasslands and permanent grasslands
Arable land	Irrigated and non-irrigated crops and horticultural crops
Woody crop	Tree-planted arable lands, vineyards, olive groves, orchards
Reforestation	Tree-planted lands, mainly with conifer trees, in previously spoiled areas
Bare area	Area lacking vegetation
Settlements	Settlements, extraction sites, buildings and roads

For each considered year, the absolute extension (hectares) and the percentage of land covered by each category of land-use were calculated. Raster maps were then overlayed for pixel-based comparison in order to obtain transition matrices for three consecutive time intervals (1850-1954, 1954-1980, 1980-2010). For each time interval $T = (t_0, t_n)$ (t_0 and t_n being the initial and final years, respectively), the transition matrix $M = [m_{ij}]$ consists of elements (cells) m_{ij} representing the amount of land (in hectares) of the class *i* which changes into the class *j* over the time interval *T* (Cousins, 2001; Carranza et al., 2003, Rocchini et al., 2006, Biró et al., 2013). The observation of the transition matrices permits to evaluate the amount and direction of transformations and the percentage of each category that remained unchanged (see Cousins, 2001; Käyhkö & Skånes, 2006).

Finally, the transition matrices were transformed into percentages of land-use cover, allowing the creating of Chord-Diagrams. The Chord-Diagram is a graphical method which allows the visual representation of the inter-relationships between data in a transition matrices (Rajbhandari et al., 2017; Komarek et al., 2018; Malavasi et al., 2018). To show the land-use cover transitions, the arrows represent the direction of the variation, while the width the percentage of the change. The outer coloured ring indicates the overall percentage cover of land-use type from the initial year

whereas the internal ring the percentage remained stable in the final year taken into consideration. Absolute values of the transition matrix, see Supplementary materials 2,3,4.
The above-mentioned diagrams were obtained through R software, version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org). For the creation of the horizontal histogram the *ggplot* function (ggplot2 package) was used, whereas for the Chord-Diagrams the *chordDiagram* function (circlize package).

3. Results

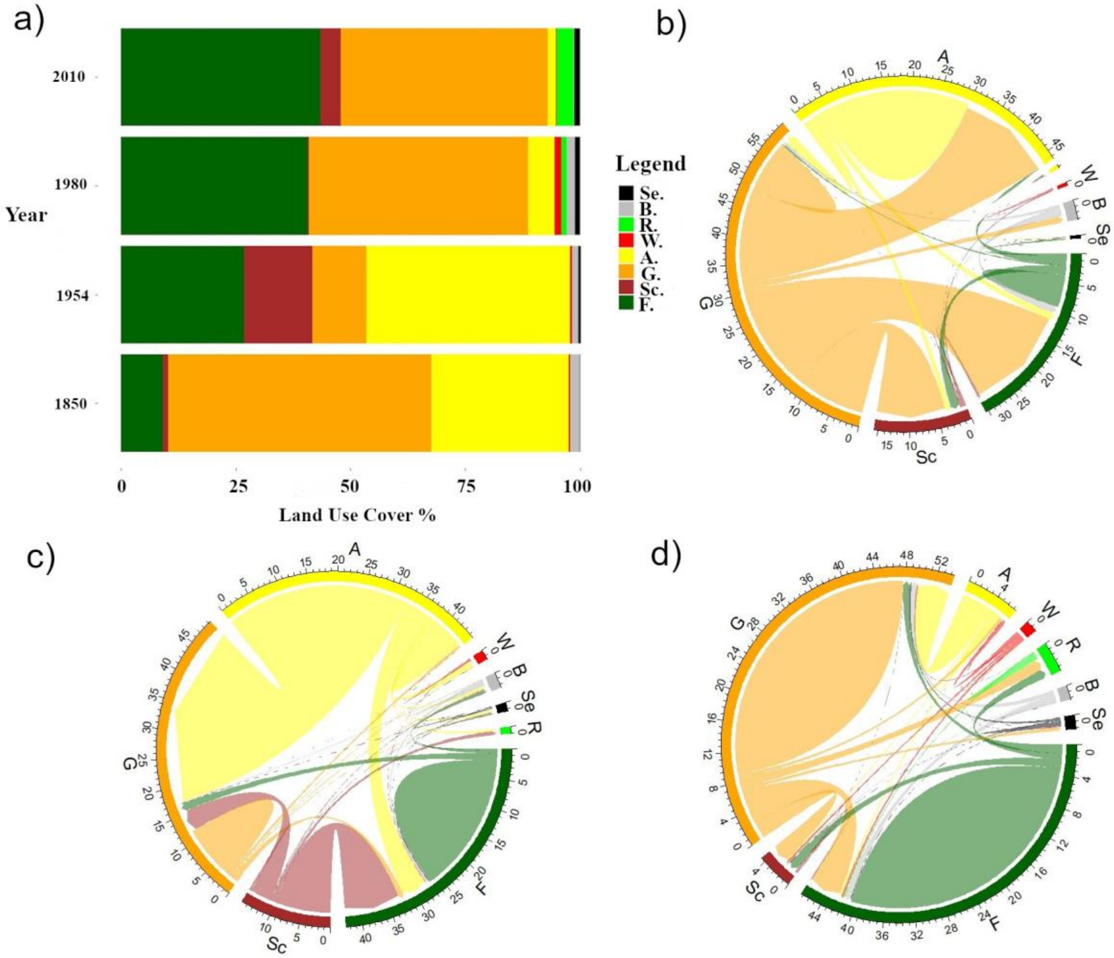
Land-use strongly changed over the studied time interval (Tab. 2). In 1850 the landscape was composed mainly of grasslands (57.3%) and arable lands (29.9%); in 1954 arable lands were the dominant land-use type (44.3%), followed by forests (26.8%); finally, in 1980 and 2010, the study area was equally composed of forests (40.6% and 43.5%, respectively) and grasslands (47.7% and 45.0%, respectively). The landscape pattern of each period taken into consideration is shown in Supplementary Material 1.

