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Article

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Multidisciplinary approach for reconstructing past local land-use practices: Two case studies from the Ligurian Apennines, north-western Italy

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Abstract

Characterising local pastoral activities and multiple management systems that shaped past and present landscapes is critical for better understanding main historical processes of biodiversification, species distributions and biomass. The aim of the present paper is to add new information on previous studies by combining biostratigraphical proxies (pollen, charcoal and non-pollen palynomorphs) with data from written historical records (cartographic and archival) and archaeological excavations for the last centuries from two sites located in the eastern Ligurian Apennines, north-western Italy. Additionally, a statistical approach was used to calculate the relative importance of temperature variations, fire dynamics, changes in arboreal coverage, presence of stagnant water/temporary pools and grazing pressure on selected groups of pollen taxa associated with different management practices for the specific study area. The use of a multiple analytical methodology allowed highlighting several phases of land-use, which could be related to different socio-economic strategies sometime associated to historical conflicts between local communities. Our analyses identified indicator species of the past presence of cultivated fields, meadows, grazing areas and use of controlled fires, as well as heathlands and wetlands managed for pasture and agriculture, and provided evidences of the disappearance of landscapes more 'complex' than today, due to the abandonment of past management practices. These results have relevance for improving the ability to manage ecosystems during current and future environmental changes.

Keywords

archaeological investigations, cartographic and archival documents, ecosystems conservation, linear regression, multiple management systems, NPPs and charcoal analysis, pollen

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Introduction

Past management practices of environmental resources (clearance for arable and pastoral land, slash-and-burn, browsing and grazing by domestic animals, coppicing, pollarding, tree planting and cutting, agricultural practices) have been a major factor influencing European land cover change during the Holocene (Ellis et al., 2021; Keller et al., 2002; Roberts et al., 2018, 2019; Ruiz and Sanz-Sánchez, 2020; Vera, 2000) and, especially for the last thousands of years, these activities have affected the main historical processes of biodiversification, species distributions and biomass (Dambrine et al., 2007; Piovesan et al., 2018).

While for deeper timescales, palaeoecological proxies are the only available sources for exploring human-vegetation interactions (Edwards and MacDonald, 1991; Pini et al., 2017; Sadori et al., 2013), for more recent periods the combination of reconstructions based on microscopic biological remains with information from historical ecology, environmental archaeology and written records make new data available for a better understanding of the role played by land-use practices on ecosystems (Mazier et al., 2009; Mensing et al., 2018; Molinari and Montanari, 2016, 2018). The reconstruction of environmental changes linked to human activities based on pollen, charcoal and non-pollen palynomorphs (hereafter NPPs) is well established (among others Bosi et al., 2019; Florenzano, 2019; Gauthier and Jouffroy-Bapicot, 2021; van Geel et al., 2003) and, for palynological studies, has mainly relied on the presence and abundance of the so called 'anthropogenic pollen indicators' (Behre, 1981, 1988; Huntley and Webb, 1988). Despite these taxa having been commonly used outside of their original calibration area (Feurdean et al., 2013; Li et al., 2015; López-Sáeza et al., 2018), Behre' indicators may not be suitable in these regions due to potential shifts in the response of plant taxa to environmental variables, such as vegetation, climatic and geographical gradients (Diekmann, 2003). For this

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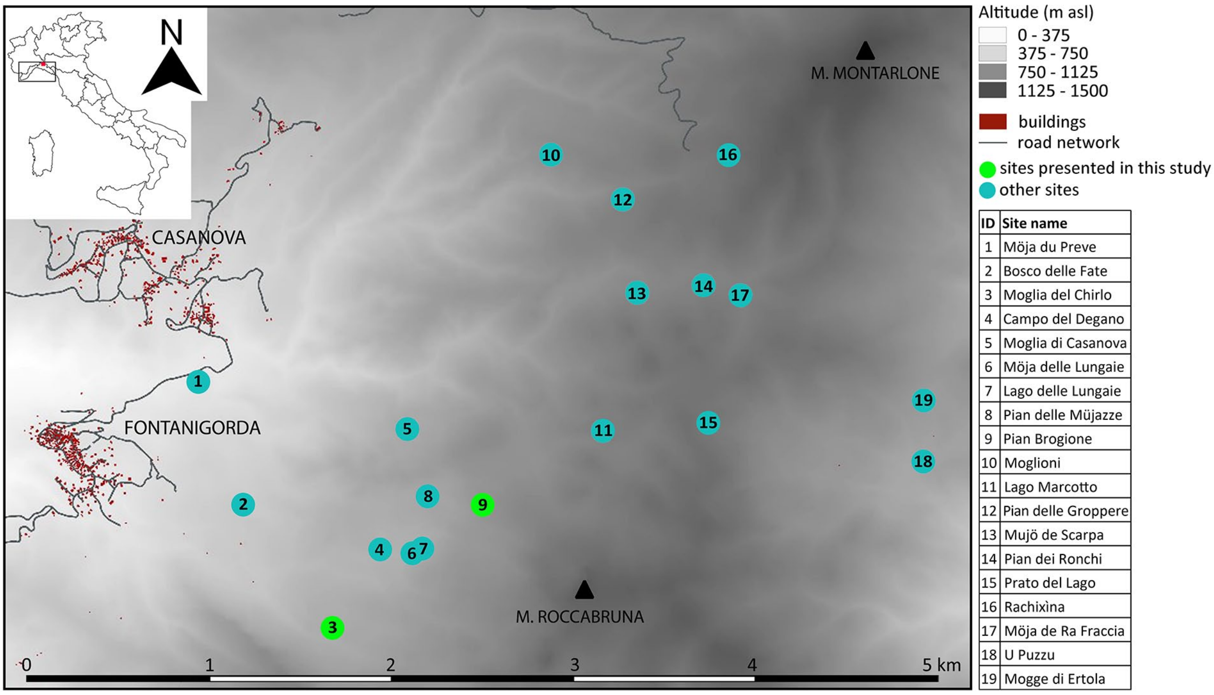

Figure 1. Location map of the biostratigraphic sites of historical-environmental interest investigated by LASA in the Upper Trebbia Valley, with the two case-studies presented in this paper highlighted (revisited after Cevasco et al., 2023).

reason, region-specific anthropogenic pollen indicators have been identified (Deza-Araujo et al., 2020; Mazier et al., 2009; Mercuri et al., 2013).

In this research framework, since 1995, the Laboratory of Archaeology and Environmental History (LASA, an Interdepartmental Research Centre of Genova University) has carried out several projects aimed at characterising past management systems of environmental resources, with particular focus on north-western Italy (Cevasco et al., 2019; Maggi et al., 2002; Moreno et al., 2005; Stagno, 2013). By adopting the perspective of historical ecology (Peterken, 1975; Rackham, 1980, 1994) and geographical-historical micro-analysis (Cevasco and Moreno, 2007; Quaini, 2018), LASA projects make use of a multidisciplinary approach involving archaeologists, archaeobotanists, botanists, historical ecologists, geologists, geographers and historians (Maggi et al., 2002; Cevasco, 2007, 2013). The results of these studies helped to better understand not only past ecosystem dynamics – underlying the existence of ancient agricultural and pastoral areas, together with multiple local systems of land-use important for the conservation and valorisation of Ligurian cultural landscapes (Cevasco, 2013; Cevasco and Molinari, 2009; Guido et al., 2002, 2013) – but also to shed light on the consequence of their abandonment, offering significant contribution to the development of new strategies for environmental conservation, by also taking into account the social relationships linked to different management practices (Moneta and Parola, 2014; Cevasco and Moreno, 2013; Stagno and Tigrino, 2020).

Within this context, the aim of the present paper is to provide new information on the characterisation of local land-use activities and multiple management systems that shaped past and present landscapes at *Pian Brogione* and *Moglia del Chirlo*, two sites located in eastern Ligurian Apennines, north-west Italy. The dense network of sites of historical-environmental interest (Figure 1) was identified thanks to studies of historical topographic cartography and ecological ground observations (Cevasco, 2002; Marullo, 2002; Stagno, 2009; Tigrino et al., 2013). In particular, we focused on the reconstruction of local vegetation dynamics and changes in management practices, trying to link these variations to historical conflicts connected to ownership and access rights to environmental resources of local communities by combining biostratigraphical proxies (pollen, charcoal and NPPs) with data from historical documents and archaeological excavations. Additionally, the use of independent datasets of temperature variations, fire dynamics, changes in arboreal coverage, presence of stagnant water/temporary pools and grazing pressure allowed us to statistically explore the relative importance of these potential drivers on selected groups of pollen taxa associated with different management practices for the specific study area. Finally, we assessed the role of main variations in land-use on vegetation diversity and how this might be managed for future ecosystems' enhancement by local stakeholders and decision makers. The results can contribute to nature conservation and the sustainable use of plant resources, important in the adaptation to socio-economic and climatic changes.

Sites description

The study sites are located in Genoa province, Upper Trebbia Valley, Casanova-Fontanigorda municipalities (Figure 1).

In the recent bioclimatic classification, the area is defined as temperate oceanic; weak semi-continental; thermotype upper supra-temperate; ombrotype lower hyper-humid (Pesaresi et al., 2017).

Both sites lie on loose sediments derived from the surroundings outcrops of basalts, serpentinites, sandstones and polygenic breccias and olistoliths (Elter et al., 2005, 2015).

Pian Brogione (44º32′45″N, 9º20′07″E; 1160 m a.s.l.) is a grassy plateau nowadays invaded by heathers (*Calluna vulgaris* (L.) Hull and *Erica herbacea* L.), junipers (*Juniperus communis* L.) and other woody species (e.g. *Sorbus aria* (L.) Crantz, *Populus tremula* L., *Abies alba* Mill. and – mostly – *Pinus nigra* J.F. Arnold, planted c. 1965–1970 AD by the Forestry Administration). On one side of the plateau grows an alder wood (*Alnus glutinosa* (L.) Gaertn.). The herbaceous layer is characterised by the presence of *Serratula tinctoria* L. and some protected species (e.g. *Arnica montana* L. and *Dactylorhiza maculate* (L.) Soó), together with several forage species (e.g. *Lotus corniculatus* L., *Plantago serpentina* All. and *Briza media* L.).

Table 1. Reconstruction of vegetation cover based on historical topographic maps, aerial photos and field observations during the last *c.* 200 years (modified after Cevasco, 2002, 2007).

