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Natural vs anthropogenic constraints address changes of plant biodiversity in Italy during the Holocene

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Abstract – **This paper explores the contribution of palynology to the reconstruction of past biodiversity, landscape dynamics, and anthropogenic impact in Italy. Pollen analysis of sediment samples recovered at selected archaeological sites provide evidence of vegetation changes in response to both climatic fluctuations and land use. The occurrence of tree species, such as *Fagus sylvatica* (beech) and *Quercus ilex* (evergreen oaks) in unusual ecological conditions illustrates the response of plants to climatic constraints and (over)exploitation, impacting on local biodiversity and regional vegetation trends. This studiy demonstrates how the application of palynological data can provide crucial insights into past human-environment interaction, offering new perspectives on ecological resilience and supporting long-term strategies for biodiversity conservation. Such an interdisciplinary approach is being used for modelling future environmental scenarios by the National Biodiversity Future Centre funded by NRRP.**

I. INTRODUCTION

Global plant biodiversity is undergoing a dramatic decline, driven by a combination of anthropogenic pressures and climate change [1]. Habitat loss due to agricultural expansion, deforestation, urban development, and pollution has led to the fragmentation and degradation of ecosystems critical for plant growing. Around 1 million km² of land is being degraded each year, largely due to forest cleaning for economic activities and soil erosion [2]. In this respect, woodlands, which account for over 80% of terrestrial biomass, are being dismantled at rates of 15–18 million hectares per year, equivalent to nearly 10 billion trees felled annually [3].

At the same time, higher temperatures, altered precipitation regimes, and increasing frequency of extreme weather events are reshaping the distribution of plant communities, often causing species to leave their natural habitats. Mediterranean ecosystems are particularly vulnerable, as they host a high number of endemic plant species with narrow ecological niches [4]. Furthermore, the combined effect of increasing land-use and climate change is accelerating the loss of genetic and functional plant diversity, with effects also in carbon storing, soil stabilisation, and water cycling [5]. Mitigating this trend is a priority for global conservation efforts.

On the other hand, landscapes once primarily modelled by economic activities are now undergoing rewilding processes, wherein human impact on land use is diminishing and natural ecosystems are being allowed to recover. For instance, nearly 117 million hectares (about 25% of the European Union's land surface) in less-disturbed rural landscapes are identified as ripe for rewilding [6]. These cases range from passive forest succession on former fields to dynamic floodplain restoration.

Such processes affecting plant biodiversity have revealed the importance of understanding how ecosystems respond to environmental pressures, both natural and anthropogenic. One of the main issues of the National Biodiversity Future Centre (NBFC) project funded by the National Resilience and Recovery Plan (NRRP) is to address long-term trajectories of plant populations, communities and ecosystems in order to evaluate the impact of conservation strategies. In this respect, the reconstruction of past biodiversity emerges as a crucial approach to obtain ecological baselines prior to and in relation to human disturbance, and manage future conservation and restoration strategies.

A. The ecological role of palynology

One of the most effective analytical methods for achieving the long-term ecological perspective is offered by palynology, which studies pollen and spores preserved in ancient sediments. This discipline provides direct evidence of past vegetation: by analysing pollen grains preserved in off-site natural deposits (lakes, peatbogs, floodplains), it is possible to get insights into community composition, ecosystem structure, and climatic conditions over time scales that span centuries to millennia [7]. Unlike modern ecological surveys, which offer a picture of current biodiversity, pollen analysis enables researchers to detect changes in plant assemblages, made of abrupt shifts or long-term trends. These events have been often linked to impacting environmental changes, including climate fluctuations, forest clearance, and agricultural intensification.

As a matter of fact, the long-term environmental dynamics have been mainly led by man since the mid-Holocene [8]. By studying pollen grains from in-site anthropogenic deposits (archaeological sites), palynologists can reconstruct the landscape evolution and gain details into land-use practices and human–environment interactions [9]. The interplay between climate change, local environment, and cultural factors has driven continuous ecological transformations, affecting plant and habitat distribution, and regional biodiversity. For this reason fossil pollen data play a crucial role in identifying areas of high ecological potential for rewilding or habitat restoration. By comparing past and present vegetation assemblages, it is possible to detect local or regional biodiversity losses, evaluate shifts in functional ecosystems, and possibly assess the success or limitations of future management strategies. In this sense, the palynological reconstructions help refine spatial conservation priorities, especially when integrated with other palaeoecological, genetic, and remote sensing data, as pursued by the activity of CN 5, Spoke 4 of the NBFC project.