Table 2: Surface area (hectares) and percentage of the overall study area occupied by the land-use classes in 1850, 1954, 1980, and 2010.

Year	1850		1954		1980		2010	
Land-use class	ha	%	ha	%	ha	%	ha	%
Forest	730.6	9.2	2120.7	26.8	3209.7	40.6	3438.9	43.5
Scrubland	86.7	1.1	1180.9	14.9	31.1	0.4	349.0	4.4
Grassland	4533.6	57.3	930.9	11.8	3772.9	47.7	3557.1	45.0
Arable land	2366.0	29.9	3503.0	44.3	456.1	5.8	151.8	1.9
Woody crop	25.5	0.3	35.9	0.5	117.5	1.5	10.4	0.1
Reforestation	0.0	0.0	0.0	0.0	90.1	1.1	288.4	3.6
Bare area	161.0	2.0	101.9	1.3	141.1	1.8	15.8	0.2
Settlements	7.6	0.1	37.7	0.5	92.5	1.2	99.6	1.3
Total	**7911**	**100**	**7911**	**100**	**7911**	**100**	**7911**	**100**

Figure 2: **a**. Percentages of land-use cover type which changed during the period of 1850-2010 for the overall study area; Chord diagrams summarizing the percentage of land-use cover changes for: **b**. 1850-1954; **c**. 1954-1980; **d**. 1980-2010. The arrows represent the direction of change, while the width of the arrows represents the extent. For the absolute values of the transition matrices see Supplementary materials 2, 3 and 4 (Se.: Settlements, B.: Bare Soil, R.:

Reforestation, W.: Woody Crop, A.: Arable Land, G.: Grassland, Sc.: Scrubland, F.: Forest).



Forests faced a consistent increase, covering 9.2% in 1850 of the total area, 26.8% in 1954, 40.6% in 1980 and finally 43.5% in 2010 (Fig. 2a; Tab. 2). Grasslands showed an initial drastic decrease, going from 57.3% in 1850 to 11.8% in 1954, and then an increase to 47.7% in 1980 and 45.0% in 2010 (Fig. 2a; Tab. 2). Other land-use types which showed important variations were scrublands, which increased going from 1.1% in 1850 to 14.9% in 1954, decreased to 0.4% in 1980 and by 2010 covered 4.4% of the total area (Fig. 2a; Tab. 2). Finally, arable lands, being equal to 29.9% in 1850, increased to 44.3% in 1954, drastically decreased to 5.8% in 1980, and further decreased to 1.9% in 2010 (Fig. 2a; Tab. 2).