Years AD	Vegetation cover	Source of information
2000	Heathland + brushland + sparse woodland	Fields observation
1995	Shrubby grassland + brushland + sparse woodland	Aerial photo Ligurian Region (scale 1:13,000 *ca*)
1986	Shrubby grassland + sparse woodland	Orthophoto map Ligurian Region (scale 1:10,000)
1954	Grassland	Aerial foto IGM Florence (scale 1:33,000 *ca*)
1936	Area without arboreal coverage	IGM Tablet, Florence (scale 1:25,000)
1878	Area without arboreal coverage	IGM Tablet, Florence, historical series (scale 1:50,000)
1853	Bushy/wooded pasture ('*gerbido*')	Gran Carta of Stati Sardi in Terraferma (scale 1:50,000)
1827	Scattered trees	Handwritten map (scale 1:9450) edited by the Sardinia Kingdom's military topographer Gustavo Scati

Moglia del Chirlo (44º32′20″N, 9º19′25″E; 1050 m a.s.l.) is a wetland dominated by a dense canopy of *Alnus glutinosa* (L.) Gaertn. (grown on few older stumps, several dying and rotting), bordering to the south with a shrubby coverage of *Rubus idaeus* L., to the east with a coverage of *Rosa canina* L. and *Prunus avium* L., and to the north with patches of *Vaccinium myrtillus* L. Plantations of *Pinus nigra* J.F. Arnold, *Pinus sylvestris* L., *Larix decidua* Mill., *Abies alba* Mill. and *Picea abies* (L.) H. Karst. dated back to c. 1930 AD are present in the surroundings.

At least since the 16th century until the beginning of the 20th century, these two areas were summer pasture points of a network of transhumance grazing routes between the Ligurian sea coast, the mountain and the Po valley and probably utilised also as watering pits (Cevasco, 2007, 2018; Moreno, 1990; Tigrino, 2007). *Pian Brogione* was a cattle pasture until the second half of 1970s and it is presently frequented by deer, while *Moglia del Chirlo* was used as cattle pasture and for temporary agricultural practices until the end of 1970s and it is currently frequented by wild boars (Cevasco et al., 2010; Montanari and Stagno, 2015). Since 1995, *Pian Brogione* and *Moglia del Chirlo* are included in the Special Area of Conservation (SAC) IT1331012 in the frame of the Natura 2000 network, and are located in a Restocking and Capture Zone (ZRC) for promoting the natural reproduction of small wild game. Furthermore, during the last years, the sites have been object of restoration and monitoring actions financed by the Liguria Region on European funds aimed at testing historical practices for innovative management of the local biodiversity, with the maintenance of stone artefacts (functional to the road network, to the management of grazing areas and to the water resource/water perimeters) and the experimentation of management practices today disappeared, such as mowing and use of controlled fires (Cevasco, 2010; Parola, 2012). In particular, in 2010, prescribed fires were conducted at *Pian Brogione* on small test plots in order to (1) maintaining wooded grassland over the development of thorny shrubs and afforestation; (2) favouring protected and forage herbaceous species which tend to be overwhelmed by populations of *Brachipodium* sp. and *Vaccinium myrtillus* L.; (3) monitoring the effects of prescribed fires on wooded pastures and on different shrub and herbaceous species (Menozzi and Montanari, 2010; Parola, 2012). In this case, the reference model was the one previously used in coastal heathlands of western Norway (Kvamme and Kaland, 2009) and in the French Pyrenees (where, since the 1980s, a process of consultation and organisation of burnings has been put in place by organisations of the agricultural profession and local administrations in order to institutionalise the traditional land management practices by fire, better manage it and reduce its risks; Bal and Métailié, 2005; Metailie and Faerber, 2003).

Previously collected information

Cartographic sources

At *Pian Brogione*, the analysis of historical cartographic documents (Cevasco, 2002) allowed the reconstruction of vegetation dynamics between 1827 and 2000 AD (Table 1).

The handwritten map edited by the Sardinia Kingdom's military topographer Gustavo Scati in 1827 defines the site as 'scattered trees'. In 1853, the *Gran Carta of Stati Sardi in Terraferma* describes *Pian Brogione* as '*gerbido*'; this term may have different meanings, as it can indicate both 'uncultivated land' and 'bushy/wooded pastures' (due to the absence of a term referring to an intermediate situation – like 'wooded pastures' or 'scattered trees' – caused by the affirmation of the dichotomous classification in 'woodland' and 'open areas' of the *Gran Carta*; Moreno et al., 1992). At this specific site, '*gerbido*' probably refers to a grazing (uncultivated) phase following a period of temporary cultivation characterised by the use of controlled fires (Cevasco, 2002, 2007).

Later, in the Military Geographic Institute (IGM) tablets dated 1878 and 1936, *Pian Brogione* is classified as an 'area without arboreal coverage'. These changes in the vegetation cover underline the progressive reduction of wooded pastures and areas with scattered trees, and their transformation in open areas in order to promote pastures and meadows, perhaps in connection with the drainage of wetlands for hay production associated with changes in husbandry organisation. In this period, in fact, it is registered an increasing role of cattle breeding and the affirmation of the mountain pasture systems ('*monticazione*') with winter stabling in the hamlet' sheds (while in the long-distance transhumance system winter quarters were located along the coast), and a consequent replacement of multiple land-uses with monocultures centred on hay production (Montanari and Stagno, 2015). The IGM aerial photo dated 1954 classifies *Pian Brogione* as a 'grassland' and confirms the presence of a sparse tree cover also at that period. On the contrary, the orthophoto map and the aerial photo dated 1986 and 1995, respectively, and the field observations carried out in recent years describe a post cultural situation, characterised by the progressive abandonment of pastures and the increasing presence of heathlands, shrublands, brushlands and sparse woodlands.

Archival sources

The study of different archival documents reported that the two selected sites are located inside a wide area of common-lands, historically belonging to the hamlet of Casanova, whose access rights were questioned by the families of the neighbouring village of Fontanigorda. Even if the origin of the conflict could be dated to the 17th century, its reconstruction was possible by analysing the fights taking place during the 1920s, when the Italian Kingdom established a specific magistrate (the 'C*ommissario per la liquidazione degli usi civici*') to solve this type of

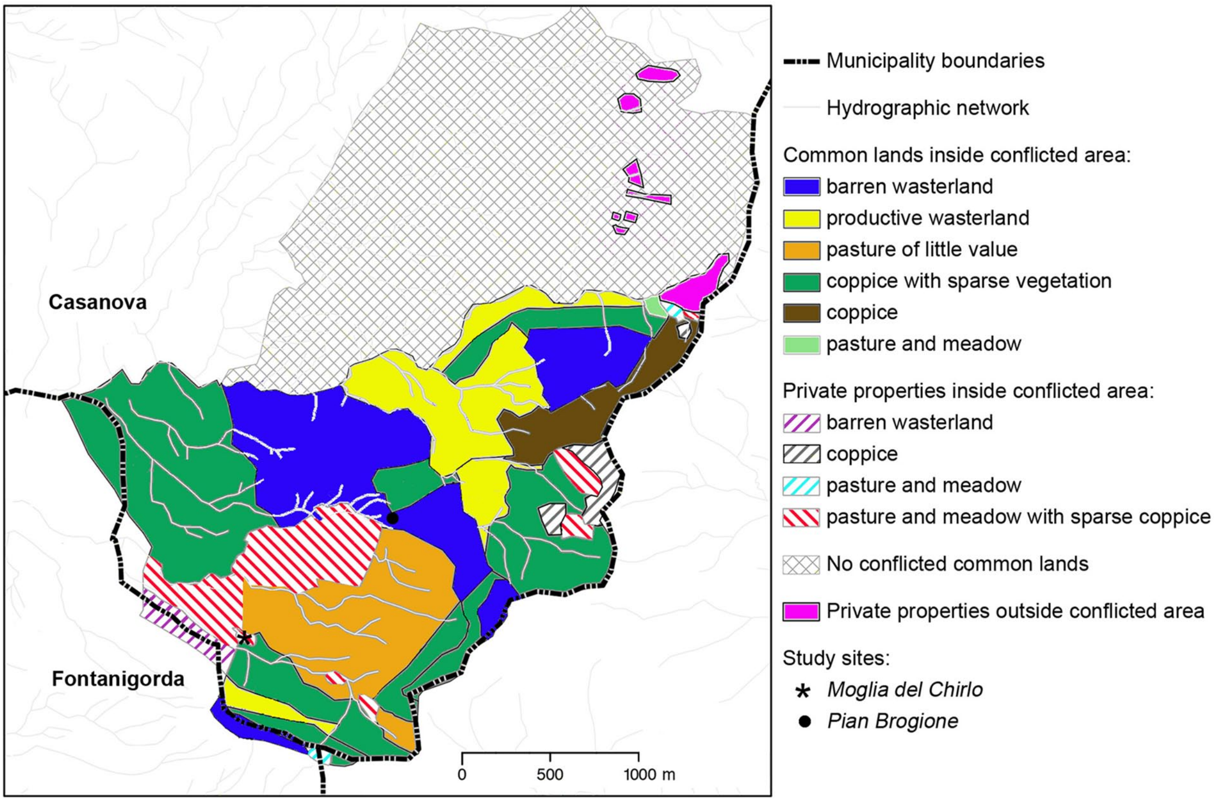

Figure 2. Cartographic representation of the topographic sketch by the surveyor Pietro Billi with land-use indications (May 1926) with the location of the two study sites (revisited after Montanari and Stagno, 2015).

jurisdictional disputes. While in that period it was a municipal controversy, in other phases it was more explicitly related to specific local social groups and kinships who characterised the socio-political organisation of this area (Beltrametti et al., 2021; Montanari and Stagno 2015; Tigrino et al., 2013). Until the end of the *Ancien Régime*, in fact, the two settlements (defined as *ville*) were part of the imperial mountain fiefdoms of Malaspina and – later – of the Doria-Pamphilj families. Thus, even if part of the Holy Roman Empire, they were poorly linked to the central administrative districts (Tigrino and Rocca, 2017) and their political and economic trajectories can be better understood in relation to the neighbouring *Repubblica di Genova* and to their privileges derived by the fact to be imperial fiefs. The *feudal families*, in fact, played also important roles in the Genoese political life (Raggio, 1990, 2018). During the post-medieval period, the hamlets network was organised in *ville*, enucleated settlements of limited demographic consistency, characterised by a sort of administrative independence and predominantly related to a single kinship (*parentela*). As in the present time, despite the process of privatisation experienced during the 19th century, many mountain fiefs were common-lands, whose access rights were historically shared by the inhabitants of a single *villa*, or together with other *ville*, or by members of a single kinship, in many cases with differentiated levels of access rights (Raggio, 1990, 1992, 2018; Tigrino et al., 2013).

