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CONSILIENCE AND PALAEOVEGETATION STUDIES: WHY PLANT ECOLOGY NEEDS THE LONG-TERM PAST

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Abstract – Ecological research increasingly addresses landscapes shaped by multiple interacting drivers, including climate change, land use, disturbance regimes, biological invasions and socio-economic transformations. This short perspective argues that consilience, understood as the convergence of independent lines of evidence, is essential for interpreting present-day vegetation and for designing future-oriented environmental policies. This short article is based on a conceptual synthesis of palaeoecology, plant ecology, historical ecology and landscape studies, with particular attention to pollen records and other palaeovegetation proxies. The main result is that modern plant communities cannot be adequately interpreted as static natural systems: they are historical configurations produced by long-term interactions among climate variability, species persistence, migration, extinction, disturbance and human management. Palaeovegetation records are therefore indispensable for defining dynamic baselines, identifying resilience thresholds, detecting land-use legacies and distinguishing natural variability from recent anthropogenic change. The main conclusion is that plant ecology and landscape reconstruction should systematically integrate long-term evidence. Past vegetation histories do not provide simple models to restore, but they define the range of ecological possibilities, constraints and risks within which future conservation, restoration and forest policies must operate.

Keywords: consilience; palaeoecology; palaeovegetation; plant ecology; historical ecology; landscape reconstruction; conservation policy; ecological baselines

Introduction

Contemporary plant ecology faces a methodological and conceptual difficulty: it often studies ecosystems at a moment when those ecosystems have already been deeply transformed. Present-day vegetation is the outcome of long histories of climate variability, disturbance, migration, local extinction, soil development, land use and socio-economic change. For this reason, the structure of a plant community observed today cannot be understood only through present environmental parameters. The current distribution of species, the openness or closure of landscapes, the apparent naturalness of forests and grasslands, and the degree of resilience of vegetation after disturbance are all historical and long-term phenomena. A long-term ecological perspective is essential for defining meaningful conservation baselines and for questioning simplified ideas of "natural" ecosystems. Willis and Birks (2006) in their article titled "What is natural?" argued that palaeoecological records are crucial for understanding the range of natural variability, the legacy of past human impact, and the historical dynamics of biodiversity. This perspective was further developed by Willis et al. (2007), who emphasized that knowledge of past ecosystem responses can help identify resilience, thresholds, and realistic targets for future conservation. Together, these studies show that the past is not merely a background for interpreting present biodiversity, but an active tool for

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designing informed conservation strategies under ongoing climate and land-use change. This problem is especially relevant in Mediterranean landscapes, where human impact and natural forcings cannot be easily disentangled (Marignani et al., 2017). They have interacted over millennia in a highly sensitive environment: rapid hydrological and seasonality changes, volcanic eruptions, natural and anthropogenic fire, grazing, agriculture, forest exploitation and abandonment shaped the present landscape. In such settings, the distinction between natural and anthropogenic vegetation is rarely straightforward. Woodlands may reflect long-term persistence in refugial areas, recent recolonization after land abandonment, historical management or secondary succession after disturbance. Likewise, open habitats may be the result of climate constraints, or forest clearance due to grazing, fire, repeated cultivation, or a combination of these factors. A consilient approach is therefore needed (Izdebski et al., 2016). In ecological research, consilience means more than interdisciplinarity in a generic sense. It implies the convergence of independent evidence, each with its own temporal scale, spatial resolution and uncertainty. Pollen records, plant macroremains, charcoal, non-pollen palynomorphs, sedimentology, geochemistry, archaeological data, historical documents, vegetation surveys and ecological modelling do not simply duplicate one another. They answer different parts of the same question: how did vegetation arrive at its present configuration, and how might it respond to future change? Since the publication of Izdebski et al. (2016), the debate on consilience between the natural sciences, archaeology and history has become increasingly operational. The key point is no longer simply that different disciplines should communicate better, but that they should formulate research questions together from the beginning, rather than involving palaeoenvironmental scientists, archaeologists or historians only as late-stage consultants. This development directly extends the argument of Izdebski et al. (2016), who stressed that true interdisciplinary research requires shared terminology, co-designed projects, multi-archive evidence and hybrid forms of publication. Recent work has reinforced this perspective by showing that climate–society relationships cannot be reduced to simple correlations between environmental proxies and historical events. Haldon et al. (2018) argued that collaboration between historical and natural sciences can deepen our understanding of past societal responses to environmental change, but only when palaeoscientific evidence is embedded within historically and archaeologically informed models of social action. Similarly, Degroot et al. (2021) proposed a rigorous framework for climate–society studies, emphasizing mechanisms, uncertainty, scale, vulnerability, adaptation and resilience, rather than deterministic narratives of climate-driven crisis or collapse. A major advance concerns the treatment of spatial and temporal resolution. Recent syntheses show that regional climate curves may conceal highly variable local trajectories, which are often the scales most relevant to past societies. For example, the Holocene hydroclimate synthesis of the Aegean by Jacobson et al. (2024) combines 31 proxy records and highlights divergent local and regional patterns, underlining the need to compare palaeoenvironmental data with archaeological and historical evidence at appropriate scales. This responds directly to one of the main methodological warnings of Izdebski et al. (2016): chronological overlap alone is not sufficient to demonstrate causality. The field has also moved towards more concrete examples of "consilience in practice". Masci et al. (2025), for instance, integrate palaeoenvironmental, archaeological and historical evidence to reconstruct social–ecological dynamics in the Lake Volvi region during the last two millennia. Such studies no longer use natural archives merely as environmental background, nor historical evidence as simple confirmation of proxy trends. Instead, they ask how environmental change interacted with land use, institutions, demographic patterns, political structures and local ecological constraints. Overall, the main progress lies in the shift from consultation to co-production. Natural scientists, archaeologists and historians are increasingly expected to work within shared analytical frameworks, explicitly discuss uncertainty, and produce narratives that are both scientifically robust and historically meaningful. The central question is therefore not whether climate or environment affected past societies, but how, where, at what scale, through which mechanisms, and within which specific historical trajectories those effects became socially relevant. The aim of this short article is to discuss why consilience is central to ecological studies and why palaeovegetation research is indispensable for plant ecology and landscape reconstruction. It also suggests how knowledge of past vegetation dynamics can inform future policies for conservation, restoration and forest management.

