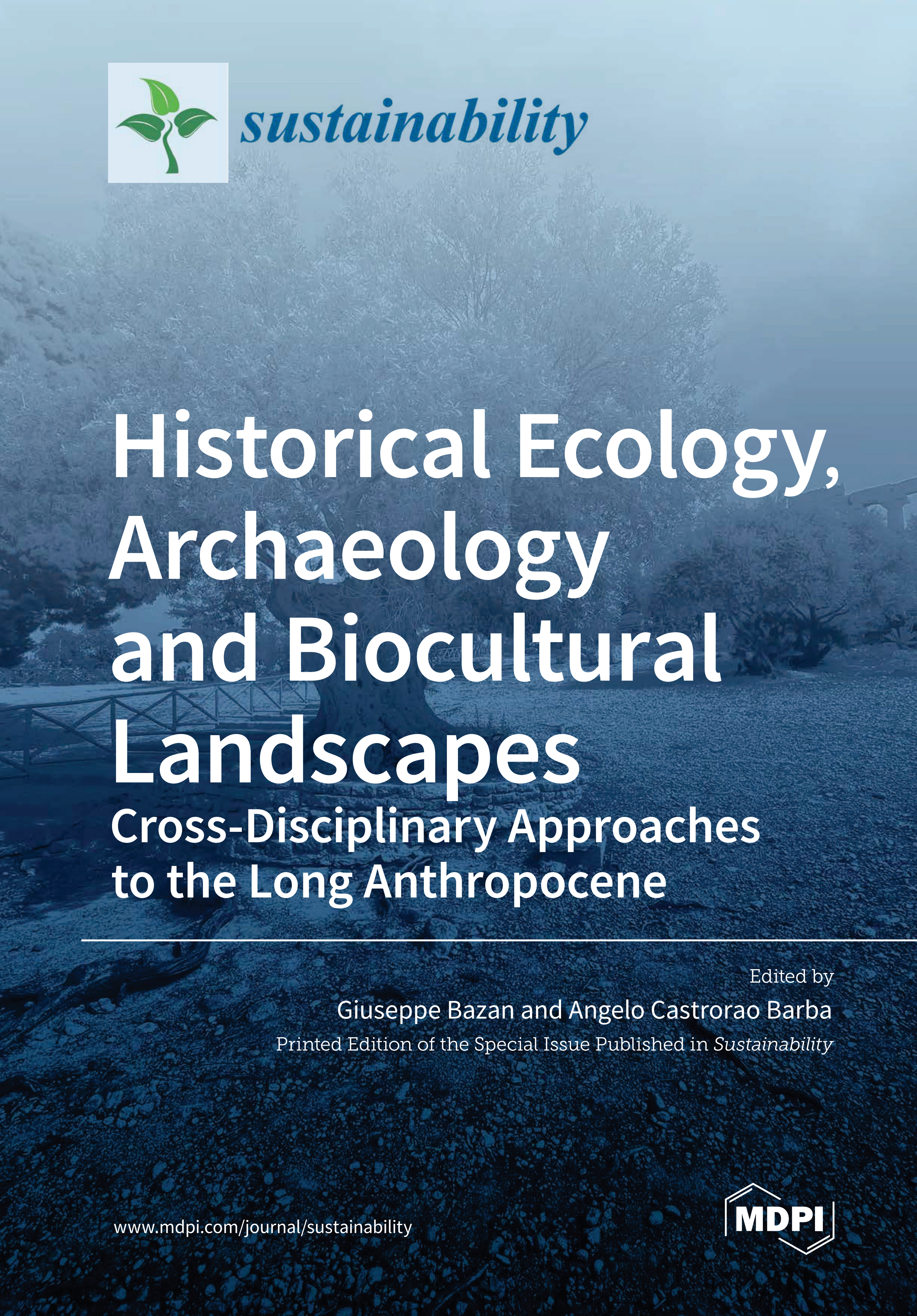

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Historical Ecology, Archaeology and Biocultural Landscapes

Cross-Disciplinary Approaches to the Long Anthropocene

Edited by
Giuseppe Bazan and Angelo Castrorao Barba

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About the Editors

Giuseppe Bazan

Giuseppe Bazan is Professor of Environmental and Applied Botany at the University of Palermo. He teaches courses of Applied Botany and Landscape Ecology in the Degrees in Urbanism and Regional and Landscape Planning, a course of Historical ecology in the Degree in Archaeology and a course of Botany in the degree in Biological Science of University of Palermo.

His research focuses on landscape ecology and, as a botanist, his principal interest is in the role plant communities play in understanding the formative processes of the land mosaic. By combining field studies on plant biodiversity and G.I.S. techniques, his research addresses many complex aspects of landscape at both spatial and temporal scales.

Another new field of research of Giuseppe Bazan concerns how the extreme environmental conditions affect the production of biologically active compounds in plants and how cultivation affects the synthesis of bioactive compounds that plants produce under stressful conditions.

Giuseppe Bazan was the Principal Investigator of the UNIPA Team of the EU FP7 Project "MEditerranean MOntainous LAndscapes: an historical approach to cultural heritage based on traditional agrosystems (MEMOLA). In this interdisciplinary project, Giuseppe Bazan placed an emphasis on the role of vegetation science in the understanding of landscape history.

He is Principal Investigator of the research project "Harvesting memories. Ecology and Archeology of Monti Sicani landscapes (Central-western Sicily)", born from the collaboration between Bona Furtuna LLC (project-funder), the University of Palermo and the Superintendency BB.CC.AA of Palermo.

Angelo Castrorao Barba

Angelo Castrorao Barba is a specialist in changes in rural settlement patterns from the Roman period to Late Antiquity and the Early Middle Ages in the Mediterranean area and in particular of Sicily during Late Antiquity, Byzantine and Islamic periods. He was postdoc researcher at the Consejo Superior de Investigaciones Científicas (CSIC)/Escuela de Estudios Árabes (EEA) of Granada (Spain), the DFG Center for Advanced Studies 'Migration and Mobility in Late Antiquity and the Early Middle Ages' of the University of Tübingen and the Royal Netherlands Institute in Rome (KNIR). He was field-director and researcher in the project "Harvesting Memories: Ecology and Archaeology of Monti Sicani landscapes (Central-Western Sicily)" (University of Palermo). Currently (2022–2024) he is post-doc researcher in the PASIFIC programme funded by Marie Skłodowska-Curie Actions (H2020-MSCA-COFUND-2018), hosted by The Polish Academy of Sciences-Institute of Archaeology and Ethnology/Centre for Late Antique and Early Medieval Studies (Warsaw/Wrocław, Poland) as PI of the project "IS_LANDAS Islamicate landscapes in southern Andalusia and western Sicily: patterns of change in settlements and rural communities between Late Antiquity and the Islamic age". He is also PI of two projects focused in Late Antique, Byzantine and Islamic Sicily: "The suburbium of Balarm (Palermo, Sicily) during the Islamic period (AD 831-1071/1072): new archaeological perspectives" funded by The Barakat Trust (2021–2022); "Patterns of change in the countryside of Late Antique, Byzantine and Islamic Sicily (5th–11th c. AD): settlements, agrarian estates, economy and environment" funded by Gerda Henkel Stiftung (2023–2024). His major publications include La fine delle ville romane in Italia tra tarda antichità e alto medioevo (III-VIII secolo) (Bari: Edipuglia 2020) and the edition of the collective volume Dinamiche insediative nelle campagne dell'Italia tra Tarda Antichità e Alto Medioevo (Oxford: Archaeopress Archaeology 2018).

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Editorial

Historical Ecology, Archaeology and Biocultural Landscapes: Cross-Disciplinary Approaches to the Long Anthropocene

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1. Conceptual Background

From the local to the global scale, human impact is the real protagonist of the Anthropocene. It is impossible to understand ecosystems and the landscape without considering the long-term processes of anthropic activities. The driving forces in landscape change are strongly related to historical dynamics. Changes in political regimes, social structures, economic modes of production, cultural and religious influences—which all traditionally fall within the domain of the humanities—are phenomena entangled with many ecological and environmental factors. Thus, understanding landscapes in the Anthropocene is impossible without a cross-disciplinary approach.

During the last few decades, the discipline of archaeology has especially increased its focus on human-environment interactions and landscape-formative processes.

Landscape trajectories can be investigated through two different points of view: reconstructing vanished landscapes and examining the historical layers in contemporary landscapes. Vanished landscapes are the main object of study for many “archaeologies” (landscape archaeology, environmental archaeology, geoarchaeology) and “paleo” disciplines (paleoecology, paleoclimatology, paleogeography) that aim to reconstruct the non-visible past. The second approach focuses on the contemporary landscape as a palimpsest formed by various historical layers in which evidence of the relationship between the human footprint and ecological patterns can be detected. Nevertheless, both approaches, one based on “hidden traces” and the other on current layered contexts, share a concept of landscape as a complex and heterogeneous mosaic of spaces where it is possible to read both the temporal dynamics (historical stratification) and the specific characteristics of individual patches situated in various ecotopes, a series of hierarchical relationships between climatic conditions, substrates, landforms, soils, vegetation and human activities.

Although the potential of a historical approach has been recognized for a full understanding of the processes in progress and in future trajectories of landscape, full interdisciplinary integration is still weak. It should be noted that an interdisciplinary approach doesn’t mean that different disciplines study the same landscape at the same time but instead means that different disciplines merge together in new integrated ways. There is a long way to go to achieve this integration.

Recently (2015–2022), a synergy between archeology and landscape ecology, declined as a “middle-earth” between landscape archaeology and historical ecology, has inspired the Harvesting Memories Project [1]. This project concentrates on the Sicani Mountains as a case study, analyzing a schedule of long-term human-environment interactions with an interdisciplinary and multi-methodological approach thanks to: surveys [2]; archaeological excavations [3]; multi temporal land use changes [4]; vegetation dynamic studies [5]; archaeobotanical and archaeozoological analyses [6] and geological raw material catchment area studies [7].

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To stimulate an interdisciplinary debate, a symposium was organized at the 10th IALE World Congress, held in Milan (Italy) in July 2019, entitled "Landscape trajectories during the long Anthropocene: dialogues between Ecology and Archaeology". The legacy of this symposium is collected in this Special Issue, whose main aim is to combine and stimulate an interdisciplinary debate between landscape archaeology, historical ecology, human-environment interaction and sustainability.

2. Structure of the Studies

The twelve papers (ten research articles and two reviews) in this Special Issue can be organized according to several aspects.

The majority of presented case studies are about Italy: four articles [8–10] and one review [11] are on Sicily and one article is on Southern Italy [12]. Four articles regard different parts of Europe, including the French Pyrenees [13], Scandinavia [14] and Slovenia [15]. The remaining studies address [16], California/French Polynesia [17] and a review on Brazil [18]. This demonstrates the global interest in the topic of Historical Ecology.

The different topics addressed by the articles of this Special Issue are divided into three thematic sections: (1) Historical Ecology; (2) Archaeology and Long Anthropocene; (3) Anthropocene and Landscape Heritage.

The first section deals with theoretical themes and case studies from the discipline of "Historical Ecology".

Crumley [19] presents the interdisciplinary and applicative context in which historical ecology moves and shows the importance of (1) bridging the past with the present (and future) to understand current ecological problems, and (2) developing solutions and strategies based on such an understanding, integrating research results into policies. In this respect, the article presents "historical ecology" as a framework to study ecosystems, landscapes, and waterscapes in a long-term perspective. This paper evaluates how practitioners could adjust aspects of practice and improve access to policy makers, and the discussion applies to regions and localities everywhere.

With their case study of Scandinavian infield systems, Eriksson et al. [14], shows how the theoretical framework of historical ecology is fundamental for understanding the meaning and intensity of landscape changes but also for applying different theoretical models such as the theory of human niche construction as a framework for evaluating the role of internal and external driving forces in human-environment interactions.

Even beyond Europe, historical ecology has had various thematic developments and interdisciplinary applications as presented by Lazos-Ruíz et al.'s [18] review regarding Brazil. Brazilian historical ecology is shown to be an interdisciplinary field in which environmental sciences, anthropology, and archeology meet to address issues such as the impact of European colonization in landscape transformations (especially of Amazon and Atlantic Forest biomes) and also in highlighting the great role played by Brazilian ethnic diversity, even if some geographic areas (such as Pantanal, Caatinga, Pampa, and Cerrado biomes) still need to be better investigated, as well as issues concerning animal species or seascapes.

The second section concerns approaches related to the long duration and the dynamics of the Long Anthropocene according to archaeological perspectives but always from an interdisciplinary perspective.

The long-term sustainability of mountain landscapes is a central theme of the case study on the Sicani Mountains, analyzed by Bazan et al. [9], in which the archaeological and archaeobotanical data shows a precise diachronic and temporal halving used to compare the phytosociological trajectories of current vegetation with the historical use of forest resources.

Mountain landscapes are proven case studies for understanding man-environment changes in the long term to try to understand the impact on sustainability of historical changes in relation to the environmental dynamics of a territory. Gragson et al.'s study [13] of the French Western Pyrenees also moves in this direction, focusing on the role of pastoralism and land change during the Long Anthropocene through the intertwining of different analysis tools such as the qualitative/quantitative study of written sources, archival sources, geospatial analyses, ethnographic interviews, surveys and archaeological excavations, in chronological and palaeoecological investigations of sedimentary archives.

A long-term correlation between historical site selection patterns and the edge effect of the ecological transition zone is addressed in the article by Zhu et al. [16] focused on mountainous and plain areas on the margins of Ningbo in Zhejiang Province in China. This approach has very promising considerations for observing the distribution of archaeological sites using tools from landscape ecology such as ecological pattern analysis or ecological patch distribution to model the characteristics of the landscape in relation to settlement location selection.

Human history, population dynamics and landscape changes of the long Anthropocene are discussed in the review by Romano et al. [11]. The cultural and demographic history of Sicily (Italy) was read through the perspectives of archaeogenetics and paleobotany, analyzing the ecological constraints imposed by the peopling of the island in relation to changes in the landscape that have taken place since prehistory. First, the paper presents the history of genetic and paleogenetic studies of the Sicilian populations, and secondly, it presents a historical study of the vegetation that aims to discover anthropization markers that could provide important insights into the reconstruction of the demographic aspects of human history.

In the third section, the concept of Anthropocene was analyzed according to various theoretical aspects and applied to different cases according to a perspective connected to the themes of cultural landscapes and seascapes.

Schicchi et al. [10] consider century-old olive trees as elements of "biocultural heritage", like some stone monuments, because these cultivated plants tell the story of the Mediterranean landscape through the Anthropocene thanks to their long lifespan. Indeed, monumental trees are key elements for the interpretation of the traditional rural landscape, in which the historical-anthropological components are intimately connected to the natural ones.

Humans are not the only active actor changing the landscape, as shown by the study by Ellis Burnet et al. [15] on the dynamics of rewilding in the Goričko Landscape Park (North-East Slovenia). It presents an interesting perspective on the concept of the Cultural Landscape in places where abandonment and de-anthropization constitute new spaces that are ecologically favorable to the restoration of new re-naturalized habitats.

The Great Acceleration of the Anthropocene and the challenges posed by transformations taking place in those landscapes defined "reserves of history" is at the center of the article by Badami [8] on the Valley of the Temples in Agrigento (Sicily, Italy) discussing the various good practices in land management that have enhanced this landscape as a natural and cultural ecosystem.

A new interpretation of the concept of Anthropocene has been proposed by Carta and Ronsivalle [12] that they call "Neoanthropocene". It consists in a radical innovation towards a renewed homeostatic relationship between Earth and mankind. The authors apply this new paradigm to the planning of Lucania Apennines Park's (Southern Italy) following a circular approach to nature preservation and territorial development, testing a new protocol based on a fertile relationship between multiple interests, stakeholders, and authorities.

The debate over the Anthropocene as a "boundary object" that can also be declined in different ways such as "Capitalocene" or "Plantationocene" is at the center of the reflections in the article by Braje and Lauer [17], which examine the history of anthropogenic seascapes in two case studies in California and French Polynesia in an innovative way to demonstrate how "Anthropocene concept stimulates new lines of inquiry into the long, discontinuous, and complicated distribution and redistribution of human and non-human agencies; necessitates trans-disciplinary research agendas; and facilitates the communication of political and environmental management messages to the public" [17].

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Article

Historical Ecology: A Robust Bridge between Archaeology and Ecology

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Abstract: How can the disintegration of ecosystems, the foundation of life on Earth, be halted and these critical systems be rehabilitated? For scholars, the action list is long: increase the pool of expertise by engaging all relevant knowledge communities, collect rapidly disappearing data, analyze with both familiar and new methods, and apply the results of actionable science to policy and practice. This enormously complex and urgent activity requires an integrated research framework with the flexibility to accommodate the global diversity of places, peoples, and processes and to examine future options. Based on evidence of environmental change and human activity, the framework termed historical ecology assembles tools to construct an evidence-validated, open-ended narrative of the evolution and transformation of specific ecosystems and landscapes. Welcoming knowledge from scholars and communities of both heritage and practice, this comprehensive and systemic understanding offers insights, models, and ideas for the durable future of contemporary landscapes. The article evaluates how practitioners could adjust aspects of practice and improve access to policy makers, and the discussion applies to regions and localities everywhere.

Keywords: historical ecology; regions; archaeology; history; ecology

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1. Finding Tools to Meet the Future

Multiple crises, which menace not just humanity but all life on Earth, are unfolding. With its link to global warming, heedless management is accelerating the collapse of ecosystems everywhere; this means that all practitioners, whether they are scholars or anchored in a landscape, must collaborate to meet this unprecedented challenge.

How can the disintegration of ecosystems, the foundation of life on Earth, be halted and these critical systems be rehabilitated? For scholars, the action list is long: increase the pool of expertise by engaging all relevant knowledge communities, collect rapidly disappearing data, analyze with both familiar and new methods, and apply the results of actionable science to policy and practice [1,2]. This enormously complex and urgent activity requires an integrated research framework with the flexibility to accommodate the global diversity of places, peoples, and processes and to examine future options.

Based on evidence of environmental change and human activity, the framework termed historical ecology assembles tools to construct an evidence-validated, open-ended narrative of the evolution and transformation of specific ecosystems and landscapes. The term historical ecology includes humans as a component of ecosystems' evolution and defines history in a way that goes beyond the written record to encompass both the history of the Earth system and the social and physical past of humans and other species. The core idea of historical ecology is that all sources of knowledge are combined to understand perspectives on the past in a specific place, so that its future can be more wisely managed [3–5].

Welcoming knowledge from scholars and communities of both heritage and practice, this comprehensive and systemic understanding offers insights, models, and ideas for the durable future of contemporary landscapes. In this article I examine historical ecological approaches to landscapes but also to oceans, seas, rivers, lakes, marshes, springs, and other moist areas, which I collectively term waterscapes. I evaluate how practitioners could adjust aspects of practice and improve access to policy makers. While examples herein rely on my greater familiarity with European and North American research, the discussion applies to regions and localities everywhere.

2. Historical Ecology in Disciplinary Contexts

Among several methodological and theoretical approaches that detail and track key elements of the human–environmental nexus and the linkages of biotic and abiotic agents and their behaviors through time (e.g., resilience, ecosystem dynamics, environmental history, and landscape biography models), the framework of historical ecology offers a comprehensive and integrated reach across knowledge sectors and clear strategies for social justice, collaboration, and application [6,7].

There is no particular need to identify one's work as historical ecology, as several other approaches employ similar principles [8]. However, the term is widely familiar, teasing ecology to embrace the historical sciences and history to learn ecology. Historical ecology is an umbrella term describing multi-faceted research programs that assure researchers and stakeholders the advantages of diverse perspectives, the means to evaluate and share information, and a community of practice. Historical ecology unites a group of core disciplines—archaeology, anthropology, ecology, geography, and history—and draws on parallel developments in these fields.

In archaeology, historical ecology derives, for the most part, from the standard practice in landscape and environmental archaeology, which routinely amalgamates information from disparate sources about the past of sites, places, landscapes, and regions; the focus is to explain human management approaches to their environments and to evaluate their consequences [9]. In ecological anthropology, historical ecology emerged through frustration with an earlier cultural ecology approach, which could not accommodate time or change [3].

In geography, early perspectives on landscapes [10,11] and temporality [12,13] reflect an enduring association between the disciplines of anthropology and geography. The holistic approach of geographer Karl Butzer [14–17] has influenced generations of practitioners in several fields of study. Along with the perspectives of naturalists [18] and environmental historians [19–22], historical ecology unites disciplines in both theory and practice.

In ecology, management approaches derived from forest history, conservation biology, and restoration ecology are also termed historical ecology or applied historical ecology [23–27]. Historical ecology is widely used as a framework to co-manage cultural heritage and natural resources and to engage in restoration and conservation ecology. For instance, the Society for Ecological Restoration International [28] structures its research and instructional programmes around historical ecology. For SERI, restoration embraces the nature/culture relation, engages all sectors of society, and enables full and effective participation of local, indigenous, and disenfranchised (LID) communities. This wide utility underscores the importance of integrating the historical sciences with ecology in their several forms and at multiple scales, while confirming a key connection between ethics and practice.

There is considerable overlap in strategy, tools, and techniques. For example, in the study of vanished landscapes, paleoecology and archaeology track changes over time in plant community dynamics, soil development, sediment history, climate, and hydrology; these are only some of the topics common to both fields [29,30]. Such close collaborations have helped archaeologists and paleoecologists to reconstruct a remarkable span of landscape history, from the ancient landscapes of early hominids [31] to early agrarian landscapes [32–34] and historic gardens [35,36].

3. Climate Change Remodels Landscapes

The availability of water will be an increasingly constraining variable in finding regions suitable for growing food as well as fibre, fuel, and fodder [37]. An ancient example comes from North and West Africa, which—due to monsoon rains in the late

Pleistocene—was a region of springs and permanent lakes; the population subsisted on abundant resources that supported hunting, fishing, and gathering. With settlements anchored near water and easy access to diverse biomes and ecotones, they voyaged like ancient mariners across arid and desertic areas to find a large selection of food in water bodies, woodlands, savannahs, and oases [38]. Drawings in rock shelters and caves depict their dead as swimmers in the sand, between the islands of life and the afterlife [39]. After ca. 6000–5000 BP, the region became steadily drier; the population began to practice pastoralism and moved to the more reliable water source of the Nile River, bringing their religion with them, and founding one of the great civilizations of the world [40].

Much can be learned from this example. The proto-Egyptians were masters of ecotonal resource use which, for a long time, enabled them to avoid moving elsewhere. While the move from a region of diminishing availability of water to one of abundance took centuries, today we do not have the luxury of time to modify our practices and adjust to new conditions; we must make the necessary changes within years and decades. This will require the gift of flexibility: the ability to conceive of novel solutions but also to draw upon the diversity of solutions that humanity has applied. That will require deep knowledge of the species, habitats, ecosystems, and ecotones upon which humans rely and a sense of reverence and protection for the sources of our food and water.

It is once again time to re-investigate how the human impact on the planet can be lessened. The relatively easy choices (e.g., recycling, less polluting materials) have been made, but more difficult choices that require the radical renovation or the abandonment of both brick-and-mortar infrastructure and supply networks have yet to be undertaken. This reinvention of the built environment and networks of commodity management must be aligned once again with regional ecology and climate [41]. A good place to begin is to coordinate ongoing research at regional and territorial scales to deliver an integrated approach to those who will plan the future. While the survey below is geographically limited, it can point to some areas worthy of greater attention.

4. Landscapes: Building Frameworks and Standardizing Practice

Persistent landscape types (forests, arable land, wetlands) and functions (community-managed land, sacred places) are of particular interest because considerable evidence can deepen the baselines for key resources and activities. The research designs of landscape ecologists and archaeologists can easily accommodate other fields of study (e.g., heritage and regional planning; climate change; sustainable management).

Early work in historical ecology focused primarily on landscape types. Many established research groups study a particular mountain, forest, or grassland landscape: an early example of historical ecology as policy is the U.S. Geological Survey's work in the southwestern Rockies [42]. An early national approach is the Swiss Federal Institute for Forest, Snow and Landscape Research [43], founded in 1885 and using historical ecology since the 1990s; researcher-driven transdisciplinary work focused on the Pyrenees began about the same time [44].

While scaling, politics, and other issues impede more recent global-scale management, mountains, uplands, and forests are often studied at regional and trans-border scales [45–52]. Landscapes that were once managed as commons have been brought back into view, using a historical ecology approach termed 'environing' [53]. Scholars and practitioners under the aegis of the International Association for the Study of the Commons has planned a forest commons conference [54].

The traditional and sustainable management practices of LID communities have been explained and promoted in several contexts; good examples are several decades of regional and cross-boundary work to explain Saami practices to Scandinavian governments [55] and to rehabilitate traditional solutions [56,57]. Connections between the ongoing disappearance of African wetlands and the expansion of agriculture offer another example of how the regional study of shifting relations among landscape elements can signal major issues such as the decline of biodiversity or looming water shortages [58–60]. Funded by the European Research Council [61], the MEMOLA project studied four mountainous European landscapes (in Spain, Albania, and Italy) to analyze agroecosystems that both maintain tradition and ensure the livelihood of rural communities over time.

These place- and region-based landscape projects serve the historical record, guide current decisions, and strengthen future management. Publishing outlets for local and regional work are expanding, notably the interdisciplinary journal Regional Environmental Change [62], the goal of which is to understand change, causation, and impacts at all territorial scales between the local and the global, whether they are defined by natural criteria (e.g., watersheds, ecosystems) or by human activities (urban areas/hinterlands).

Among the newest of international programs in this arena is the UNESCO BRIDGES global research coalition. BRIDGES [63] aims to integrate with UNESCO's Management of Social Transformations [64] intergovernmental science program. The aim of the coalition is to better integrate humanities, social science, and local and traditional knowledge perspectives into research, education, and action for global sustainability at local and territorial scales.