Regarding the observed land-use changes, the transition matrices (see Supp. Mat. 2,3,4), visually represented by chord diagrams (Fig. 2b, c, d), illustrated the land-use transformations for the different time periods considered. The first modification, going from 1850 to 1954 (Fig. 2b), was characterized by the increase in arable lands mainly from grasslands and in smaller amounts from forests. Approximately 3,717 ha of grasslands transformed into agricultural, scrubland and forests areas (Supp. Mat. 2). The second, starting in 1954 to 2980 (Fig. 2c), was characterized with an increase or natural land-use types, ~2,557 ha of croplands changed into grasslands (Supp. Mat. 3), and a further ~342 ha changed into grasslands from 1980 to 2010 (Supp. Mat. 4). Overall,

arable lands showed a drastic decrease, covering around 44.3% of the study area in 1954 and in 2010 were further reduced to 1.9% (Tab. 2). Finally, the third process was the pattern of dynamic processes of vegetation recovery and degradation of land, following the pattern typical of the Apennine vegetation series (natural succession). In fact, the first chord diagram showed an increase of scrublands and forests, starting from grasslands (Fig. 2b). The second, instead, showed an increase of grasslands, deriving from arable lands, and the third an increase of forests deriving from scrublands (Fig. 2c).
Overall, only 16.4% of grasslands and 11.8% of forest areas observed in 2010 have seen continuity since 1850 (Supp. Mat. 5).

4. Discussion

Land-use variations and transformations

During the period 1850-1954 the main landscape variation was the increase of anthropization, underlined by the loss of grasslands and the spread of agricultural lands besides the very low amount of wooded areas. It is noteworthy that in the same period the percentage of forests in the Sibillini mountains never exceeded 10% (Gobbi, 2003), with values comparable to those found in our study area, thus highlighting a general trend of the central Apennines.
In the first half of the 19th century, as observed by Agnoletti et al., (2007), the landscapes of the Apennines were mainly characterized by pastures while forests, consistently with other European countries (Kirby & Watkins, 1998), were at the lowest extent in their history, even if the particularities of the agro-environmental mosaic of such period probably allowed a considerable environmental and biological diversity (Agnoletti et al., 2007). In the following decades, the growing demographic pressure (Del Panta & Detti, 2019) could only be answered by extending crops achieved by tilling new areas and reducing the residual woods (Paci, 2002), as we confirmed in the present study.
The period after 1954 saw the opposite trend, with the vegetation succession due to the abandonment of the mountains and the human migration towards industrial cities (Falcucci et al., 2007). This is apparent through the increase of forest and grassland covers. This phenomenon characterized the entire Italian territory. For example, in 1936 forests covered 6 million ha (Forest Map of the Italian Kingdom), which increased to 8.5 million ha in 1985 (First Italian Forest Inventory, IFNI85), 10.5 million in 2005 (Second Italian Forest Inventory, INFC05) and are currently estimated to cover more than 11 million (Ferretti et al., 2018).
Our results are consistent with previous research showing how the abandonment of agricultural areas and pastures caused an expansion of shrub communities and forests (Mazzoleni et al., 2004; Geri et al., 2010; Bracchetti et al., 2012; Assini et al., 2015). The same processes were observed in Mediterranean mountains of Spain (Lasanta-Martínez et al., 2005; De Aranzabal et al., 2008), France (Roura-Pascual et al., 2005; Mottet et al., 2006), and Greece (Kizos & Koulouri, 2006; Petanidou et al., 2008).
Finally, our results seem to be in line with the Forest Transition process (*sensu* Pagnutti et al., 2013) which have characterized especially the European and Mediterranean regions in the last 50-70 years (Grove & Rackham, 2003).

Ecosystem stability and ecological implications

The element of novelty obtained from this study is the stressing of how the environmental and socio-economic crisis of the end of the 19th century constituted a marked temporal discontinuity of ecosystems. In specific, the vanishing of agro-forest and wood-pasture mosaics may have led to a biodiversity loss that endangered landscapes' ecosystem services and biocultural heritages (Basnou et al., 2013; Agnoletti & Rotherham, 2015). This is likely due to the fast encroachment of young and homogeneous woodland cover in former cultural landscapes left abandoned, while the mature forest units were sparse (Cervera et al., 2019) and restricted to the most rugged and inaccessible areas (Assini et al., 2015).