Several disputes between Casanova and Fontanigorda related to the use of common-lands (e.g. grazing or woodland access rights, cultivations) are documented since at least the 17th century (Beltrametti et al., 2021). The conflicts increased at the beginning of the 19th century, when the two settlements were incorporated to the Kingdom of Sardinia (later Kingdom of Italy) and their territories were divided both administratively and ecclesiastically: Fontanigorda became an autonomous municipality and, after centuries of belonging to the hamlet of Casanova, was granted its independent parish, while Casanova was annexed to the community of Rovegno (Beltrametti et al., 2021). However, despite this administrative separation, common-lands previously shared were not divided between the two new municipalities and conflicts increased, due to different economic aims for the exploitation of the area, locally defined as '*Selva di Roccabruna*'. After the establishment of the *Commissario*, the local contenders solicited the intervention of a probationary officer to solve the dispute (at that time, mainly related to the cutting of trees). The intervention resulted in a precise mapping of the contested lands, considered the first step for a possible division between the competing parties. The survey was conducted by Pietro Billi, who, in 1926, drew up a topographic sketch (on a scale of 1:4000) based on cadastral plans (built on previous cadastral plans dated 1884–1895) and on-site visits, where he classified the land according to the main use of environmental resources and of the ownership (Figure 2). What emerges from the analysis of this document is an extremely complex organisation: while in not-contested areas the private properties are reduced to small enclaves, in the common-lands claimed by Casanova and contested by Fontanigorda a wide area today characterised by the presence of wetlands (included *Moglia del Chirlo*) are fragmented in different private lands, assigned to few local families, suggesting their specific role in the conflicts (Beltrametti et al., 2021). Another important aspect is that the classification used by the surveyor was based on the dichotomy cultivated/uncultivated and failed to recognise the complexity of multiple uses of the same piece of land (shifting between grazing, temporary cultivation, sowing of grasses, firewood, timber production and leaves for fodder), as highlighted by archaeological and historical ecology investigations (Cevasco, 2007; Moreno, 1990; Stagno, 2015). It is also interesting to note that the wetlands (certainly visible at that time) were not recognisable in Billi's sketch. In the contested commons, where also *Pian Brogione* is located, they are classified as 'barren wasteland', not distinguishable from the surrounding areas (Montanari and Stagno, 2015). *Moglia del Chirlo*, instead, is defined in Billi'

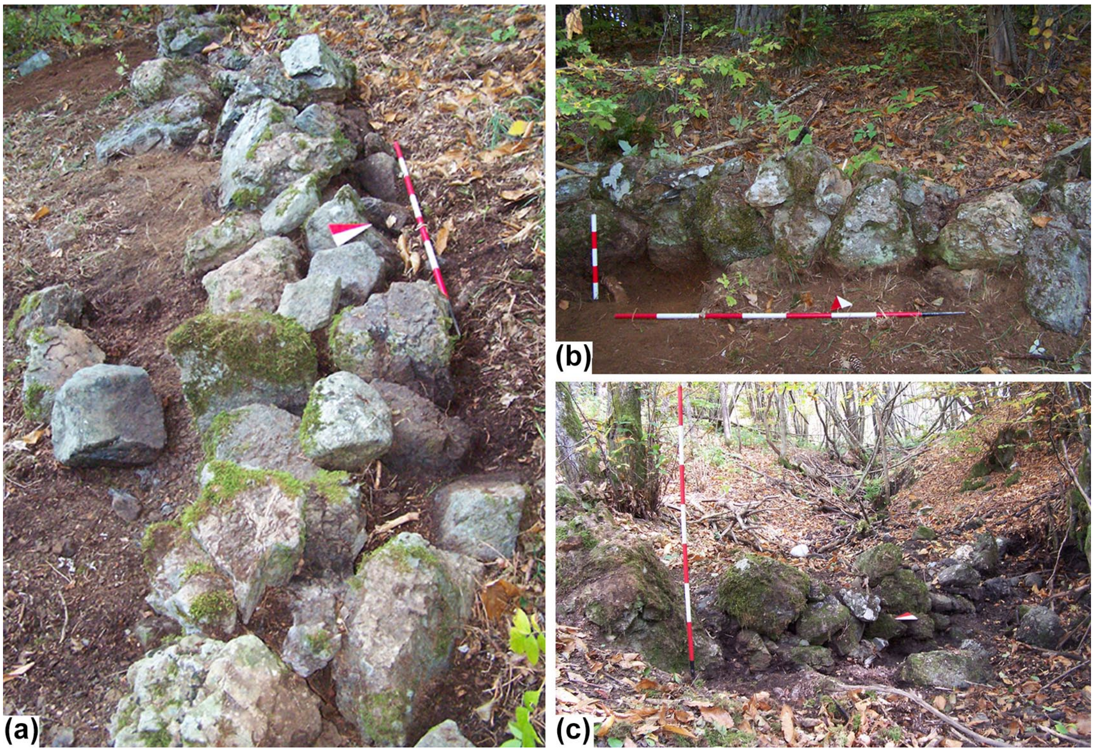

Figure 3. Drystone walls documented by the archaeological investigations at *Moglia del Chirlo* (Stagno, 2009). (a), (b) Portion of the drystone wall surrounding the wetland (UT33). (c) Bridle/water retaining wall located at the margin of the wetland (UT 56).

survey as a 'pasture and meadow with sparse coppice' within a larger parcel with the same land use, both privately owned (Montanari and Stagno, 2015). The same category is assigned to all the privately owned plots of land where wetlands are present. It is also interesting to note that the area of *Moglia del Chirlo* wetland is precisely delimited in the map (Figure 2). These enclaves may be evidence of the previous appropriation of part of commonlands, as well documented in other parts of Ligurian Apennines. This sort of 'usurpation' of commons by private individuals or by family groups – often resulted in the formation of new private properties – is frequent throughout European mountain during the *Ancien Régime* (Raggio, 1992; Stagno, 2015).

Lastly, the analysis of historical cadastral maps (dated 1884–1895) suggested that both *Pian Brogione* and *Moglia del Chirlo* were used as wet meadows for hay production, possibly in relation to the establishment of the mountain pasture systems ('*monticazione*') since the late 18th century (Montanari and Stagno, 2015). On the contrary, in the current cadastre (dated 1954 AD), *Pian Brogione* is classified as 'barren wasteland', while *Moglia del Chirlo* (even if still defined as a private property inside the common-lands of Casanova) is described as 'pasture', pointing out – at both sites – to the abandonment of hay production (Beltrametti et al., 2021).

Archaeological investigations

Archaeological surveys were aimed to understand if the appropriation of certain lands in the area of *Pian Brogione* and *Moglia del Chirlo* (documented by archival sources) was related to the intensification of agriculture for hay production (also linked to a variation in rearing practices), or – instead – it was part of a previous process of exclusive access rights on some commonlands by the Fontanigorda families, as the presence of enclosures could suggest.

The archaeological surveys at *Pian Brogione* and *Moglia del Chirlo* highlighted that both wetlands presently contain traces of past pastoral and temporary cultivation practices (Stagno, 2009; Beltrametti et al., 2021). Furthermore, in the area, a considerable growth of structures linked to local husbandry (mainly spaces dedicated to stables and barns associated with a transition from transhumant to sedentary breeding) was documented between the 18th century and the end of the 19th century (Cevasco, 2012; Stagno and Molinari, 2014; Tigrino et al., 2013). However, the presence or absence of fences and other artefacts around the sites allow a discussion about the relationship between collective, shared or private uses of the spaces, and the management practices of environmental resources (Beltrametti et al., 2014). In fact, *Moglia del Chirlo* (Figure 3), like all other wetlands privately owned, is partially bordered by low drystone walls coincident with the perimeter of the cadastral division (sort of 'fences' built for preventing the spread of livestock to the wetland or to the hay meadows, Montanari and Stagno, 2015), and is characterised by the presence of quite well-preserved bridles and filter walls (built to regulate water inflow and outflow from the wetland, Montanari and Stagno, 2015). Unfortunately, the excavation of these archaeological remains did not return datable artefacts (like pottery) or charcoal fragments, making impossible to establish a chronology (Beltrametti et al., 2021).

On the contrary, at *Pian Brogione*, despite traces of appropriation aimed at cultivation, no fence walls surrounding the wetland have been documented (Beltrametti et al., 2021).

Materials and methods

Biostratigraphic analyses

Analyses of pollen, NPPs, and micro- and macro-charcoal fragments were carried out at the selected sites with the aim of identifying specific palynological assemblages associated with past management practices. This analytical characterisation was also aimed to better correlate main land-use changes to the strategies of construction and legitimation of the ownership, which emerged from the study of the conflicts on the '*Selva di Roccabruna*' and from the different archaeological remains identified in the area.

Table 2. Description of the profiles sampled for pollen, NPPs, micro- and macroscopic charcoal analyses.

Site	Depth (cm)	Description
Pian Brogione	0–20	Water
	20–58	Brownish herbaceous peat, slightly humified
	58–63	Grey-brownish silted clay with organic debris
	63–80	Light orange-brownish silted clay with gravel
	80–112	Light orange-brownish silted clay
	112–130	Light orange-brownish silted clay with gravel
	130–153	Light orange-brownish silted clay
	153–178	Light orange-brownish silted clay with gravel
	178–194	Dark brownish organic silted clay
	194–260	Dark brownish/black herbaceous peat with silt and fine sand, slightly humified
Moglia del Chirlo	0–30	Dark brownish peat, high humified
	30–46	Dark brownish peat, slightly humified
	46–65	Grey-brownish clay

At *Pian Brogione*, a 260 cm sediment core was sampled from a wetland located at the south-west margin of the plateau, in a small *Alnus incana* (L.) Moench grove. The stratigraphy (Table 2 and Figure 7) indicates the presence of fine mineral sediment at the bottom of the profile (260–194 cm), followed by fine mineral sediment and gravel (194–63 cm), and by peat at the top of the sequence (63–20 cm). Two sediment slices (from 82.5 and 245 cm depth) were sent to the Radiocarbon Dating Laboratory of the University of Waikato (New Zealand) for accelerator mass spectrometry (AMS) radiocarbon dating. For this site, a preliminary pollen diagram (lacking absolute dating) was published in Branch et al. (2003), allowing to explore different phases of peat sedimentation and their possible correlation to human activities. In addition, microcharcoal counting and NPPs analysis (restricted to fire-indicators fungi, coprophilous fungi and eggs of cattle parasites) were carried out as part of a follow-up LASA research project, enabling the identification of main palynological indicators of the use of controlled fire and grazing in the area (Menozzi and Montanari, 2010).

At *Moglia del Chirlo*, a total of 65 cm of peat sediment core was recovered from the centre of the wetland. The stratigraphy (Table 2 and Figure 7) shows the presence of clay at the bottom of the profile (65–46 cm), followed by quite humified peat (46–30 cm), and by high humified peat at the top of the sequence (30–0 cm). One sediment slice (from 35 cm depth) was sent to LABEC (Laboratory of nuclear techniques for Environment and Cultural Heritage, Florence, Italy) and other two sediment slices (from 8 and 48 cm depth) were sent to the Radiocarbon Dating Laboratory of Lund University (Sweden) for accelerator mass spectrometry (AMS) radiocarbon dating.