The European Research Council has funded additional future-oriented landscape projects. HERCULES [65] has a focus on the empowerment of public and private actors to protect, manage, and plan for sustainable landscapes of significant cultural, historical, and archaeological value at local, national, and pan-European scales. The European Commission has funded TERRANOVA [66], which trains next-generation researchers by charting shifting energy regimes as they have impacted land use strategies in Europe and demonstrates how landscape managers can draw on place-based solutions. The Commission also funds HERILAND [67], which addresses heritage management by exploring new ideas, tools, and training to ensure that interdisciplinary, research-based heritage, landscape management, and spatial planning are positively integrated with business activity, development, and democratic decision making.

At the national level, the U.S. National Park Service [68] published their strategy to manage cultural resources and climate change [69]. This inspired a group of researchers to form Climate Change Strategies and Archaeological Resources [70]. The group wishes to enhance archaeology's effectiveness with policy makers to increase knowledge about the multiple challenges that climate change has posed to the valuable and irreplaceable historical record.

Researcher-led coalitions have established the Historical Landscape Ecology Working Group [71], where members of the International Association for Landscape Ecology [72] and the International Association of Landscape Archaeology [73] share research and perspectives [74,75]. A group of researchers from many disciplines formed the project Integrated History and Future of People on Earth [76] in 2004. Founded on the principles of historical ecology, this global network has projects that feature collaboration with LID communities.

Global warming has already begun to transform familiar landscapes in ways that are difficult to predict in detail. French growers have begun to prepare for the future of their storied wines by working closely with climatologists, biologists, economists, sociologists, geographers, and geneticists to begin the process of adapting to anticipated climate change [77,78]. In Sicily, olive growers have embraced historical ecology to prepare for changing conditions [79]. A geological and archaeobotanical approach to land-use change is used to identify and protect High Nature Value (HNV) Sicilian farmlands for the future [32,80].

5. The Land-Water Ecotone: Policy-Oriented Research Design

Seventy-one percent of the Earth's surface is water. Oceans and brackish water comprise about 97% of that quantity and play an important role in feeding the world's population. Fresh water—from rivers, springs, streams, lakes, and ponds—while accounting for only 2.5% of the planet's water, is vitally important for human consumption and for agriculture [37,81,82]. Throughout human history and just like the early Egyptians, people have chosen to live at ecotones, where several ecosystems converge and the biotic diversity is greatest. Lacustrine and riverine environments nourished our species; especially favored were places where a short distance separates fresh and saltwater, where rivers meet the sea.

Archaeologists can read past and present landscapes that allow them to find these places, even as shorelines and the courses of rivers have remodeled the landscape. There, they excavate the debris from long-ago expeditions to locate food, entwining human activity with the health and behavior of many species. Thus, sites containing the remains of kills and catches enter the archaeological record and allow deep knowledge of both prey and their environments. Particularly important in wildlife introductions and species history, genetic analysis can be undertaken with material from archaeological sites and collections [83]. These sites are time capsules for land and water species' histories, ecosystems, water quality, and the resource management and culinary practices of the searchers. As millennia-deep ice sheets melt, rising sea and lake levels and floods threaten these shoreline archives [84,85].

An important advantage of collaboration among archaeologists, zooarchaeologists, and paleoecologists is that baselines—a guideline or beginning point of reference—chart the history of entities (such as species) or phenomena (such as salinity) over time [86–88]. Thanks to a variety of techniques, it is now possible to trace species and ecosystems over centuries and millennia, enabling the assessment of shifts in climate, ecosystems, and species' abundance and health; these tools are especially useful in conservation [89–91].

Marine historical ecology (MHE) offers fruitful applications of historical ecology and environmental history to marine ecosystems [92], shorelines [93–96], and island ecosystems [97–99]. The continuing importance of coastal wetlands is underscored in the long-term analysis of their storm protection [100]. Much of this work has been accomplished by collaborating regional groups. The vibrant alliance of scholars with indigenous groups along the North Pacific façade has re-invigorated ancient practices to ensure the health of coastal resources such as herring and clams [101,102]. In south Florida, a deep-time study of marine resources in the Gulf of Mexico traces more than a thousand years of fishing and collecting [103]. The Distributed Long-term Observing Networks of the Past [84] assess human behavior and environmental change in the Arctic and subarctic regions over space and time. All these collaborations engage multiple knowledge communities, both of heritage and of practice, while addressing climate change [104–108].

A seminal article [109] outlines how MHE researchers have taken the integrated methods of historical ecology directly to policy makers, and then followed up by analyzing whether the desired effects are reached and maintained. This muscular approach is a blueprint for action, precisely what is needed to ensure that historical ecology changes the thinking of policy makers and is thereby standardized.

The article identifies six policy themes: climate change, biodiversity conservation, ecosystem structure and function, habitat and seabed integrity, food security, and the importance of including social and economic considerations and facilitating 'bottom-up' governance to balance 'top-down' policies. It would not be too difficult to craft similar items for landscapes, thus clarifying collective goals while placing emphasis on policy.

MHE research reflects and explores these principles [8,110].

6. Regional Collaborations

How has this integrated, regional-to-global approach to marine ecosystems been successful in reaching policy makers? For MHE, a variety of international and regional organizations and collaborative communities support the integration and dissemination of research. In the last quarter century, MHE has become a distinct discipline in the marine sciences, bringing a systematic, long-term perspective to the study of interactions between human societies and the world's seas, oceans, and coastlines [109].

Previous research at the global scale offered a valuable platform. The International Geosphere-Biosphere Programme [111] (1987–2015) led a global effort to study how planet Earth functions and how it has—and will—change. A sort of mega-ecotonal framework linked land, sea, and sky projects where they meet: land–atmosphere, land–ocean, and atmosphere–ocean. Building on the IGBP research into planetary biogeophysics, today's international projects recognize the ubiquitous role of humans and have added contemporary concern for the inclusion people who are affected by decisions made at other scales. To better understand past and present management strategies, today's regional coalitions welcome collaboration with communities of heritage (e.g., indigenous groups) and practice (e.g., fisheries large and small) along with practitioners of archaeology, history, and the social sciences.

Future Earth [112] inherited Land–Ocean Interactions in the Coastal Zone (LOICZ) from IGBP and the International Human Dimensions Programme. Now termed Future Earth Coasts [113], it is a community of several organizations and a platform for translating sustainability knowledge into action. In the spirit of historical ecology, Future Earth Coasts focuses on equitable and sustainable coastal development, community adaptive capacity, and the translation of knowledge into action. Another inherited program from IGBP is the Integrated Marine Biosphere Research (IMBeR) [114]. The IMBeR program supports research to understand, quantify, and compare the historic and present ocean/human systems to predict changes and develop scenarios and options for transitioning towards ocean sustainability.

Dynamic researcher-led programs have also been important. An example is the Oceans Past Initiative [115], which facilitates historical research in marine sciences, policy making, and resource management. OPI addresses the issue of shifting baselines for numerous species and ecosystems, coordinates resources, and provides useful information to the marine historical research community, decision-makers, and the public. A recent European Research Council [61] grant has funded NorFish, an OPI project with focus on the 16th century North Atlantic Fish Revolution as an early example of the disrupting effects of globalization and climate change. In the Pacific northwest, U.S. and Canadian funders support the Clam Garden Network [116] and the Herring School [117]; these collaborations among scholars and indigenous groups cross national boundaries to learn about and rehabilitate ancient marine gardens.

Early and enduring support for Arctic research from the United States' National Science Foundation [118] enabled the researcher-led North Atlantic Biocultural Organization [119] to begin research in 1992. This large collaborative network of scholars and projects is one of the earliest efforts to cross-cut national and disciplinary boundaries and to help North Atlantic scholars to realize the immense research potential of the region. NABO works to improve basic data comparability, to engage in practical fieldwork with indigenous and local participants, to train students and citizen scientists, and to communicate findings to scholars, funding agencies, and the public. NABO also collaborates with the Humanities for Environment Observatories [120], a global network to identify, explore, and demonstrate the contributions that humanistic and artistic disciplines make to solving global social and environmental challenges. These researcher-led programs are largely open for participation to anyone who registers and follows the rules.

As with landscapes, attention to all scales (from local to global) is essential for MHE research, but to reach policy makers the marine researchers have tied together temporally and spatially diverse projects with themes [109]. Some examples are species with both economic and cultural meaning (e.g., herring, salmon), regions or ecosystems at risk (islands, wetlands), or the comparison of community-led and industrial management strategies. This meta-language is intellectually fruitful for researchers and is much more understandable to policy makers.

7. Conclusions

What strategies could increase the importance of landscapes and local/regional research to policy makers? Given the diversity of climatic conditions and global ecosystems, no uniform scheme can be sufficient. The place-based, human scale approach of historical ecology, paired with its flexible toolbox, can increase support from planners and administrators, elected officials, citizen-powered associations, and the public.

The need to anchor the elements that comprise landscapes within broader physical and social contexts is a key feature of historical ecology. Considerable landscape research is already addressing many topics of enduring interest to managers. We have seen projects in Sicily and France that anticipate climate change, and additional examples address the global comparison of innovation in agricultural economies [121,122]; the genetic history of crops and contemporary food security [123]; and the economic and environmental consequences of agriculture, forestry, and other practices [124,125]. Engelhard and colleagues' six policy themes (climate change, biodiversity conservation, habitat integrity, ecosystem structure and function, food security, socioeconomic considerations, and more democratic governance) offer some good ideas for increasing this trend and adapting them to landscapes. By consolidating the interests of multiple local and regional stakeholders, thematic research can catch the interest of funding entities and policy makers.

Another important theme of historical ecology is the investigation of baselines. With shared research and clear policy goals, landscape ecology/archaeology can routinely extend baselines, examine contexts, and compare management and policy strategies [90]. This is particularly useful for conservation planning, to evaluate species health, abundance, and social/economic contexts under different management regimes. Species that evoke contentious community response (e.g., wolves, boars, deer) have long been of interest to environmental historians, geographers, and cultural anthropologists whose work links well with zooarchaeology and genomics. Engelhard and colleagues' [109] six policy themes (climate change, biodiversity conservation, habitat integrity, ecosystem structure and function, food security, socioeconomic considerations, and more democratic governance) offer some good ideas for increasing this trend and adapting them to landscapes.

Contentious issues such as these need not end badly; there are means to adjudicate disputes [126–128]. The Harvard University Law School's Program on Negotiation publishes the Negotiation Journal and other teaching materials [129]. Trade-offs can be examined against payoffs [130,131] and ways forward can be found. While environmental regulation is often controversial, it is imperative that solid science and stakeholder voices be a critical component of good policy.

Wherever they work, historical ecological researchers have concentrated on supporting communities that, together with their scholarly collaborators, set goals. These alliances include citizen scientists (especially young people and knowledgeable elders) whose local knowledge enhances discovery, monitoring, and other activities. Collaborative heritage management benefits diverse actors.

Both marine historical ecology and landscape ecology/archaeology communities have found allies in like-minded funding agencies and alliances with international and global entities. Such alliances can offer many forms of support (e.g., funding, publicity, logistics, advice, access). While the MHE researchers were building networks and exploring citizen science, landscape researchers have focused on management technologies and training the next generation of scholars. Of course, the MHE projects were also training scholars, and the landscape projects were reaching out to communities; both have, quite rightly, been fine-tuning important arenas of competence and engagement with funders.

Taken together, they are building an increasingly integrated historical ecology. A research design that uses a complex systems approach (that is, to identify multiple temporal and spatial drivers of systemic change) integrates researchers across disciplinary boundaries and encourages the participation of other stakeholders. However, if all this work is meant to benefit the future, it is now time to wade into areas of conflict, not as proponents of one side or another but to offer peer-reviewed, stakeholder-supported assessments and management options for landscapes and waterscapes across time and space. This is the power of the past for the future.

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Article

Historical Ecology of Scandinavian Infield Systems

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Abstract: Infield systems originated during the early Iron Age and existed until the 19th century, although passing many transitions and changes. The core features of infield systems were enclosed infields with hay-meadows and crop fields, and unenclosed outland mainly used for livestock grazing. We examine the transitions and changes of domesticated landscapes with infield systems using the framework of human niche construction, focusing on reciprocal causation affecting change in both culture and environment. A first major transition occurred during the early Middle Ages, as a combined effect of a growing elite society and an increased availability of iron promoted expansion of villages with partly communal infields. A second major transition occurred during the 18th and 19th centuries, due to a then recognized inefficiency of agricultural production, leading to land reforms. In outlands, there was a continuous expansion of management throughout the whole period. Even though external factors had significant impacts as well, human niche construction affected a range of cultural and environmental features regarding the management and structure of domesticated landscapes with infield systems. Thus, niche construction theory is a useful framework for understanding the historical ecology of infield systems.

Keywords: agrarian history; Iron Age; hay-meadows; land reforms; landscape history; niche construction

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1. Introduction

Research in historical ecology is cross-disciplinary, as the core objectives are to understand how interactions between societies and environments develop through time, and how these interactions have formed cultures and landscapes, e.g., [1–4]. Thus, historical ecology integrates topics from the humanities (e.g., history, archaeology, anthropology) and the natural sciences (e.g., ecology, vegetation science). These different academic disciplines have their own concepts and theories, as well as their own ways of understanding causation, i.e., why something happens, e.g., [5,6]. Accordingly, there is a need for conceptual frameworks with the ability to address questions and problems relevant for both the humanities and natural sciences, and also promote communication among researchers from these different disciplines.

Niche construction theory [7] is one framework that has been suggested as suitable for this purpose [8,9] (see Section 2 below). The overarching aim of this paper is to examine this suggestion, applied to the historical ecology of Scandinavian domesticated landscapes based on infield systems. Infield systems refer to a particular way of managing land and structuring land use, established during the early Iron Age, i.e., from the first centuries BC onwards [10–12]. Land was divided into infields (Swedish: *Inägor*) and outland (Swedish: *Utmark*). Infields were enclosed areas located near settlements incorporating semi-natural hay-meadows (i.e., manipulated, but comprising a native pool of species) used for production of livestock fodder, and permanent crop fields. The outland was located outside enclosures and was used mainly for livestock grazing, but also for collection of other resources. The outland may have been open land, but was probably mostly forest, or at least land with some cover of trees. Despite many later changes in organization and management of land, for example concerning agricultural implements, crop rotation, land ownership, and land reforms, the key elements of infield systems were maintained until the modernization of agriculture and forestry initiated mainly during the 19th century. In present-day landscapes, there are plenty of legacies from historical infield systems, for example wood pastures [13] and semi-natural grasslands [14]. These remnant habitats are often species-rich, and are a concern for conservation biology. Forests today are mostly used for production of pulp and timber, and legacies of former land use are generally overlooked in forests as compared with the semi-natural grasslands, despite the fact that outland forests were an essential component of the historical infield systems [15].

Several previous studies have dealt with different aspects of the remains of old cultural landscapes in Scandinavia, for example the origin of infield systems, e.g., [16,17], the origin of meadow management [18], land-use changes during the last century [19], and historical perspectives on species-pools and species richness in semi-natural grasslands, e.g., [14,20–26].

In our examination of the historical ecology of infield systems, we cover the whole c. 2000 years of these systems' existence, including remaining legacies of infield systems in today's landscapes. A brief introduction to niche construction theory is useful before we present the specific objectives and questions.

2. Niche Construction as a Conceptual Framework for Historical Ecology

Niche construction theory [7,27] is based on the idea that there is a continuously ongoing interaction between a niche-constructing agent (typically a species) and its environment. Niche construction is defined broadly as a process by which a species alters its own ecological niche, or the niches of other species, and the feedback of these alterations to the niche-constructing species. There are two different aspects of niche construction, the alteration of the environment (the niche) by a species (which may affect many other species as well), and the response by the niche-constructing species to the altered environment [27]. The ecological niche refers to resources and requirements utilized by the niche-constructing species, or any other conditions affecting the species. Two key points in niche construction theory are that as species alter their environment, they not only respond to it, and that there is a reciprocal causation, generally meaning that the processes affecting change in the niche-constructing species and in the environment are mutually influencing each other [28]. Over time, along with changes in the niche-constructing species, there is an ecological inheritance (memory) of past environmental alterations.

Niche construction may apply to any species, but when focusing on humans, it has been termed cultural niche construction or human niche construction, e.g., [8,29,30]. In human niche construction, cultural changes are mediated by learning, memory, and knowledge transfer, i.e., components of cultural evolution, e.g., [31], or, in general terms, expressions of learned knowledge [27]. Since the dawn of the human species, people have been able to manipulate natural resources; agriculture was the big leap in such a manipulation, and the development of early agriculture and domestication of plants and animals has been considered as a prime example of human niche construction, e.g., [29,32,33]. In addition, human niche construction has, for example, been applied to a general understanding of the history of human societies, e.g., [34], and to impacts of the human society on other biota, e.g., [35].

Analogously to domesticated plants and animals, one may consider whole landscapes as domesticated, e.g., [36], thus incorporating also different ways of organizing and managing land, i.e., how land use is conducted and how it is spatially structured across landscapes. A starting-point for this paper is the notion that niche construction theory would be suitable for handling the processes underlying how landscapes are domesticated. A key question is thus whether there is a feed-back loop between the changing landscapes and how people conceive, utilize, and manage land.

There has been some disagreement about whether human niche construction necessarily reflects human intentionality. Hodder [37,38] criticized human niche construction theory for its presumed assumption of goal-directed behavior of humans to improve the resource base of societies. "If humans deliberately enhance their environments, it is not because they just decide to do that or because they have been forced to by unexplained increases in population or by climate change, but because they have become caught up in particular bio-socio-material entanglements that make specific intentions and adaptive responses possible" [37] p. 172. Indeed, one of the advocates for human niche construction clearly presumes goal directed intentions: "Humans utilize their capacity for goal-directed behavior to engineer environments in ways that enhance the productivity and predictability of economically important species" [33] p. 326. In a sense, the whole idea with niche construction theory is that a species (e.g., humans) modify its own niche by manipulating resources and environment. However, there is no reason why human niche construction necessarily reflects human intentions. Actions can be goal-directed and intentional, but they could as well be unintentional, with unexpected consequences.

3. Objectives

As will be described in more detail in Sections 5 and 6 below, infield systems in Scandinavia existed from the early Iron Age, more than 2000 years ago, until the 19th century, and during this time-period, several changes took place without altering the infield systems' core components, i.e., enclosed managed semi-natural meadows and crop fields, and outland grazing by livestock. As a first reflection, it may seem obvious that this farming system was a way to: "(...) engineer environments in ways that enhance the productivity and predictability of economically important species" [33] p. 326. However, an essential feature of niche construction is reciprocal causation, that the processes changing the culture and the environment are mutually influencing each other. This would, for example, be manifested as a response of culture to the altered environment, in turn leading to new alterations in the environment, in turn leading to responses in culture, and so on. Our main objective is to examine whether this was the case. In order to do this, we first need to identify the most important changes in infield systems, from their origin to their end.

Thus, we ask two main questions: (1) Which were the key phases of transitions and change of domesticated landscapes with infield systems? (2) To what extent were these transitions and changes the result of niche construction, involving reciprocal causation between cultural features (e.g., management and how landscapes were perceived and organized), and features of the environment and landscape?

4. Some Remarks on Approach and Terminology

4.1. A Retrospective Approach

One methodological problem in historical ecology is how to examine land use far back in time, before we have access to written sources and maps. This study extends back to the early Iron Age, more than 2000 years ago. There are few written sources from Scandinavia before the 13th and 14th centuries AD (except from rune stones, raised from the 4th century onwards, with a particularly intensive phase in the 11th century). More extensive information regarding land use is not available before the 17th century, when cadastral maps (with associated information) were produced. Before that time, and certainly for the first millennium AD, interpretations are based mainly on material evidence such as remains of settlements, field systems, stone walls, etc. Pollen analyses contribute important information regarding general aspects of vegetation such as landscape openness and diversity, e.g., [39,40], and macrofossils contribute information on crops, e.g., [41], but information about the way people shaped and managed domesticated landscapes remains quite vague, e.g., [42]. Furthermore, the mind-set of people, such as conceptions on property and rights to use land, and how people understood the ecological mechanisms behind different kinds of management, for example manuring of crop fields, are mostly beyond reach for us. Thus, when examining how land use affected the landscape and vegetation before we have direct evidence, and the rationale for people's decisions, a few assumptions are needed. Firstly, it was assumed that historical effects of land use such as livestock grazing and production of fodder (hay, and leaf-hay) were similar to the effects we have knowledge about from recent times. A similar assumption was used for conceptions of ownership and land rights, as they have been interpreted based on the earliest written sources, e.g., [43]. Secondly, it was assumed that people behaved rationally, i.e., the way people used land (fields, meadows, pastures, etc.) was rational from the viewpoint of promoting productivity and securing subsistence, as far as that could be achieved within the frames of the material conditions (vegetation, crops and livestock, buildings, tools, etc.) available at that time. Taken together, these assumptions reflect a kind of retrospective approach to historical ecology.

4.2. Terminology

Most studies referred to in this paper have been conducted in Sweden, and some are from other countries, mainly Denmark and Norway. As these nation states did not exist at the time when infield systems were formed, the region is referred to as Scandinavia, as in the title of the paper. However, the history of infield systems after the formation of the Scandinavian nation states focuses on Sweden. The time-frames mentioned in the text refer to those used in Sweden: The Bronze Age (1800–500 BC), the Iron Age (500 BC–AD 1050), incorporating the early Iron Age (500 BC–AD 400), the Migration Period (AD 400–550), the Vendel Period (AD 550–750), and the Viking Age (AD 750–1050) [44]. The Middle Age is considered to begin around AD 1050 and continue until the beginning of the 16th century (In Sweden, AD 1520 is commonly used). For specification of times after the Middle Ages, we used the century (e.g., 19th century).

In the literature, there are different terms used for the farming people and their settlements through the historical period examined here, e.g., [10,45]. Throughout this paper, we use the term farmer, and we use the term farm to denote the basic agricultural unit, i.e., the settlement (we imagine) typically hosting a family, or a larger group of related people, and the land utilized by these people. Farms could be located in isolation, or they may have occurred in groups, e.g., [46]. The term used for such clusters of farms is village (Swedish: *By*), irrespective of their size.

5. Infield Systems: Origin and Basic Features

An infield system is a farming system where the essential features relate to the management of land and the spatial structuring of different land use [16,18,47,48]. Figure 1 shows the major components of infield systems, and the background of these components are summarized in Table 1. The area closest to settlements was enclosed by fencing (wooden fences or stone walls) in order to avoid uncontrolled grazing from livestock and wild herbivores. Within this area, land was used for the production of livestock fodder on semi-natural hay-meadows, and for permanent crop fields. There were many types of hay-meadows: Wooded meadows, producing both leaf-hay (twigs and leaves) and grass-hay (including also forbs), open dry meadows, and wetland meadows. The latter were dependent on settlement locations close to water bodies. The crop fields were fertilized with livestock manure. An old saying, "the meadow is the mother of the field", e.g., [49], reflects the tight connection between the two major land uses within the infields. Livestock mediated a nutrient transfer from fodder, not accessible as food for humans, via manure, to the crops.

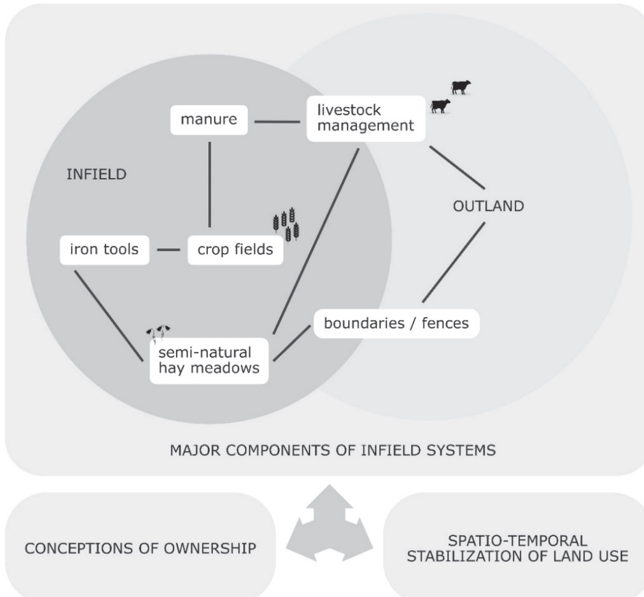

Figure 1. Schematic representation of the main components of Scandinavian infield systems.

Table 1. The main components of infield systems (see Figure 1) and their historical background.

Components of Infield Systems	Historical Background
Iron tools	Iron production started during the late Bronze Age, but iron became generally available in Scandinavia during the first centuries BC [50], and allowed for the development of tools and efficient agricultural management, particularly the introduction of scythes necessary for efficient use of hay-meadows [16].
Boundaries and fencing systems	Various fencing systems, ditches, and wooden fences, were used long before infield systems appeared [18]. Depending on availability of material, fences could be wooden or made of stone. The importance of boundaries manifested in the landscape developed before infield systems [51].
Semi-natural hay-meadows	Collection of additional fodder for livestock has occurred since the Neolithic, but land specifically constructed and managed for this purpose developed during the centuries around 1 BC/AD 1 [18].
Livestock management	Livestock, i.e., goats, sheep, and cattle, were already part of the farming package during the Scandinavian Neolithic [52], and it is likely that livestock were sometimes held in enclosures although they otherwise mostly were herded on non-enclosed land. Pastoralism, i.e., farming systems based on free-ranging livestock in extensive, probably communal, pastures was common during the Bronze Age [53,54]. Stalling (keeping livestock indoors) occurred long before the infield systems appeared, and was probably related to factors such as preventing cattle-raiding, or increasing efficiency of milk production [55,56].
Manure	Manuring of fields occurred already during the Neolithic [57], but became a necessity along with the development of permanent fields.
Crop fields	The crop fields during the Scandinavian Neolithic were temporary [58]. Permanent field systems managed by wooden ards were introduced during the first millennium BC, but probably before manure was available in sufficient amounts, e.g., [59].