In our study area the most relevant impact in the years between 1850 and 1954 was the extensive destruction of grasslands. In fact, only ~725 ha of the grasslands originally present in 1850 was still recognizable in 1954. From an ecological point of view, such abrupt interruption of continuity over time, besides fragmentation of the residual patches causing the interruption of the ecological network, might have had deep impacts on taxonomic structure and biodiversity of grasslands. Catorci & Gatti, (2010) demonstrated how the coenological composition of several grasslands types is strongly related to the historical land-use and management. In addition, patch turnover might affect the persistence of some species. For instance, seed recruitment of xerophilous taxa is generally limited (Zeiter et al., 2006) because of low dispersal ability. This hampers the colonization of new patches (in relation with their turnover as seen in the present study), increasing the risk of local species extinction (Willis et al., 2014).

During this same period, also the forest state saw drastic changes, leading to some ecologically interesting remarks. Considering the type of forest management in the 1800s (coppiced every nine years and branches used as forage supply every year – Sansa, 2003), it is conceivable that coppicing and the related alteration of soils (Hermy, 1994; Verheyen & Hermy, 2001) allowed only the most heliophilous and xerophilous tree species (e.g. *Ostrya carpinifolia* Scop., *Fraxinus ornus* L. subsp. *ornus*, and *Quercus pubescens* Willd. subsp. *pubescens*) to persist. In fact, throughout this period the most ecologically demanding species, e.g. silver fir (*Abies alba* Mill.), linden (*Tilia cordata* Mill., T. *platyphyllos* Scop.), holly (*Ilex aquifolium* L.), yew (*Taxus baccata* L.), and beech (*Fagus sylvatica* L. subsp. *sylvatica)*, were reported as extinct or strongly declining (Reali, 1871). Therefore, the current coppiced woods may be considered as a legacy of the socio-economic conditions of the nineteenth century and the current forests composition may mainly depend on the woody species that survived such ecological and management conditions (see Chiarucci et al., 2010). Considering the small area of stable forest observed during the period 1850-1954 (405.5 ha; Supp. Mat. 2), we can confirm the interpretation of the current hilly forest of the Apennines as an overexploited secondary wood mosaic, which almost completely replaced the primary ones (Blasi et al., 2006; Catorci et al., 2011). Cervera et al., (2019) asserted that the regrowth of the forests in former overexploited territories were caught in low ecological quality states, preventing them from maturing into more complex and stable formations. In addition, this inability can also be connected to the disappearance of old growth forest species.

Instead, during the period 1954-1980, the mountain landscape started to acquire the current ecological structure, reorganizing the existing vegetation elements and landscape structures.

5. Conclusions

Overall, in the last 160 years the studied territory has experienced a long-term change going from overexploitation and deforestation towards a subsequent forest transition period driven by underuse and abandonment. The temporality of this double process could have potentially affected the current ecological state of ecosystems. While the former overuse, together with cropland expansion, not only decreased forests but also reduced the quality of woods that remained. The ensuing fast and widespread forest transition processes following rural exodus has entailed a woodland expansion without no quality recovery (Otero et al., 2015).
It emerged that only a small percentage of the forests and grasslands, ~12% and ~16% respectively, have seen ecological continuity over time.
These considerations call attention to the issues related to the temporal continuity of ecosystems and biodiversity loss (Bracchetti et al., 2012). Efforts in the management of biodiversity and in the recovery of degraded or lost ecosystems should consider that modern niches are also the consequence of the interplay between a long and complicated series of socio-economic changes and their ecological consequences (Piovesan et al., 2018).
Our findings seem to confirm that the history and changes of the ecological processes are as diverse and complex as the history of human socio-economical changes (Piovesan et al., 2018). We need to recognize that, while human activities are widely acknowledged to contribute globally to environmental change, the effects at smaller spatial scales can drastically vary based on the different territorial and local histories. An extensive and detailed analysis based on the local historical situations is fundamental and should be a central point for conservational policies and plans.

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Competing Interests. The authors declare that no conflict of interest exists.

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Winner of the scholarship “Ecology and Management of the Apennine grassland systems” at the University of Camerino, Italy, is a plant ecologist focusing mainly on the use of functional traits in the study of plant community composition and assembly. Her skills range from data collection in the field, data elaboration in the lab and data analysis with the use of R software. Starting 2020 attendant at the Centre for Ecological Research, Institute of Ecology and Botany in Hungary, for the Erasmus program, integrating the use of plant functional traits with ethnoecology.