For both sites, sediment samples (2 cm^3) were prepared for pollen, NPPs and microscopic charcoal (fragments between 10 and 200 µm) analyses using standard pollen extraction techniques (Berglund, 1986). For *Moglia del Chirlo*, macroscopic charcoal (fragments > 250 µm) samples (2 cm^3) were prepared following Halsall et al. (2018) and processed with digital analysis estimation of particle area (mm^2 cm^{-3}) by using the software ImageJ v.1.54 (Abramoff et al., 2004; Schneider et al., 2012). Palynomorphs were identified with pollen atlas (Moore et al., 1991; Reille, 1992–1995) and the collection and photos of the Palynological and Archaeobotanical Laboratory of Genoa University. NPPs identification was based on previously published articles (e.g. Barthelmes et al., 2006; Carrión and Navarro, 2002; Cugny et al., 2010; Doveri, 2004; Ellis and Ellis, 1998; Feeser and O'Connell, 2010; Gelorini et al., 2011; Haas, 1996; Hawksworth et al., 2016; Kuhry, 1997; Liu et al., 2019; Pals et al., 1980; Payne et al., 2012; Prager et al., 2006, 2012; Van der Wiel, 1982; van Geel and Aptroot, 2006; van Geel et al., 1981, 1983, 1989, 2003; van Geel, 1978) and on two online image databases (Shumilovskikh et al., 2022; Wieckowska-Lüth et al., 2020).

Diagrams with pollen percentages, NPPs concentrations (no/g), micro- and macroscopic charcoal concentrations (no/g and mm^2/cm^3, respectively) were constructed using TILIA software (version 3.0.1.; ©1991–2020 Eric C. Grimm). The pollen sum (Total Land Pollen or TLP) includes trees, shrubs and herbs, excluding aquatics, spores and indeterminable grains. The pollen data were divided into Pollen Assemblage Zones (PAZ) based on the results of the cluster analysis (CONISS, sum of square roots, Grimm, 1987).

The number of pollen types in sediment samples – the so-called palynological richness (Birks and Line, 1992) – is one of the simplest and widely used proxies of past vegetation and landscape diversity (Berglund et al., 2008; Seppä, 1998; Veski et al., 2005). Palynological richness (Figure 7) was estimated by rarefaction analysis (Birks and Line, 1992). By removing the effect of different count sizes on the number of pollen taxa recorded, this method assesses the expected palynological richness if the pollen sum (usually the lowest total sum in the sequence) had been the same for each pollen sample (Odgaard, 2001).

Data analysis

In order to explore main land-use changes, for both sites we selected three groups of pollen taxa associated with different management practices for the specific study area, based on our knowledge of their relationship with different disturbances and their ecology (Nowak, 1987; Vagge and Mariotti, 2010): (1) taxa related to cultivated fields (i.e. Cerealia type, *Cannabis* type, *Centaurea cyanus* type, Papaveraceae), (2) anthropogenic/ruderal taxa (i.e. *Artemisia, Plantago major* type, *Rumex* type, Amaranthaceae, Urticaceae), and (3) taxa related to meadows/pastures (i.e. *Plantago lanceolata* type, *Centaurea nigra/jacea* type, *Lotus* sp., *Helianthemum* sp.). Due to the different production and dispersal of pollen amongst taxa and in order to achieve a closer approximation to land cover, for these reconstructions we used a simplification of the REVEALS model (Sugita, 2007) by applying correction factors developed by Binney et al. (2011) (Supplemental Table 1).

Concentrations of pasture-indicator NPPs (i.e. HdV-55A *Sordaria* type, HdV-113 *Sporormiella* type, HdV-261 *Arnium* type, HdV-368 *Podospora* type, TM-6 *Delitschia* type, HdV-546 *Trichodelitschia*), tree-cover-indicator NPPs (HdV-140 *Valsaria* cf. *variospora*, HdV-143 *Diporotheca webbiae*, EMA-3/4 *Melanconium alni*, HdV-44 cf. *Ustulina deusta* and *Hyphomycetes* cf. *Bactrodesmium*) and water-indicator NPPs (i.e. HdV-72 *Alona rustica*, *Centropyxis* sp., *Neorhabdocoela* (*Microdalyella* type 1-A, *Gyratrix* type 1-A, *Strongylostoma*), HdV- 28 *Copepoda*, KIU-117, HdV-179, HdV-170 *Rivularia* type) were used as independent estimations of grazing pressure, arboreal coverage and presence of stagnant water/temporary pools, respectively (e.g. Blackford and Innes, 2006; Carrión and Navarro, 2002; Cugny et al., 2010; Di Rita et al., 2010; Ellis, 1971; Feeser and O'Connell, 2010; Haas, 1996; Hawksworth et al., 2016; Jaklitsch et al., 2015; Jankovska and Komarek, 2000; Mitchell et al., 2001; Mudie et al., 2002; Pem et al., 2019; Prager et al., 2006, 2012; Scott, 1992; Shumilovskikh and van Geel, 2020; van Geel, 1978; van Geel and Aptroot, 2006; van Geel et al., 1983, 1989, 1996, 2007; Wieckowska-Lüth et al., 2020).

Charcoal fragments preserved in sediments are widely assumed to provide a record of past fire occurrence (Whitlock and Larsen, 2001). Unlike pollen, which stratifies continuously in fairly constant amounts, charcoal is produced in large quantities but at irregular intervals, as a function of fire regimes (i.e. the characteristic frequency, size and intensity of fire). The fire regime results from complex interactions between long-term trends in climate and local fuel availability (Heyerdahl et al., 2008), and human use and control of fire (Bowman et al., 2011). According to several studies on charcoal dispersal and deposition (e.g. Blackford, 2000; Carcaillet et al., 2001; Clark et al., 1998; Gardner and Whitlock, 2001; Long et al., 1998; Ohlson and Tryterud, 2000; Patterson et al., 1987; Tinner et al., 1998; Whitlock and Millspaugh, 1996), smaller, lighter microscopic particles (generally transported over long distances from the fire) were considered an indication of regional/extra local fire events. Local fires activity was instead estimated based on larger and heavier macroscopic fragments (normally settled closer to the fire edge) and on fire-indicator NPPs (i.e. HdV-1 *Gelasinospora* sp. (Kuhry, 1997; Shumilovskikh and van Geel, 2020; Shumilovskikh et al., 2015; van Geel, 1978) and charred coniferous wood fragments).

Finally, mean July air temperature reconstructions (Figure 7) based on fossil chironomid midges from Lago Verdarolo in the Tuscan–Emilian Apennines (Samartin et al., 2017) were used as a proxy for climate variations (Eggermont and Heiri, 2012).

Statistics

The R package relaimpo (Grömping, 2006) implements different metrics for assessing the relative importance of predictors in linear models. For our analyses, relaimpo was chosen to calculate the relative importance (RI) of climate variability (mean July air temperature), regional/extra local fire activity (microscopic charcoal), local fire activity (macroscopic charcoal and fire-indicator NPPs), grazing pressure (pasture-indicator NPPs), arboreal coverage (tree-cover-indicator NPPs) and presence of stagnant water/temporary pools (water-indicator NPPs) on selected groups of plant taxa associated with different management practices ('corrected' pollen data). To select the 'optimal' model given all possible sets of predictors, we used the Akaike's Information Criterion (AIC) values (Akaike, 1973). AIC incorporates both model fit and model complexity, with more complex models being penalised relative to simpler ones. Given a set of candidate models for the data, the one with the lowest AIC value was selected as the 'optimal' model, i.e. the most appropriate one in explaining the variation in the selected groups of plant taxa associated with different management practices during the time period recorded (Anderson, 2008; Zuur et al., 2009). As multiple tests were performed based on the same dataset, we increased the rate of type I error. To control this error rate, we adjusted the *p*-values by using the Holm-Bonferroni correction (Holm, 1979), a standard procedure which incrementally decreases the α levels to reach significance. The metric (lmg) proposed by Lindeman et al. (1980) decomposed the explained variance (R^2) into non-negative contributions based on semi-partial correlation coefficients that automatically sum to the total R^2. *p*-values indicating whether predictors differed significantly from each other in their contributions (in an exploratory sense) were obtained by bootstrap resampling. Information about the direction of the relationship between the variables (positive or negative correlation) was assessed by the value of the correlation coefficients (r).

Due to the limited number of NPPs taxa identified for the *Pian Brogione*' sequence (because of the specific research objective of the previous research, Menozzi and Montanari, 2010), the statistical analyses were run only for *Moglia del Chirlo.*

Results

Dating

AMS radiocarbon dates were calibrated into calendar years (cal. BP) using Clam software v.2.3.2 (Blaauw and Christen, 2011) (Table 3). For each site, the relationship between the calibrated calendar age and depth of sediment is presented in Supplemental Figure 1.

Pollen, non-pollen-palynomorphs, micro- and macroscopic charcoal

Pollen percentages are graphically displayed together with micro- and macroscopic charcoal concentrations (no/g and mm^2/cm^3, respectively) in Figure 4. Pollen assemblage zones (PAZ) are defined to facilitate the description and the interpretation of major vegetation and land-use changes. NPPs concentrations (no/g) are displayed in Figure 5.

Pian Brogione. PB1 (180–260 cm, *c.* 1210–1380 AD): Arboreal taxa reach ~43% of TLP and are dominated by *Fagus* and *Quercus* dec., with *Alnus*, *Corylus*, *Pinus* and *Abies*, and small amounts

Table 3. AMS radiocarbon dates and their calibration into calendar years (cal. BP).