Table 1. *Cont.*

Components of Infield Systems	Historical Background
Outland	Livestock probably grazed freely in the area surrounding settlements already during the Neolithic, e.g., [60]. However, the recognition of outland as a defined part of land use presumes that infields have been established.
Conceptions of land rights	Indirect evidence from various sources suggests that a conception of land as belonging to individuals or families developed during early Iron Age, i.e., along with the infield systems [43,61]. During the first centuries AD, there is also a trend of increasing inequality among farms, reflecting developing societal power hierarchies, e.g., [62].
Spatio-temporal stabilization	Before the establishment of infield systems, settlement patterns were more 'floating', i.e., farm locations were changed each generation, e.g., [63]. Based on the remains of buildings, grave fields, and place names, many farms in present-day Scandinavia have remained located at the same place since the middle first millennium AD, or even longer, e.g., [16,64].

The introduction of infield systems greatly increased the basis for people's subsistence [48]. The dominating crop during the Iron Age was hulled barley, but from late Iron Age and the Middle Age, other crops such as oats, wheat, and rye became more common, and could be regionally dominating [16]. Enclosed cattle paths led from the settlement to the outlands (sometimes referred to as outlying land or outfields), where livestock grazing took place during the vegetation period. The outland could be open tree-less vegetation, but it is likely that it most often was forest, perhaps semi-open due to the impacts of the grazing livestock. Figure 2 shows an example of an infield system from the first century AD in southeastern Sweden. In the following, we use this description of infield systems as a basic model, acknowledging that there was regional variation in Scandinavia in how infields were structured during the Iron Age [65].

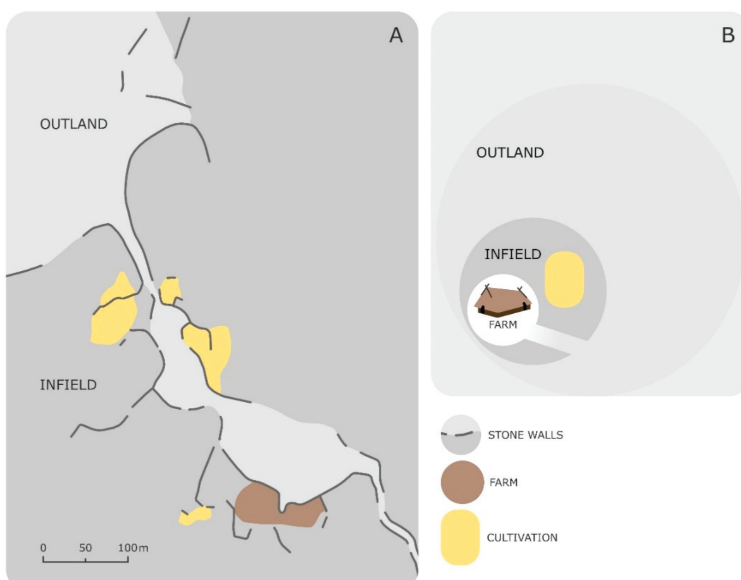

Figure 2. An infield system from the early Iron Age in southeastern Sweden. (**A**) A reconstruction based on remains of stone walls and interpretations of land use. (**B**) A generalized illustration of the basic structure of infield systems in the early Iron Age. (Re-drawn from Ref. [47]).

In older literature infield systems were often understood as resulting from a need for keeping livestock indoors (stalling) due to a deteriorating climate during the first millennium BC. As a consequence of livestock stalling, it became necessary to produce winter fodder on meadows close to settlements, and these meadows needed to be protected from livestock grazing during summertime. Thus, infields developed. On close inspection, this explanation does not hold [16,18,55]. For example, stalling of livestock occurred long before the introduction of infield systems, and probably for other reasons than protection from an adverse climate. These reasons could be, for example, protection from cattle robbery, and enhancing production of milk and manure. The use of permanent fields also seems to precede the establishment of infield systems, and the earliest permanent field systems were not intensively manured [59,66].

We should recognize that answering the question of origin is complex, and it is reasonable that there was a whole suite of processes, for example regarding livestock management, crops, and tools ultimately leading to establishment of this farming system, e.g., [11,16,17,55]. In this framework, it is also possible that the establishment of infields was associated with an emerging new mind-set in which it became important to manifest boundaries visualized in the landscape [51] and land became seen as a property, most likely of a family, e.g., [43]. Based on a synthesis of various evidence [18], it was concluded that a key to the origin of infield systems was the introduction of generally available iron tools necessary for efficient hay-meadow management. This timing also coincides fairly well with material evidence of stone wall systems such as those shown in Figure 2 [47,67]. The origin of infield systems was thus connected to a technological innovation, iron production, and can be placed in time in the early Iron Age.

6. Major Transitions and Changes in Infield Systems

The first question we ask in this paper is: Which were the key phases of transitions and change of domesticated landscapes with infield systems? We will first focus on this question for infields and outland, respectively, and thereafter consider the resilience of infield systems, and the processes that led to the end of infield systems.

6.1. Key Transitions and Change in Infields

Enclosed crop fields and hay-meadows, surrounded by outland used for livestock grazing, were largely maintained until the 19th century, and in some marginal regions even into the 20th century. Figure 3 gives an example of a cadastral map illustrating infields and outland during the 18th century. This does not mean that agriculture was static during this long period of time. Many features of agriculture changed, for example regarding agricultural implements and other technologies. In addition, the society changed considerably, and along with this also the general conditions under which farming was conducted. But the *longue durée* (cf. [68]) of infield systems implied that the basis for people's subsistence was largely the same: Livestock had a key role in the transfer of nutrients from hay, via manure, to crops. Crops, dairy products, and meat from livestock fed the human population, and the basic means to maintain this subsistence was a use of landscapes, structured as infields and outland.

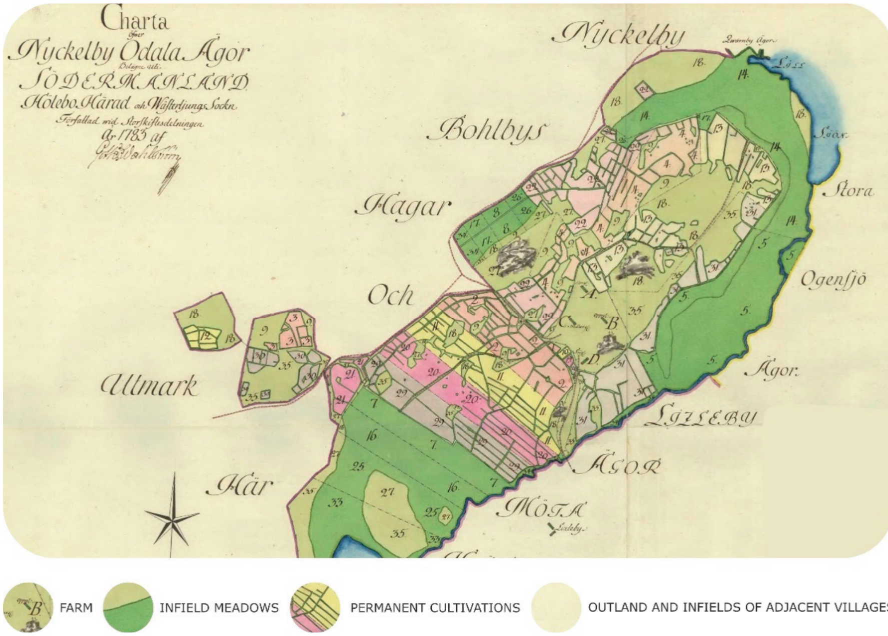

Figure 3. A cadastral map from the 18th century. Note that the cultivated fields are divided into strips of land belonging to individual farms in the village.

As with the question of the origin of infield systems, we should recognize that the changes during the following almost 2000 years were complex, and it may seem as too simplified to identify certain key transitions describing this change. However, when viewing this change at a broad resolution, it is reasonable to identify two major transitions altering management of infields and their spatial organization, before the ultimate end of infield systems (which is treated in Section 6.4).

The first of these key transitions was associated the introduction of crop rotation systems, and the implications this had for organization and structure of land use. At the initial phase of infield systems, the model used is a single farm with its own infields, meadows, and crop fields, surrounded by fences separating them from the outland (Figure 2B). Although implements made of iron (sickles, scythes) occurred, it seems likely that availability of iron was still quite limited. The fields were managed by wooden ards, and sown yearly by crops. After a crisis, probably related to a drastic climate change during the 6th and 7th centuries (see Section 6.3 below), many settlements were abandoned or relocated. Agriculture again expanded during the Viking Age and early Middle Age, but the conditions during this expansion was different than during the early Iron Age. This expansion was associated with a complex of changes, both regarding the agricultural technology and regarding the society as a whole [45]. The agricultural population increased, and settlements became more clustered. Villages became common, e.g., [46], and this implied that the organization of infields changed. These changes occurred in a context of a growing elite society, probably established in the aftermath of the 6th and 7th century crisis and consolidated during the Viking Age [44]. The elite society ultimately linked to a form of feudalism which developed along with the introduction of Christianity and the formation of the Scandinavian nation states between the 11th and 13th centuries [45]. Farmers had to pay tax to the King and the Church, or rent to a landlord. The villages became embedded in a feudal-like social network, which also became encoded by laws.

During the same period, an innovation in iron production technology, the introduction of the blast furnace, drastically increased the amount of available iron [69]. The consumption of iron in agriculture increased considerably [70], something that spurred innovation of agricultural technology, such as longer blades of scythes, iron-shod spades, and ploughs and ards with iron shares [45]. The latter implements made it possible to break the soil efficiently (not only scratch it, as with the wooden ard). This innovation was essential, as it allowed crop fields to be laid fallow for longer periods. Altogether, these changes in the conditions (societal and material) allowed for an efficient use of crop rotation systems, i.e., that a part (half, or a third) of the crop field area was used as fallow, grazed by livestock. Thus, in contrast to the initial infields during the early Iron Age, livestock would now continuously graze within the infields. In turn, this demanded new fencing practices, and as there were village communities with many farms, these had to be collectively organized, i.e., with fallows used as commons within the infield area. The overall implication of these changes, the expansion of agriculture in general, the altered way of locating settlements in villages, and the enforced collective fencing of the components of infields, was that the total areas of interconnected infields, i.e., hay-meadows, crop fields, and fallows, increased. The shape and structure of the domesticated landscape had been transformed.

This domesticated agricultural landscape was, with only minor changes, basically unaltered until the 18th and early 19th century [48], when a second major key transformation of infield systems occurred, an 'agricultural revolution' culminating in the launching of land reforms [71]. This agricultural revolution was driven by increasing demands for food, and spurred innovations and an increasing exploitation of land used for agriculture, including land that until then had been outland. The rationale behind the land reforms was to counteract what was recognized as inefficiency in agricultural management. First introduced in southern Sweden, the reforms ultimately concerned most of the country, except a few regions in central and northern Sweden. The essential idea was to re-allocate the infields so that each individual farmer managed interconnected land instead of strips of fields (Figure 3). As a consequence, villages were broken up into individual farms, located some distance from each other, resulting in a settlement structure that is still visible in the countryside of Sweden. When the land reforms were introduced, about a third of Sweden's farmers were free-holders, i.e., they owned their land [71]. The reforms were not always accepted voluntarily by these farmers, as they saw no immediate advantage of the reorganization of land, e.g., [72]. An important feature of the land reforms was that the outland, hitherto managed as commons, also started to become enclosed and allocated to individual farms [71,73]. A second implication was that an increasing fraction of the agricultural population became landless crofters, establishing small crofts in what was formerly outland [71].

Thus, for a second time since the Iron Age, the shape and structure of the domesticated agricultural landscape was transformed. This was, however, only a forerunner to the ultimate termination of infield systems.

6.2. Key Transitions and Change in Outlands

The outland was an integrated part of infield systems. A conception of infields presumed a contrast to the land located outside the enclosures, the outland, defined as beyond the infields. In the Swedish medieval landscape laws, there are various regulations for the use of outlands, illustrating their importance, e.g., [74]. However, since the outland was not described as detailed as the infields in cadastral maps, and the remains of previous management have been overlaid by modern forestry, thus usually being only vaguely visible in the current landscapes, we have much less knowledge about how outlands were used, as compared to infield hay-meadows and crop fields.

Outlands were used for various purposes, not only for livestock grazing. Production of iron and the necessary charcoal, e.g., [75] was conducted in the outland, and the same holds for production of tar, e.g., [76]. Materials used for buildings and fences were also gathered from the outland. In addition, ship building during the Viking Age demanded massive quantities of wood, obtained from the outland [44].

The focus here is, however, on the direct role of outland for agricultural production, and in what sense this was transformed during the history of infield systems. Except from the obvious change resulting from the land reforms described above, when outland commons were allocated to individual farms, it is difficult to identify specific transformations concerning the outland. It was rather a continuously ongoing expansion of outland use, which was manifested in different ways.

Livestock grazing was a dominating activity. Burning forest areas was used deliberately to improve grazing for cattle, sheep, and goats [77–79]. Studies based on analyses of fire scars and tree ring dating suggest that fire frequency increased from the Middle Age onwards, until the 19th century, most likely due to intentional burning [79,80]. In one study area in Southern Sweden, the fire interval was as small as c. 20 years [81]. In the most densely populated agricultural areas, the outland was heavily exploited by grazing livestock, e.g., [82]. One author remarked [83] (p. 395): "(. . .) in the 19th century, southern Sweden was to a great extent a large cow pasture".

In large tracts of Scandinavia, however, outland forests dominated the landscapes, especially in the central and northern parts, e.g., [74]. These forested areas started to become colonized by farmers around the time when the infield system was established in the early Iron Age, a colonization probably driven by a quest for iron production sites [75,84,85], and hunting for crafts and trade [86,87]. Agriculture was thus established outside the main previously occupied agricultural regions, in an environment that initially can be described as a kind of macroscale outland in relation to agricultural regions. As people brought with them their knowledge of agriculture, they established infield systems comprising fields and meadows, surrounded by outland used for livestock grazing [18,74,88].

Fodder for livestock was not only obtained from infield meadows, but also from wetlands located in the outland, e.g., [89]. From the last centuries, it is known that these outland wet meadows were often subjected to manipulation of the water regime in order to promote fodder production [90]. It is unclear when such manipulations initially were invented. Fodder was also obtained from harvesting twigs and leaves from deciduous trees and shrubs. The harvesting of such leaf hay was massive in Sweden until the 19th century [91]. All kinds of deciduous trees and shrubs were used. If available, tree species such as ash (*Fraxinus excelsior*), elm (*Ulmus glabra*), lime (*Tilia cordata*), and maple (*Acer platanoides*) were preferred. If these species were not available, for example in the central and northern parts of Sweden, other species such as birch (*Betula* spp.), goat willow (*Salix caprea*), aspen (*Populus tremula*), and rowan (*Sorbus aucuparia*) were used. It is likely that this type of hay was dominating initially during the colonization of outland forests [18].

Another manifestation of an increasing use of outlands was slash-and-burn cultivation, i.e., temporary fields established after the burning of forests. This management is often associated with a colonization from late 16th century onwards by people from Finland [48,92]. However, slash-and-burn cultivation occurred in southern Sweden much earlier, during the Middle Age, probably as a complement to the infield crop production [93]. There may have been a mutual relationship between slash-and-burn cultivation and other outland activities such as charcoal production (for production of iron), and, after a few years of cultivation, livestock grazing [94].

In central and northern Sweden, the landscape is generally less productive than in the south, implying that the area available for infields is more restricted. In order to expand the area useful for livestock grazing beyond the vicinity of a main farm, secondary farms (shielings) were established. It is controversial when the use of secondary farms originated, either already during the Iron Age, e.g., [74,95], or not until the late Middle Age [96]. There is, however, no doubt that the use of secondary farms increased until the late 19th century. The use of secondary farms implied transhumance. People (mostly females) moved to the secondary farm during summertime, herding the livestock and engaging in dairy production, for example cheese [96].

Thus, although it is difficult to identify specific transitions in outland use, there was a clear trend of expansion into outlands, and increasing exploitation of outlands (Figure 4).

This exploitation also implied that new farms, with their own infields, were established beyond the borders of formerly occupied agricultural land. As mentioned above, establishing new farms in former outland was part of the agricultural revolution during the 18th and early 19th centuries. The expansion into the outland included innovations, such as systems of transhumance based on secondary farms, manipulation of outland wet meadows to promote fodder production, and a possible synergism between various activities, such as charcoal production, cultivation of crops, and improved conditions for livestock grazing.

Figure 4. Schematic representation of the expanding outland management (viewed in one direction from the infields). (Inspired by Ref. [97]).

The outlands were generally regarded as commons, although they were subject to rules which from the Middle Age were defined by laws; these commons promoted and regulated cooperation among farmers, and they are likely to have been instrumental for joining people together in local communities, e.g., [73]. Even after the land reforms, which divided commons into privately owned land, some aspects of these commons remained, and still remain until today. One example is the Swedish legislation (similar in Norway and Finland) which gives right to public access to forests, and also allows for free collection of berries and mushrooms.

6.3. Crisis and Resilience of Infields

Despite the changes described in the two previous sections, one may remark that a farming system that existed for about 2000 years should have been very resilient. On closer inspection, this is indeed true. During this long period of time, there were several crises, among which two stand out as exceptional. It is instructive to briefly examine how these two crises played out within the frame of infield systems, and what features of the systems promoted resilience.

The first crisis occurred in the 6th century and was most likely caused by several gigantic volcanic eruptions (it is unclear where on Earth these were located) commencing in AD 536, resulting in a drastic reduction of sunlight and declining temperature, and initiating a period which has been termed the Late Antique Little Ice Age [98]. Possibly, the crisis was exacerbated by a plague (the Justinian plague). There is no direct evidence, material or written, describing how this crisis affected people in Scandinavia. However, in the time period between AD 300 and AD 650, there was a reorganization of settlement patterns in large parts of Scandinavia, and it is likely that the climate crisis was an important factor behind the late phase of this reorganization. Many settlements were abandoned, and new settlements were established [64,99–101], often on slightly higher and drier ground [102]. It has been suggested that the memories of this crisis led to the legend of the *Fimbulwinter*, known from the Old Norse literature as a cold period without much sunlight during several consecutive summers [102]. It is likely that the direct impact on plant growth, and declining temperatures, severely hampered crop production. It has been suggested [103] that the crisis spurred a renegotiation of property rights for land that had been abandoned, promoting an increasingly unequal society. To use a modern term, land grabbing laid a foundation for new elites, forming the strongly stratified society which developed during the Vendel Period and the Viking Age [44]. In addition, the formation of villages increased during the Viking Age [46]. These changes were thus forerunners of the feudal-like society during the early Middle Age [45].

While the settlement structure changed, there are few indications of change in the basic land use [99]. The reliance of livestock may have increased [103], which is reasonable if the crops failed, and such a change would be manageable within the frame of infield systems. When land was abandoned, this would have increased the possibility to keep livestock for those farmers that survived the crisis. Even if crops failed, there should have been leaf-hay available for the livestock, provided that sufficient land areas (forests) were available for harvesting leaf-hay. A recent study from Finland [104] suggests that a general reliance of a multitude of food resources implied that people could withstand and survive the *Fimbulwinter* crisis.

A second crisis occurred during the 14th and 15th century, initiated by a plague (the 'Black Death'), but exacerbated by climate change, the Little Ice Age [105]. It has been termed the Late Medieval Agrarian Crisis, and it is estimated that up to half the population may have died [106,107]. Numerous farms were abandoned [108,109]. Again, it is likely that abandoned farms were used as meadows and pastures by surviving farmers [103,109]. There is also evidence that farmers initially most dependent on outland resources were those least affected by the crisis [110].

Both these crises were associated with deteriorating climate conditions (colder, and most likely wetter). The practice of stalling livestock, as mentioned earlier, promoted by other advantages such as preventing cattle robbery (early Iron Age) and making production of milk and manure more efficient (throughout the whole period), may here ultimately turn out as advantageous for the very reason that previously was suggested as the cause for stalling: Protecting animals from adverse weather conditions [18].

The response to these crises shows that the inbuilt flexibility of infield systems promoted resilience. This flexibility was due to a resource base comprising multiple food sources, not only crops, but also livestock maintained by various outland resources, and the possibility for additional production of commodities from outlands, e.g., iron and tar, useful for trade. The flexibility of outlands thus served as a key factor for the resilience of infield systems.

6.4. The End of Infield Systems

The ambitions to increase agricultural production initiated during the 18th century implied an expansion of the agricultural area, and included several land reforms [71]. These processes premised the end of infield systems. The expansion of crop fields was partly executed by exploiting productive hay-meadows, and several detailed accounts of agriculture around the turn of the 18th–19th centuries show that deficiency of fodder became recognized as a problem, in turn implying deficiency in manure for fertilizing crop fields, e.g., [72,82]. This dilemma was ultimately solved by the introduction (from mid-19th century) of commercial fertilizers and leys, i.e., grass-legume mixtures cultivated on fields [111]. Thus, the old crop rotation systems were replaced by a new crop rotation including fodder-cropping on plowed fields maintained by commercial fertilizers, and much less fallow. Semi-natural meadows became obsolete. Meadows on clay and silty soils were turned into crop fields [112]. Less productive meadows were abandoned and transformed into forest. Some meadows close to settlements were used as enclosed pastures. Detailed studies of these land-use changes indicate that most infield grasslands were lost during the 19th and early 20th centuries [19,113,114].

A parallel trend was an increased importance of the growing forestry industry, which saw forest grazing as detrimental for forest production, e.g., [115]. As forest grazing was viewed as incompatible with modern forestry, new legislation was enforced leading to a more or less total abandonment of forest grazing during the first decades of the 20th century [116].

Thus, during the 19th century the tight coupling between livestock and crop production was broken. This was followed during early 20th century by a corresponding break in the tight coupling between infields and outlands. Forests, and thereby outlands, became decoupled from agriculture. The infield systems were gone.

7. Niche Construction and Development of Infield Systems

The second question we ask in this paper is: To what extent were transitions and change of domesticated landscapes with infield systems the result of niche construction, involving reciprocal causation between cultural features and features of the environment and landscape?

We will first (in Section 7.1) consider the alteration of the environment of domesticated landscapes caused by human activities in infields and outlands. These alterations affected not only the resource base for humans, but also many other species, and they include effects that were not intentional. We will thereafter (in Section 7.2) consider what we regard as the key question for assessing the impact of niche construction on the infield systems: Whether there was a feedback relationship (reciprocal causation) between features of the altered environment and culture, in turn changing the way environment was altered. The cultural features in focus are aspects of management and how landscapes were perceived and organized. In Section 7.3. we briefly consider legacies of infields systems in present-day landscapes.

7.1. Niche Construction as Alteration of the Environment

The alterations of the environment associated with infield systems were multifaceted, and it is helpful to categorize these alterations into those manifested locally, and those which are manifested at the scale of whole landscapes. Local alterations of the environment could be, for example, construction and management of infield meadows, forest burning to promote forest grazing, or manipulation of water regimes to promote hay production at outland mires. However, one may also consider alteration of the environment with regard to the overall structure of the domesticated landscape, for example, the basic structuring of landscapes into infields and outlands, the expansion of infields associated with the emergence of villages, or the development of secondary farms located in the outland. Thus, a range of interconnected, constructed, and manipulated local environments together constitute the domesticated landscape, ultimately serving as a basis for people's subsistence. Intentionality, or goal-directed behavior [33], may seem obvious. However, the alteration of environments also includes features that were not intentional. Many other species than those directly used for hay, crops, and livestock were affected.

The most obvious alteration of the environment was within the infields, for example the deliberate disturbance necessary to create crop fields, the construction of meadows, and the transfer of nutrients from hay-meadows to crop fields. Infields were not necessarily open. Trees were maintained in wooded meadows for production of leaf-hay and for promoting production of grass-hay, e.g., [117,118]. A sparse cover of trees, and some shrubs, for example hazel (*Corylus avellana*), is beneficial for preventing drought, and for mobilizing soil nutrients. Furthermore, guardian trees were probably held during the Iron

Age for their sacred role, [119] p. 36, and were actually maintained with a similar role until modern times, a remaining element of paganism almost thousand years after the transition to Christianity in Sweden.

The infield environment therefore comprised a diversity of micro-habitats which contributed to make infields suitable for a native pool of species, as this is illustrated by the exceptionally high local plant species diversity in still remaining historical meadows and pastures, e.g., [13,14,20]. Acknowledging that evidence is still scarce, evolutionary responses may have occurred among the favored species [120]. The high species richness in infield meadows was also influenced by structural features of the domesticated landscapes [26]. The total area of open or semi-open land increased, favoring the species pool associated with open grassland vegetation. Although the area of open landscapes had increased steadily (although periodically interrupted) since the Neolithic, e.g., [39], infield systems were associated with an agricultural expansion commencing in the early Iron Age [16], which continued throughout the whole period of the infield systems' existence (although with a few interruptions; see Section 6.3). Infield systems implied that the location of farms and the enclosed managed land became spatially stabilized. This means that the management, for example harvest of hay, took place at the same place repeatedly for a long period of time. Furthermore, dispersal of species was promoted in landscapes with many farms or villages, connected by paths for movement of people and livestock. The increased connectivity promoted colonization of these species at available infield meadows. Whether the species richness per se may have been perceived as favorable by the farmers is difficult to say, but it is probably far-fetched to consider most indirect effects on species richness as intentional.

