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Measuring Millennial Biodiversity with Pollen: Archaeo-Data from Southern Italy

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***Abstract* – This research focuses on Southern Italy, where archaeo-palynological research from 14 archaeological sites in Campania, Basilicata, and Sicily provides high-resolution (decadal to centennial scale) data on past floristic diversity and land use over millennia. Pollen analysis reveals rich palaeo-floristic records reflecting ecosystems surrounding ancient settlements, with both quantitative and qualitative insights. β-diversity analysis, based on species composition and abundance, was used to assess the biological uniqueness of each site through Local Contribution to Beta Diversity (LCBD). Results demonstrate how pollen data are effective to assess long-term biodiversity changes and human impact on landscapes. Integrating archaeology, palaeoecology, and landscape analysis enables a comprehensive reconstruction of human–environment interactions, offering a valuable framework for the use of bioarchaeological data in cultural heritage and environmental monitoring. By linking past and present biodiversity, this research supports future conservation strategies for Mediterranean ecosystems. It aligns with NRRP-driven research and contributes to the development of predictive models for interpreting past ecosystems and informing future biodiversity scenarios.**

I. INTRODUCTION

A. Palynological and Archaeobotanical Research within the National Biodiversity Future Center (NBFC) Framework

The Laboratory of Palynology and Palaeobotany (LPP) of Modena contributes to the research activities within Spoke 3 of the National Biodiversity Future Center (NBFC), aiming to advance knowledge and awareness of plant biodiversity into long-term environmental transformations.

LPP's research is structured around two complementary approaches. The first focuses on reconstructing long-term trends in plant diversity through the analysis of both micro-remains (pollen, non-pollen palynomorphs [NPPs], and charcoal particles) and macro-remains (seeds and fruits). Archaeological and natural contexts—such as lake basins and high-altitude environments—are first selected for archaeobotanical and palynological sampling, after which standardized chemical treatments and microscopic analyses are applied to outline floristic inventories of past plant communities at each site. Pollen data, in particular, provide key insights for tracing endangered, native, and non-native invasive species, as well as for reconstructing fire activity, climatic variability, and human influence. All the resulting datasets are integrated into the BRAIN (Botanical Records of Archaeobotany Italian Network; [1]) database, ensuring structured data archiving and broad comparative potential. The second line of research concerns the review, digitalization, and expansion of archaeobotanical plant collections. This includes the update of reference materials, the acquisition of new specimens from national and international institutions, and the refinement of taxonomic identification protocols. In this context, the development of a unified and coherent data entry framework for plant records within BRAIN is currently underway, aiming to enhance data interoperability and analytical efficiency. BRAIN integrates both new metadata and available raw data. This advancement enables new, large-scale comparative studies across multiple archaeological and natural sites.

Within this framework, the present study explores millennial patterns of floristic diversity and land management in Southern Italy through a selection of case studies from the BRAIN database [2].

B. Applying Archaeo-Palynological Methods to Southern Italian Contexts

To investigate the change of biodiversity in past landscapes, we selected a series of archaeobotanical pollen studies conducted in archaeological sites distributed across Southern Italy, namely in the

Campania, Basilicata, and Sicily regions. This study is a further step of data elaboration on these sites [2]. The research explores floristic diversity via a palynological approach, providing qualitative and quantitative insights into the flora under long-term human pressures.

Palynology, as a multi-layered science, allows different interpretative scales—from landscape reconstruction to ecological and floristic detail. While the palaeoecological dimension of pollen studies is well established [3–7], the floristic level remains less explored due to intrinsic difficulties in taxonomic identification. However, the continuous improvement and wider accessibility of advanced optical equipment, combined with the creation of extensive and representative modern pollen reference collections, the publication of increasingly updated comparative keys and pollen atlases (e.g., [8]), and significant progress in pollen morphology studies, have enabled the identification of pollen types that were once considered indistinguishable (e.g., [9]). This includes the ability to detect cultivars and hybrids and differentiate between wild and domesticated varieties [10–13].

Changes in species composition, resilience, and distribution over time enhance our understanding of past Mediterranean ecosystems dynamics. These findings not only deepen our understanding of past cultural landscapes, but also provide data applicable to current biodiversity monitoring, conservation, and sustainability strategies—objectives strongly aligned with the mission of the NBFC and the broader goals of the National Recovery and Resilience Plan (NRRP).