Site	Lab. no.	Depth (cm)	Material dated	Uncal. 14C-yr BP	Cal. BP	Probability (%)
Pian Brogione	Wk-25049	80–85	Bulk sediment	279 ± 30	356–442	53.3
					285–332	38.3
					156–166	3.3
	Wk-25050	240–250	Bulk sediment	790 ± 47	665–783	95
Moglia del Chirlo	LuS 17943	8	Bulk sediment	55 ± 30	225–256	27.5
					110–139	25.8
					87–109	6.3
					77–85	2.2
					33–73	33.1
	Fi3425	35	Burned wood	315 ± 40	299–473	94.9
	LuS 17942	48	Bulk sediment	360 ± 35	422–494	44.3
					316–410	50.6

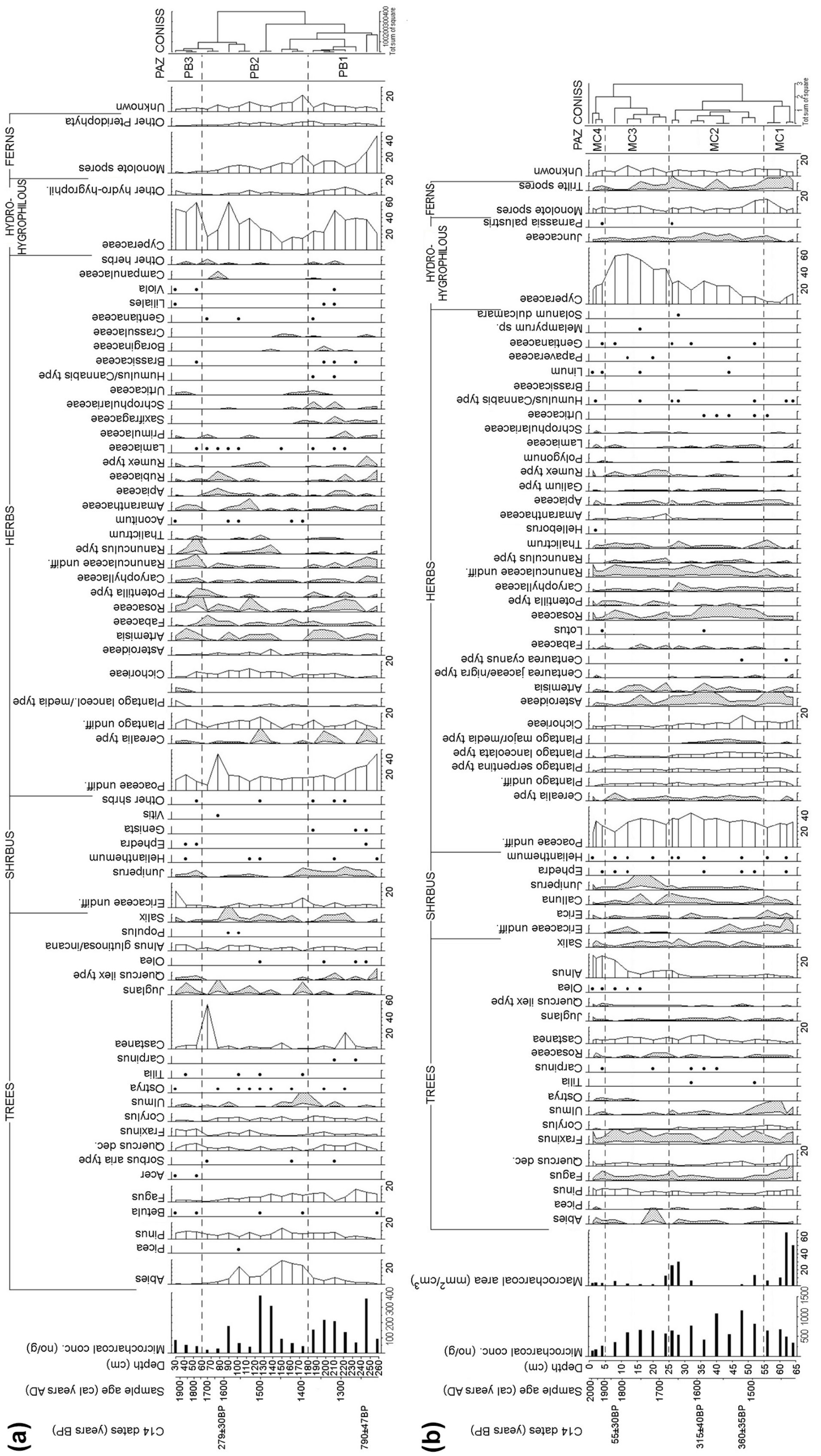

Figure 4. Diagram showing pollen percentages and micro- and macroscopic charcoal fragment concentrations (no/g and mm^2/cm^3, respectively). Pattern outlines indicate ×5 exaggeration. (a) *Pian Brogione*. (b) *Moglia del Chirlo.*

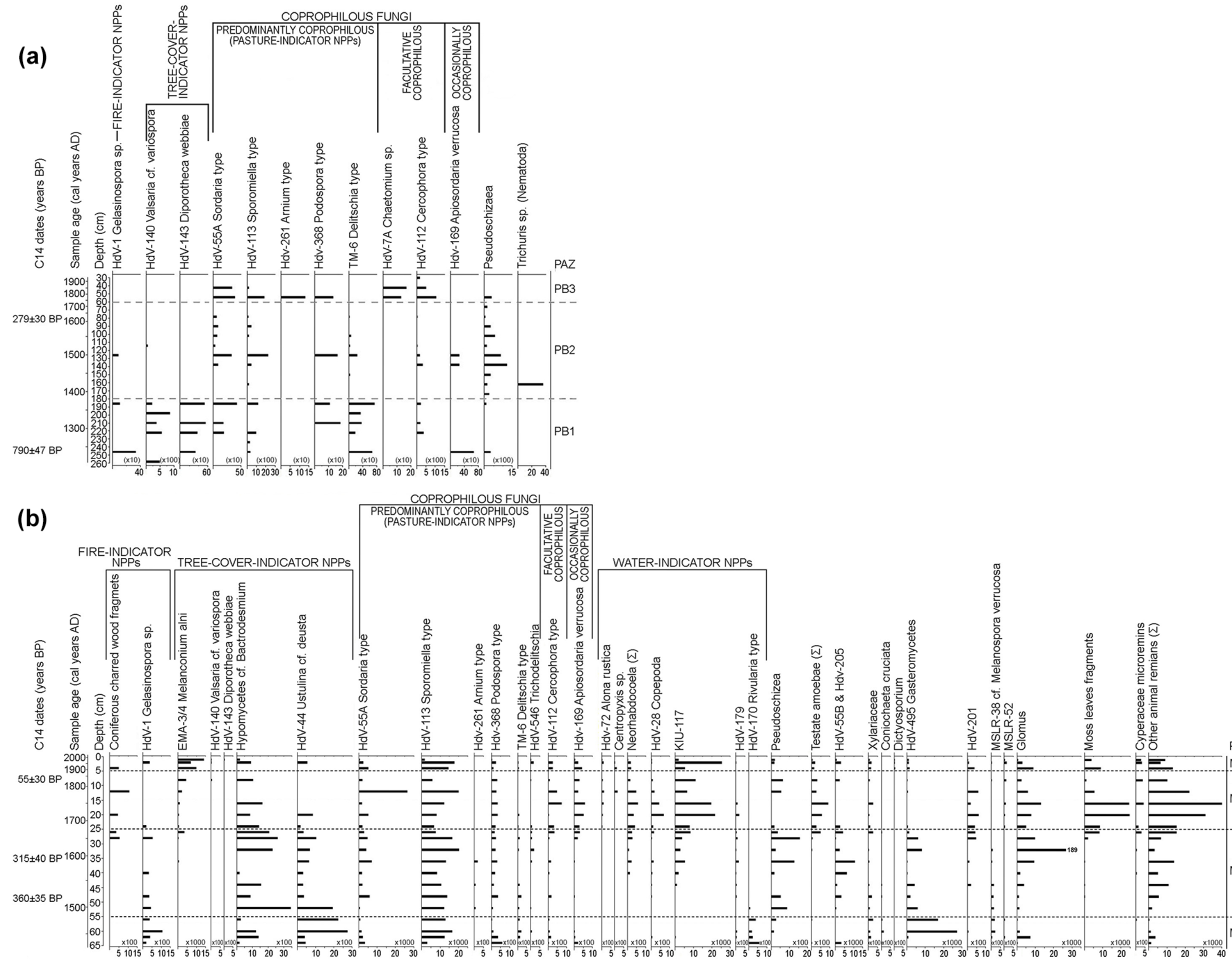

Figure 5. NPPs concentrations (no/g). (a) *Pian Brogione*. (b) *Moglia del Chirlo*.

of *Fraxinus*. A peak in *Castanea* (20%) is recorded around 1290 AD. Shrubs (6%) are mainly represented by Ericaceae (3.5%) and *Juniperus* (1.5%). Herbs make up over 50% of the TLP and are dominated by Poaceae, with *Plantago* and Cichorieae, and low percentages of *Artemisia*, Rosaceae, Ranunculaceae and Asteroideae. Some Cerealia pollen grains have also been identified. Quite high amounts of Cyperaceae and ferns are present (~33% and 20%, respectively). Palynological richness reaches its maximum around 1310 AD, and it is generally high during the whole period. Among NPPs, HdV-140 *Valsaria* cf. *variospora*, TM-6 *Delitschia* type, HdV-143 *Diporotheca webbiae*, HdV-169 *Apiosordaria verruculosa*, Hdv-1 *Gelasinospora* sp. and HdV-368 *Podospora* type have their highest value during this phase. HdV-113 *Sporormiella* type, HdV-55A *Sordaria* type, HdV-112 *Cercophora* type and *Pseudoschizaea* are also present, but with lower concentrations. Microscopic charcoal values are discontinuous, but quite high comparing to the following phases (with a peak around 1240 AD).

PB2 (60–180 cm, c. 1380–1740 AD): An increase in arboreal taxa (~52% of TLP, dominated by *Abies*, with *Pinus*, *Fagus, Alnus* and *Corylus*, with low percentages of *Quercus* dec. and *Fraxinus*) and a peak in *Castanea* (~55%) around 1700 AD characterise this period. A slight increase in Ericaceae (4%) and decrease in *Juniperus* (0.5%) are also registered. Herbs (~44%, mainly Poaceae, *Plantago* and Cichorieae, with small amounts of Asteroideae, Fabaceae and Rosaceae), Cyperaceae (26%) and ferns (12%) decrease. Few Cerealia pollen grains have been identified also in this phase. Palynological richness has its minimum around 1450 AD, and it is generally low compared to the previous period. NPPs are mostly represented by *Pseudoschizaea*, together with HdV-113 *Sporormiella* type, HdV-55A *Sordaria* type and HdV-368 *Podospora* type. Decreasing values comparing to the previous phase are instead registered for HdV-112 *Cercophora* type, HdV-169 *Apiosordaria verruculosa*, TM-6 *Delitschia* type, HdV-1 *Gelasinospora* sp., HdV-140 and *Valsaria* cf. *variospora*. HdV-531 *Trichuris* sp. (*Nematoda*) has also been identified. Microscopic charcoal concentrations are lower than during the first phase and are characterised by a discontinuous trend, with two peaks around 1480 AD.

PB3 (20–60 cm, c. 1740 AD–present): A decrease in arboreal taxa (40% of TLP, dominated by *Pinus*, *Fraxinus*, *Alnus* and *Quercus* dec., with low percentages of *Fagus*, *Juglans* and *Corylus*) and ferns (2%) is registered during this phase. *Abies* totally disappears. Shrubs (11%, with a maximum in Ericaceae at the top of the sequence) and herbs (49%, dominated by Poaceae and *Plantago*, with Rosaceae, Cichorieae, Ranunculaceae, *Artemisia* and Amaranthaceae) increase, as well as Cyperaceae (52.5%). Palynological richness rises until *c.* 1850 AD and then constantly decreases until the present time. The most common NPPs are HdV-113 *Sporormiella* type, HdV-112 *Cercophora* type, HdV-55A *Sordaria* type, HdV-7A *Chaetomium* sp., HdV-261 *Arnium* type and HdV-368 *Podospora* type. *Pseudoschizaea* is present, by with lower values than before. Microscopic charcoal concentrations are generally low compared to the previous phases.