Turning to alterations of the environment in outlands, we should recognize that these effects were spatially more extensive, and it is likely that their spatio-temporal permanency was not the same as in the infields. The use of the outland was more like a dynamic mosaic, where different parts were used different years, perhaps even with long intervals. The major use of outland was livestock grazing, and it is well established that until the late 19th century, and well into the 20th century in marginal regions, vast areas of forest were still used for livestock grazing, e.g., [83,116].

In boreal and nemoboreal forests (the vegetation zones covering most of Sweden), natural wildfires are major drivers of ecosystem processes, e.g., [121], and natural fire intervals have been estimated to be on average c. 80 years (52–160 years, depending on forest type) for northern Sweden, i.e., slightly more than 1% of the forest area burns annually [122]. Although the effects of natural wildfires could have been capitalized on for grazing livestock, fire was also used deliberately to improve grazing conditions by increasing the abundance and biomass of deciduous species such as birch (*Betula* spp.) and aspen (*Populus tremula*), and grasses such as *Deschampsia flexuosa*, and herbs such as *Chamaenerion angustifolium* [77,123,124]. Resprouting of heather (*Calluna vulgaris*), valuable as feed for livestock, is also promoted by fire [77,124]. Furthermore, increasing fire frequency promotes soil microbial activity, decomposition rates, and availability of soil nitrogen [121,125], effects which have generally positive effects of plant growth, and promoting grasses and herbs. Remains of charcoal may also act to reduce any effect of various allelopathic chemical compounds, i.e., compounds that have negative effects on other species' recruitment and growth [126].

Thus, burning improves the conditions for livestock grazing. But what about the direct effects of grazing per se? There are surprisingly few studies on grazing effects by livestock in forests, given the interest this old-fashioned land use currently receives from conservation biology, e.g., [127,128]. The paucity of studies on direct effects of forest grazing motivates some caution, but it is fairly obvious that forest grazing creates (or maintains, if the forest has been cleared by burning) relatively open forests, and that the ground flora becomes dominated by grasses and herbs. It is likely that the grazing effects are similar to those in open semi-natural grasslands, i.e., altering competitive interactions so that competitively subordinate species maintain viable populations, reducing litter accumulation, causing heterogeneity by disturbance due to trampling and dung deposition, and promoting a transformation from podzol to mull [115,128]. Up to a certain limit, these effects (and the effects of regular burning) would initiate a positive feedback process; the changing conditions due to grazing promote the productivity of feed for livestock. Although solid data is scarce, these changes promote local-scale species richness [115,129]. The effects on species richness may, however, be small [130], and they may depend on site productivity so that the effect may even be reversed in low-productive systems [131].

In contrast to the positive effects on local species richness in infields (which was probably mostly unintentional side-effects of management), the positive effects on species richness in outlands may have been part of the intentions behind management of grazing livestock. Of course, there were indirect side-effects as well. Other plant species were favored by burning management, for example *Lycopodium [Diphasiastrum] complanatum* [132] and *Geranium bohemicum* [133], and it would be far-fetched to interpret these effects as intended by people conducting forest burning.

What was certainly intended was the expansion of livestock management and agriculture in the outland. This expansion was manifested as a new structuring of the domesticated landscape, incorporating an increasing fraction of the outland (Figure 4), including managed hay-meadows on mires, and the establishing of secondary farms. These establishments created new focal points in the outland where infields were constructed.

7.2. Niche Construction as Reciprocal Causation

Viewing the whole period from the origin to the end of infield systems, it is obvious that there are several important factors for these system's development which are external, and which cannot be considered as reflecting reciprocal causation, i.e., effects emanating from responses to previous alternations of the environment in the infield systems. First and foremost, the technological innovations regarding iron production had a significant impact not only on the origin of infield systems [18], but also on their transformation. In particular, the invention of the blast furnace technology during the early Middle Age greatly increased the amount of iron available for agricultural implements such as ploughs and ards with iron shares [70], and this was one of the major factors in the transformation to communal infields with enclosed fallows. Furthermore, societal changes, the growing elite societies during the Vendel Period and the Viking Age, ultimately embedding farming in a feudal-like society during the Middle Age, and the formation of nation states some centuries later, cannot be seen as reflecting reciprocal causation directly involving the infield systems. Additionally, the expanding market economy, making agricultural production integrated with other parts of society, such as towns [134] and the iron industry [45], is likely to have influenced the farmer's decisions regarding agricultural production. Although the land reforms launched in the 18th and 19th centuries were partly driven by features of infield systems (in this case, these system's inefficiency), these reforms, as with the whole agricultural revolution [71], were also inspired by a range of technological innovations concerning agricultural implements and management. To the external factors we should also add climate change, which was contributing to the two crises described earlier.

A first conclusion is therefore that niche construction involving reciprocal causation cannot be used as a single explanatory model for important parts of the general development of infield systems. External factors defined the possibilities and constraints under which infields systems originated and developed. However, as was made clear in the preceding section, infield systems were associated with numerous alterations of the environment (both direct and indirect, and intentional and unintentional), and these may have initiated processes of reciprocal causation involving aspects of culture and the environment. Thus, niche construction may operate within infield systems, in such a way that both culture and environment changed.

If we first consider niche construction involving reciprocal causation related to local alternations of environment, the clearest example concerns a continuous change of management. It is reasonable that farmers continuously adapted management practices as a response to their goals regarding production (food, but also other resources, such as building material, etc.). One may see farming as a continuous learning process concerning tools, management practices, and choices of crops, related to local conditions dependent on previous alternations of environment. This knowledge was transferred laterally (among farmers) and through generations. For example, through the late Iron Age and the Middle Age, the blades of scythes became successively longer [16], a direct response to a need for increasing efficiency of hay-making, and in turn affecting the outcome of the management. Another example is the knowledge behind the intricate management of wooded infield meadows, as known from the early 20th century, e.g., [117,118,135] with actions conducted in a specific sequence, either yearly or less regularly, including raking during spring, choice of harvest time, and management of pollarded or coppiced trees. This knowledge is likely to have been built up over many generations and transferred across communities of farmers, and the chosen management affected the outcome of the hay-harvest, and indirectly also other species inhabiting these species-rich environments.

There are examples from the outland as well. Based on how wetland meadows located on mires were managed during early 20th century, we know of a plethora of intricate means by which the water regime was manipulated with the purpose of increasing hay production [90]. This knowledge must have accumulated over many generations, in response to the outcome of hay harvest, and as with the wooded meadows, the management altered the mire environment. Another example is the synergism between charcoal production (which opened up forest cover), and slash-and-burn cultivation followed by forest grazing, which benefitted from the favorable conditions created by the preceding cutting and burning of the forest [94]. It seems highly likely that such a combination of activities developed over time, as result of accumulated knowledge gained in response to the effects of the altered environment.

Reciprocal causation also lies behind development of cultural and environmental features manifested at whole domesticated landscapes. The use of commons was encoded in medieval laws, e.g., [74], and this cultural feature is likely to have developed in continuous interaction with the development and management of commons. For example, the change to communal infields, with fallows used as village commons, and the associated use of outland as commons, did not only change the infield environment, as it also had profound effects of social relations within villages. Although the laws where these social relations (or parts of them) were encoded certainly were formed for many other reasons as well, it is possible to causally connect various aspects of social relationships with the altering of environments. However, it is difficult to identify "what is the hen and what is the egg". For example: Were laws reflecting social relations resulting from a new form of communal management? Or, were communal management a result of social relations enforced by laws? The answer is that none of these alternatives is fully correct. The causality worked in both directions, just as implied in theory of human niche construction.

Another example concerns secondary farms. Irrespective of the outcome of the debate about when secondary farms first appeared, this form of transhumance is interpreted as a response to a poorly productive forest environment, e.g., [85,96]. In order to avoid over-exploitation of the near surroundings of the infields, secondary farms inhabited summertime were located at some distance from the main farm. Thus, out-located small infield systems were constructed in the outland, and with this came environmental alterations due to forest grazing and meadow management (as described in the previous section). During the centuries preceding the abandonment of most secondary farms in the early 20th century, these were used particularly for dairy production, butter, and cheese, available for trade, thus contributing to the farming economy [96]. There are several cultural features associated with outland use specifically related to secondary farms. Their management was largely a female activity, including not only handling milking and dairy products, but also transporting and herding of cattle, in turn creating a mind-map of large tracts of the outland landscapes, manifested as paths, resting stones, and messages carved into trees [136,137]. Again, we have a complex of aspects of both culture and environment, obviously causally related to each other, but where it is difficult to define a direction of the causal arrow. The causality worked in both directions.

So far, we have dealt with reciprocal relationships where the components of culture and environment in a sense enforce each other, i.e., the relationships are allowing, for example: "Better tools and innovative management lead to increased hay harvest, increased amount of manure, increased crop production, in turn promoting innovation etc.". However, niche construction may also concern constraining relationships, where the altered environment is pushed to a limit and where the cultural response initiates a more drastic shift in the future alteration of the environment. This can be considered as a trap for the niche constructing agent (humans, in this case), and it may lead to consequences not foreseen or intended when the process started [138]. The events preceding the end of infield systems described above in Section 6.4 is an example. The deficiencies of infield systems to satisfy the need for agricultural products encouraged expansion of the crop field area. This was done partly by transforming productive infield meadows to crop fields, which in turn led to a lack of livestock fodder and ultimately manure, bouncing back to reduced crop production. The infield systems were caught in a trap. The solution that ultimately came implied the initial steps to abandon the infield systems, by replacing manure with commercial fertilizers (again an external factor), thus decoupling livestock from crop production. This process also involves reciprocal causation, but associated with a shift in the altered environment such that one component of the infield systems, managed meadows, disappeared and was replaced by leys.

Finally, we remark on two speculative examples of how infield systems may have influenced people's conceptions. In Old Norse mythology, the place where humans live was named Midgard (Old Norse: *Miðgarðr*). Outside Midgard was Utgard (Old Norse: *Útgarðr*), the place beyond the world of humans, inhabited by trolls and evil powers [44]. It has for long been speculated that this cosmology is a reflection of infields and outland, although the idea has also been questioned [119]. Linguistically it makes sense, as *garðr* literally means enclosed space, i.e., infields. However, as we have seen, the outland was far from a place beyond the world of humans, but rather a key to the functioning of the infield system, and a major contributor to the resilience of the system. Therefore, even if the Iron Age mythological universe was divided into Midgard and Utgard, and this somehow corresponded to a landscape with infields and outland, it seems unlikely that people in their everyday life considered the outland as dangerous and beyond their homeland.

The second example concerns the Old Norse mythological world-tree, the ash *Yggdrasill* [119]. Ash (*Fraxinus excelsior*) is probably the best tree to have in wooded meadows. World-trees exist in many different cultures [119]. Of course, it is impossible to know, but one may wonder whether the choice of species for the world-tree in the Old Norse culture was a coincidence.

In conclusion, the development of infield systems, from their origin in the early Iron Age and until their final demise during the 19th century, involves a range of inter-related changes affecting both culture and the environment, and where the causalities are reciprocal. Viewing the changes in a temporal sequence, they work alternately in either direction, or simultaneously in both directions (Figure 5). Niche construction processes are thus essential for an understanding of the development of infield systems, even though, as remarked above, external factors must be considered as well.

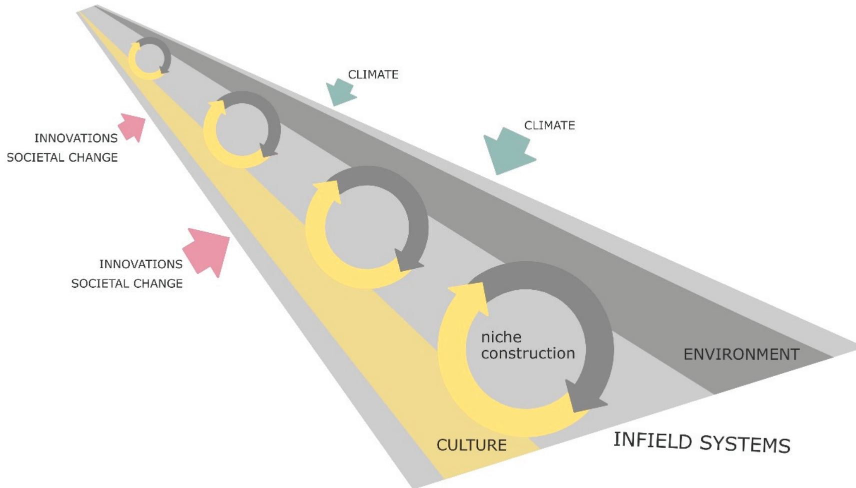

Figure 5. Visualization of niche construction through time in infield systems.

7.3. Legacies of Infield Systems and Current Niche Construction

The infield systems are gone, but they have left plenty of legacies. For example, in the Swedish countryside, many farms have maintained their Iron Age location, e.g., [64], and they often have pagan names, referring to Old Norse gods such as *Odin*, *Thor*, *Freyr*, and *Freyja*. Traveling through the landscape thus means that one experiences the basic spatial structure of the former infield systems. Another kind of legacy is the public rights to access land outside farms and private gardens that is special for the Nordic countries (except Denmark), a legacy that has been maintained despite the abandonment of outland commons in the 19th century.

Focusing on the ecological memory, i.e., the alterations of environment which still remain visible in present-day landscapes, the most obvious and common legacy is what is today termed semi-natural grasslands [14]. This term is a bit vague, but generally it means grasslands (including those with a sparse cover of trees, such as wooded meadows) which previously were used for production of livestock fodder or for grazing, and which have no obvious traces of previous fertilization and plowing. Semi-natural grasslands are usually very species-rich, and are nowadays a concern mainly for conservation biology, but to some extent also for managing and preserving cultural heritage. About a third of Red-Listed species in Sweden is associated with remains of old agricultural landscapes [139]. There are no exact data on the present-day extent of semi-natural grasslands in Sweden, but it is estimated that between 255,000 and 270,000 hectares of valuable semi-natural grasslands remain, of which semi-natural meadows (still managed by mowing) are below 10,000 hectares [140,141]. Even though many of these grasslands have a background as semi-natural meadows, most of them are currently maintained by livestock grazing, sheep or cattle. Forest grazing more or less ceased during the 20th century, but is again used for conservation purposes. Currently, about 16,000 hectares in Sweden are subjected to forest grazing, excluding those associated with still maintained secondary farms [127].

It is worth noting that features resulting from historical niche construction processes, in the modern society have been reinterpreted to values related to modern conceptions such as ecosystem services, cultural heritage, aesthetics, and species richness. This implies a new kind of niche construction dynamics, a reciprocal causation involving various conservation programs and subsidies, interacting with the effects these programs have on these different values [142]. Although it is unclear whether current conservation programs will be successful in the long-term, and maintain the perceived values of the legacies of former infield systems, e.g., [141,143], human niche construction is still ongoing, but by different means.

8. Concluding Remarks

The main conclusion from this examination of the historical ecology of Scandinavian infield systems is that the theory of human niche construction contributes to an understanding of how domesticated landscapes with these infield systems developed and changed during the two millennia of their existence. The essential components of human niche construction, alterations of the environment by humans, cultural response to these alternations, and an ongoing interaction between the processes of change in environment and culture, a reciprocal causation, are applicable to several of the environmental and cultural features of infield systems. However, it was also clear that human niche construction is insufficient as a model for several of the major transitions and changes that occurred in the infield systems. External factors, which were not directly involved in the reciprocal causation, had decisive impacts on the development and change. Examples include innovations such as blast furnace technology for iron production, the rise of an elite society ultimately leading to feudalism and formation of nation states, availability of commercial fertilizers, and the growth of a modern forestry industry.

A second conclusion stems from the fact that infield systems proved exceptionally resilient despite several severe crises affecting farming and people's livelihood. Twice during these two millennia, in the 6th and in the 14th centuries, possibly as much as half the human population succumbed due to famine and plague, and large fractions of settlements were abandoned. The inherent flexibility in infield systems, in particular the diversified use of outlands, enabling survival of livestock, and use of a manifold of resources, was vital for people's survival. Ultimately however, the infield systems turned out to be insufficient for feeding a growing human population, and during a period of around hundred years, infield systems were replaced with the basic landscape infrastructure characteristic for the modern industrial society: An agriculture focusing on managed fields with both crops and fodder and maintained by artificial fertilizers and fossil fuel, and a forestry industry producing timber and pulp.

The infield systems have left many legacies, both in terms of cultural heritage, beautiful landscapes, and species-rich environments, particularly semi-natural grasslands. Currently, considerable research efforts are allocated to various issues relating to aspects of what formerly were infield systems, for example concerning conservation biology, species diversity, ecosystem services, sustainable food production, and carbon sequestration. Deeper insights into the historical ecology of infield systems would therefore seem to be in order, and hopefully our examination of the niche construction processes behind this old farming system will prove valuable.

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Review

Historical Ecology in Brazil: A Systematic Mapping of Scientific Articles (1998–2021)

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Abstract: Historical Ecology is a multidisciplinary field that studies long-term relationships between humanity and the environment. There is a missing synthesis effort to organize and present the state of the scholarship in Historical Ecology in Brazil. We aimed to characterize by whom, when, where, what, and how research in Historical Ecology has been conducted in Brazil. We made a systematic mapping of 118 scientific articles published in Portuguese, Spanish, and English that fit our inclusion criteria. The results showed articles from 1998 to May 2021, published in 79 different journals. We found 264 national and international authors (60% men and 40%women); 91% of all investigations were carried out in the Amazon and Atlantic Forest biomes. There are few works about Cerrado, Caatinga, and Pampa, and none for Pantanal. The most mentioned keywords were historical ecology, Amazon, forest, and archaeology. Twenty-three articles focused on a particular species, primarily plants; 37% of all articles used Historical Ecology as its central axis of research, and 63% as auxiliary. We found more than 35 methodological procedures, both from the social and natural sciences. This overview revealed achievements, research gaps, and opportunities in this field.

Keywords: biomes; methodologies; historical approach; multidisciplinarity; research gaps

1. Introduction

The term "Historical Ecology" has been defined by two different research scholarships: (1) as a field that draws upon diverse evidence to trace complex, long-term relationships between humanity and Earth [1]; and (2) as a field related to evolutionary ecology and the use of phylogenetic systematics [2], which may or may not involve anthropogenic agency [3]. In this paper, we embrace and refer to the first definition. Hence, Historical Ecology is a multidisciplinary field (or research program) that investigates human-environment relationships resulting in continuous interactions of spatial, environmental, historical, and cultural dimensions. Its primary focus is the physical evidence etched in the landscape. The use of landscape as an analytical framework and spatial unit is valuable and widely used in Historical Ecology. It is at the same time both a physical reality and a social construct [4]. Landscapes go beyond landform; thus, they are not limited to land but extensive to marine environments. They encompass a mixture of subtle and evident marks in the present as a result of the accumulation of past activities and processes, including the responses of all life forms to human activities and distinctive archaeological marks such as anthropogenic soils, material culture, and landesque capital [5–12].

Historical Ecology recognizes that human activity can be considered an ecological factor influencing the biophysical environment [13]. Nature and culture are impossible to tell apart, making it challenging to define a "natural" landscape [3]. Balée [6] proposes four central postulates to the research program of Historical Ecology. One of those considers that humans have affected every environment on Earth. Changing one part of a system (e.g., species composition, management system, settlement pattern) inescapably influences all other parts since all the variables are intertwined [3]. In our understanding, Carole Crumley's definition of Historical Ecology best encapsulates how we understand this field:

> "Historical Ecology traces the ongoing dialectical relations between human acts and acts of nature, made manifest in the landscape. Practices are maintained or modified, decisions are made, and ideas are given shape; a landscape retains the physical evidence of these mental activities. Past and present human use of the Earth must be understood in order to frame effective environmental policies for the future" [14] (p. 9).

The marks on the landscape resulting from the interaction between human and non-human nature, analyzed through Historical Ecology, have contributed to expanding knowledge about ecological patterns and processes related to specific cultural aspects of societies [15–17]. Historical Ecology studies are often related to ecological restoration studies (for a deeper reflection on this issue, see [3,11,18]) and are a valuable source of information for conservation and management. The latter connotation is based on the logic of knowing and understanding the past to properly manage ecosystems and landscapes for the present and the future [1,19,20], especially as it shows the uniqueness of every site [11].

As a multidisciplinary field [21], Historical Ecology does not have a single research methodology [18,22] but rather aggregates several methods from various academic disciplines that incorporate cultural, historical, linguistic, biological, and environmental data [23]. These include the use of natural (e.g., palynology, packrat middens, dendrochronology) and documental (e.g., forest inventories, climate records, remote sensing) archives [20]. Historical Ecology also integrates different sources, including physical evidence such as archaeological vestiges of material culture or pollen records, and sources from the humanities like oral history or historical archival consultation [19]. In any case, an essential characteristic of the methods is the spatio-temporal component, necessary when investigating a specific landscape and its historical processes [23]. According to William Balée [6], Historical Ecology received contributions from many fields such as environmental history, historical geography, palaeoecology, and landscape archaeology [18]. Solórzano, Oliveira, and Guedes-Bruni [24] also identify bridges between Historical Ecology, environmental history, and historical geography in their goals to investigate the relationships between humans and nature in landscapes throughout time, with different interconnections among these three fields. Historical Ecology, on the one hand, has roots in European (paleo)ecology and landscape history/archaeology, and on the other hand, roots in North American cultural/historical geography, specifically Carl Sauer's Berkeley school, and also in environmental anthropology, especially in the 1990s [3,18,22].

In Brazil, Historical Ecology was addressed initially in studies located in the Amazon region [25], for example, in the course of the Xingu River [6,26]. One of the leading research topics has been forest management by indigenous societies, which results in changes in the landscape and modification of species composition [27–29]. Several Historical Ecology publications have appeared in the last twenty years, not only for the Amazon but also for other biomes—especially the Atlantic Forest—with diverse temporal and spatial scales and using assorted methodologies.

Historical Ecology often uses biocultural approaches [30]. In the Brazilian biomes, biocultural diversity refers to the interdependence between biological and cultural diversity, indicating how significant sets of biological diversity are managed, conserved, and created by different cultural groups (including indigenous and other traditional communities) [31]. Current research in Historical Ecology and correlated fields have revealed interconnections between culture and biodiversity in the Amazon [32,33], Atlantic Forest [34–37], Caatinga [38,39], Cerrado [40–42], Pampa [43,44], and Pantanal [45,46]. Historically informed environmental investigation coupled with cross-disciplinary conceptual frameworks (such as biocultural diversity, social-ecological systems, and novel ecosystems) are key to understand current landscape dynamics and help inform decision-making [36].

Two recent works make a synthesis effort revising publications in the field of environmental history in Brazil: one from José Augusto Pádua and Alessandra Izabel de Carvalho [47], who published a thorough review on Brazilian environmental history analyzing books; and the book chapter of Lise Sedrez and Eunice Nodari [48] presenting an overview of research and principal themes in the same field. However, there is no work organizing and presenting the state of the scholarship in Historical Ecology in Brazil.

This paper aims to explore the published scientific articles of Historical Ecology in Brazil through a systematic mapping, presenting by whom, when, where, what, and how research has been conducted. This study reveals the achievements, research gaps, and opportunities in this field from the perspective of published articles.

2. Methods

Systematic mapping is a method to describe the literature across a broad subject of interest. It does not attempt to answer questions that require critical analysis; instead, it describes available evidence; this is useful to identify general patterns and knowledge gaps about the research topic [49]. Systematic mapping formulates a narrative description of the state of the evidence base [50]; this descriptive approach is similar to other published review studies [50–52]. We conducted a systematic mapping to catalog all the published scientific articles about Historical Ecology in Brazil in Portuguese, English, and Spanish until May 2021. We excluded other publications such as books, book chapters, theses, congress memories, and other grey literature, as the amount of information, accessibility, and effort overpassed our ability to manage all the information. We are aware that many research results are published in the form of books in the Humanities. We found some titles specifically about Historical Ecology in Brazil [53–56]. Other books contain chapters dedicated to Historical Ecology research in Brazil [57–60]. The majority of the editors of these books have also authored scientific articles selected in this systematic mapping. The books and book chapters mentioned are mostly about studies in the Amazon. In a quick search for examples of postgraduate theses, we found a greater diversity of biomes studied [61–65]. We pursued the following steps:

1. We searched for articles containing the words "Historical Ecology" and "Brazil" in the three selected languages. We did not set any data limit. The search engines that we consulted were Scopus, Scielo, Web of Science, and Google Scholar. To our surprise, Scielo did not find any work, while Web of Science showed only one (which also appeared in Google Scholar results). Therefore, Scopus and Google Scholar were our main sources of data. The results for Portuguese and Spanish were the same; the spelling difference is only one accent.
2. We excluded all publications different from scientific articles. This was especially difficult with Google Scholar because its filters did not separate the publication types correctly. We found out that Google Scholar has an error when reaching page 99; this problem has already been reported [66]; yet, it provided much information that we could not access with the other search engines.
3. We downloaded all the articles selected up to this point. We then excluded the articles containing the words "Historical Ecology" and "Brazil" (in Portuguese, Spanish or English) only in the references, but not in the main text.
4. After that, we excluded those articles which (a) used Brazil only as an example, that appeared only once in a list of countries, or that the main research was conducted

somewhere else; (b) referred to Historical Ecology as a field related to evolutionary ecology [2]. After these four stages of filters, we had 118 articles to review in-depth.

While reading the articles, we discovered that, in many cases, Historical Ecology was explicitly the main research topic. In contrast, in other times, it was applied as an auxiliary notion to support or to dialogue with an investigation topic in a correlated field. Some examples about the use of Historical Ecology as an auxiliary notion are a publication in environmental public policy [67] and another in political ecology [68] that only mention briefly Historical Ecology in its research. This study includes articles having both, Historical Ecology as main or as an auxiliary research topic.