II. MATERIALS AND METHODS

A multidisciplinary approach was adopted, integrating botanical expertise, and statistical, geospatial and data analysis tools to ensure a comprehensive re-evaluation of palynological data [2]. The investigation began with a query to the BRAIN database to identify archaeological and natural sites in Southern Italy with available palynological data (i.e., analyzed by the LPP team). A total of 14 archaeological case studies from Campania, Basilicata, and Sicily were selected for re-analysis, covering multiple chronological phases. Original pollen counts were standardized, and taxonomic updates were applied to align with current botanical nomenclature.

β-diversity, which quantifies the variation in species composition among sites within a region, was used here to assess past plant biodiversity. It is the amount of differentiation in community composition among a set of sampled units, with high values indicating strong compositional heterogeneity and low values indicating limited compositional variation [14]. By means of β-diversity-based statistical analyses, the biological uniqueness of the sites was assessed, exploring specific biodiversity properties such as compositional heterogeneity and the distinctiveness of local assemblages within each region. Due to potential limitations in pollen taxonomic resolution, β-diversity is defined here as the variation in pollen taxa composition among the analyzed sites. β-diversity was calculated region-wise from Jaccard-transformed pollen count data following the methods in Legendre & De Cáceres [15]. Each record's contribution to its region's β-diversity – Local Contribution to Beta Diversity (LCBD) – was then computed [15]. Significance threshold was set at 0.05. All elaborations were performed with R v. 4.5.0 [16] and the *adespatial* package v. 0.3-26 [17]. Plots were made with the package *ggplot2* v. 3.5.2 [18].

This integrated, standardized approach enhances the comparability of legacy datasets and supports more robust reconstructions of past biodiversity, in line with NRRP priorities and sustainability goals.

III. RESULTS

A. Selected Archaeological Sites from Southern Italy: Overview and Key Findings

Based on the established selection criteria, fourteen archaeological sites from Southern Italy were suitable for detailed data analysis due to their extensive sampling, well-documented contexts, and decadal- to centennial-scale resolution (**Table 1; Fig. 1**).

These sites, distributed across Campania, Basilicata, and Sicily, are comprehensively described in Clò et al. [2]. Total β-diversity was similar for the three regions: 0.31 for Basilicata, 0.35 for Campania, and 0.34 for Sicily, out of a maximum obtainable value of 0.5. Statistically significant LCBD values were found for one record (SBA4) out of five in Basilicata, one (SCA36) out of three in Campania, and two (SSI6, SSI32) out of six in Sicily. It must be underlined that a non-significant LCBD value is associated with a more generalist, less unique flora, but not necessarily less diverse (**Fig. 2**). The slightly higher β-diversity in Campania suggests greater compositional differentiation among sites, which may reflect more heterogeneous habitats or varying degrees of human impact across the region. Overall, these results demonstrate that pollen assemblages effectively capture both unique and widespread components of past vegetation, providing insights into long-term ecological and anthropogenic influences.

Although on-site deposits may exhibit lower pollen concentrations and some preservation issues compared to off-site contexts (**Fig. 3**), these characteristics are inherent to such settings and are carefully considered in the analytical approach. For metadata, chronological frameworks, and palynological interpretations, we refer to the original publication and the citations therein.

Table 1. List of the sites selected for this study and their BRAIN ID. The alphanumeric identifier code includes: (1) S for Southern Italy; (2) two-letter region codes (CA = Campania, BA = Basilicata, SI = Sicily); (3) number of site entry into BRAIN. Chrono-cultural phase abbreviations are as follows: B = Bronze Age; I = Iron Age; H = Hellenistic period; R = Roman Age; Ma = Middle Age.

BRAIN ID	**Site name** **Chrono-cultural phase**
SCA34	Stabiae—Villa San Marco R
SCA35	Stabiae—Villa Arianna R
SCA36	Pompeii—Civita Giuliana R
SBA1	Altojanni R, Ma
SBA4	Difesa S. Biagio H
SBA5	Fattoria Fabrizio H
SBA9	Pantanello (Pizzica Pantanello) H, R
SBA12	Torre di Satriano H
SSI6	Piazza Armerina—Villa Romana del Casale R
SSI7	Philosophiana (Sofiana) R, Ma
SSI8	Taormina—Teatro greco-romano H, R
SSI9	Stromboli—San Vincenzo B
SSI32	Morgantina—agorà R
SSI39	Mozia—Stagnone di Marsala I, R