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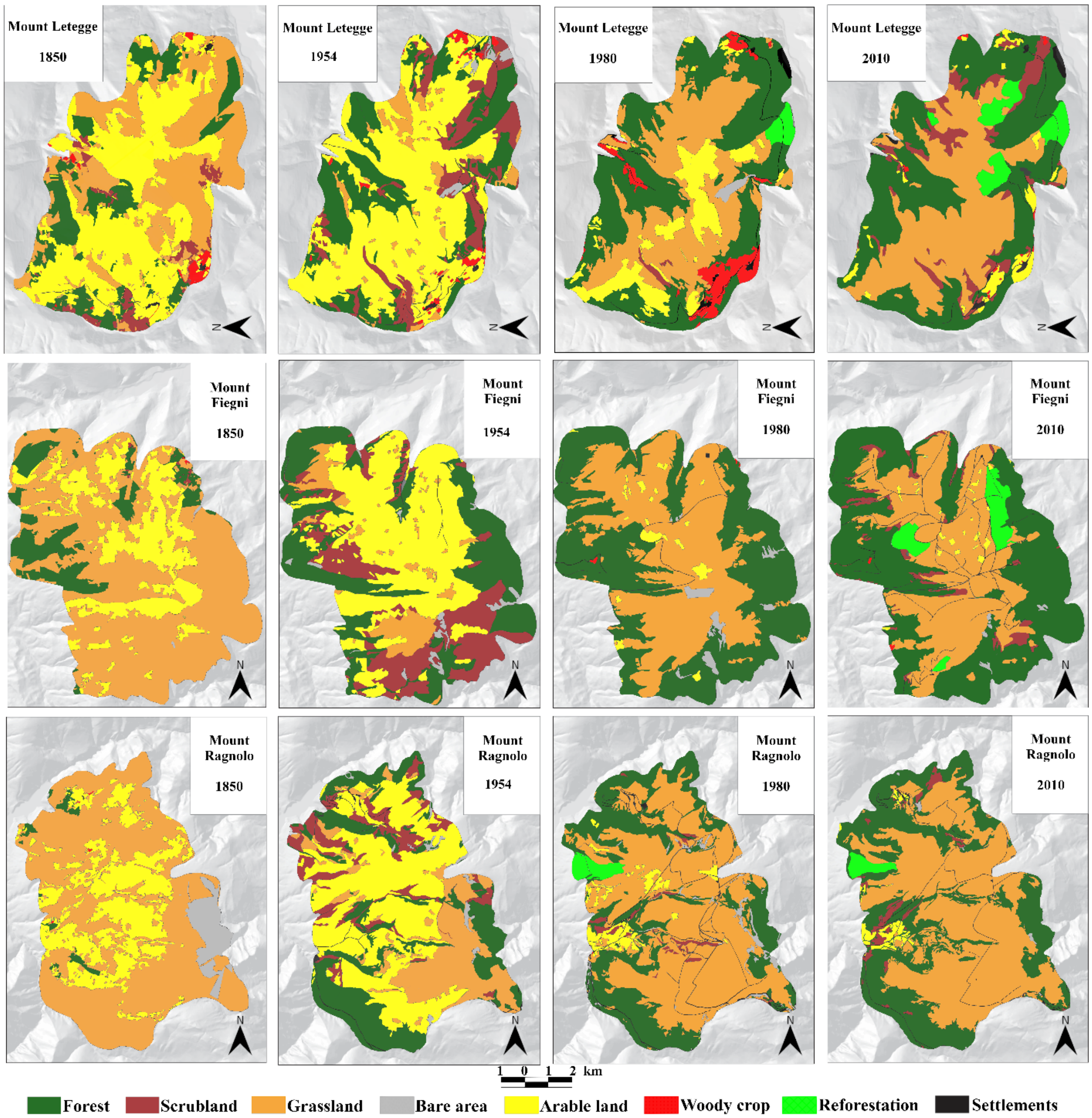
Supplementary Material:

Supplementary Material 1: Covers of the different land-use types in three the sub-study in 1850, 1950, 1980 and 2010 (Mount Letegge; Mount Fiegni; Mount Ragnolo; Map scale 1:60.000)



Supplementary Material 2: Transition matrix between different land-use classes from 1850 to 1954 (hectares) for the overall study area. Portions of unchanged land-use are highlighted in light grey.