2.1. Variable Design and Analyses

We designed the variables to overview by whom, where, when, what, and how Historical Ecology research was conducted in Brazil. For the question "by whom"—we included variables of authors' affiliations (as stated in the article at the moment of publication), gender, journal of publication, and language. We determined gender through the author's name and an author information search on the internet and applied a classification of women and men. Although we are aware of the diversity of gender types, we opted for a binary gender classification for practical reasons as questioning all authors about their gender affiliation was out of the scope of this study. We classified the departments and research centers of affiliation of the authors in general fields of knowledge. This gives an idea of the fields that embrace Historical Ecology in their research. It is common to find a department named with more than one field of knowledge, for example, "Department of Geography and Environment," in these cases, we counted it in both areas, geography and environment. Another frequent union is of archaeology and anthropology, or ethnology and history. Concerning the publication journals, we verified their inclusion in the CAPES/MEC Portal of Journals from the Brazilian Ministry of Education (http://www.periodicos.capes.gov.br/, accessed on 1 June 2021). This virtual library subsidizes and provides free access to scientific publications for all education and research institutions in Brazil.

For the question "when"—we had two different approaches. On the one hand, we registered when the articles were published. On the other hand, we were interested in the historical period studied in the papers; we categorized the temporal scales: geological era, before the 16th century, 16th, 17th, 18th, 19th, 20th, and 21st centuries. We registered the references to different times of history in the articles. Each article often referred to several epochs, and so we registered.

For the question "where"—we had two different approaches. On the one hand, we considered the studied biome and, on the other hand, the spatial scale of the research. In Brazil, the biomes are well-characterized as Amazon, Atlantic Forest, Cerrado, Pampa, Caatinga, and Pantanal [69]. To have a spatial idea of where research is concentrated, we mapped the number of authors in Brazil per city according to affiliation and the number of works per biome. We also compared the biome of affiliation's city with the studied biome to know if the authors research where they are based. Concerning the spatial scales, we categorized them as local (i.e., specific sites or landscapes), regional (e.g., a large river basin or portion of a biome, like southeastern Atlantic Forest), biome, national, international (i.e., global, continental, intercontinental studies).

For the question "what"—we included the keywords and the specific species studied. We gathered all the keywords, translated and standardized for singular (i.e., we count the word 'forests' as 'forest'). We placed them in a word cloud (https://www.wordclouds.com, accessed on 1 June 2021), where the font size differentiates the number of mentions; the bigger the letter, the more it was mentioned. For the plant species, we revised the updated scientific names in the Tropicos database (http://tropicos.org, accessed on 1 June 2021).

For the question "how"—we verified whether Historical Ecology was the main research topic or if it was used as an auxiliary topic, as explained in the previous section. We also focused on the methodologies employed in the papers. The use of a mix of methods is usual in Historical Ecology studies. However, we considered it relevant to differentiate between theoretical and in situ fieldwork-based approaches. We classified an article as 'practical' when the researchers did fieldwork, using diverse methodologies in situ; when they explicitly expressed that they went to the location of study to collect data, such as archaeological excavations, botanical collections, water and soil sampling, interviews to local people, among others. In contrast, we classified as 'theoretical' research papers to those that did not carry in situ fieldwork, such as consulting historical archives, literature reviews, or other ex situ methods.

In order to assess these variables, we had two members of our team reading each article and extracting the information for each variable. After that, if there were any conflicting interpretations about the assessment, it was discussed in our weekly meeting.

In the results section, we cited each of the 118 articles found in this systematic mapping at least once so that the readers have access to a comprehensive review of the Historical Ecology in Brazil through the references. The multiple citations to the studied articles along the text are helpful to present various perspectives and topics dialoguing with Historical Ecology.

2.2. Limitations

We worked only with digital scientific articles, leaving out other important publications such as books and theses. Although unlikely, it is possible that we are leaving out some scientific articles published in paper format with no current online access (likely to be older than 1998). Another possibility is that some articles were not included in the results of our search engines; this happened with one of the author's research [12]. Another limitation can be that our proposed scales of time and space could be subject to debate.

3. Results

3.1. Whom

This section presents information related to the authors and publishers.

3.1.1. Authors

We found that 43% of the articles were written by one author, 13% by two authors, 14% by three authors. The articles with the most authors have 14 and 16. There are a total of 264 authors, being 158 men researchers (60%) and 106 women researchers (40%). Concerning the country of affiliation of the authors: 68% belong to Brazil, 11% to the United States of America, 6% to the United Kingdom, 3% from The Netherlands, 2% from Argentina, and 2% from Spain. The rest of the affiliations are from other countries such as Australia, Canada, Finland, France, Germany, Italy, Korea, Mexico, Norway, Panamá, Portugal, South Africa, Spain, Uganda, and Venezuela. Four of these countries were included in the last three years. In six cases, the authors had affiliations in two countries; thus, we counted as one participation for each country. The foreign institutions with the largest amount of authors are Wageningen University (The Netherlands) with nine authors; the University of Florida (USA) with six authors; Oxford University (UK), the Autonomous University of Barcelona (Spain), the University of Montpellier (France) with four authors each, and La Plata National University (Argentina), the University of New Hampshire (USA), the University of Zulia (Venezuela) with three authors each.

There is a participation of 34 Brazilian universities (state, federal, communitarian, and private), and other affiliations including federal institutions - Brazilian Agricultural Research Corporation (Embrapa), National Research Institute of the Amazon (INPA), National Institute of Spatial Research (INPE), Museu Paraense Emílio Goeldi, Rio de Janeiro Botanical Garden (JBRJ), Oswaldo Cruz Foundation, Chico Mendes Institute for Biodiversity Conservation-; state institutions—Rio de Janeiro State Secretary of the Environment, Rio de Janeiro State Environment Institute (INEA), Paulistan Agency of Technology for Agribusiness (APTA), São Paulo State Secretary of Education, Acre State Secretary of Administrative Management-; and other non-governmental organizations-Bird Life/SAVE Brasil, C&T Assessoria e Consultoria Ambiental, Itati Environmental Consultancy, Mamirauá Sustainable

Development Institute, Socioenvironmental Institute. These results show the diversity of research centers that recognize Historical Ecology as a topic worth researching.

The institutions with more publications are University of São Paulo (including its different campi, schools, and institutes) (23), Museu Paraense Emílio Goeldi (16), Federal University of Pará (12), Amazonia National Research Institute (8), Tulane University (7), Federal University of Santa Catarina (7), Federal University of Rio de Janeiro (7), University of Florida (7), Federal University of West Pará (6), Pontifical Catholic University of Rio de Janeiro (5), Mamirauá Sustainable Development Institute (4), Amazonas Federal University (4), Pernambuco Federal Rural University (4). The states of Rio de Janeiro and São Paulo hold the largest amount of research institutions.

The authors with more publications are: William Balée (Tulane University) (7), Nivaldo Peroni (Federal University of Santa Catarina) (6), Charles R. Clement (Amazonia National Research Institute) (5), Eduardo Goés Neves (University of São Paulo) (5), Glenn Harvey Shepard Jr. (Emílio Goeldi Paraense Museum) (5), Helena Pinto Lima (Emílio Goeldi Paraense Museum) (5), Michael Heckenberger (University of Florida) (5), Morgan J. Schmidt (Emílio Goeldi Paraense Museum) (5), Denise Schaan (Federal University of Pará) (4), Marcos Pereira Magalhães (Emílio Goeldi Paraense Museum) (4), Rogério Ribeiro de Oliveira (Pontifical Catholic University of Rio de Janeiro) (4), Alexandro Solórzano (Pontifical Catholic University of Rio de Janeiro) (3), André Pinassi Antunes (Amazonia National Research Institute) (3), Carolina Levis (Federal University of Santa Catarina) (3), Simone Rezende da Silva (University of São Paulo) (3).

The recurrent fields of knowledge in the departments and centers of affiliation with more than 40 authors are ecology, environment, and biology; anthropology appears with 34 authors. Humanities and social sciences have 28 authors. Archaeology and geography have 22 and 20 authors, respectively. Ethnosciences count with 17 authors. Agriculture (which includes agronomy, aquaculture, and soil science) has 15 authors. History has seven authors. Other departments that appeared only once or twice are Language, pedagogy, education, and rural development. The wide array of knowledge areas confirms the multidisciplinary nature of Historical Ecology.

3.1.2. Journals

The selected articles were published in 79 different journals. The journals with the most publications are the Boletim do Museu Paraense Emílio Goeldi (6), Diversity (5), Human Ecology (4), Revista de Arqueologia (4), Cadernos do LEPAARQ (Laboratório de Ensino e Pesquisa em Antropologia e Arqueologia da Universidade Federal de Pelotas) (4), Amazônica-Revista de Antropologia (3), Forest Ecology and Management (3), Journal of Archaeologic Science (3), and Ocean and Coastal Management (3). Concerning the inclusion of journals in the CAPES/MEC Portal of Journals, we found that most Brazilian journals are included in the CAPES/MEC Portal of Journals. In contrast, most of the international journals are not (Table 1).

Table 1. Inclusion of studied Brazilian and international journals in the CAPES/MEC Portal of Journals.

		Brazilian	**International**
CAPES/MEC Portal	in	22	14
	out	9	34

3.1.3. Languages

Concerning the publication language, 60% of the articles were written in English, 38% in Portuguese, and 2% in Spanish.

3.2. *When*

On the one hand, this section is about the year of publication of Historical Ecology articles; on the other hand, it is about the historical periods studied in the research papers.

3.2.1. Years of Publication

Figure 1 shows the number of articles published per year, the oldest we found is from 1998 [70]. The year 2010 presented a peak, 2015 reached the highest number of publications, and 2020 had another peak. Even though we include the information of all 118 articles in the whole article, we did not include the year 2021 in Figure 1 because the data is incomplete for this year as our search ended in May 2021. There is a trend of increasing the number of Historical Ecology publications, as shown by the trend line.

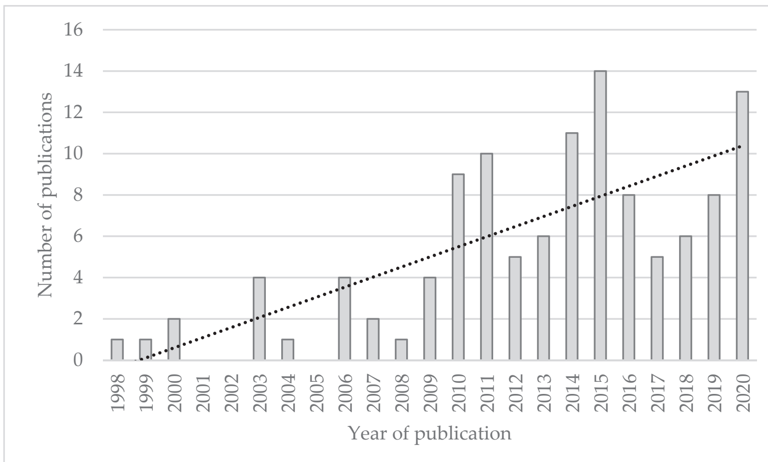

Figure 1. Year of publication of 115 articles until 2020. There is an increasing trend in the number of publications. For 2021, we found three publications but did not include them here, as the yearly data is incomplete.

3.2.2. Historical Periods Studied

Concerning the historical periods investigated, a total of 90% of the articles study the 21st century, whereas 83% study the 20th century, 56% refer to the time before the 16th century, 44% to the 19th century, around 30% consider the 16th, 17th and 18th centuries, and 8% point out different geological eras. We must remember that the articles often refer to various periods.

3.3. *Where*

On the one hand, this section presents the biome studied, and on the other hand, the spatial scale of the research.

3.3.1. Studied Biome and Affiliations Per Biome

We registered in which Brazilian biome the research was conducted. There were cases where the research dealt with more than one biome. We found that five articles did not work with any biome: two of them are studies about marine environments, and therefore, the terrestrial biomes classification could not be used. Totalizing, 60% worked in the Amazon, 31% in the Atlantic Forest, making 91% of the articles (these figures include the articles studying one or more biomes). Five works study the Amazon and the Atlantic Forest [68,71–74]; three articles study the Cerrado Biome (Brazilian savannah) and the Atlantic Forest [75–77]; one studies the Amazon, the Atlantic Forest, and the Cerrado [78];

one studies the Atlantic Forest and Pampa [79]; two study the Cerrado [80,81], one the Pampa [82] and three the Caatinga [83–85]. There are no articles about Pantanal. Figure 2 shows the number of works per biome, the number of authors per affiliation in Brazil, and the city of localization (for a more detailed list of affiliations, please see Table A1 of Appendix A). Some cities such as Bauru, São Carlos, and Belo Horizonte are located in the transition zone between the Atlantic Forest and the Cerrado.

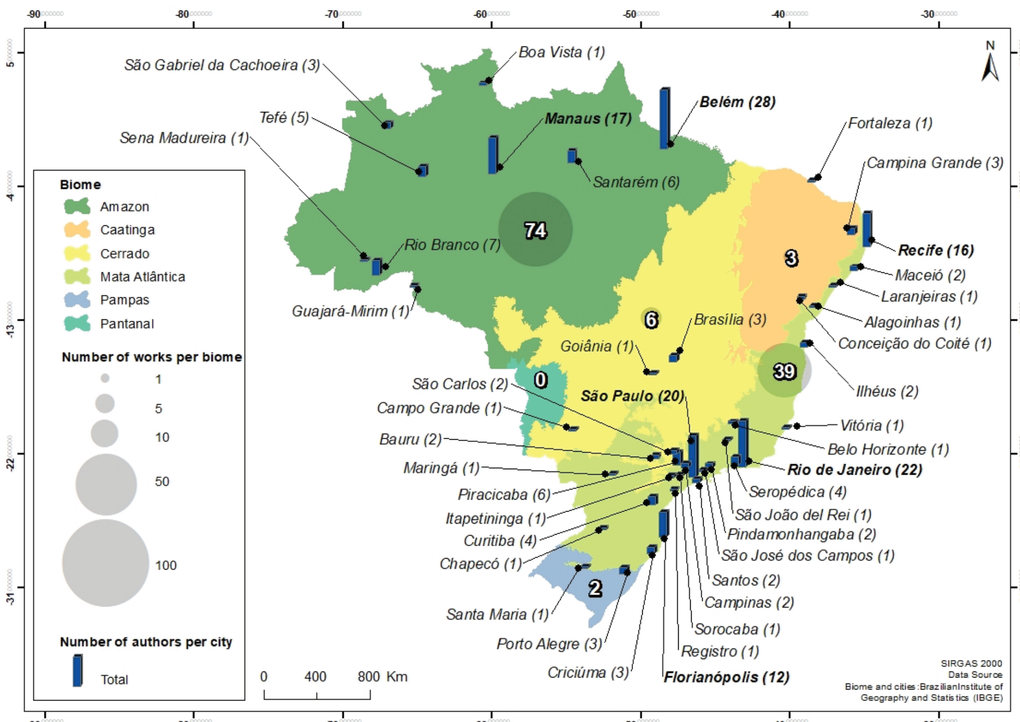

Figure 2. Informative map of the number of works per biome and number of authors by city according to affiliation in Brazil. For more detailed information on affiliations, please see Appendix A.

Figure 3 shows the relation between works per studied biome and biome of affiliation's city. This is helpful to know if the authors research in the biome where they are based. Almost 80% of the authors with international affiliation -outside Brazil- researched the Amazon, 12% in the Atlantic Forest, and the rest studied the other biomes. Argentina stands out as the country that researches the Pampa: an ecological region shared between the southern part of Brazil, the northern part of Argentina, and Uruguay. For studies in the Amazon, 77% of authors are affiliated to institutions located in the Amazon, whereas 19% are located in the Atlantic Forest. For research in the Atlantic Forest, on its own or in combination with other biomes like Cerrado, Pampa, or the Amazon, 79% of the authors are affiliated to institutions in the Atlantic Forest. For Caatinga, 75% of the authors are affiliated to institutions in the Atlantic Forest, the rest in the Caatinga. Cerrado and Pampa are studied by authors affiliated with institutions out of these biomes. There are no works and no authors affiliated in any city in Pantanal.

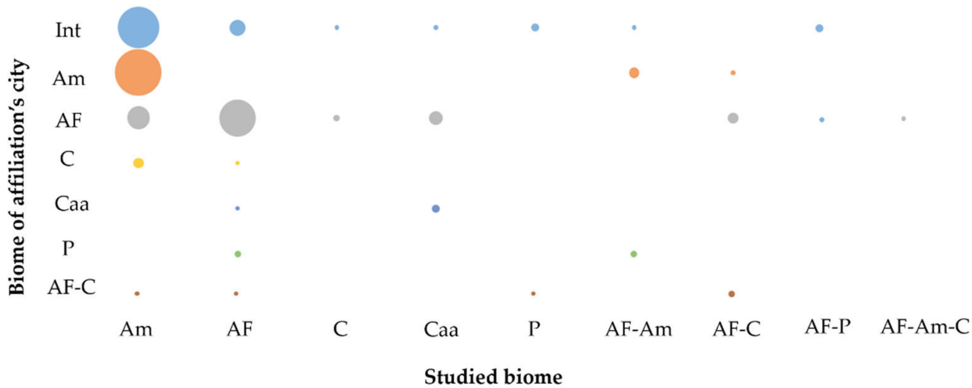

Figure 3. Relation between works per studied biome and biome of affiliation's city. The size of the circles represents the number of works done–the bigger the circle, the higher amount of works- in each specific combination of studied biome and biome where the city of affiliation is located. Int-International; Am-Amazon; AF-Atlantic Forest; C-Cerrado; Caa-Caatinga; P-Pampa; AF-C—Atlantic Forest, Cerrado; AF-Am—Atlantic Forest, Amazon; AF-P—Atlantic Forest, Pampa; AF-Am-C—Atlantic Forest, Amazon, Cerrado.

3.3.2. Spatial Scale of the Study

Regarding the spatial scales, the most common one is working at a regional scale with 49% of the articles [68,86–92], 25% were conducted at a local level [93–95], 11% worked at a biome level [96–99], 10% worked at the international level [100–102], and 4% analyzed the national level [72,103,104].

3.4. What

This section is about the research topics of the articles. We addressed them in two ways, through the keywords and the specific species studied.

3.4.1. Keywords

The keywords show the essential topics of an article (Figure 4). From 502 keywords, the words with at least 10 mentions were historical ecology (32 mentions), Amazon (27 mentions), forest (24 mentions), archaeology (20 mentions), landscape (19 mentions), environmental (15 mentions), indigenous (15 mentions), conservation (14 mentions), dark-earth (12 mentions), Amazonian (11 mentions), Brazil (11 mentions), management (10 mentions), and traditional (10 mentions). As Historical Ecology works with the relationship between people and the environment, numerous keywords refer to ethnosciences such as ethnoarchaeology [105], ethnobiology [106], ethnobotany [107], ethnoecology [84], ethnomusicology [15], ethnoprimatology [71], and ethnotaxonomy [84]. The suffix anthro also reveals this relationship as in Anthropocene [97], anthropogenic forests [108], anthrosols [109], anthropogenic landscapes [110], and ecological anthropology [111]. Other examples of this people-environment relationship are biocultural diversity [87], biopolitics [94], cultural ecology [111], domesticated forest [109], domesticated landscape [112], environmental history [113], environmental management [114], environmental racism [68], human ecology [115], and local ecological knowledge [116]. There are also works about indigenous peoples and traditional populations, for instance, the Ka'apor [15,117], the Guajá [118], the Guarani [114], the Nadahup-Arawak-Tukano [119], the Marajoara [120,121], indigenous groups of the Middle Purus [122]; *quilombolas* [77,94,123,124], *beiradeiros* [125], and *caiçaras* [126] have also been included. There are also mentions to immigrant groups such as the Japanese [124] and the German [127].

Figure 4. Most found keywords in the systematic mapping.

Quilombolas are traditional Afro-descendant Brazilian people, formed by ex-enslaved people, enslaved who fled from captivity, and the ones that were born free. Their name derives from the places where they sought refuge, the *quilombos*. This ethnic group developed characteristic relationships with the environment surrounding them, amalgamating African knowledge with indigenous practices and some cultural traits from the Europeans.

Beiradeiros (also translated as forest peasants) or *ribeirinhos*, are considered a traditional group for the way they relate to the abundant rivers in the Amazon basin. With substantial indigenous influence, it also comprises European and African traits. The name given to those groups reflects how they live: at the river margins, relying on the seasonal oscillation of river water levels to obtain food through fishing, hunting, and short-cycle agriculture amongst the forest.

Caiçaras are groups that make up the traditional Brazilian populations, formed by the syncretism between indigenous people, European descendants, and Africans (on a smaller scale). This ethnic group can be characterized by populations who remained isolated on the Atlantic Forest coast for many years, developing artisanal fishing and other unique relations with nature.

The keywords highlight the importance of the dark-earth studies in the Amazon [28,90,105,108,109,112,128–132] for Historical Ecology research in Brazil. The field of archaeology stands out. Some other interesting topics that appear only a few times in the keywords are: African influence [101,133], defaunation [134], fire [81,90], gender [127], geoglyphs [135], mining pollution [80], shamanism [122], among others.

3.4.2. Species

Out of the whole universe of articles, 23 focused on a particular species. The species that figured as the central theme of investigation are a protozoan species from the genus *Plasmodium* as an agent of malaria in humans and other primates [71]; fish species such as largetooth sawfish (*Pristis pristis*) and goliath grouper (*Epinephelus itajara*) [116], and lane snapper (*Lutjanus synagris*) [106]; the neotropical otter (*Lontra longicaudis*) and the giant otter (*Pteronura brasiliensis*) [136]. The remainder of the 19 articles is regarding plant species. Manioc (*Manihot esculenta* Crantz) [73,113,129] and Brazil nut (*Bertholletia excelsa* Bonpl.) [137–140] stand out with three and four works, respectively. Concerning other arboreal species, there are two articles about mangrove species (*Rhizophora mangle* L., *Laguncularia racemosa* (L.) C.F. Gaertn., *Avicennia germinans* (L.) L., *Avicennia schaueriana* Stapf & Leechm. Ex Moldenke, *Conocarpus erectus* L.) [83,141], two articles about cocoa (*Theobroma cacao* L.) [117,140], two for araucaria (*Araucaria angustifolia* (Bertol.) Kuntze) [134,142], one for carrapeta (*Guarea guidonia* (L.) Sleumer) [143], one for treegourd (*Crescentia cujete* L.) [107], one for jackfruit (*Artocarpus heterophyllus* Lam.) [144], one for rubber tree (*Hevea brasiliensis* (Willd. Ex A. Juss.) Müll. Arg.) [145], one for feijoa (*Acca sellowiana* (O. Berg) Burret) [134], and one for exotic species eucalyptus (*Eucalyptus* spp.) [146]. There is also one work about bamboo (*Guadua* spp.) [135] and one about grass (*Spartina alterniflora* Loisel.) [147].

3.5. How

This section is how the research in Historical Ecology has been conducted. We differentiated between using Historical Ecology as the main research topic or as an auxiliary topic as detailed in the Methods section. We determined that 37% (44 articles) of the publications had Historical Ecology as the main topic and 63% (74 articles) as auxiliary. We distinguished between practical and theoretical works. Practical studies—using in situ fieldwork methodologies—represent 57% of the works, whereas theoretical—using only ex situ methodologies—are 43% [111,148].

We identified more than 35 different methodological procedures used in the 118 articles. It is worth stressing that many studies comprised more than one method to achieve their objectives. All articles include the traditional literature review, 33 of them conducted interviews [27,95,123,132,133,149], 26 used Geographical Information Systems (GIS) and remote sensing techniques [144,150–155], 26 made floristic and phytosociological analyses, including botanical collections [131,135,142,143,156], 19 collected archaeological materials [74,120,157–160], 16 made soil analysis [80,105,115,161–163], 13 analyzed laws and decrees [124,164,165], 12 made some kind of material dating, including C_{14} [79,93,158], 11 used free listing [27,166–168], 10 used oral history [117,169], and 10 worked with historical archives consultation [110,113,150], including hemerographic material (newspaper files) [170], and commercial shipping records [136]. With less than 10 works, other methods used were participatory research techniques—including participative cartography and participative archaeology—[84,149,171], travelers' journals consultation [113,147], anthracological analysis (analysis and identification of charcoal based on carbonized wood anatomy) [74,130,143,172], water analysis [155], participative observation [77,121,173], guided tour [127,168], linguistic analysis [117,169], archaeology of the landscape [174,175], photographic sequences analysis [176], discourse analysis [17], among others.

4. Discussion

4.1. Authors

There is important participation of authors affiliated with foreign countries doing Historical Ecology in Brazil, especially in the Amazon biome, though the Brazilian affiliations still hold the majority. This shows the importance of the Amazon biome for international research due to it historically being regarded as the largest tropical forest remnant in the world and its relevance to global ecology and climate change [177]. Furthermore, it has attracted the attention of numerous foreign anthropologists, ecologists, and biologists, many of which helped develop the field of Historical Ecology (e.g., William Balée, Michael Heckenberger).

Concerning the gender perspective, men make up a higher proportion of historical ecology researchers in Brazil within our study period compared to women. Considering only the researchers with Brazilian affiliation, we find a slightly more equitable proportion of 58% men and 42% women. This is more equitable than a gender study analyzing the differences between men and women researchers getting the scientific productivity funding from the Brazilian National Council for Scientific and Technological Development (CNPq), which shows a significantly bigger proportion in absolute numbers of men researchers getting the funding. However, if we focus on Applied Social Sciences and Biological Sciences, where Historical Ecology topics might be included, the disproportion is smaller [178].

4.2. Affiliations

Rio de Janeiro and São Paulo are the main centers of research aggregating different institutions in the southeastern region (Table A1 of Appendix A). The results showed the participation of many public universities. Sedrez and Nodari [48] explained that the federal universities in Brazil were strengthened by federal government funding and the creation of new universities in the early 2000s with a pro-science and education platform (Lula and Dilma era). The ample funding opportunities and science-friendly scenario (different from Brazil's current research funding policy) increased research agendas in federal universities and improved their research outcomes. Even though we found broad participation of institutions across Brazil, the most productive institutions on Historical Ecology investigation are based in the Amazon and the Atlantic Forest, coinciding with the results on research per biome.