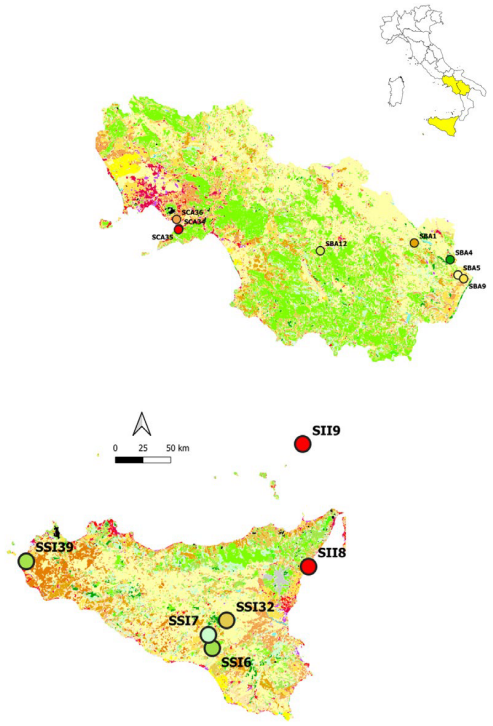

Fig. 1. Map showing the 14 selected research sites, with their BRAIN IDs in bold [1]. Colors correspond to the Corine Land Cover classification [19]. The map is an excerpt from the original version published in Clò et al. [2] and was created using QGIS version 3.42 [20].

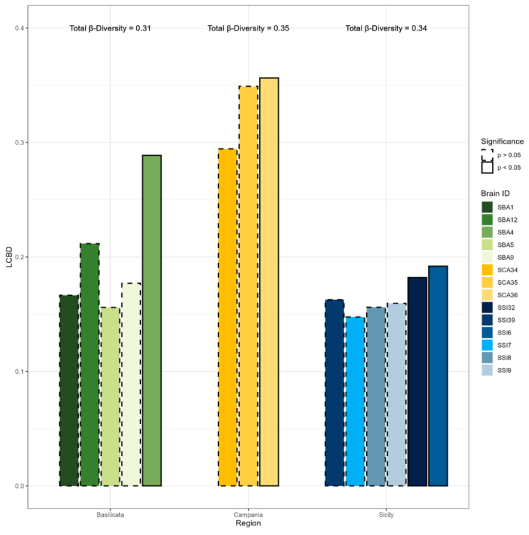

Fig. 2. Total β-diversity for Basilicata (green), Campania (yellow), and Sicily (blue). Bars indicate the Local Contribution to Beta Diversity (LCBD) for each site. Dashed lines: $p > 0.05$; solid lines: $p < 0.05$.