Moglia del Chirlo. MC1 (55–65 cm, c. 1430–1480 AD): The pollen record is dominated by herbaceous taxa (over 61% of TLP), mainly composed by Poaceae, with *Plantago* and Cichorieae, together with small amounts of Asteroideae. Some Cerealia pollen grains have also been identified. Arboreal taxa (~34% of TLP) are dominated by *Quercus* dec., *Pinus* and *Corylus*, with small percentages of *Alnus, Fagus, Castanea, Ulmus* and *Fraxinus*. Ericaceae reach ~5% of the total pollen sum. Cyperaceae make up ~7% and ferns ~11.5%. Palynological richness is characterised by generally low values compared to the following phases. Among NPPs, HdV-495 *Gasteromycetes*, HdV-170 *Rivularia* type, HdV-44 cf. *Ustulina deusta*, Xilariaceae, MSLR-38 cf. *Melanospora verrucispora*, TM-6 *Delitschia* type, *Coniochaeta cruciata* and HdV-1 *Gelasinospora* sp. have their highest value during this phase. HdV-113 *Sporormiella* type, HdV-368 *Podospora*, *Glomus*, HdV-55A *Sordaria* type, other animals remains, HdV-55B & HdV-205, *Hyphomycetes* cf. *Bactrodesmium*, HdV-169 *Apiosordaria verruculosa* and HdV-112 *Cercophora* type are also present with quite high concentrations (but lower compared to the following periods). Microscopic charcoal concentrations are quite high and increasing throughout the period; macroscopic charcoal values are high, with two peaks at the bottom of the sequence.

MC2 (25–55 cm, c. 1480–1670 AD): This period is characterised by a further increase in herbs (~71% of TLP, mainly Poaceae, with *Plantago* and Cichorieae, and small amounts of Asteroideae, Ranunculaceae, Rosaceae and Amaranthaceae). Some Cerealia pollen grains have also been identified. A rise in Cyperaceae (~21%, progressively increasing) and a decrease in ferns (~9%) is registered. Ericaceae decrease (~2.5%, mainly *Calluna*), while *Juniperus* (~1%) is first recorded. The percentages of arboreal taxa also decline (~26%, dominated by *Castanea, Alnus*, *Pinus* and *Quercus* dec., and small percentages of *Fraxinus*, *Corylus*, *Fagus* and *Salix*). Palynological richness is higher than previously but discontinuous, with peaks around 1500, 1540 and 1580 AD (maximum value for the whole sequence), and a minimum around 1615 AD. NPPs are mostly represented by *Glomus*, HdV-113 *Sporormiella* type, HdV-55B & HdV-205, *Hyphomycetes* cf. *Bactrodesmium* and *Pseudoschizea.* Other animals remains, HdV-55A *Sordaria* type, HdV-495 *Gasteromycetes*, KIU-117, HdV-368 *Podospora* type, HdV-201, mosses leaves fragments, *Neorhabdocoela*, HdV-112 *Cercophora* type, Xilariaceae, HdV-44 cf. *Ustulina deusta, Testate amoebae*, HdV-169 *Apiosordaria verruculosa*, TM-6 *Delitschia* type, MSLR-38 cf. *Melanospora verrucispora*, HdV-549 *Trichodelitschia* and Cyperaceae microremains are also present but with lower concentrations compared to the other periods. Microscopic charcoal concentrations are characterised by discontinuous but generally high values (peaks around 1520 and 1560 AD); macroscopic charcoal values are low, with an increase around 1650 AD.

MC3 (5–25 cm, c. 1670–1900 AD): During this phase decreasing values are recorded for herbs (~59%, largely dominated by Poaceae, with Cichorieae, *Plantago*, Amaranthaceae and Ranunculaceae). Some Cerealia pollen grains have been identified. Instead, arboreal taxa make up over 36% of TLP and are dominated by *Alnus*, with *Castanea, Pinus*, *Quercus* dec., and small amounts of *Fraxinus* and *Fagus*. Ericaceae remains constant (~2.5%), while *Juniperus* increases (~2%). Cyperaceae (~53%) are characterised by maximum values during this phase, while ferns decrease (~6.5%). Palynological richness is still quite high and discontinuous (lower values compared to the long-term mean around 1680, 1750 and 1820 AD, and peaks c. 1720 and 1790 AD). In this period the most common NPPs are other animal remains, KIU-117, mosses leaves fragments, HdV-55A *Sordaria* type, *Testate amoebae*, *Neorhabdocoela*, HdV-169 *Apiosordaria verruculosa*, HdV-201, HdV-112 *Cercophora* type, HdV-368 *Podospora* type, HdV-28 Copepoda, EMA-3/4 *Melanconium alni*, HdV-72 *Alona rustica* and HdV-179. Quite high concentrations of HdV-113 *Sporormiella* type, *Glomus*, Cyperaceae microremains, *Hyphomycetes* cf. *Bactrodesmium*, HdV-55B & HdV-205, Xilariaceae and MSLR-52 are also present (but lower compared to the previous phases). Microscopic charcoal values are characterised by more stable values, decreasing towards the end of the period; macroscopic charcoal concentrations are low.

MC4 (0–5 cm, c. 1900 AD–present): During this period arboreal taxa reach their highest values (~53% of TLP) and are dominated by *Alnus*, with *Pinus*, *Castanea* and *Quercus* dec., and small amounts of *Fraxinus* and *Fagus*. Ericaceae and *Juniperus* decrease (both <1%). A decline is also recorded for herbs (~45.5%, mainly Poaceae, with Cichorieae, *Plantago* and Ranunculaceae, and small percentages of Rosaceae). Few Cerealia pollen grains have been identified. Cyperaceae are characterised by decreasing values (22%), while ferns remain constant (~6.5%). The mean value of palynological richness for this period is slightly lower than previously, with a peak c. 1920 and a decrease *c*. 1970 AD. NPPs are mostly represented by HdV-113 *Sporormiella* type, KIU-117, EMA-3/4 *Melanconium alni*, other animals remains, mosses leaves fragments, *Glomus*, HdV-55A *Sordaria* type, HdV-169 *Apiosordaria verruculosa*, Cyperaceae microremains (with mean higher value compared to the previous phases), HdV-112 *Cercophora* type, HdV-201, *Neorhabdocoela*, HdV-368 *Podospora* type, HdV-55B & HdV-205, HdV-55B & HdV-205, Xilariaceae, *Testate amoebae*, HdV-495 *Gasteromycetes*, HdV-549 *Trichodelitschia* and MSLR-52 (the last two with higher concentrations compared to the previous periods). Both microscopic and macroscopic charcoal concentrations are low and decreasing towards the most recent times.

Data analysis

For *Moglia del Chirlo*, the results of the statistical analyses between the three selected groups of plant taxa associated with different management practices and climate variability, fire activity, grazing pressure, changes in arboreal coverage and presence of stagnant water/temporary pools are presented in Figure 6 and Table 4. At this site, the occurrence of taxa related to cultivated fields (i.e. Cerealia type, *Cannabis* type, *Centaurea cyanus* type and Papaveraceae) was associated with a combination of local fire activity (based on NPPs (21.65%, significant negative correlation) and on macrocharcoal fragments (6.88%, not significant positive correlation)) and extra-local fire activity (6.89%, not significant positive correlation). Instead, mean July air temperature (45.95%, significant positive correlation) and tree coverage (12.34%, significant negative correlation) account for most of the variance in the presence of anthropogenic-ruderal taxa (i.e. *Plantago major* type, *Rumex* type, Amaranthaceae, Urticaceae). Finally, tree coverage (18.46%, significant negative correlation) is the strongest indicator of the presence of taxa related to meadows and pastures (i.e. *Plantago lanceolata* type, *Centaurea nigra/jacea* type, *Lotus* sp., *Helianthemum* sp.).

Discussion and interpretation

The observed changes in pollen, non-pollen palynomorphs and charcoal data allowed a comprehensive environmental history to be built and, in combination with information acquired from historical and archaeological data, helped us to address some specific issues posed in this study.

Vegetation structure and composition has significantly changed through time at the two selected sites and these variations are due to changes in land-use, fire management and altered water levels for pastoral purposes. These most important modifications are presented in Figure 7 (a and b), where lithology, climate variations, fire dynamics, palynological richness, sum of trees, shrubs, herbs, trends of taxa related to cultivated fields, anthropogenic/ruderal taxa, taxa related to meadows/pastures and hydro-hygrophilous taxa are summarised together with concentrations of fire-indicator NPPs, tree-cover-indicator NPPs, pasture-indicator NPPs and water-indicator NPPs.

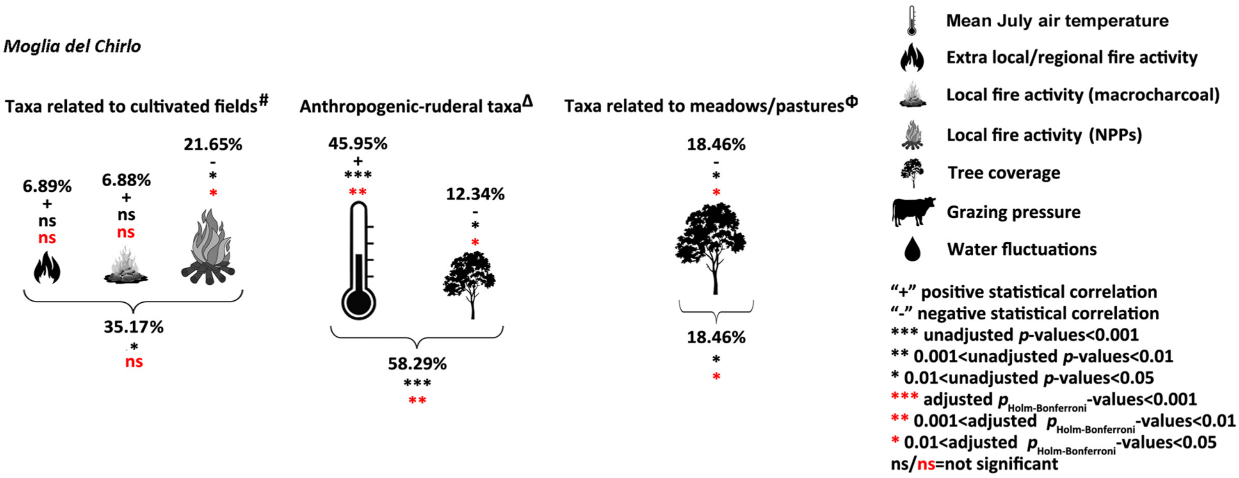

Figure 6. Best-fitted models according to the AIC and results of the relative importance analysis. The significance values, the direction of the relationship and the proportion of variance explained by each predictor are indicated.
#: Cerealia type, *Cannabis* type, *Centaurea cyanus* type, Papaveraceae; Δ: *Plantago major* type, *Rumex* type, Amaranthaceae, Urticaceae; ϕ: *Plantago lanceolata* type, *Centaurea nigra/jacea* type, *Lotus* sp., *Helianthemum* sp.