4.3. Practical Work

Considering that more than half of the articles needed in situ fieldwork, it is understandable that given the physical dimensions of Brazil (*circa* 8,500,000 km^2) and the difficulty of access to many places, there is a need for generous funding for in situ fieldwork. In some cases, foreign universities have more access to research grants than national institutions (especially since the second half of the 2010s). Therefore, strategies like alliances between national and international institutions, reinforcement of institutions, and an urgent and serious strengthening of national support for research should be encouraged.

Here we may discuss in more detail about accessibility and difficulties to conduct in situ fieldwork in Historical Ecology so that it is easier to understand the situations that researchers face. Let us use as examples some of the methodologies found in the results, and which the authors of this paper have extensively explored: floristic and phytosociological analyses and botanical collections. Our experiences include a fair amount of in situ fieldwork, comprising many hours climbing trees and learning how to identify leaf morphological traits, bark tree textures, and odors to determine the species or genus of Atlantic Forest trees. It is difficult to identify large trees in some forest tracts because of their sheer height and the dense understory vegetation, not being possible to see the foliage on the treetop. This becomes especially challenging for the Atlantic Forest, that albeit it has been significantly transformed, it still harbors great biodiversity. In the case of the Cerrado, research is conducted under extreme climatic conditions when it is hot and dry (for up to nine months, depending on the portion of the biome). Therefore, water and hydration are critical limiting factors, whereas data collection becomes challenging during the rainy season (especially vegetation samples). Also, due to the current rate of land conversion, it is tough to find specific physiognomies of Cerrado vegetation, such as the *cerradão*, a very rare form of woodland savanna. Land degradation and habitat loss are accelerating at a rate much faster than Historical Ecology research is being done in the Cerrado biome. Other factors that influence in situ fieldwork are the accessibility to roads, the availability and costs of transport, the coexistence with mosquitoes, snakes, and other animals, time, and safety. Safety is especially critical in the northern region of Brazil as it has been reported as a hostile environment for women and their research activities [179]. This situation should not discourage women, but it demands careful planning and accompaniment, finding partners to avoid that women go on their own.

4.4. Fields of Study

Historical Ecology appears to be dominated by environmental sciences, anthropology, and archaeology; the little participation of history departments is noticeable. Nonetheless, the contribution of historians in the similar field of environmental history [47,48] is remarkable. It is worth considering that affiliation departments are not a precise indication of research fields, especially in interdisciplinary departments. For instance, some researchers may be housed within Geography or Environmental Policy programs and identify themselves as historical ecologists.

4.5. Journals

Regarding the journals of publication, it is remarkable that most Brazilian journals are included in the CAPES website; thus, they are available for a free consultation, which makes a strong publications body. In contrast, most international journals are not contained in the open CAPES site; this is usually compensated with the university's libraries. The usual dilemma of publication language for non-English speakers is an important decision for researchers, as English-written articles target a worldwide audience and help to increase the possibility of the journals being more widely known. In contrast, Portuguese written articles may be more available to a lusophone audience, especially undergraduate students and policymakers.

4.6. The Beginnings of Historical Ecology

The first publications of Historical Ecology in Brazil that we found in the present systematic mapping are about archaeology in the Amazon [70,169,180]. Interestingly, Neves's 1998 [70] article is an overview of twenty years of archaeological research in the Amazon, where he brings about the Historical Ecology concept from Balée works [54,181] as a kind of paradigm change. However, the fundamental understanding of the relationship between humans and the environment throughout history might have been addressed before the term 'Historical Ecology' or 'Environmental History' appeared. We coincide with Sedrez and Nodari [48], who argue that some authors delivered early efforts in this direction. For instance, the work "*Nordeste*" [182] by the anthropologist and sociologist Gilberto Freyre, which narrates the history of sugarcane in the Brazilian Northeast; or "*Caminhos e fronteiras*" [183] by the historian and sociologist Sergio Buarque de Holanda, which is about the territorial occupation of Brazil, discussing the tensions between nature, indigenous peoples and the colonizers.

4.7. Temporal Scales

Concerning the temporal scale in the articles, it is interesting to observe the capacity of Historical Ecology to address and answer questions in a lengthy scope of time. It also demonstrates the necessary collaboration with fields such as archaeology or geology. Some methodologies like palynology, anthracology, or C_{14} dating can bring data from thousands of years ago, whereas some other methods like hemerographic consultation or analysis of photographs show information on the contemporary period. We noticed the constant references to the European colonization of Brazil as a critical driver of landscape transformation in the 16th century. This made us fine-tune our categories from the 16th century onwards but not before that. Even though there are fewer articles from the 16th, 17th, and 18th centuries, there are many topics that can be further investigated that occurred within this time, such as the effects in the landscape from sugar cane plantations or mining exploitation, the earliest introductions of foreign plants and animals during colonization, whale hunting, the early influence of the African diaspora in the landscape, and so on. There is research about these topics, but we did not find articles published under the perspective of Historical Ecology. This seems a good opportunity to team up with researchers from other fields.

4.8. Biomes

One of the most obvious results of our paper is the small number of articles in the biomes different from the Amazon and the Atlantic Forest. We do not underestimate the merits of the research in these biomes; it is necessary and useful. There is still much room for further research questions and tackling contemporary problems. However, given Brazil's biomes' biocultural diversity and ecological importance, it is essential to indicate the spatial gaps to encourage more research in the Pantanal, Pampa, Caatinga, and Cerrado. Interestingly, Sandro Dutra points out that the definition of biomes in Brazil historically favored the protection of the Amazon and the Atlantic Forest, leaving other regions out of the spotlight and deemed less important [184]. This observation coincides with our results showing the prominent attention on these two biomes.

4.9. Spatial Scales

It is interesting and enriching to have works at local, regional, biome, national, and international scales. They all have advantages and disadvantages in terms of focus, degree of detail, and availability of information. At a local level, the concrete, the sensitive, and the individual behavior become more critical, whereas, at a regional level, the landscape becomes an intellectual construction where details are often blurred [185]. All scales are necessary as each of them addresses different problems and perspectives.

4.10. Ethnic Diversity

One remarkable point is the diversity of ethnic groups revealed through the compilation of keywords in the works surveyed. Even though the groups' names did not appear in the word cloud (Figure 4) because they had few mentions, we highlighted them in the description of the results. These ethnic groups are both from traditional communities (e.g., *quilombolas* and *caiçaras*) that have their origins linked to the colonization process, and the indigenous people (e.g., Ka'apor, Nadahup-Arawak-Tukano) that resisted—and still resist—for more than 500 years. This demonstrates part of the Brazilian ethnic diversity and the relationship between this diversity and ecological diversity, a central theme in Historical Ecology.

4.11. Study of Species

There is a vast opportunity to research different species in Historical Ecology. We can think about the footprints in the landscape derived from the relationship between the history of Brazil and the brazilwood tree (*Paubrasilia echinata* (Lam.) Gagnon & H.C.Lima & G.P.Lewis). There is much to do considering animals, plants, and organisms from other kingdoms like fungi, algae, bacteria, or even viruses. Ironically, we are confined in our houses while writing this paper due to the global expansion of a zoonotic virus that is forcing humanity to change our ways of working, organizing, and relating to each other. The socio-environmental effects of Covid-19 constitute an interesting raw material for Historical Ecology.

4.12. Methodologies

Regarding methodologies, our results confirmed the multidisciplinary nature of Historical Ecology. We tried to categorize the methodologies in disciplinary origins. Some methodologies have an obvious disciplinary origin, such as stratigraphic excavations, shovel tests, archaeological material collection coming from archaeology, or Geographic Information Systems, and cartography coming from geography. However, other methods are used across various disciplines, such as interviews and statistical analysis. We even had trouble with classifying between social and natural sciences origin. Santana and Szabó [23] mentioned the various approaches used in Historical Ecology, such as qualitative, quantitative, and experimental. Szabó highlights that "the higher variety of sources of information, the more secure knowledge about the past (and therefore about the present) is" [3] (p. 384). This opens the possibilities to search not only for documental sources but also for other historical data corresponding with periods during which human impacts were not registered as ecological data [19]. Social perception studies can be helpful when no official data is available or incomplete [106].

We learned about the importance of the participation of local people in different research approaches, given the various participatory research methods reported, such as participatory archaeology, participatory cartography, oral history, or interviews. More concealed (often considered in the Acknowledgements section of published articles) and yet essential is the local people collaboration as guides localizing research sites, identifying species, protecting from local dangers, helping with local remedies, leading to key informants, and so on. Teaming up with local populations, not only as informants but also as colleagues for exchanging ideas, recognizing the value of empirical knowledge, is required to conduct field research in Historical Ecology.

5. Conclusions

This study provided a comprehensive overview of the scientific articles on Historical Ecology in Brazil, informing by whom, when, where, what, and how research has been conducted. It also found achievements, research gaps, and opportunities for this field:

5.1. Achievements

Some of the achievements in the field of Historical Ecology in Brazil are:

- The generation of a large body of knowledge of anthropogenic dark-earth and the anthropogenic forests/landscape domestication in the Amazon. This could be used as a solid scientific argument to demonstrate how indigenous populations have historically shaped the Amazon forest, harboring rich biocultural diversity. There is still much to be done regarding the conservation of its biocultural patrimony.
- Historical Ecology in Brazil has grown in diverse research topics, methodologies, departments, national and international institutions in the last two decades.

5.2. Research Gaps and Opportunities

Some of the research gaps and areas of opportunity are:

- Historical Ecology research brings a perspective that valorizes the environmental and cultural importance of landscapes. This approach could be helpful to make better management decisions, for example, in environmental restoration, and become a more policy-driven applied science.
- In terms of the spatial gap, more research is needed in the Pantanal, Caatinga, Pampa, and Cerrado biomes. Research in these biomes is crucial because they are reservoirs of unique biodiversity and provide particular environmental services on the local and regional scales. This implies the need to strengthen institutions and research groups promoting cross-disciplinary research located in these biomes.
- More research is needed focusing on animal species. This would require social scientists to work with experts in zoology, biology, ecology, and *vice versa*. Other life kingdoms should also be explored.
- Special attention should be paid to marine environments, especially the interface between the land and the ocean, which is key to understanding the dynamics of the Brazilian population in the coastal Atlantic Forest.
- Given Brazil's dimensions, diversity, and accessibility, there is a need for generous funding for conducting in situ fieldwork research, both with national funds and with international collaborations, given the biocultural importance of all Brazilian biomes not only for the country but also at a global level. Cooperation with neighboring countries for research in biomes such as Amazon, Pampa, and Pantanal is necessary, as demonstrated in the Pampa region.

- The overview presented by whom, when, where, what, and how research has been conducted in Historical Ecology in Brazil. It showed a great diversity of authors, institutions, journals, study sites, periods of study, research topics, and methodologies. The further development of Historical Ecology research in Brazil, valorizing the achievements and considering the research gaps and opportunities, can provide solid scientific evidence to support informed actions towards the urgent need for better conservation and management of the biocultural patrimony in all biomes.

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Appendix A

Table A1. Details of affiliations per city of localization of all authors working in Brazil.

Affiliation	Abbreviation	City, State [1]	Biome
Universidade do Estado da Bahia	UNEB	Alagoinhas, BA	Atlantic Forest
Universidade Sagrado Coração	UNISAGRADO	Bauru, SP	Atlantic Forest and Cerrado
Museu Paraense Emílio Goeldi		Belém, PA	Amazon
Universidade Federal do Pará	UFPA	Belém, PA	Amazon
Universidade Federal de Minas Gerais	UFMG	Belo Horizonte, MG	Atlantic Forest and Cerrado
Intituto Socioambiental		Boa Vista, RR	Amazon
Universidade de Brasília	UnB	Brasília, DF	Cerrado
Universidade Federal de Campina Grande	UFCG	Campina Grande, PB	Caatinga
Universidade Estadual de Campinas	Unicamp	Campinas, SP	Atlantic Forest
Universidade Federal do Mato Grosso do Sul	UFMS	Campo Grande, MS	Cerrado
Universidade Comunitária da Região de Chapecó	Unochapecó	Chapecó, SC	Atlantic Forest
Universidade do Estado da Bahia	UNEB	Conceição do Coité, BA	Caatinga
Universidade do Extremo Sul Catarinense	UNESC	Criciúma, SC	Atlantic Forest
Universidade Federal do Paraná	UFPR	Curitiba, PR	Atlantic Forest
Universidade Federal de Santa Catarina	UFSC	Florianópolis, SC	Atlantic Forest
Universidade Federal de Ceará	UFC	Fortaleza, CE	Caatinga
Universidade Federal de Goiás	UFG	Goiânia, GO	Cerrado
Universidade Federal de Rondônia	UNIR	Guajará-Mirim, RO	Amazon
Universidade Estadual de Santa Cruz	UESC	Ilhéus, BA	Atlantic Forest
C&T Assessoria e Consultoria Ambiental		Itapetininga, SP	Atlantic Forest
Universidade Federal de Sergipe	UFS	Laranjeiras, SE	Atlantic Forest
Universidade Federal de Alagoas	UFAL	Maceió, AL	Atlantic Forest
Instituto Nacional de Pesquisas da Amazônia	INPA	Manaus, AM	Amazon
Universidade Federal do Amazonas	UFAM	Manaus, AM	Amazon
Universidade Estadual de Maringa	UEM	Maringá, PR	Atlantic Forest
Agência Paulista de Tecnologia dos Agronegócios–Polo Regional do Vale do Paraíba	APTA - Polo Regional do Vale do Paraíba	Pindamonhangaba, SP	Atlantic Forest
Escola Superior de Agricultura Luiz de Queiroz / Universidade de São Paulo	ESALQ/USP	Piracicaba, SP	Atlantic Forest

Table A1. *Cont.*

Affiliation	Abbreviation	City, State [1]	Biome
Escola Superior de Agricultura Luiz de Queiroz / Universidade de São Paulo	ESALQ/USP	Piracicaba, SP	Atlantic Forest
Universidade Federal do Rio Grande do Sul	UFRGS	Porto Alegre, RS	Pampa
Instituto Bioma Brasil		Recife, PE	Atlantic Forest
Universidade Federal Rural de Pernambuco	UFRPE	Recife, PE	Atlantic Forest
Universidade de São Paulo	USP	Registro, SP	Atlantic Forest
Secretaria de Gestão Administrativa do Estado do Acre		Rio Branco, AC	Amazon
Universidade Federal do Acre	UFAC	Rio Branco, AC	Amazon
Empresa Brasileira de Pesquisa Agropecuária - Solos	Embrapa Solos	Rio de Janeiro, RJ	Atlantic Forest
Fundación Oswaldo Cruz	Fiocruz	Rio de Janeiro, RJ	Atlantic Forest
Instituto de Pesquisas do Jardim Botânico do Rio de Janeiro	JBRJ	Rio de Janeiro, RJ	Atlantic Forest
Instituto Estadual do Ambiente	INEA	Rio de Janeiro, RJ	Atlantic Forest
Pontifícia Universidade Católica do Rio de Janeiro	PUC-Rio	Rio de Janeiro, RJ	Atlantic Forest
Secretaria de Estado do Ambiente do Rio de Janeiro		Rio de Janeiro, RJ	Atlantic Forest
Universidade Federal do Rio de Janeiro	UFRJ	Rio de Janeiro, RJ	Atlantic Forest
Universidade Federal de Santa Maria	UFSM	Santa Maria, RS	Pampa
Universidade Federal do Oeste do Pará	UFOPA	Santarém, PA	Amazon
Universidade de Santa Cecília	UniSanta	Santos, SP	Atlantic Forest
Universidade Federal de São Paulo	Unifesp	Santos, SP	Atlantic Forest
Universidade Federal de São Carlos	UFSCar	São Carlos, SP	Atlantic Forest and Cerrado
Escola Indígena Baniwa e Coripaco Pamáali		São Gabriel da Cachoeira, AM	Amazon
Instituto Socioambiental		São Gabriel da Cachoeira, AM	Amazon
Universidade Federal de São João Del-Rei	UFSJ	São João Del-Rei, MG	Atlantic Forest
Instituto Nacional de Pesquisas Espaciais	INPE	São José dos Campos, SP	Atlantic Forest
BirdLife/SAVE Brasil		São Paulo, SP	Atlantic Forest
Itaiti Consultoria Ambiental		São Paulo, SP	Atlantic Forest
Universidade de São Paulo	USP	São Paulo, SP	Atlantic Forest
Instituto Chico Mendes de Conservação da Biodiversidade		Sena Madureira, AC	Amazon
Empresa Brasileira de Pesquisa Agropecuária–Embrapa Agrobiologia	Embrapa Agrobiologia	Seropédica, RJ	Atlantic Forest
Universidade Federal Rural do Rio de Janeiro	UFRRJ	Seropédica, RJ	Atlantic Forest
Secretaria de Educação do Estado de São Paulo		Sorocaba, SP	Atlantic Forest
Instituto de Desenvolvimento Sustentável Mamirauá		Tefé, AM	Amazon
Universidade Federal do Espírito Santo	UFES	Vitória, ES	Atlantic Forest

[1] States of Brazil: AC-Acre, AL-Alagoas, AM-Amazonas, BA-Bahía, CE-Ceará, DF-Distrito Federal, ES-Espírito Santo, GO-Goiás, MS-Mato Grosso do Sul, MG-Minas Gerais, PA-Pará, PB-Paraíba, PR-Paraná, PE-Pernambuco, RJ-Rio de Janeiro, RS-Rio Grande do Sul, RO-Rondônia, RR-Roraima, SC-Santa Catarina, SP-São Paulo, SE-Sergipe.

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Historical Suitability and Sustainability of Sicani Mountains Landscape (Western Sicily): An Integrated Approach of Phytosociology and Archaeobotany

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Abstract: Since 2015, the ongoing project "Harvesting Memories" has been focused on long-term landscape dynamics in Sicani Mountains (Western Sicily). Archaeological excavations in the case study site of Contrada Castro (Corleone) have investigated a settlement which was mainly occupied during the Early Middle Ages (late 8th–11th century AD). This paper aims to understand the historical suitability and sustainability of this area analysing the correlation between the current dynamics of plant communities and the historical use of woods detected by the archaeobotanical record. An integrated approach between phytosociology and archaeobotany has been applied. The vegetation series of the study area has been used as a model to understand the ecological meaning and spatial distribution of archaeobotanical data on charcoals from the Medieval layers of the Contrada Castro site. The intersection between the frequency data of the archaeobotanical record and the phytosociological analysis have confirmed the maintenance of the same plant communities during the last millennium due to the sustainable exploitation of wood resources. An integrated comparison between the structure and composition of current phytocoenoses with archaeobotanical data allowed us to confirm that this landscape is High Nature Value (HNV) farmland and to interpret the historical vegetation dynamics linked to the activities and economy of a rural community.

Keywords: historical ecology; landscape archaeology; vegetation science; anthracology; vegetation series; Mediterranean woods; high nature value (HNV) farmlands; historical landscapes; early middle ages

1. Introduction

In long-term anthropized landscapes, the biodiversity has been preserved over time thanks to agricultural, pastoral and silvicultural practices that we would define today as sustainable. The high biodiversity, maintained during the long interaction between natural processes and human history, is a peculiarity of certain types of landscapes and agrarian systems that, for this reason, are recognized as High Nature Value (HNV) farmlands [1]. The strong connection between biodiversity conservation and the maintenance of traditional agricultural activities has been the concept behind the development of the definition of HNV farmlands in Europe [2]. In particular, seminatural pastures and woods are essential elements of traditional and historical agricultural landscapes for the maintenance of the high degree of naturalness [3]. High presence of seminatural areas, extensive mosaic landscapes and areas hosting species of conservation concern are elements for the definition of an HNV farmland [4]. In most cases, the HNV farmlands are "historical landscapes" and are intended to be landscapes that are long-standing in a certain territory without or with gradual changes [5,6]. However, what is it meant by "long-standing" in a given area? The understanding of a historical landscape is based on the analysis of natural factors and historical dynamics that have determined its characteristics and on the interpretation of human–environment interactions. In fact, the landscape as a biological and cultural system is the result of processes of changes that have determined a stratified and dynamic pattern over time, notably also in the Mediterranean [7,8].

Vegetation studies are useful to describe landscape patterns and transformations. The structure and floristic compositions of plant communities are strictly connected to the environmental set-up of the ecosystems. For this reason, the pool of community species has been recognized as an indicator of environmental conditions and the characterization of the ecosystems [9–11]. Phytocoenoses are not only the result of natural processes but also derive from the anthropic action that changes their characteristics. Secondary formations such as shrubs, pasture meadows, ruderal and weed communities are examples of vegetation derived from sylvo-pastoral and agricultural activities [12] and in many cases are of considerable phytogeographic interest [13–15]. The structure, diversity and floristic composition of these communities have been influenced by the current and historical use of the territory. In particular, fire, deforestation and grazing are the anthropic activities that have influenced the pattern of natural plant communities present in rural landscapes [16–18]. In summary, the characteristics of a plant association—such as the result of interactions between natural and human factors—are fundamental keys to understanding the landscape. However, this is not sufficient; to gain a wider view of the landscape, it is necessary to interpret the mosaic of associations generated by the anthropic disturbance in terms of series of vegetation [12,19–21]. The study of the landscape from the perspective of vegetation series allows us to interpret the territorial mosaic both in terms of spatial patterns (different associations that share the same ecology) and in the temporal dynamics (the phytocoenosis that occurs over time in relation to anthropic activities). In fact, the spatial distribution of a vegetation series is influenced by environmental factors (e.g., climate, lithology, landforms), which change over the long term, often measured with the geological time scale. The anthropic factors do not change the entire spatial distribution of a series but modify, in a shorter time scale, the plant associations (the different stages) that compose it. However, the diachronic analysis of the landscape in terms of vegetation series—as for all ecosystem ecology analyses [22]—is limited only to a time-range of just over a century [12].

The improvement of the temporal depth in the analysis of landscape dynamics is possible through a Historical Ecology approach that integrates historical and archaeological data with ecological information [23] and specifically—in this "vegetation series perspective"—with the dynamic–catenal phytosociology (see Rivas-Martínez [20]). This multidisciplinary perspective makes it possible to study the interaction between human societies and biophysical environments while also considering long-term dynamics [24,25].

The reconstruction of past landscape dynamics and the impact of agricultural, pastoral and forestry practices on vegetation during the long term can be significantly improved by archaeobotanical data [26]. The impact of anthropic activity on vegetation over the centuries can be assessed using pollen [27,28] but also archaeobotanical macroremains [29,30]. In particular, the study of the charcoals found in archaeological excavations provides a fundamental tool for the reconstruction of past landscapes and for interpreting strategies for the exploitation of forest resources by human communities [31–33].

Archaeobotanical studies and analyses of wood charcoals for the reconstruction of paleoenvironments are a practice in most current archaeological projects in the Mediterranean area [34–36], although in Sicily the picture is still rather limited [37–39]. The presence of wood remains, often charred, in archaeological contexts is filtered by the process of human selection—for different purposes—of the plant resources available in the surrounding environment [40–42].

The Sicani Mountains, in central-western Sicily, have several historical landscapes with a high degree of biodiversity and a diversified territorial mosaic rich of peculiar phytocoenosis [43–45] that have been recognized by the European Environment Agency as HNV farmland (Figure 1) [46].

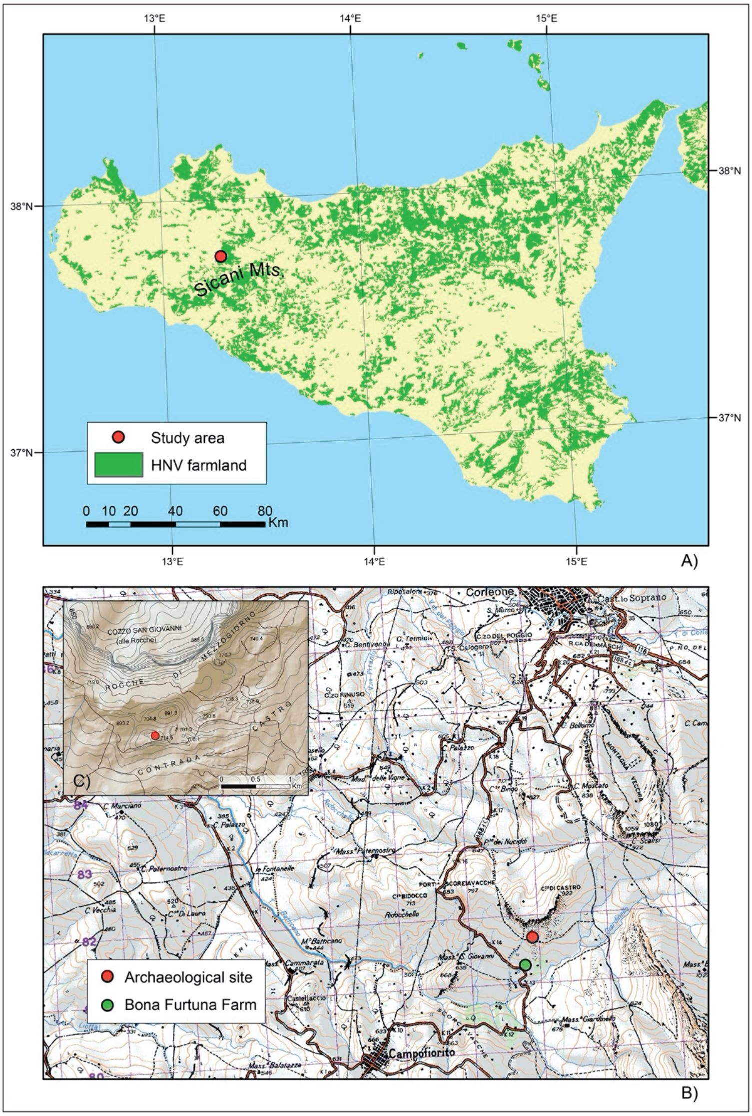

Figure 1. (**A**) Case study area and distribution of High Nature Value (HNV) farmland in Sicily (Source: European Environment Agency [46]). (**B**) Location of archaeological site (Contrada Castro) on topographic base map by the Italian Geographic Military Institute (aut. n. 4848 27/07/1998). The U.T.M. grid, in purple, has an interval of 1000 metres. (**C**) Topographical map of the location of the archaeological excavation in Contrada Castro (Redrawn from: Regional Geographical Information System of Sicily—[47]).