B. Aim of the study

In this framework, the present study applies a palynological approach to investigate long-term biodiversity dynamics in Italy during the Holocene. In particular it highlights the potential of pollen analysis from in-site deposits in detecting past biodiversity and reconstructing ancient landscapes, through the examination of pollen data from selected archaeological contexts in Sardinia and Marche regions. In these areas the environment was shaped by complex interactions between natural processes and millennia of human influence, which affected the evolution of vegetation and biodiversity over times. By integrating botanical and ecological perspectives, this paper demonstrates how palynological research can contribute to support more grounded, site-specific strategies for habitat restoration, conservation prioritization, and environmental sustainability.

II. STUDY SITES

We focus on unpublished pollen data from two Italian archaeological sites, investigated by the Laboratory of Archaeobotany and Palynology of Sapienza University of Rome.

C. Monte Croce-Guardia

Monte Croce-Guardia, located near Arcevia (Ancona, Marche region), is one of the most significant Late Bronze Age settlements in central Italy. It is dated between the 12th and 10th c. BCE. The site lies on the Apennine Mountains at 670 meters asl on two adjacent hills and was extensively excavated between 2015 and 2022 by Sapienza University of Rome. Archaeological and geophysical investigations revealed a large village spanning approximately 22–25 hectares, with dozens of rectangular huts and additional structures organized in clusters [10].

This high-elevation site developed after the abandonment of smaller settlements in the surrounding lowlands, likely in response to socio-political and environmental changes following the collapse of the Terramare culture in northern Italy [11]. Archaeobotanical analyses at Monte Croce-Guardia have being provided crucial insights into past vegetation and plant use, contributing to understand the human-environment interaction and landscape transformations during a climatically unstable period at the end of the Bronze Age.

D. S'Urachi

Nuraghe S'Urachi is located in west-central Sardinia, near the Cabras lagoon and the Gulf of Oristano. The site, first established around the mid-2nd mill. BCE, consists of a central complex with multiple towers surrounded by a fortified wall and ditch. Excavations since 2013 have focused not only on the nuraghe itself but also on its surrounding context, aiming to explore how local communities interacted with external influences during periods of Phoenician, Carthaginian, and Roman contact [12].

A key feature is a large ditch dug in the 8th c. BCE, which accumulated organic-rich refuse under waterlogged conditions. This has led to exceptional preservation of organic remains. The pollen data obtained from the ditch filling, especially from layers dated to the 7th–6th c. BCE, provide insights into the site's environment and economy, revealing anthropogenic impact and changing land use in a dynamic cultural and ecological landscape.

III. METHODS

Pollen analyses were carried out on sediment samples recovered from archaeological layers in stratigraphic order. Fossil pollen was extracted from dry sediments using the chemical treatment (HCl 37%, HF 40%, NaOH 10%) and the ultrasonic sieving (10 µm) in use at the Laboratory of Archaeobotany and Palynology of Sapienza University of Rome [13]. In order to estimate pollen concentration, tablets with known content of *Lycopodium* spores were added to the sediments [14]. The identification of pollen grains was based on atlases and a reference collection available at the Laboratory [15-17].

IV. RESULTS AND DISCUSSION

Palynological researches in the investigated regions show the response of specific tree taxa to natural and anthropogenic constraints, impacting on local biodiversity and regional vegetation dynamics.

Pollen data from S'Urachi site reveals the presence of beech (*Fagus sylvatica*) outside its natural distribution range. The European beech is a mesophilous, shade-tolerant tree, whose distribution is influenced by rainfall and temperature. In Italy and southern Europe summer water shortage restricts beech trees to the moist temperate and submediterranean montane above 1000 m asl [18]. Extra-zonal beech woods are present at low elevations (400-800 m a.s.l. and even below) in meso-Mediterranean thermotype environments, taking advantage of particularly favourable pedological and microclimatic local conditions that prevent summer drought [19]. These lowland beech trees have a key role in the forest biodiversity due to its association with mesophilous and thermophilous deciduous species. Lacustrine pollen records and genetic data suggest that *Fagus* spread from small scattered populations after the Last Glacial Maximum. From the Early Holocene (ca. 11 ka BP), when higher average temperatures and rainfall precipitations progressively occurred, beech spread from its glacial refuges on the Southern Apennines and from lower reliefs of central Italy [20].