Table 4. Best-fitted model according to the AIC and results of the relative importance analysis for *Moglia del Chirlo*.

Group of taxa associated with different management practices	'Optimal' model	Predictors	lmg	*r*	*p*-value	adjusted *p*-value
Taxa related to cultivated fields#	Extra-local fire activity, local fire activity (charcoal) local fire activity (NPPs)				**0.048**	0.143
		Extra-local fire activity	6.64	+0.25	0.166	0.332
		Local fire activity (charcoal)	6.88	+0.26	0.193	0.332
		Local fire activity (NPPs)	21.65	-0.46	**0.011**	**0.043**
Anthropogenic-ruderal taxaΔ	Mean July air temperature, tree coverage				**0.0006**	**0.001**
		Mean July air temperature	45.95	+0.68	**0.0002**	**0.001**
		Tree coverage	12.33	-0.35	**0.013**	**0.013**
Taxa related to meadows/ pasturesϕ	Tree coverage		22.75	-0.48	**0.033**	**0.033**

The proportion of each predictor to the total explained variance (lmg), the correlation coefficient (*r*) and the significance value (both unadjusted *p*-values and adjusted *p*-value calculated with the Holm-Bonferroni method) are shown. Significant *p*-values (<0.05) are highlighted in bold.
#: Cerealia type, *Cannabis* type, *Centaurea cyanus* type, Papaveraceae; Δ: *Plantago major* type, *Rumex* type, Amaranthaceae, Urticaceae; ϕ: *Plantago lanceolata* type, *Centaurea nigra/jacea* type, *Lotus* sp., *Helianthemum* sp.

In particular, at *Pian Brogione*, between *c*. 1210 and 1380AD the landscape is dominated by a quite dense arboreal coverage (mainly *Fagus* and *Quercus*), also attested by high concentrations of tree-cover-indicator NPPs. At the same time, the peak in *Castanea* pollen around 1290AD suggests the existence of sweet chestnut cultivations (at the altitudinal upper limits of fructification of the species in this area of the Apennines), while the identification of Cerealia pollen grains between 1210–1240AD and 1320–1340AD indicates the possible presence of agricultural areas in the surroundings. Additionally, the occurrence of anthropogenic/ruderal taxa (i.e. *Rumex* type, Amaranthaceae and Urticaceae), taxa related to meadows and pastures (i.e. *Plantago lanceolata* type and *Helianthemum* sp.) and coprophilous fungi points to the presence of pastoral activities close to the sampled site. The high (with a maximum at *c*. 1240AD) but discontinuous values of microcharcoal concentrations and the identification of *Gelasinospora* (peaks at 1240 and 1370AD) suggest the use of fire for temporary agricultural practices or for controlling the heathland and opening up of new grazing areas. Furthermore, the abundance of Cyperaceae and other hydro-hygrophilous taxa points at the presence of a humid environment. Finally, the discontinuous values of palynological richness (with a minimum *c*. 1260 and a maximum *c*. 1310AD) are probably connected to modifications in vegetation openness during this period. Variations in palynological richness have in fact been previously explained in terms of changing forest density and presence of spatial heterogeneity and mosaic-vegetation structure (Birks and Line, 1992; Meltsov et al., 2011; Odgaard, 1999; Veski et al., 2005).

Between *c*. 1380–1740AD, the simultaneous local presence of *Abies, Pinus* and *Fagus*, together with Ericaceae, *Juniperus* and taxa related to meadows and pastures (mainly *Plantago lanceolata* type) suggests the existence of wooded-meadows close to the sampled site. However, the scarcity of coprophilous fungi compared to the previous phase may indicate a lesser frequentation of domestic animals in this period, while the low percentages of Cerealia suggest a reduction of agricultural activities. Instead, the peak in *Castanea* around 1700AD points again to the existence of sweet chestnut cultivations, maybe in the form of wooded-meadows managed with controlled fires (suggested by the discontinuous trend in microscopic charcoal concentrations and the sporadic presence of *Gelasinospora*). This spread of sweet chestnut groves in the area is probably connected to a phase of demographic expansion between 1650 and 1750AD attested for the Casanova parish and recorded by archival documents (Bagnara Mattrel, 1998). Furthermore, the oscillation in the percentages of Cyperaceae and other hydro-hygrophilous taxa and the high concentrations of *Pseudoschizea* suggest seasonal fluctuations of the water level (Di Rita et al, 2010; Revelles and van Geel, 2016; Scott, 1992), probably linked to land-use management. Palynological richness decreases at the beginning of this period, when the

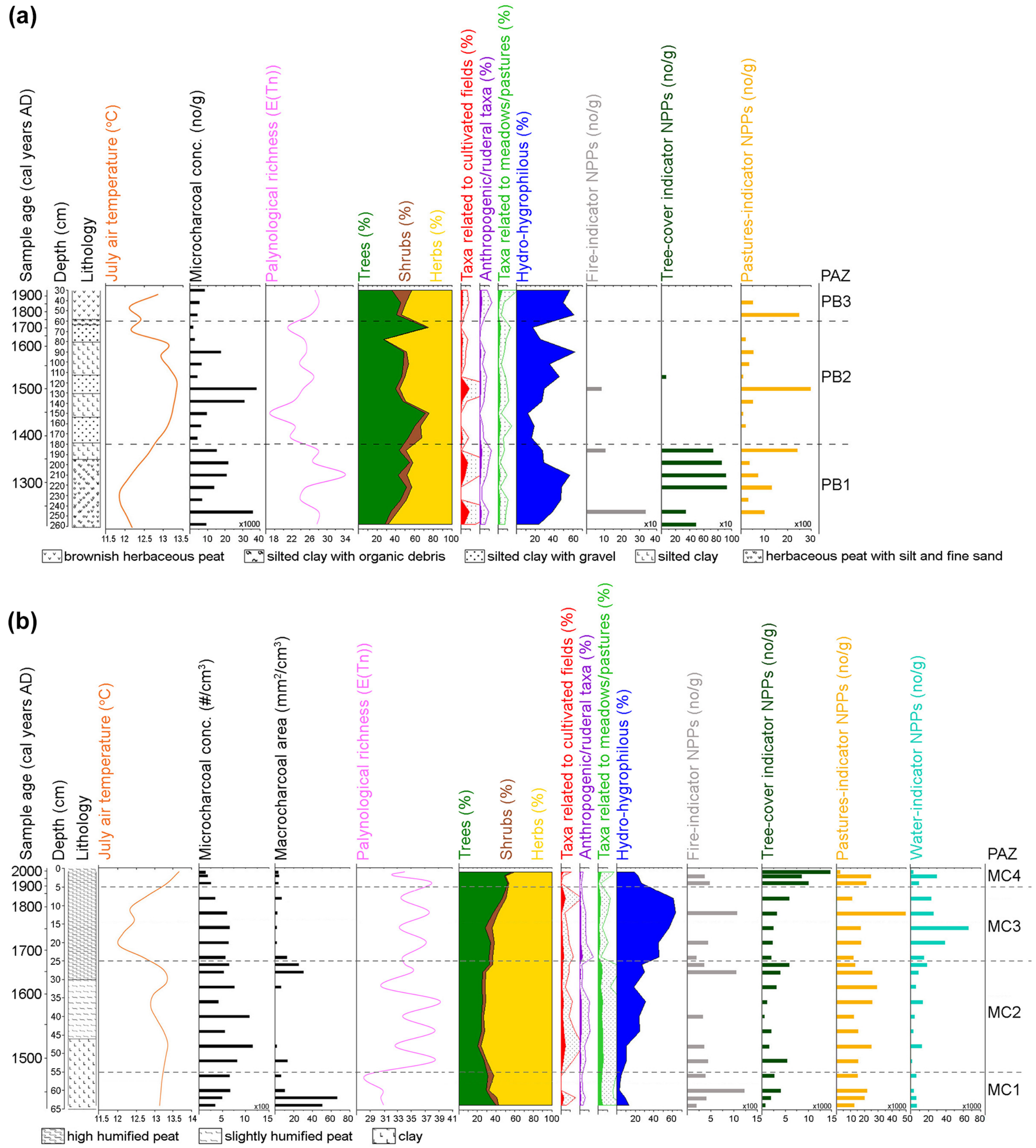

Figure 7. Summary diagrams showing information on the lithology and trends of mean July air temperature (°C), micro- and macroscopic charcoal fragment concentrations (no/g and mm^2/cm^3, respectively), palynological richness (E(Tn)), pollen percentages of total trees, shrubs, herbs, taxa related to cultivated fields ('corrected' pollen data), anthropogenic/ruderal taxa ('corrected' pollen data), taxa related to meadows/pastures ('corrected' pollen data), hydro-hygrophilous taxa, and concentrations (no/g) of fire-indicator NPPs, tree-cover-indicator NPPs, pastures-indicators NPP, water-indicators NPP. Pattern outlines indicate ×5 exaggeration. (a) *Pian Brogione*. (b) *Moglia del Chirlo*.

landscape is characterised by a higher arboreal coverage, and reaches its minimum *c.* 1450AD simultaneously with a peak in *Abies* and *Pinus* percentages. Then its values rise, pointing to more open conditions, with higher landscape diversity. Another decline in palynological richness is registered around 1700AD, concurrently with the presence of a denser arboreal cover due to the peak in *Castanea*.

Since 1750AD onwards, the site is characterised by the presence of a rather sparse woodland, dominated by *Pinus, Fraxinus, Alnus* and *Quercus*. *Castanea* and Cerealia abruptly decrease, pointing to the abandonment of sweet chestnut groves and temporary agricultural practices, as registered by the historical topographic map dated to 1827AD (Table 1). The subsequent increase in Ericaceae and in taxa related to meadows/pastures (only represented by *Plantago lanceolata* type) indicate the presence of heathlands and grazing areas, as described by the historical map dated 1853AD (Table 1). Simultaneously, the low values of microcharcoal concentrations and the disappearance of *Gelasinospora* indicate a less frequent use of fire for controlling the heathland. Rising percentages of Cyperaceae and other hydro-hygrophilous taxa, and decreasing concentrations of *Pseudoschizea* point to the presence of a humid environment (Revelles and van Geel, 2016), possibly connected to the creation of wet meadows for hay production attested by historical cadastral maps dated 1885–1895 (but not by the archival sources that classified the site as 'barren wasteland' (Figure 2), like all the wetlands inside the contested common-lands). As recorded by the cartographic sources and recent fields observations (Table 1), since the end of the 19th century, trees and herbs percentages decrease, while shrublands continue to increase, showing the gradual transformation of the area from grassland/pasture (even if the cadastral maps dated 1954 AD already describe the site as 'barren wasteland') to heathland, brushland and sparse woodland in 2000 AD. During this last phase, palynological richness is characterised by quite high values, probably connected to the presence of an open patchy landscape.