Recent research in the Castro-Giardinello area (Corleone, Palermo) [48,49], the study area of this paper, has shown that a small area of about 400 hectares preserves a biodiversity of about 502 taxa of vascular flora that have also been an important resource in traditional food habits [50]. As a result of the dynamics of the renaturalization which has taken place in the last 60 years, this sector of the Sicani Mountains (Figure 2) retains a high degree of naturalness and a low anthropic impact [10]. This interesting biodiversity is linked to a territory with long-term human occupation as evidenced by a recent archaeological survey [48].

The aim of this paper is to detect the relationship between the geobotanical characteristics of the landscape (phytosociological analysis of current vegetation dynamics) and the effective historical use of wood resources (anthropological analysis on charcoal finds from the Medieval phases of Contrada Castro site) in order to understand the long-term suitability and sustainability of this historical landscape and HNV farmland in Sicani Mountains district (central-western Sicily).

(**a**)

(**b**)

Figure 2. Sicani Mountains landscape: Farmland in Contrada Giardinello (**a**) and olive groves (**b**) near Pizzo Castro (Corleone). The area depicted in these photos is free of anthropic elements (buildings, roads, electric lines, etc.). Photos by Pasquale Marino.

2. Archaeological Background of the Site

Since 2015, the Castro-Giardinello area located in the Sicani Mountains district, in the southern part of the territory of Corleone (central-western Sicily), has been investigated by archaeological survey and excavation (directed by the Soprintendenza BB.CC.AA. of Palermo) within the project "Harvesting Memories" focused on the investigation of long-term landscape trajectories and human dynamics [49]. In particular, the project area is located in the Bona Furtuna LLC estate (a 100% organic farm) between the valley of the Giardinello creek and the south-western side of Barraù mount (maximum height 1475 m a.s.l.) (Figures 1b and 2). The long-term anthropic occupation of this area has been detected by a field survey that identified various sites dating back to the Bronze Age, classical, medieval and postmedieval periods [48].

For its topographical position on a hill-top plateau (715–713 m a.s.l.) and its remarkable presence of pottery, the site of Contrada Castro has been chosen for archaeological excavations from 2017, and these are still ongoing (Figure 3). The site extends over a flat, raised, east-west plateau (0.54 ha) on brown marls substrate. To the north, it is adjacent to a sinkhole that separates it from the steep slopes of Pizzo Castro, and to the south, there is an almost vertical slope towards the valley of the Giardinello river (Figure 1b).

Figure 3. The hill-top plateau of the archaeological site of Contrada Castro (Corleone, Palermo, Sicily). Drone photo by Filippo Pisciotta.

In this area, the surveys have highlighted the presence of dispersed ceramic sherds which indicated a potential occupation during the Early Middle Ages (Byzantine and Islamic periods, 7th–11th centuries AD), while rare fragments of black-gloss pottery also indicated an earlier occupation during an archaic/classical period [48]. The initial hypothesis was therefore related to the possible presence of a site that was intensely populated during the Early Middle Ages and subsequently abandoned and never again permanently resettled. The first archaeological seasons have confirmed this hypothesis [48]. The earlier period of the site is documented by some wall remains associated with ceramic finds of the late 6th–5th centuries BC. On the collapses of these structures, some evidence of a reoccupation of the site are related to two perinatal burials dated by radiocarbon analysis between the 7th and the mid-8th centuries AD (sigma 1 65%: AD 662–AD 778). Later, during the late 8th–9th centuries AD, this area was further exploited for the installation of a building dedicated in the first phase to the production of ceramics and tiles, as evidenced by the discovery of two circular kilns. The chronology of these structure is also based on radiocarbon analysis of *Pistacia terebinthus* wood charcoals (sigma 1 65%: AD 774–AD 878) from a burnt layer related to the productive activity of one of the two kilns. This structure was reused after a short time, changing its function because one of the pottery kilns was converted into a food oven (possibly for bread). The collapse of this building occurred during the 9th century AD. On the ruins of this building, which is no longer visible, another building was built with two phases, which can be placed chronologically between the first half of the 10th and the 11th century AD. For this period, the chronology was confirmed by pottery chronotypology and by radiocarbon analysis of an *Equus asinus* bone (sigma 1 65%: AD 965–AD 1042) [48]. The largest number of archaeobotanical findings comes from the medieval layers of the site and can be subdivided into two periods: Period 1, late 8th–9th centuries AD; Period 2, 10th–11th centuries AD.

3. Materials and Methods

3.1. Vegetation Data

The syn-phytosociological study of the vegetation allowed us to define a forest landscape model (current and potential) of the Sicani Mountains, which was necessary for the interpretation of anthracological data from the Contrada Castro sequence. The analysis of landscape patterns in terms of vegetation series followed the approach outlined in detail by Bazan et al. [21].

The vegetation surveys were conducted based on the classical phytosociological approach [51] including recent methodological advances [19]. A total of 24 relevés, in 100 m^2 plots, were created during the spring 2019 (Table S1). The survey was carried out with a Stratified Random Sampling by dividing the study area into different physiognomical homogeneous contexts, based on the stages of the vegetation series defined by Bazan et al. [12] and randomly sampling within each of these smaller areas [52].

In order to get a more complete picture of the floristic composition and structure of the forest and preforest associations, the relevés of Gianguzzi et al. [53] were also considered. The complete data set consisted of 106 relevés which were summarized in a synoptic table (Table 1).

The mean coverage of each woody species (phanerophytes and nanophanerophytes) within each association was calculated by transforming the Braun-Blanquet cover-abundance scale into a quantitative form (0–100%) as proposed by McNellie et al. [54]. A mean coverage curve was constructed for the associations of the vegetation series describing our forest landscape model.

The syntaxonomical nomenclature followed the “International Code of Phytosociological Nomenclature” [55]. Species identification was done using the identification key of Pignatti et al. [56] and for the nomenclature, the online database “The Plant List” [57], was used. The complete names of specific and subspecific taxa of this paper, including the authors’ citations of plant names, are given in Table 1.

The bioclimatic data followed the framework developed for Sicily by Bazan et al. [58]; other ecological information was obtained from Gianguzzi et al. [59].

Table 1. Synoptic table of the associations of vegetation series. Column numbers: 1 = *Ampelodesmo mauritanici-Quercetum ilicis*; 2 = *Sorbo torminalis-Quercetum ilicis*; 3 = *Oleo oleaster-Quercetum virgilianae*; 4 = *Sorbo torminalis-Quercetum virgilianae*; 5 = *Euphorbio characiae-Prunetum spinosae*; 6 = *Roso siculae-Prunetum spinosae*; 7 = *Roso corymbiferae-Rubetum ulmifolii*; 8 = *Crataegetum laciniatae*; 9 = *Ulmo-Salicetum pedicellatae*. Roman numbers indicate the presence classes of species in the phytosociological relevés of Table S1 as follows: I = 0–20%, II = 20–40%, III = 40–60%, IV = 60–80%, V = 80–100%. The values of diagnostic species of association and alliance are in the grey boxes.

Column Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Total Number of Relevés	**27**	**18**	**5**	**9**	**14**	**8**	**8**	**7**	**10**
Characteristics and diff. of ass. and subass. *Ampelodesmo mauritanici-Quercetum ilicis*									
Quercus ilex L.	V	V	II	IV	I	.	.	.	.
Hippocrepis emerus (L.) Lassen subsp. *emeroides* (Boiss. & Spruner) Lassen	IV	.	IV	.	I	.	.	.	II
Ampelodesmos mauritanicus (Poir.) T. Durand & Schinz.	IV	II	II	II	III	.	III	.	.
Lonicera implexa Aiton	IV	II	.	.	.	.	.	.	.
Viburnum tinus L.	III	.	.	I	.	.	.	.	.
Arbutus unedo L.	III	I	.	.	.	.	.	.	.
Characteristics and differentials of ass. and subass. *Sorbo torminalis-Quercetum ilicis*									
Acer campestre L.	.	V	.	II	.	I	.	III	.
Euphorbia amygdaloides subsp. *arbuscula* Meusel	I	III	.	V	I	II	V	II	.
Brachypodium sylvaticum (Huds.) P. Beauv.	IV	III	.	V	III	V	V	IV	.
Daphne laureola L.	I	II	.	IV	I	V	III	IV	.
Characteristics and differentials of ass. and subass. *Oleo oleaster-Quercetum virgilianae*									
Quercus virgiliana (Ten.) Ten.	IV	II	V	V	.	.	.	.	.
Prasium majus L.	II	I	II	.	.	.	.	.	.
Characteristics and differentials of ass. *Sorbo torminalis-Quercetum virgilianae*									
Sorbus torminalis (L.) Crantz	.	III	.	V	.	.	.	.	.
Characteristics of the alliance *Fraxino-Quercion ilicis and of the upper units*									
Asparagus acutifolius L.	V	IV	III	IV	IV	III	V	II	.
Dioscorea communis (L.) Caddick & Wilkin	V	IV	.	IV	II	.	V	I	V
Ruscus aculeatus L.	V	IV	V	IV	IV	.	V	II	II
Smilax aspera L.	V	III	IV	II	II	.	IV	I	.
Rubia peregrina L. subsp. *longifolia* (Poir.) O. Bolòs	V	III	IV	IV	IV	.	IV	.	IV
Cyclamen hederifolium Aiton	V	II	III	IV	.	.	II	I	.
Fraxinus ornus L.	IV	IV	I	II	.	I	.	.	.
Allium subhirsutum L.	IV	III	.	IV	III	.	.	II	.
Festuca drymeja Mert. & W.D.J.Koch.	III	II	.	IV	.	.	.	.	.
Osyris alba L.	III	I	III	.	III	.	.	.	V
Pistacia terebinthus L.	III	.	.	.	.	.	.	.	.
Cyclamen repandum Sm.	II	IV	V	III	.	.	.	.	.
Rosa sempervirens L.	II	I	I	III	II	.	I	.	.
Teucrium flavum L.	II	I	I	.	.	.	.	.	.
Pistacia lentiscus L.	II	.	.	.	.	.	.	.	.
Lonicera etrusca Santi	I	V	II	IV	II	I	IV	II	.
Cistus creticus L. subsp. *creticus*	I	II	III	II	.	.	.	.	.
Viola alba Besser. subsp. *dehnhardtii* (Ten.) W. Becker	I	I	I	.	.	.	.	II	.
Arisarum vulgare Targ.Tozz.	I	I	.	II	III	.	.	.	.
Carex distachya Desf.	I	I	.	II	.	.	.	.	.
Clinopodium vulgare L. subsp. *orientale* Bothmer	I	.	II	.	.	.	II	.	.
Pulicaria odora (L.) Rchb.	I	.	.	I	.	.	.	.	.

Table 1. *Cont.*

Column Number	1	2	3	4	5	6	7	8	9
Total Number of Relevés	**27**	**18**	**5**	**9**	**14**	**8**	**8**	**7**	**10**
Characteristics of the alliance *Fraxino-Quercion ilicis and of the upper units*									
Chamaerops humilis L.	I	.	.	.	.	.	.	.	.
Cephalanthera longifolia (L.) Fitsch	I	.	.	.	.	.	.	.	.
Daphne gnidium L.	I	.	.	.	.	.	.	.	.
Polystichum setiferum (Forssk.) Moore ex Woyn	I	.	.	.	.	.	.	.	.
Myrtus communis L.	I	.	.	.	.	.	.	.	.
Anthriscus nemorosa (M. Bieb.) Spreng.	.	II	.	II	.	.	II	I	.
Asplenium onopteris L.	.	I	II	.	.	.	.	.	.
Calicotome infesta (C. Presl) Guss. subsp. *infesta*	.	.	I	.	.	.	.	.	.
Quercus amplifolia Guss.	.	.	.	I	.	.	.	.	.
Char. and diff. of ass.*Euphorbio characiae-Prunetum spinosae*and *Roso siculae-Prunetum spinosae*									
Euphorbia characias L.	III	II	.	.	V	.	.	.	.
Prunus spinosa L.	I	II	I	II	IV	V	V	III	.
Rosa sicula Tratt.	.	.	.	II	.	V	.	IV	.
Rosa glutinosa Sibth. & Sm.	.	.	.	.	.	V	.	II	.
Characteristics and differentials of ass. *Roso corymbiferae–Rubetum ulmifolii*									
Rubus ulmifolius Schott	II	II	IV	IV	V	IV	V	I	II
Crataegus monogyna Jacq. var. *monogyna*	IV	III	I	III	IV	.	V	III	.
Paeonia mascula (L.) Mill. subsp. *russoi* (Biv.) Cullen & Heywood	II	II	.	IV	.	II	IV	III	.
Rosa corymbifera Borkh.	.	I	.	.	III	.	V	III	.
Characteristics and differentials of ass. *Crataegetum laciniatae*									
Crataegus rhipidophylla Gand.	.	.	.	.	.	V	II	V	.
Characteristics and differentials of the alliance *Pruno–Rubion ulmifolii* and of the upper units									
Hedera helix L. subsp. *helix*	V	V	II	IV	IV	II	V	III	II
Rosa canina L.	II	II	III	III	V	V	V	II	.
Pyrus spinosa Forssk.	.	.	.	.	III	I	V	IV	.
Rosa micrantha Sm. ex Sm.	.	.	.	.	.	.	II	.	.
Rosa balsamica Besser	.	.	.	.	.	.	I	.	.
Clematis vitalba L.	III	II	I	I	I	III	.	I	.
Rhamnus alaternus L.	.	.	.	.	I	.	.	.	.
Characteristics and differentials of the alliance *Berberido aetnensis–Crataegion laciniatae*									
Lamium flexuosum Ten.	.	.	.	.	.	II	.	II	.
Rubus canescens DC.	.	I	.	III	.	III	.	III	.
Char. and diff. of *Ulmo-Salicetum pedicellatae* and the alliance *Populion albae* and upper									
Salix pedicellata Desf.	.	.	.	.	.	.	.	.	V
Ulmus minor Mill.	.	I	.	.	I	.	.	.	IV
Populus nigra L.	.	.	.	.	.	.	.	.	V
Hypericum hircinum L. subsp. *majus* (Aiton) N. Robson	.	.	.	.	.	.	.	.	II
Solanum dulcamara L.	.	.	.	.	.	.	.	.	II
Other species									
Sorbus domestica L.	.	II	I	.	.	.	.	.	.
Erica multiflora L. subsp. *multiflora*	II	I	.	.	.	.	.	.	.
Buglossoides purpurocaerulea (L.) I.M.Johnst.	II	I	II	.	II	.	.	.	.
Anthyllis vulneraria L. subsp. *busambarensis* (Lojac.) Pignatti	I	.	.	.	.	.	.	.	.

Table 1. *Cont.*

Column Number	1	2	3	4	5	6	7	8	9
Total Number of Relevés	**27**	**18**	**5**	**9**	**14**	**8**	**8**	**7**	**10**
Other species									
Achillea ligustica All.	.	.	.	II	.	I	IV	III	.
Opopanax chironium (L.) W.D.J. Koch	.	I	.	.	I	III	.	I	.
Malus sylvestris Mill.	.	.	.	II	.	I	.	.	.
Euonymus europaeus L.	.	.	.	II	.	.	.	.	.
Cytisus villosus Pourr.	.	.	.	I	.	.	.	.	.
Mespilus germanica L.	.	.	.	I	.	.	.	.	.
Sorbus graeca (Lodd. ex Spach) Kotschy	.	.	.	II	.	.	.	.	.
Acanthus mollis L.	III	.	III	.	.	.	.	.	.
Arum italicum Mill. subsp. *italicum*	II	II	.	.	II	.	II	.	IV
Geranium lucidum L.	.	III	.	.	.	.	.	II	.
Geranium robertianum L.	I	.	.	II	.	.	.	.	.
Magydaris pastinacea (Lam.) Paol.	I	.	.	.	II	.	.	.	.
Reichardia picroides (L.) Roth	I	.	.	.	.	.	.	.	.
Ranunculus pratensis C.Presl	I	.	.	.	.	.	.	.	.
Thalictrum calabricum Spreng.	.	II	II	II	.	II	.	I	.
Geum urbanum L.	.	I	.	.	.	.	.	.	.
Galium aparine L.	.	I	.	.	I	I	.	II	.
Centranthus ruber (L.) Dc. subsp. Ruber	I	.	.	.	.	.	.	.	.
Picris hieracioides Sibth. & Sm.	I	.	.	.	.	.	III	.	.
Asperula laevigata L.	.	I	.	.	.	.	.	.	.
Conium maculatum L.	.	I	.	.	.	.	.	I	.
Erysimum bonannianum C.Presl	.	I	.	.	.	.	.	.	.
Bituminaria bituminosa (L.) C.H.Stirt.	.	.	II	.	.	.	.	.	.
Rhus coriaria L.	.	.	I	.	.	.	.	.	II
Hypericum perforatum L.	.	.	I	.	I	.	.	.	.
Ranunculus bulbosus L.	.	.	I	.	.	.	.	.	.
Leontodon siculus (Guss.) Nyman	.	.	I	.	I	III	.	II	.
Agrimonia eupatoria L.	.	.	I	.	.	.	.	.	.
Anagyris foetida L.	.	.	.	.	I	.	.	.	.
Arrhenatherum elatius (L.) J. & C. Presl subsp. *bulbosum* (Willd.) Schübler & G. Martens	.	.	.	.	.	II	.	.	.
Asphodeline lutea (L.) Rchb.	.	.	.	.	II	.	II	.	.
Clinopodium nepeta (L.) Kuntze.	.	.	.	.	.	II	.	.	.
Cerastium glomeratum Thuiil.	.	.	.	.	.	.	.	II	.
Crataegus laevigata Jacq.	.	.	.	.	I	.	.	.	.
Dactylis glomerata L. subsp. *hispanica* (Roth) Nyman	.	.	.	.	I	.	.	.	.
Elymus panormitanus (Parl.) Tzvelev	.	.	.	.	.	I	.	II	.
Euphorbia ceratocarpa Ten.	.	.	.	.	III	.	I	.	II
Fedia graciliflora Fisch. & C.A. Mey.	.	.	.	.	.	.	.	II	.
Ficaria verna Huds.	.	.	.	.	.	.	.	II	.
Hyoseris radiata L.	.	.	.	.	II	.	.	.	.
Ostrya carpinifolia Scop.	.	.	.	II	.	.	.	.	.
Piptatherum miliaceum (L.) Coss.	.	.	.	.	I	.	I	.	.
Pteridium aquilinum (L.) Kuhn subsp. *aquilinum*	.	.	.	.	.	.	I	.	.
Rumex thyrsoides Desf.	.	.	.	.	I	.	.	.	.
Salvia argentea L.	.	.	.	.	.	I	.	.	.
Sanguisorba minor Scop.	.	.	.	.	.	I	.	.	.
Scandix pecten-veneris L.	.	.	.	.	.	.	.	I	.
Festuca arundinacea Schreb.	.	.	.	.	I	.	.	.	.
Senecio squalidus L. subsp. *microglossus* (Guss.) Arcang.	.	.	.	.	.	I	.	.	.

Table 1. *Cont.*

Column Number	1	2	3	4	5	6	7	8	9
Total Number of Relevés	**27**	**18**	**5**	**9**	**14**	**8**	**8**	**7**	**10**
Other species									
Silene vulgaris (Moench) Garcke	.	.	.	.	.	I	.	.	.
Smyrnium perfoliatum L.	.	.	.	.	.	.	.	II	.
Smyrnium rotundifolium Mill.	.	.	.	.	.	.	II	.	.
Vicia villosa Roth subsp. *villosa*	.	.	.	.	II	.	.	.	.
Vicia villosa subsp. *varia* (Host) Corb.	.	.	.	.	.	.	II	.	.
Carex pendula Huds.	.	.	.	.	.	.	.	.	II
Equisetum telmateia Ehrh.	.	.	.	.	.	.	.	.	V
Eupatorium cannabinum L.	.	.	.	.	.	.	.	.	IV
Allium triquetrum L.	.	.	.	.	.	.	.	.	II
Viola alba Besser subsp. *alba*	.	.	.	.	.	.	.	.	II

3.2. *Archaeobotany*

The soil samples in this investigation were selectively collected during the 2017 and 2018 excavation campaigns.

For each archaeological layer—also defined by Harris [60] units of stratification (US)—, soil samples equal to about five litres were taken manually and randomly, while only in a particular case—that is, the layer of burnt soil relating to the early medieval furnace—was a total sampling of the layer carried out. The stratigraphic units were analyzed, dividing them by the three chronological phases, but this analysis subsequently focused only on the two medieval phases.

The samples were water floated at the Botanical Garden of Palermo, using two different sieves (5 and 1 mm) to separate the clayey matrix of the soil. Subsequently, the samples were screened using a binocular microscope at the Department of Biological Chemical and Pharmaceutical Sciences and Technologies (STEBICEF) of the University of Palermo.

For each stratigraphic unit, quantitative data (absolute number of fragments) and volumetric data (volume of each wood charcoal remain) for each species were measured. The comparison between the quantitative and volumetric numerical data resulted in a deviation of up to 16% per species. In most cases, for small quantities, this could be considered negligible, while in large quantities, the difference increased exponentially; for example, in the case of *Quercus ilex* in the second phase.

Only a significant fraction of the stratigraphic unit was observed by microscopic analysis rather than the whole record, considering that the variability in excess of 13–15 wood charcoals usually did not increase [41].

A total of 436 wood charcoals were observed for the three archaeological phases, and among them, 346 samples were related to the two medieval phases analyzed in this work. For the Period 1 (late 8th–9th centuries AD), 276 samples were analyzed (from earlier to later: Phase 1, US 43, 47, 49, 52; Phase 2, US 14, 40, 42, 50, 61; Phase 3, US 9, 12, 37; Phase 4, US 8, 36) and 70 samples (US 1, 2) for the Period 2 (10th–11th centuries AD). The chronology of these phases was based on stratigraphic sequence and radiocarbon analysis. Of these, 19% were not taxonomically identified (due to the small size of the fragments in some US or the state of preservation, where combustion had strongly deformed the xylem).

To identify the genera/species, a comparison was made with the reference atlases [61,62], with some scientific papers and with the two available online tools—InsideWood [63] and Microscopic Wood Anatomy [64]—as well as with some reference samples which were not available for all species.

Each sample was observed in the three transversal, tangential and radial sections at a maximum of 40x and measured to obtain a value for the total volumes by species, and therefore their incidence not only numerically but also regarding their actual size with reference to the total was measured. Whenever possible, the diameters of some small branches were measured.

4. Results

4.1. The Current Plant Landscape

The natural vegetation of this area is composed of remnant forest patches, shrublands and extensive grasslands which are stages of degradation of pre-existing forest due to anthropic activities. Five different woods have been identified according to the environmental characteristics (bioclimate belts and substrate). The main forests formation are holm oak woods (*Ampelodesmo mauritanici-Quercetum ilicis* and *Sorbo torminalis-Quercetum ilicis*) and downy oak woods (*Oleo oleaster-Quercetum virgilianae* and *Sorbo torminalis-Quercetum virgilianae*) (Figure 4). Along the rivers also grow hygrophilous forests with poplars and willows (*Ulmo canescentis-Salicetum pedicellatae*). Shrublands of thorny bushes of Rosaceae and other evergreen Mediterranean bushes are the result of wood degradation due to cutting or fire. Grazing and fire normally lead to the establishment of *Ampelodesmos mauritanicus* grassland. These natural and seminatural vegetation patches are embedded in a matrix of agricultural land uses characterized by cereals, grapevines and olive trees, "the Mediterranean triad" [65].

The syn-phytosociological analysis allowed us to characterize the associations from a floristic and structural point of view (Table 1) and to define the dynamic relationships among seral stages (Figure 4). Four climatophilous vegetation series and one edapho-hygrophilous vegetation series, which together define the forest landscape of this area of the Sicani Mountains, were identified.

For each of them, the association head of series, the main seral stages and the ecological and geographical distribution in the region are described below.

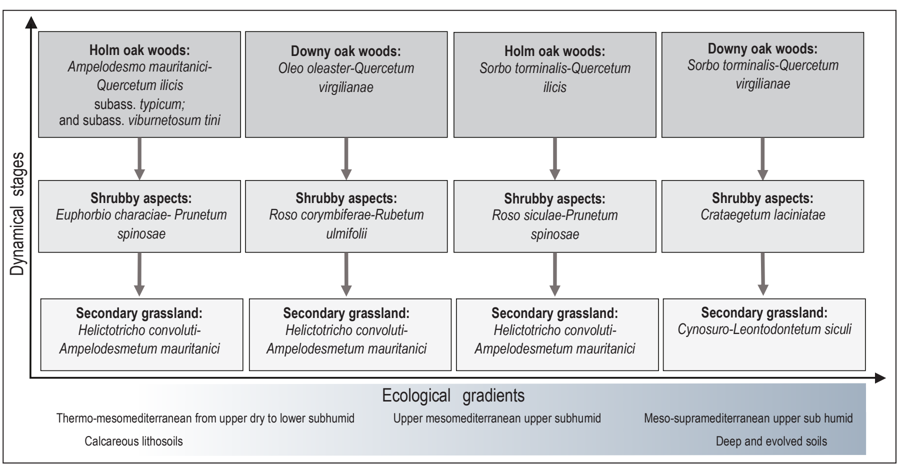

Figure 4. Dynamical and catenal contacts among forest associations of the Sicani Mountains.