Materials and Methods

This paper is a conceptual perspective based on published literature in palaeoecology, historical ecology, conservation biology and Mediterranean vegetation history. Rather than presenting new primary data, it synthesizes the contribution of long-term records to current ecological interpretation. Particular attention is given to pollen-based palaeovegetation studies, because pollen sequences provide one of the most continuous and spatially informative archives of past vegetation change. However, pollen data are considered here as part of a wider consilient framework, including charcoal records, archaeological evidence, documentary sources and ecological reasoning. The discussion is structured around three questions. First, what does consilience add to ecological interpretation? Second, why are palaeovegetation records necessary for understanding present landscapes? Third, how can information on past vegetation change support policies designed for future environmental uncertainty?

Results

Consilience as a condition for ecological interpretation

The value of consilience lies in its ability to reduce interpretative ambiguity. A decline in arboreal pollen, for example, may indicate climatic aridification, human clearance, fire, grazing pressure, soil degradation, or a combination of these processes. Without independent evidence, each explanation remains plausible but weakly constrained. If the same interval also contains increased microcharcoal, cereal-type pollen, coprophilous fungal spores, archaeological indicators of settlement and historical evidence for agricultural expansion, the interpretation becomes more robust. Conversely, if forest decline occurs without evidence of local human activity but in parallel with regional hydroclimatic stress, a climatic explanation becomes more likely. Recent developments have further strengthened the need to integrate palaeoecology, archaeology, botany, and ecology in the study of Mediterranean landscapes. Mercuri & Florenzano (2019) developed the concept of the Long-Term Perspective of Human Impact on Landscape for Environmental Change (LoTEC), explicitly linking botany, archaeobotany, palynology, interdisciplinarity, and sustainability. This represents a direct conceptual continuation of Marignani et al. (2017): the past is not only a contextual background, but an operational tool for interpreting environmental change and supporting landscape management. A major methodological advance is represented by BRAIN — Botanical Records of Archaeobotany Italian Network. BRAIN is presented as the first database focused on archaeological sites and human-induced environments in Italy and neighbouring Mediterranean regions, and as a large integrated collection of archaeo- and palaeobotanical data structured to facilitate FAIR data recovery. This directly addresses the problem, already highlighted in 2017, of data fragmentation and the need for comparable syntheses across sites and regions. ARBOREA — ARchaeoBOtanical geoReferenced rEcords of Ancient Italy (Moricca et al., 2025) further develops this framework by adding a finer analytical level focused on plant macro-remains from Central Italy, linking BRAIN site codes to standardized, georeferenced records of contexts, samples, taxa, plant parts, preservation types, and chronological phases, thus enabling multi-factor queries and more detailed diachronic comparisons.