Moglia del Chirlo, instead, between *c.* 1430–1480 AD, is characterised by the presence of a scattered arboreal coverage dominated by *Quercus* dec., *Pinus* and *Corylus*, also attested by an increase in tree-cover-indicator NPPs throughout this period. The presence of taxa related to meadows/pastures (i.e. *Plantago lanceolata* type and *Centaurea nigra/jacea* type) and of coprophilous fungi suggests the use of management practices of environmental resources in the area. This is also confirmed by increasing microscopic charcoal concentrations and by peaks in macroscopic charcoal fragments and in fire-indicator NPPs around 1450 AD, probably linked to the use of controlled fire for opening up of new grazing areas at the local scale. Finally, the low percentages of hydro-hygrophilous taxa and of water-indicator NPPs attest the existence of a quite dry environment. Palynological richness is characterised by low values, possibly connected to the presence of a quite homogenous landscape (Veski et al., 2005).

Between *c.* 1480–1670 AD the site is characterised by a scarcer arboreal coverage (also testified by a general decrease in tree-cover-indicator NPPs) and by an increase of taxa related to meadows/pastures (i.e. *Plantago lanceolata* type and *Centaurea nigra/jacea* type), anthropogenic/ruderal taxa (i.e. *Plantago major* type, *Rumex* type, Amaranthaceae and Urticaceae) and taxa related to cultivated fields (i.e. Cerealia type, *Humulus/Cannabis* type and *Centaurea cyanus* type). This, together with low percentages of Ericaceae and *Juniperus* and quite high concentrations of coprophilous fungi, suggests the occurrence of meadows, grazing and agricultural areas close to the sampled site. The discontinuous but generally high microcharcoal values (compared to the other phases) and the low concentrations of macrocharcoal fragments and of fire-indicator NPPs (with only a peak at *c.* 1650) indicate a more sporadic use of controlled fire for management practices, at least close to the sampled site. Furthermore, the discontinuous values of hydro-hygrophilous taxa and of water-indicator NPPs suggest the presence of temporary pools. Finally, palynological richness in characterised by discontinuous values (with minimum *c*. 1520, 1560 and 1615, and peaks *c*. 1500, 1540 and 1580), probably due to changing vegetation openness during this period.

Between *c*. 1670–1900 AD a progressive rise of arboreal coverage (mainly *Alnus*) and of tree-cover-indicator NPPs is recorded at *Moglia del Chirlo*. A slight increase in taxa related to cultivated fields (i.e. Cerealia type and Papaveraceae) and anthropogenic/ruderal taxa (i.e. *Rumex* type and Amaranthaceae) points to the existence of agricultural areas close to the sampled site. Ericaceae and *Juniperus* increase, while taxa related to meadows/pastures (only represented by some pollen grains of *Plantago lanceolata* type) are characterised by a decrease, suggesting a possible reduction of grazing areas. Similarly, the decline in micro- and macroscopic charcoal concentrations indicates a decreasing use of controlled fire for management practices. The exponential increase in hydro-hygrophilous taxa together with high values of water-indicator NPPs between 1750 and 1790 AD suggest the occurrence of stagnant water at the sampled site, possible related to the construction of filtering walls built to regulate water inflow and outflow from the wetland as recorded by the archaeological investigations (Figure 3). These peaks are probably also connected to the presence of wet meadows for hay production attested by archival (Figure 2) and cadastral documents, in order to emphasise the productive use and economic importance of private properties. Finally, discontinuous values of palynological richness point to changing vegetation openness during this period, consistent with the use of cyclical management practices based on the rotation, on the same plot, of woodland, grassland and temporary cultivations.

Since *c*. 1900 AD onwards, the site is characterised by an exponential increase of alder woodlands (also supported by the presence of conidia of *Melanconium alni*, Prager et al., 2006). The decreasing presence of Cerealia and anthropogenic/ruderal taxa (only few pollen grains of *Rumex* type and Amaranthaceae) suggests a progressive abandonment of land-use practices (with the exception of tree management and grazing activities, as attested by the cadastral maps dated 1954 AD where the area is classified as a 'pasture'). Furthermore, the decline in micro- and macroscopic charcoal concentrations and in fire-indicators NPPs is possibly linked to the abandonment of the use of controlled fire. The progressive decrease in hydro-hygrophilous taxa until the present time (with a similar trend to water-indicator NPPs) indicate the gradual reduction of stagnant water at the sampled site, probably as a consequence of the abandonment of the filtering walls, which previously regulated the outflow of the water from the wetland (Figure 3). Finally, palynological richness decreases at the end of this period, pointing to closer forest conditions with lower landscape diversity, as suggested by other studies (Valsecchi et al., 2010).

Conclusions

This paper explored the relationships between vegetation dynamics and changes in management practices detectable from palynological analyses, and studied the access rights to environmental resources emerged from archival and archaeological sources. Past changes connected to land-use activities started a progressive process of landscape transformation, involving deforestation or burning in order to open clearings for agriculture, grazing or meadows close to the sampled areas. Likewise in other European contexts (Hjelle et al., 2012; Novenko et al., 2017; Revelles, 2021), indicator species of past agro-sylvo-pastoral systems have emerged in the form of wooded-pastures, temporary and permanent cultivations, as well as heathlands and wetlands managed for pasture and agriculture both at *Pian Brogione* and *Moglia del Chirlo*. Additionally, as pointed out both in other Ligurian (Cevasco and Moreno, 2013; Molinari and Montanari, 2018), Italian (Agnoletti et al., 2022; Fiore et al., 2024) and European areas (Tasser et al., 2007; Trosper et al., 2011), evidences of the disappearance of landscapes more 'complex' than today have been provided by our study. This complexity is not only linked to the existence of a landscapes mosaic derived from the cyclical use of management practices (based on the rotation, on the same plot, of grazing, sylviculture and temporary cultivations), but also to historical conflicts between local communities connected to ownership and access rights to environmental resources closely linked to these activities. The earlier abandonment of temporary agricultural practices at *Pian Brogione* (with a consequent increase of heathlands and pastures already since the end of the 19th century) compared to *Moglia del Chirlo* (where the presence of agricultural areas – together with the establishment of wet meadows – was recorded until (at least) the beginning of the 20th century) could in fact suggest not only a differentiation in the productive strategies of the two areas, but also a different connection with the ownership. At the end of the 19th century, in fact, while palynological analyses show that the two areas were characterised by a similar land-use (i.e. presence of hay meadows and pastures), the archival documents mention the productive use of *Moglia del Chirlo* but not of *Pian Brogione*, emphasising the presence of hay-meadows only in the private properties (owned by Fontanigorda families – who claimed the right of use, stressing the economic importance of the area – but located inside the common-lands of Casanova).

Our study also underlined the complexity of applying a multi-analytical approach. The information derived from the archival sources (documenting different strategies used by local actors and connected to ownership and access rights to environmental resources) allowed, in fact, a more articulate interpretation of the pollen diagrams: the reconstruction was not limited to the description of different land-use changes but tried to identify the socio-economic strategies responsible of these variations. At the same time, the palynological results made more difficult the deciphering of historical documents, bringing to light main reasons of lands' appropriation: all of them are, in fact, wetlands, suggesting the importance of water resources' control. Furthermore, by matching multiple sources, it was possible to achieve results not reachable otherwise: biostratigraphical analyses permitted, in fact, to propose a chronology for the construction of the filtering walls recorded by the archaeological investigations at *Moglia del Chirlo* (concurrent with the establishment of the wet meadows and – probably – also to the appropriation of part of common-lands). As a final point, our outcomes enabled a critical evaluation of the risks correlated to the processes of protection of the environmental heritage, which often take into account only the naturalistic importance but not to the social values responsible for the identification of different areas to be protected. By clarifying the nature, variety and intensity of past human activities that cannot be understood by analysing modern systems alone, the results here presented can increase the ability of decision makers and local stakeholders to anticipate future variations in ecosystems composition and dynamics, helping them to better evaluate the consequences of different conservation and valorisation strategies (Gillson and Marchant, 2014; Kozdasová et al., 2024; Plancher et al., 2024; Szabó et al., 2024). Coordination with governance actions that focus on ecosystem services, human well-being values, management and environment-friendly technologies is in fact a key opportunity for incorporating environmental archaeology and historical perspectives into the sustainability development dialogue, which contains both environmental and social dimensions (Bond and Morrison-Saunders, 2011; Dearing et al., 2012). However, it is important that these studies are integrated into governance structures and planning processes (including adaptive management and policy frameworks) and that the results are presented in accessible formats for different stakeholder groups (i.e. public, private or civil society sector), in order to urge land-users to preserve biodiversity and use natural resources more cautiously (Gelderblom et al., 2003; Jackson et al., 2009).

In agreement with ecological observations (Araújo, 2003; Fischer et al., 2008; Lavorel et al., 2017), our study confirms that the overall floristic richness is closely related to land-use at the two selected sites. Thus, even if promoting natural regeneration of forests in protected areas and concentrating land-use in open areas is important to promote diverse landscapes, it should also be taken into consideration that the maintenance of small wetlands (today considered areas of high naturalistic interest as part of priority habitats, but until the early 2000s only valued for their wildlife and hunting interest) needs different kind of management, due to their site-specific ecological and geophysical conditions and human-environmental interactions (Odgaard et al., 2018). Our aim was not only to characterise main dynamics of bio-diversification processes, but also to bring to light the historical dimension of the environmental dynamics of southern European mountains, increasingly influenced by the abandonment of historical agro-sylvo-pastoral practices. Long welcomed as processes of re-naturalisation, only in recent times, both in research and planning, the negative effects of these dynamics (i.e. loss of historical cultural landscapes, reduction of biodiversity, progressive disappearance of habitats resulting from past management practices of environmental resources, increasing risks of forest fires due to the excessive growth of natural forest formations and increasing risk in terms of hydrogeological disturbance due to the lack of slopes' management) have been finally pointed out, also in connection to issues linked to socio-economic and climatic changes. After decades of abandonment, management actions at *Pian Brogione* and *Moglia del Chirlo* may require an experimental re-introduction of historical practices (mowing of ancient grasslands, heathlands and bogs, use of controlled fire to restrain shrubby vegetation and promote the herbaceous layer, restoration of wetlands and their perimeters, etc.) in order to prevent the current pattern of natural forest succession that causes the continuous increase of woodlands (between 2005 and 2015 the total forested area of the Liguria region rose from 69.2% to 73.4%, Gasparini and Tabacchi, 2011; Gasparini et al., 2022), and the consequent loss of part of the environmental and cultural Ligurian heritage.

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Supplemental material

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