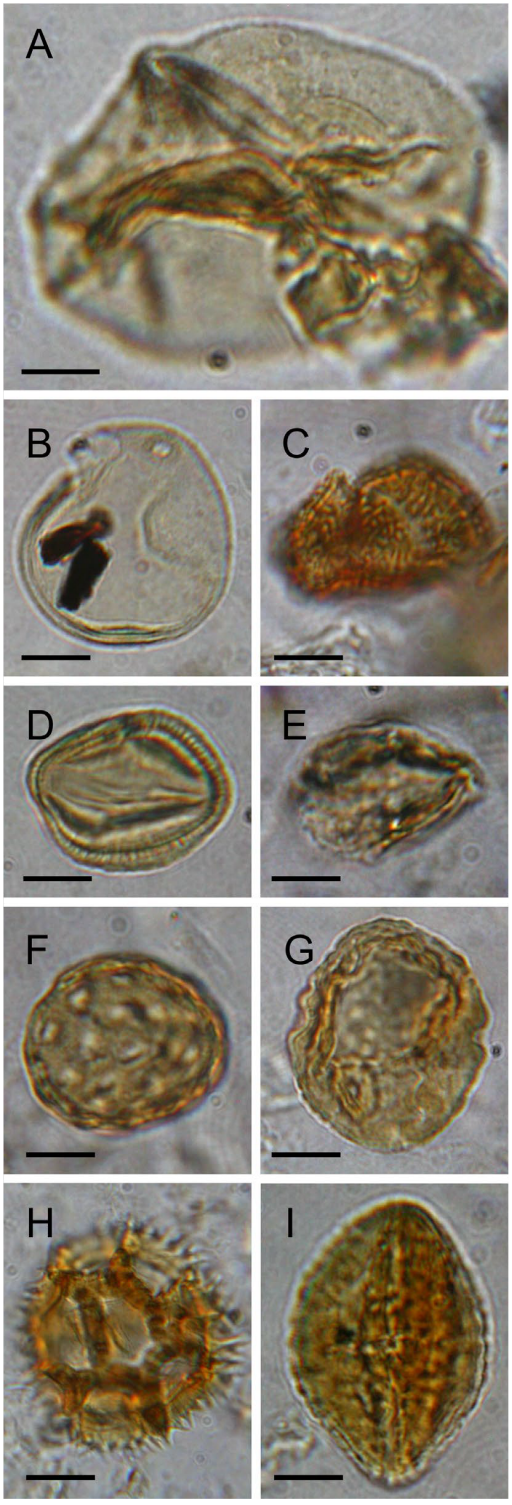

Fig. 3. Pollen from the site of Pantanello-Basilicata: A) Avena/Triticum *group; B) Poaceae wild grass group; C)* Olea europaea*; D)* Artemisia*; E)* Vitis vinifera*; F) Chenopodiaceae/Amaranthaceae; G)* Plantago*; H) Cichorieae; I)* Centaurea*. Scale bar is 10 µm.*

IV. DISCUSSION

Palynological analysis of archaeological sites requires multidisciplinary expertise, primarily from botanists, geologists, and archaeologists. Despite challenges like dating uncertainties and pollen preservation issues, careful sampling and detailed analysis allow for reliable palaeoecological reconstructions.

The selected sites across Southern Italy exhibit high floristic diversity (ranging from 34 to 131 pollen taxa per site), reflecting different degrees of anthropogenic influence. Distinct regional patterns emerge [2]: urban sites in Campania are characterized by evidence of arboriculture and ornamental plants, whereas sites in Basilicata and Sicily reflect agro-pastoral land use, with dominance of Mediterranean vegetation and pasturelands.

As shown by the β-diversity and LCBD computations, a considerable fraction of each region's records significantly contributes to the regional palaeofloristic diversity with their unique floras. Records with non-statistically significant LCBD values still show a contribution that is, in many cases, very close to the significant ones. Despite their non-significant LCBD, these sites are not characterized by poor biodiversity, but rather by a flora composed of more common and generalist taxa. This reflects the remarkable historical plant diversity of South Italy [2], further emphasizing the biodiversity and floristic importance of sites that is often seen as poor because of the long-lasting human impact.

Comparing past and present flora reveals the lasting influence of human activity on Mediterranean landscapes. Morphological pollen studies enhance understanding of plant diversity, including the identification of cultivars and archaeophytes. Pollen evidence also documents changes in species distribution, such as the disappearance of wild *Nymphaea alba* L. from Sicily; notably, the species has not been recorded in the region since the 20th century, according to floristic analyses [21].

V. CONCLUSIONS AND FUTURE PERSPECTIVES

This study demonstrates the potential of palynological analysis in archaeological contexts as a powerful tool to investigate past biodiversity, landscape management, and long-term human–environment interactions.

Through a multidisciplinary approach—integrating botanical, archaeological, statistical, and geospatial expertise—we examined pollen records from fourteen key sites in Southern Italy, revealing distinct regional patterns and varying anthropogenic impacts over time.

Pollen analyses offer crucial insights into past ecosystems, demonstrating their effectiveness in capturing high-resolution floristic-level information and enabling reliable morphological identifications. Although knowledge of plant diversity patterns traditionally relies on local, regional, and national floras or species distribution maps, palynology adds a complementary and diachronic perspective, enhancing our understanding of

flora dynamics over time. The pollen evidence also underscores how cultural choices, such as ornamental and agricultural use, contributed to shaping Mediterranean landscapes, highlighting a blend of aesthetic and functional land-use strategies.

These findings align with the objectives of the NBFC, the first Italian research and innovation center entirely dedicated to biodiversity. Funded by the Ministry of University and Research through the European Union's NextGenerationEU program, the NBFC supports scientific knowledge and innovation aimed at monitoring, conserving, restoring, and valorizing biodiversity across Italy. Within this framework, our research provides crucial insights into the ecological vocation of the territory and contributes to understanding the long-term dynamics of species and habitats-knowledge essential to inform current conservation strategies and policies, especially those targeting the protection of 30% of national territory by 2030 [22,23].

Looking ahead, this research paves the way for future studies that can deepen the comparison between past and present biodiversity. Matching palaeo-floristic lists with contemporary vegetation data of a site will allow us to evaluate local species continuity, loss, or reappearance, and understand ecological resilience or vulnerability through time. This approach may also contribute to modelling future scenarios in biodiversity conservation and sustainability.

Expanding this approach to underexplored areas, such as wetlands and inland habitats, will further enrich our knowledge of Mediterranean biodiversity dynamics and help identify conservation priorities supporting nature-based solutions for a more sustainable future [24].

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