Another important contribution comes from LandCover6k. Morrison et al. (2021) proposed a simple hierarchical classification of land-use systems based on archaeological and historical data, designed for global-scale synthesis and harmonization. For Mediterranean palaeoecology, the key point is that independent archaeological and historical land-use evidence can be combined with vegetation-cover records, including pollen data, to improve interpretations of long-term human impact. Archaeobotany has also gained renewed relevance in broader ecological debates. De Vareilles et al. (2021) reviewed the role of archaeobotany in identifying and describing past arable land use, emphasizing that developments in botanical, chemical, and ancient DNA analyses have increased the capacity of archaeobotany to address questions related to the Anthropocene and landscape transformations. The most recent and directly connected development is the proposal of Precision Land Knowledge of the Past (PLKP) by Mercuri et al. (2025). This approach uses site-specific palaeoenvironmental reconstructions to design tailor-made conservation and restoration strategies, avoiding generalized solutions and treating each landscape as the result of a specific historical trajectory. In this sense, PLKP can be considered an operational development of the approach proposed by Marignani and colleagues (2017). Finally, new pollen-based climate syntheses have updated the climatic side of the “climate versus human impact” problem. D’Oliveira et al. (2025) analysed 38 pollen records from southern France and Italy to reconstruct Holocene climate dynamics in the central Mediterranean, testing four quantitative reconstruction methods. Their results confirm the spatial and seasonal complexity of the Mediterranean climate signal and provide a stronger framework for distinguishing climatic forcing from anthropogenic landscape transformation. This logic is central to historical ecology. Mensing et al. (2020) explicitly proposed a consilience-driven approach to reconstruct forest land-use legacies, combining palaeoecological and socio-economic evidence. Their approach is important because it avoids both environmental determinism and simplistic human-impact narratives. Climate matters, but the same climatic phase may produce different vegetation outcomes depending on institutions, demography, land tenure, economic incentives and management goals. Human impact matters, but it cannot be understood without considering climatic constraints, ecological memory and species availability. Consilience is therefore not simply the accumulation of data. It is the critical comparison of independent lines of evidence. This comparison can confirm an interpretation, reveal contradictions, or show where uncertainty remains. In this sense, consilience is also a safeguard against overinterpretation, a common risk in landscape reconstruction.

Why palaeovegetation matters for plant ecology

Palaeovegetation studies are essential because they extend ecological observation beyond the short duration of instrumental records and modern surveys. Many ecological processes relevant to plant communities unfold over centuries or millennia: tree migration, forest expansion after deglaciation, loss of thermophilous or moisture-demanding taxa, soil development, repeated burning, grazing legacies and post-abandonment succession. These processes cannot be fully understood from contemporary data alone. Long-term evidence helps answer a deceptively simple question: what is natural? Willis and Birks (2006) argued that palaeoecological records are needed to address conservation problems such as biological invasions, wildfire regimes, climate change and natural variability. This point remains crucial. A plant community that appears degraded today may in fact preserve long-term ecological continuity; conversely, a woodland that appears natural may be a recent product of abandonment, plantation or selective management. Without temporal depth, ecological assessment risks confusing age, origin and conservation value. Pollen records are particularly informative because they document changes in vegetation composition through time. They show whether a species is a recent arrival, a long-term component of the landscape, a taxon formerly more widespread, or a remnant of past ecological conditions. They also reveal trajectories: gradual decline, abrupt collapse, recovery, resilience, threshold crossing or regime shift. These trajectories matter more than isolated states. Plant ecology often measures what is present; palaeovegetation explains how it became present. Mediterranean examples illustrate this clearly. Long pollen sequences from the Balkans, such as Lake Ohrid (Sadori et al., 2016, Donders et al., 2021) and from Italy, such as the dried out Lake Fucino (Vera-Polo et al., 2024, Roberts et al., 2025), show the role of refugia, persistence and long-term diversity loss under glacial–interglacial variability. Pollen sequences from central Italy show that Holocene forests were not uniform and static, but included changing combinations of deciduous oaks, beech, alder and evergreen taxa (Sadori, 2018; Beffa et al., 2025). Records from Sicily document the interplay between postglacial humidity, progressive aridification, fire and human land use (Sadori & Narcisi, 2001, Sadori et al., 2013, Palli et al., 2025). These cases demonstrate that modern vegetation is only one stage in a much longer sequence of ecological reorganization.