		1954							
	Land-use class	Forest	Scrubland	Grassland	Arable land	Woody crop	Bare area	Settlements	**Total 1850**
1850	Forest	440.5	116.3	22.6	124.2	0.0	0.0	27.0	**730.6**
	Scrubland	36.4	26.0	1.7	3.5	17.3	0.0	1.7	**86.7**
	Grassland	1450.8	952.1	725.4	1314.7	0.0	90.7	0.0	**4533.6**
	Arable land	94.6	71.0	142.0	2051.4	0.0	0.0	7.0	**2366.0**
	Woody crop	0.8	0.3	0.5	5.4	18.1	0.0	0.5	**25.5**
	Bare area	96.6	14.5	38.6	0.0	0.0	11.3	0.0	**161.0**
	Settlements	1.0	0.8	0.0	3.8	0.4	0.0	1.5	**7.6**
	Total 1954	**2120.7**	**1180.9**	**930.9**	**3503.0**	**35.9**	**101.9**	**37.7**	**7911**

Supplementary Material 3: Transition matrix between different land-use classes from 1954 to 1980 (hectares) for the overall study area. Portions of unchanged land-use are highlighted in light grey.

		1980								
	Land-use class	Forest	Scrubland	Grassland	Arable land	Woody crop	Reforestation	Bare area	Settlements	**Total 1954**
1954	Forest	1951.0	0.0	106.0	0.0	0.0	0.0	42.4	21.2	**2120.7**
	Scrubland	779.4	29.8	295.2	0.0	0.0	55.0	14.6	6.8	**1180.9**
	Grassland	74.5	0.0	791.2	37.2	9.3	0.0	9.3	9.3	**930.9**
	Arable land	350.3	0.0	2557.2	416.4	83.1	35.0	35.0	26.0	**3503.0**
	Woody crop	8.3	0.0	1.8	1.1	23.0	0.0	0.0	1.8	**35.9**
	Reforestation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	Bare area	34.7	1.0	15.3	0.0	0.0	0.0	38.9	12.1	**101.9**
	Settlements	11.6	0.3	6.1	1.5	2.1	0.0	0.9	15.2	**37.7**
	Total 1980	**3209.7**	**31.1**	**3772.9**	**456.1**	**117.5**	**90.1**	**141.1**	**92.5**	**7911**

Supplementary Material 4: Transition matrix between different land-use classes from 1980 to 2010 (hectares) for the overall study area. Portions of unchanged land-use are highlighted in light grey.

		2010								
	Land-use class	Forest	Scrubland	Grassland	Arable land	Woody crop	Reforestation	Bare area	Settlements	**Total 1980**
1980	Forest	2952.9	96.3	64.2	0.0	0.0	96.3	0.0	0.0	**3209.7**
	Scrubland	12.4	13.4	4.7	0.6	0.0	0.0	0.0	0.0	**31.1**
	Grassland	339.6	188.6	3056.0	37.7	0.0	113.2	0.0	37.7	**3772.9**
	Arable land	22.8	13.7	342.1	68.4	4.6	4.6	0.0	0.0	**456.1**
	Woody crop	27.0	22.3	14.1	42.3	5.9	0.0	0.0	5.9	**117.5**
	Reforestation	14.4	0.9	1.8	0.0	0.0	73.0	0.0	0.0	**90.1**
	Bare area	62.2	8.5	50.8	0.0	0.0	0.0	14.1	5.5	**141.1**
	Settlements	7.4	5.3	23.5	2.7	0.0	1.4	1.7	50.5	**92.5**
	Total 2010	**3438.9**	**349.0**	**3557.1**	**151.8**	**10.4**	**288.4**	**15.8**	**99.6**	**7911**

Supplementary Material 5: Extent of stable areas from 1954 and 1850 to 2010 for each land-use class in the overall study area.

Land-use class	Surface area in 2010	Stable surface area from 1954 to 2010		Stable surface area from 1850 to 2010	
	ha	ha	%	ha	%
Forest	3438.9	1951.0	56.7	405.5	11.8
Scrubland	349.0	8.9	2.6	0.0	0.0
Grassland	3557.1	713.9	20.1	584.8	16.4
Arable land and woody crops	162.2	114.2	70.4	65.7	40.5
Reforestation	288.4	-	-	-	-
Bare area	15.8	9.7	61.1	0.0	0.0
Settlements	99.6	13.8	13.9	1.2	1.2