In Sardinia, the attestation of *Fagus* suggests that the reliefs of the island provided locally favourable conditions for this species, before it disappeared due to climatic and biogeographical constraints. Other palynological evidence of extinct mesophilous taxa (e.g. *Betula pendula*, *Tilia cordata*) seems to demonstrate that these species were present in the Sardinian highlands during the Holocene [21]. In addition, archaeobotanical data confirm the occurrence of beech trees in Italian lowlands until the Late Holocene and reveal that these areas played an important role in terms of biodiversity conservation. In fact, *Fagus* woods were a very common feature of the Italian forest landscape from 2 m a.s.l. to 800–900 m a.s.l. until recent times, when the rarefaction/disappearance of beech trees was mainly due to forest overexploitation [22]. The evidence from Nuraghe S'Urachi confirms the rapid vegetation dynamics of Mediterranean landscapes and the value of palaeoecological evidence in reconstructing past distributions of species now absent. It also deepen our understanding of how climate change, geography, and human activity have shaped the biodiversity patterns we observe today in Italy.

Pollen data from Monte Croce-Guardia site indicate that the Apennine landscape of the past was dominated by extensive evergreen oakwoods, with a significant presence of *Quercus ilex* (holm oak). This Mediterranean tree species was once much more widespread on the hilly slopes of eastern Apennine than it is today, when it survives only as scattered stands and isolated individuals, mainly on the calcareous southern slopes and ecologically niches of Parco Naturale Gola della Rossa e di Frasassi.

Palynological studies of Holocene natural sequences in central Italy especially revealed the imprints of economic activities on the landscape since the Bronze Age: changes in forest cover and the use of fire are clearly attested from the mid-Bronze Age in association with the expansion of cultivation and grazing [23]. Since climatic oscillations occurred during this time span, they could have exacerbated the effects of woodland clearance depauperating forest composition and structure of the Apennine Mountains, as well as causing erosion processes. In particular palaeoclimatic and palaeohydrological data seem to indicate conditions of aridity during the Late Bronze Age and suggests different drivers of vegetation dynamics in central Italy [24]. The contrast between present vegetation and past environments highlighted by fossil pollen from Monte Croce-Guardia suggests a different forest composition during the Late Bronze Age, with the expansion of evergreen oaks in the surrounding of the site likely due to more warm and arid conditions. Through times, a significant transformation of the landscape occurred: the forest cover was gradually reduced due to the intensification of agro-pastoral activities combined with deforestation, that favoured a transition from evergreen to deciduous woodland or to open anthropogenic landscapes. In this respect, the high abundance of wood remains of evergreen oaks found in the same archaeological contexts of the site confirms the natural occurrence of *Quercus ilex* in the area, as well as its systematic exploitation by human communities for fuel and craft-related purposes. For these reasons, the regression of evergreen oakwoods in the Apennine region can be interpreted as a palaeoecological indicator of environmental change over the Holocene, as well as the effects of human activities on biodiversity in a Mediterranean submontane ecosystem.

V. CONCLUSIONS

Pollen data presented in this paper demonstrate how palynology can reveal not only past plant diversity and forest composition, but also tangible evidence of anthropogenic pressure, landscape management strategies, and ecological responses to climatic shifts. The study of pollen taxa thus enables the reconstruction of biodiversity dynamics in Italy over time, in relation to environmental and climatic changes. Notably, on-site palynological analyses increase the quantity and resolution of pollen data available from regional off-site records. This enhanced detail allows for a more complete reconstruction of vegetation dynamics led by natural or anthropogenic pressure in the regions under examination. As such, palynology can meaningfully contribute to the definition and assessment of conservation strategies for present-day plant biodiversity in terrestrial ecosystems, taking into account the resilience of plant communities to past climatic changes and the cumulative impact of human activities on local environments.

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