The past as a guide for future policy

The policy relevance of palaeovegetation does not lie in providing a single past landscape to restore. This is a misunderstanding. The past offers multiple reference conditions, each linked to specific climatic, ecological and cultural contexts. A Roman-period landscape, a medieval landscape, a preindustrial landscape and an early Holocene landscape are not interchangeable. Each represents a different combination of climate, population, technology, disturbance and land use. The first policy implication is that baselines must be dynamic. Restoration targets should not be selected as if ecosystems had a fixed natural state. Instead, managers should ask which historical states are ecologically plausible, socially desirable and resilient under future climates. Palaeoecology can identify the range of past variability and help distinguish long-term ecosystem properties from recent anomalies. The second implication concerns resilience and thresholds. Palaeovegetation records show that some ecosystems recover rapidly after disturbance, while others cross thresholds beyond which recovery is slow or incomplete. Forest expansion after demographic collapse, post-abandonment succession and vegetation recovery after reduced grazing pressure are important examples. However, recovery depends on propagule availability, soils, hydrology, climate, landscape connectivity and subsequent disturbance. Policies that assume automatic rewilding may therefore fail if ecological memory has been lost. The third implication concerns fire and land use. Fire is often treated either as a natural Mediterranean process or as a human disturbance. The long-term record shows that both views are incomplete. Fire regimes change through time according to climate, fuel availability, vegetation structure and human practice. Future fire policies should therefore consider historical fire regimes, but should not reproduce past practices mechanically. Current conditions, including rural abandonment, fuel accumulation, invasive species and climate warming, may have no exact historical analogue. The fourth implication concerns climate adaptation. Palaeovegetation records reveal how species and communities responded to past climatic changes, including arid phases, cooler intervals and rapid transitions. Such information can help identify refugial areas, climatically buffered habitats, taxa with long-term persistence, and landscapes vulnerable to drought-induced transformation. In a warming Mediterranean, these data are relevant for assisted regeneration, protected-area planning, ecological corridors and forest diversification.

Discussion and Conclusions

Consilience changes the way plant ecology interprets evidence. It shifts attention from single causes to interacting processes, from static states to trajectories, and from local observations to multi-scale histories. This is particularly important when ecological data are used to support public policy. Decisions on forest restoration, biodiversity conservation, fire management and landscape planning often depend on assumptions about what a landscape should be. Those assumptions are rarely neutral. They may privilege a recent memory of the landscape, a cultural ideal, or an imagined natural state.

Palaeovegetation studies make these assumptions visible. They show that landscapes have changed repeatedly and that ecological communities have histories. They also show that human societies have not only degraded vegetation, but have also created, maintained and transformed habitats. Some traditional landscapes contain high biodiversity because of long-term management. Other landscapes are impoverished legacies of overuse. Still others are undergoing spontaneous recovery after abandonment. A consilient approach helps distinguish among these cases. This perspective is especially relevant for the reconstruction of current landscapes. Landscape reconstruction should not be limited to mapping present vegetation or identifying former land cover. It should reconstruct processes: how forests contracted or expanded, how open habitats were maintained, how fire regimes changed, how species persisted in refugia, how cultivation and grazing altered vegetation, and how abandonment reshaped ecosystems. In this sense, palaeovegetation data are not ancillary to plant ecology; they are part of its evidential foundation. There is also a cautionary point. Long-term records do not remove uncertainty. Chronological resolution, proxy representation, pollen dispersal, taphonomy and spatial scale all affect interpretation. Pollen percentages are not vegetation maps, and charcoal particles are not direct counts of fires. Consilience is valuable precisely because it forces the researcher to compare imperfect evidence critically. Strong interpretations emerge not from a single proxy, but from coherence among independent records and from explicit recognition of uncertainty.

Plant ecology needs the long-term past because present vegetation is historically produced. Palaeovegetation studies reveal the temporal depth of plant communities, the role of refugia, the effects of climate variability, the legacy of land use and the conditions under which recovery or transformation occurred. Without this information, ecological interpretation risks treating recent states as natural, mistaking legacies for equilibria, and designing policies on inadequate temporal foundations. Consilience provides the methodological framework for overcoming these limitations. By integrating palaeoecology, historical sources, archaeology, modern vegetation data and ecological theory, researchers can produce more robust reconstructions of landscape change. These reconstructions are not only retrospective. They are essential for future-oriented policy. They help define dynamic baselines, identify resilience thresholds, evaluate rewilding potential, design climate adaptation strategies and avoid restoration targets that are historically or ecologically unrealistic. For plant ecology and landscape planning, the past is not a museum of lost environments. It is a source of ecological evidence about change, persistence and possibility. In an era of rapid climate warming and accelerating land-use transformation, palaeovegetation studies should therefore be considered indispensable to understanding the present and planning the future.

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