4.1.1. Mesomediterranean Series of Holm Oak (*Ampelodesmo mauritanici-Querco ilicis* Sigmetum)

Ampelodesmo mauritanici-Quercetum ilicis Gianguzzi, Cuttonaro, Cusimano & Romano 2016 is a woody vegetation whose tree layer is clearly dominated by *Quercus ilex* and sometimes associated with *Quercus virgiliana* and *Fraxinus ornus* (Column 1 in Table 1). From the floristic point of view, this community is characterized by the occurrence of *Ampelodesmos mauritanicus*, *Hippocrepis emerus* subsp. *emeroides* and *Lonicera implexa*. In addition to the typical aspect, the subass. *viburnetosum tini* Gianguzzi et al. 2016 was surveyed in the more humid and cool stands.

This association represents the most evolved stage of an edapho-climatophilous series that includes various secondary communities derived from the degradation of woodlands. In particular, on quite sloped and sunny stands, it is often replaced by a low shrubby vegetation characterized by

Euphorbia characias and *Anagyris foetida*, referable to *Euphorbio characiae-Anagyridetum phoetidis* Gianguzzi, Cuttonaro, Cusimano & Romano 2016, while a further community, named *Euphorbio characiae-Prunetum spinosae* Gianguzzi, Cuttonaro, Cusimano & Romano 2016, is linked to very eroded and less inclined surfaces (Column 5 in Table 1). The degradation of these communities favors the settlement of the dry grasslands belonging to *Helictotricho convolute-Ampelodesmetum mauritanici* Minissale 1994.

This vegetation occurs in the mesomediterranean belt with an upper subhumid ombrotype, generally at an altitude from 450 to 1000 m. It prefers the most inclined slopes with northern exposure, colonizing calcareous lithosols with a significant detrital component derived from erosion and landslides. Currently, this series is known only from the Sicani mountains [52].

4.1.2. Supramediterranean Series of Holm Oak (*Sorbo torminalis-Querco ilicis* Sigmetum)

The head series is represented by mesophilous holm oak woods with a closed structure, referable to the *Sorbo torminalis-Quercetum ilicis* Gianguzzi, Cuttonaro, Cusimano & Romano 2016. From the floristic point of view, the association is characterized by the occurrence of some nemoral species with mesic requirements, such as *Daphne laureola*, *Paeonia mascula* subsp. *russoi* and *Euphorbia amygdaloides* subsp. *arbuscula*, etc. (Column 2 in Table 1).

In addition to *Sorbo torminalis-Quercetum ilicis*, this series is constituted by some secondary stages, which are often very frequent due to the strong anthropization of the investigated area; this vegetation should be represented only in the higher altitudes of the Barraù mountain. *Roso siculae-Prunetum spinosae* Gianguzzi, Cuttonaro, Cusimano & Romano 2016 (Column 6 in Table 1) is an orophilous shrubby community that replaces the woods on very shallow soils, forming a very dense and closed vegetation with *Rosa sicula* and some species belonging to *Berberido aetnensis–Crataegion laciniatae* Gianguzzi et al. 2011, such as *Crataegus rhipidophylla* and *Rubus canescens*. A further degradation of the woody vegetation leads to the establishment of dry grasslands belonging to *Helictotricho convolute-Ampelodesmetum mauritanici* Minissale 1994.

This series is linked to stands with eroded calcareous soils, above 1000 m a.s.l., which are characterized by a meso or supramediterranean bioclimate with an upper subhumid ombrotype. It was surveyed only in the Sicani mountains, representing a geographical vicariant of *Acer campestri-Querco ilicis* sigmetum from the Madonie area. In the investigated area, only small, floristically impoverished relicts of this vegetation remain.

4.1.3. Thermo-Mesomediterranean Series of Downy Oak (*Oleo oleaster-Querco virgilianae* Sigmetum)

The *Oleo oleaster-Quercetum virgilianae* Brullo 1984 represents the most evolved stage of this series, as a woody vegetation dominated by *Quercus virgiliana* (Ten.) Ten. and *Quercus amplifolia* Guss. (Column 3 in Table 1). It is a deciduous woodland with a rich xeric-thermophilous component belonging to *Quercetalia calliprini* Zohary 1955, represented by *Olea europaea* L. var. *sylvestris* Brot., *Pistacia lentiscus*, *Teucrium fruticans* L., *Prasium majus*, etc. Moreover, *Quercetalia ilicis* Br.-Bl. ex Molinier 1934 is well represented by several species, such as *Quercus ilex*, *Rubia peregrina* subsp. *longifolia*, *Carex distachya* Desf., *Osyris alba*, *Asparagus acutifolius*, *Smilax aspera*, *Calicotome infesta*, *Arisarum vulgare*, *Lonicera implexa*, *Ruscus aculeatus*, etc.

The secondary stages of *Oleo sylvestris-Quercetum virgilianae* include the garrigues of the Cisto eriocephali–Ericion multiflorae Biondi 1997 and the deciduous shrubs of Crataego-Prunetea Tx. 1962, such as *Roso corymbiferae-Rubetum-Rubetum ulmifolii* Gianguzzi, Cuttonaro, Cusimano & Romano 2016 in the investigated area (Column 7 in Table 1). The degradation of these shrubby communities, mainly due to fires, leads to the establishment of dry grasslands belonging to *Avenulo cincinnatae-Ampelodesmion mauritanici* Minissale 1995. The further degradation of the soil due to erosive phenomena determines the establishment of ephemeral communities of *Trachynion distachyae* Rivas-Martinez 1978.

This series occurs on more or less deep and evolved soils, developing on various kinds of substrates (limestone, dolomite, marl, clay, basalt, sandstones, schist, etc.). Generally, its potential area coincides with the places which are most suitable for agricultural activities; for this reason, it is currently fairly localized and covers only small surfaces. From the bioclimatic perspective, it falls within the thermo-mediterranean belt, with some penetrations in the subhumid mesomediterranean belt. Its distribution range includes Sicily and southern Italy [66].

4.1.4. Supramediterranean Series of Downy Oak (*Sorbo torminalis-Querco virgilianae* Sigmetum)

Sorbo torminalis–Quercetum virgilianae Gianguzzi, Cuttonaro, Cusimano & Romano 2016 is a woodland dominated by *Quercus virgiliana*, whose mesic character is emphasized by the occurrence of *Sorbus torminalis* and a rich herbaceous component characterized by some rare umbellifers, among them *Physospermum verticillatum* (Waldst. & Kit.) Vis., *Geocaryum cynapioides* (Guss.) Engstrand. and *Cnidium silaifolium* (Jacq.) Simonk. (Column 4 in Table 1).

This association has completely disappeared from the area in which it could potentially be present, such as the summit plains of Monte Barraù. It has been replaced by the *Crataegetum laciniatae* Brullo & Marcenò 1984, an orophilous scrub dominated by *Crataegus rhipidophylla*, which is sometimes associated with *Pyrus spinosa* and scattered shrubby specimens of *Acer campestre* (Column 8 in Table 1). However, larger surfaces are covered by a mosaic of mesophilous meadows belonging to *Cynosuro-Leontodontetum siculi* Brullo & Grillo 1978 and *Cachyretum ferulaceae* Raimondo 1980, while the most eroded surfaces and the rocky outcrops are characterized by the prostrate chamaephytic vegetation of *Carduncello pinnati-Thymetum spinulosi* Brullo & Marcenò in Brullo 1984.

It colonizes deep calcareous soils, preferring the fresh and shady northern slopes at altitudes between 800 and 1400 m a.s.l. From the bioclimatic viewpoint, it is localized from the mesomediterranean to the supramediterranean belt with an upper subhumid ombrotype. This series is restricted to the higher belt of the Sicani area [52].

4.1.5. Thermo-Mesomediterranean Edapho-Hygrophilous Series of Mediterranean Willow (*Ulmo canescentis-Salico pedicellatae* Sigmetum)

The riparian forest dominated by *Salix pedicellata* should be referred to the *Ulmo canescentis-Salicetum pedicellatae* Brullo & Spampinato 1990 (Column 9 in Table 1). The canopy of this vegetation, which can reach a height of 10–15 m. is characterized by the occurrence of *Salix alba*, *Populus alba*, *P. nigra* and *Ulmus canescens*. The *Alno-Populetea* P. Fukarek & Fabijanić 1968 class is represented by many species, such as *Carex pendula*, *Equisetum telmateia*, *Hypericum hircinum* subsp. *majus* and *Arum italicum* subsp. *italicum*.

This association is the most mature stage of an edapho-hygrophilous series. The degradation stages are mainly represented by shrubby communities belonging to *Pyro spinosae–Rubetalia ulmifolii* Biondi, Blasi & Casavecchia in Biondi et al. 2014 (*Crataego-Prunetea* class), such as *Rubo ulmifolii–Tametum communis* R. Tx. in R. Tx. & Oberd. 1958 or *Roso sempervirentis–Rubetum ulmifolii* Blasi, Di Pietro & Fortini 2000.

This azonal vegetation has its optimal conditions at altitudes between 300 and 800 m, within the thermo and mesomediterranean belts. Its geographical distribution includes several rivers and streams of northern and central Sicily [67], including the Giardinello watercourse within the investigated area.

The analysis of the woody components of current plant communities considered 56 taxa among the phanerophytes and nanophanerophytes of the nine forest and preforest associations recognized in the area (Table 2).

The analysis of the frequency of taxa, based on presence–absence data, highlights the ubiquitous nature of many species that are not exclusive to one association. Among the dominant trees, *Quercus ilex* (with a frequency equal to 1.00 in Holm Oak woods) has a frequency value of 0.40 and 0.67 in Downy Oak woods (*Oleo oleaster-Quercetum virgilianae* and *Sorbo torminali-Quercetum virgilianae*).

Table 2. Frequency of taxa and mean values of Braun-Blanquet's cover data of relevés for each association (A-Qi = *Ampelodesmo mauritanici-Quercetum ilicis*; S-Qi = *Sorbo torminalis-Quercetum ilicis*; O-Qv = *Oleo oleaster-Quercetum virgilianae*; S-Qv = *Sorbo torminalis-Quercetum virgilianae*; E-Ps = *Euphorbio characiae-Prunetum spinosae*; R-Ps = *Roso siculae-Prunetum spinosae*; R-Ru = *Roso corymbiferae-Rubetum ulmifolii*; Cl = *Crataegetum laciniatae*; U-Sp = *Ulmo-Salicetum pedicellatae*). The values of diagnostic species of association and alliance are in the grey boxes.

			Forest Vegetation								Shrubby Vegetation								Riparian veg.	
		Taxa	A-Qi		S-Qi		O-Qv		S-Qv		E-Ps		R-Ps		R-Ru		Cl		Sa-p	
id	L. f.		*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*
		Characteristics and differentials of association and subassociation *Ampelodesmo mauritanici-Quercetum ilicis*																		
1	P SCAP	*Quercus ilex* L.	1.00	77.58	1.00	73.66	0.40	0.62	0.67	4.85	0.14	0.62	.	.	.	.	.	.	.	.
2	NP	*Hippocrepis emerus* (L.) Lassen subsp. *emeroides* (Boiss. & Spruner) Lassen	0.78	1.47	.	.	0.80	16.41	.	.	0.14	0.74	.	.	.	.	.	.	0.33	0.49
3	P LIAN	*Lonicera implexa* Aiton	0.70	2.39	0.28	0.64	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4	P CAESP	*Viburnum tinus* L.	0.59	19.43	.	.	.	.	0.11	0.74	.	.	.	.	.	.	.	.	.	.
5	P CAESP	*Arbutus unedo* L.	0.52	5.20	0.11	0.62	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		Characteristics and differentials of association and subassociation *Sorbo torminalis-Quercetum ilicis*																		
6	P SCAP	*Acer campestre* L.	.	.	1.00	5.09	.	.	0.33	0.66	.	.	0.13	0.74	.	.	0.43	33.98	.	.
7	P CAESP	*Daphne laureola* L.	0.04	0.74	0.33	0.62	.	.	0.78	4.26	0.14	0.62	1.00	14.35	0.50	6.84	0.71	11.58	.	.
		Characteristics and differentials of association and subassociation *Oleo oleaster-Quercetum virgilianae*																		
8	P SCAP	*Quercus virgiliana* (Ten.) Ten.	0.70	6.20	0.39	6.60	1.00	73.72	1.00	70.79	.	.	.	.	.	.	.	.	.	.
		Characteristics and differentials of association and subassociation *Sorbo torminalis-Quercetum virgilianae*																		
9	P CAESP	*Sorbus torminalis* (L.) Crantz	.	.	0.44	6.43	.	.	1.00	5.30	.	.	.	.	.	.	.	.	.	.
		Characteristics of the alliance *Fraxino-Quercion ilicis* and of the upper units																		
10	NP	*Asparagus acutifolius* L.	1.00	1.88	0.61	1.40	0.60	0.66	0.67	0.66	0.79	6.44	0.50	0.55	0.88	7.35	0.29	0.62	.	.
11	NP	*Smilax aspera* L.	1.00	7.95	0.44	2.61	0.80	4.78	0.33	0.66	0.36	25.15	.	.	0.63	0.54	0.14	0.49	.	.
12	P LIAN	*Rubia peregrina* L. subsp. *longifolia* O. Bolòs	0.93	0.62	0.50	0.52	0.80	0.62	0.67	2.03	0.64	0.60	.	.	0.75	3.31	.	.	0.67	0.49
13	P SCAP	*Fraxinus ornus* L.	0.67	7.69	0.78	5.20	0.20	0.74	0.33	0.74	.	.	0.13	0.74	.	.	.	.	.	.
14	NP	*Osyris alba* L.	0.48	4.85	0.17	0.49	0.60	3.48	.	.	0.43	2.03	.	.	.	.	.	.	1.00	0.57
15	P CAESP	*Pistacia terebinthus* L.	0.41	1.44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16	NP	*Rosa sempervirens* L.	0.37	0.59	0.17	0.66	0.20	0.49	0.44	2.73	0.29	2.67	.	.	0.13	0.49	.	.	.	.
17	P CAESP	*Pistacia lentiscus* L.	0.26	0.67	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	P LIAN	*Lonicera etrusca* Santi	0.19	0.54	0.83	1.14	0.40	0.62	0.67	1.98	0.29	10.19	0.13	0.74	0.75	0.70	0.29	0.62	.	.
19	NP	*Cistus creticus* L. subsp. *creticus*	0.15	0.49	0.28	0.64	0.60	3.39	0.33	0.49	.	.	.	.	.	.	.	.	.	.
20	P SCAP	*Chamaerops humilis* L.	0.19	0.64	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
21	P CAESP	*Daphne gnidium* L.	0.04	0.74	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
22	P CAESP	*Myrtus communis* L.	0.04	0.74	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
23	P CAESP	*Calicotome infesta* (C. Presl) Guss. subsp. *infesta*.		.	.	.	0.20	0.74	.	.	.	.	.	.	.	.	.	.	.	.
24	P SCAP	*Quercus amplifolia* Guss.	.	.	.	.	.	.	0.11	0.74	.	.	.	.	.	.	.	.	.	.
		Characteristics and differentials of association and subassociation *Euphorbio characiae-Prunetum spinosae* e *Roso siculae-Prunetum spinosae*																		
25	NP	*Euphorbia characias* L.	0.41	1.37	0.33	0.53	.	.	.	.	1.00	7.33	.	.	.	.	.	.	.	.
26	P CAESP	*Prunus spinosa* L.	0.19	0.59	0.33	0.62	0.20	0.49	0.33	0.66	0.71	71.84	1.00	74.19	0.88	3.09	0.57	4.78	.	.
27	NP	*Rosa sicula* Tratt.	.	.	.	.	.	.	0.22	0.62	.	.	1.00	9.60	.	.	0.71	3.92	.	.
28	NP	*Rosa glutinosa* Sm.	.	.	.	.	.	.	.	.	.	.	0.88	0.67	.	.	0.29	0.62	.	.

Table 2. *Cont.*

			Forest Vegetation								Shrubby Vegetation								Riparian veg.	
		Taxa	A-Qi		S-Qi		O-Qv		S-Qv		E-Ps		R-Ps		R-Ru		Cl		Sa-p	
			freq.	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*	*freq.*	*cov.*
		Characteristics and differentials of association and subassociation *Roso corymbiferae-Rubetum ulmifolii*																		
29	NP	*Rubus ulmifolius* Schott	0.26	0.53	0.33	0.62	0.80	2.73	0.67	3.48	0.93	5.52	0.75	0.53	1.00	44.69	0.14	0.74	0.33	0.49
30	P CAESP	*Crataegus monogyna* Jacq. var. *monogyna*	0.63	1.11	0.44	0.58	0.20	0.49	0.56	4.02	0.79	1.44	.	.	1.00	31.32	0.43	6.13	.	.
31	NP	*Rosa corymbifera* Borkh.	.	.	0.06	0.49	.	.	.	.	0.50	3.09	.	.	1.00	0.62	0.43	0.74	.	.
		Characteristics and differentials of association and subassociation *Crataegetum laciniatae*																		
32	P CAESP	*Crataegus rhipidophylla* Gand.	.	.	.	.	.	.	.	.	.	.	1.00	4.85	0.25	0.49	1.00	47.46	.	.
		Characteristics and differentials of the alliance *Pruno-Rubion ulmifolii* and of the upper units																		
33	NP	*Rosa canina* L.	0.37	1.44	0.28	2.23	0.60	3.48	0.44	0.74	1.00	15.50	0.88	1.81	1.00	5.87	0.29	4.72	.	.
34	P SCAP	*Pyrus spinosa* Forssk.	.	.	.	.	.	.	.	.	0.57	0.71	0.13	0.49	0.88	4.26	0.71	14.91	.	.
35	P LIAN	*Hedera helix* L. subsp. *helix*	0.81	2.75	0.94	4.59	0.40	4.85	0.67	7.54	0.79	7.56	0.38	0.57	0.88	2.98	0.57	12.30	0.33	0.74
36	NP	*Rosa micrantha* Sm.	.	.	.	.	.	.	.	.	.	.	.	.	0.25	0.74	.	.	.	.
37	NP	*Rosa balsamica* Besser	.	.	.	.	.	.	.	.	.	.	.	.	0.13	0.49	.	.	.	.
38	P LIAN	*Clematis vitalba* L.	0.56	1.17	0.33	3.44	0.20	0.74	0.11	0.49	0.14	0.62	0.50	0.74	.	.	0.14	0.74	.	.
39	P CAESP	*Rhamnus alaternus* L.	.	.	.	.	.	.	.	.	0.07	0.74	.	.	.	.	.	.	.	.
40	P CAESP	*Ulmus minor* Mill.	.	.	0.06	8.95	.	.	.	.	0.07	0.74	.	.	.	.	.	.	0.67	0.74
		Characteristics and differentials of the alliance *Berberido aetnensis-Crataegion laciniatae*																		
41	NP	*Rubus canescens* DC.	.	.	0.11	0.62	.	.	0.44	0.62	.	.	0.50	0.55	.	.	0.57	4.72	.	.
		Characteristics and hygrophilous differentials of *Salicetum albo-pedicellatae* and the alliance *Populion albae* and upper																		
42	P CAESP	*Salix pedicellata* Desf.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.00	49.98
43	P SCAP	*Populus nigra* L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.70	5.43
44	NP	*Hypericum hircinum* subsp. *majus* N. Robson.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.33	0.49
45	NP	*Solanum dulcamara* L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		0.49
		Other species																		
46	P SCAP	*Sorbus domestica* L.	.	.	0.28	9.89	0.20	8.95	.	.	.	.	.	.	.	.	.	.	.	
47	NP	*Erica multiflora* L. subsp. *multiflora*	0.33	3.37	0.11	0.74	.	.	.	.	.	.	.	.	.	.	.	.	.	.
48	P SCAP	*Malus sylvestris* Mill.	.	.	.	.	.	.	0.22	0.74	.	.	0.13	0.74	.	.	.	.	.	.
49	P CAESP	*Euonymus europaeus* L.	.	.	.	.	.	.	0.22	0.74	.	.	.	.	.	.	.	.	.	.
50	P CAESP	*Cytisus villosus* Pourr.	.	.	.	.	.	.	0.11	0.74	.	.	.	.	.	.	.	.	.	.
51	P CAESP	*Mespilus germanica* L.	.	.	.	.	.	.	0.11	0.49	.	.	.	.	.	.	.	.	.	.
52	P CAESP	*Sorbus graeca* (Lodd. ex Spach) Kotschy	.	.	.	.	.	.	0.22	8.95	.	.	.	.	.	.	.	.	.	.
53	P CAESP	*Rhus coriaria* L.	.	.	.	.	0.20	0.74	.	.	.	.	.	.	.	.	.	.	0.33	0.74
54	P CAESP	*Anagyris foetida* L.	.	.	.	.	.	.	.	.	0.14	0.74	.	.	.	.	.	.	.	.
55	P CAESP	*Crataegus laevigata* Jacq.	.	.	.	.	.	.	.	.	0.14	0.74	.	.	.	.	.	.	.	.
56	P CAESP	*Ostrya carpinifolia* Scop.	.	.	.	.	.	.	0.33	26.09	.	.	.	.	.	.	.	.	.	.

In contrast, *Quercus virgiliana* (with a frequency equal to 1.00 in Downy Oak woods) has a frequency value of 0.70 in *Ampelodesmo-Quercetum ilicis* and a value of 0.39 in *Sorbo-Quercetum ilicis*. *Fraxinus ornus* is a species which is always present in the forest formations, except in the riparian forest, while *Sorbus torminalis* grows only in forests with a meso-supramediterranean bioclimate (Figure 4). *Acer campestre*, in the same bioclimatic belt, is quite common both in forest and in secondary shrublands, such as *Roso siculae-Prunetum spinosae* and *Crataegetum laciniatae*. In contrast, species such as *Smilax aspera*, *Prunus spinosa* and *Rosa canina* are present in all climatophilous associations.

The mean coverage of woody plants, phanerophytes and nanophanerophytes (Table 2 and Figure 5) is the information that allowed us to statistically determine the probability of finding (and therefore collecting) a species in a community. The mean coverage of *Quercus ilex* is 77.58% and 73.66% in *Ampelodesmo-Quercetum ilicis* and in *Sorbo-Quercetum ilicis,* respectively, and the value dramatically drops to 0.62% in *Oleo-Quercetum virgilianae* and 4.85% and in *Sorbo torminalis-Quercetum virgilianae*.

In contrast, Downy Oak (*Quercus virgiliana*) shows mean coverages of 73.72% and 70.79% in *Oleo-Quercetum virgilianae* and in *Sorbo-Quercetum virgilianae*, respectively, becoming less significant in *Ampelodesmo-Quercetum ilicis* (6.20%) and in *Sorbo torminalis-ilicis* (6.60%).

In the forest associations, in addition to the oaks, which are the most abundant species, *Hippocrepis emerus* subsp. *emeroides* (16.41% in *Oleo-Quercetum virgilianae*) and *Viburnum tinus* (19.43% in *Ampelodesmo-Quercetum ilicis*) show higher values of coverage. In the secondary shrubland, species such as *Crataegetum laciniatae*, *Crataegus rhipidophylla* (47.46%), *Acer campestre* (33.98%), *Pyrus spinosa* (3.92%) and *Hedera helix* subsp. *helix* (12.30%) are dominant.

More generally, thorny Rosaceae are the species that shape the physiognomy of secondary shrub communities. *Rubus ulmifolius* (44.69%) and *Crataegus monogyna* var. *monogyna* (31.32%) are abundant in *Roso corymbiferae-Rubetum ulmifolii; Prunus spinosa* is common in *Roso siculae-Prunetum spinosae* and *Euphorbio characiae-Prunetum spinosae* (with mean cover values equal to 74.19% and 71.84%, respectively). In this latter association, *Rosa canina* shows a significant mean cover equal to 15.50%.

In the riparian forest dominated by *Salix pedicellata* (mean cover = 49.98%), *Populus nigra* is the second most abundant species in the association.

Table 3. Frequency of taxa per chronological phase: Phase 1, late 8th–9th century AD; Phase 2, 10th–11th century AD. Each column shows the indication of the absolute number of wood charcoals, their volumes in mm^3 and their incidence as a percentage of the total per phase.

Taxa		Phase 1			Phase 2		
		Count	*Vol (mm^3)*	*Freq.*	*Count*	*Vol (mm^3)*	*Freq.*
Fagaceae	*Quercus ilex*	97	6350	0.55	23	1547	0.62
Fabaceae	-	1	30	0.01	2	181	0.07
Aceraceae	*Acer campestre*	.	.	.	2	95	0.04
Anacardiaceae	*Pistacia terebinthus*	24	1161	0.10	4	40	0.02
Oleaceae	*Fraxinus ornus*	4	98	0.01	.	.	.
Fagaceae	*Quercus virgiliana*	11	647	0.06	.	.	.
Rosaceae	*Sorbus torminalis*	9	342	0.03	.	.	.
Corylaceae	*Ostrya carpinifolia*	6	447	0.04	3	120	0.05
Rosaceae	*Prunus spinosa*	2	64	0.01	2	42	0.02
Rosaceae	-	13	600	0.05	6	252	0.10
Rhamnaceae	*Rhamnus alaternus*	9	546	0.05	2	42	0.02
Ulmaceae	*Ulmus minor*	10	616	0.05	3	148	0.06
Salicaceae	*Populus nigra*	8	684	0.06	3	18	0.01

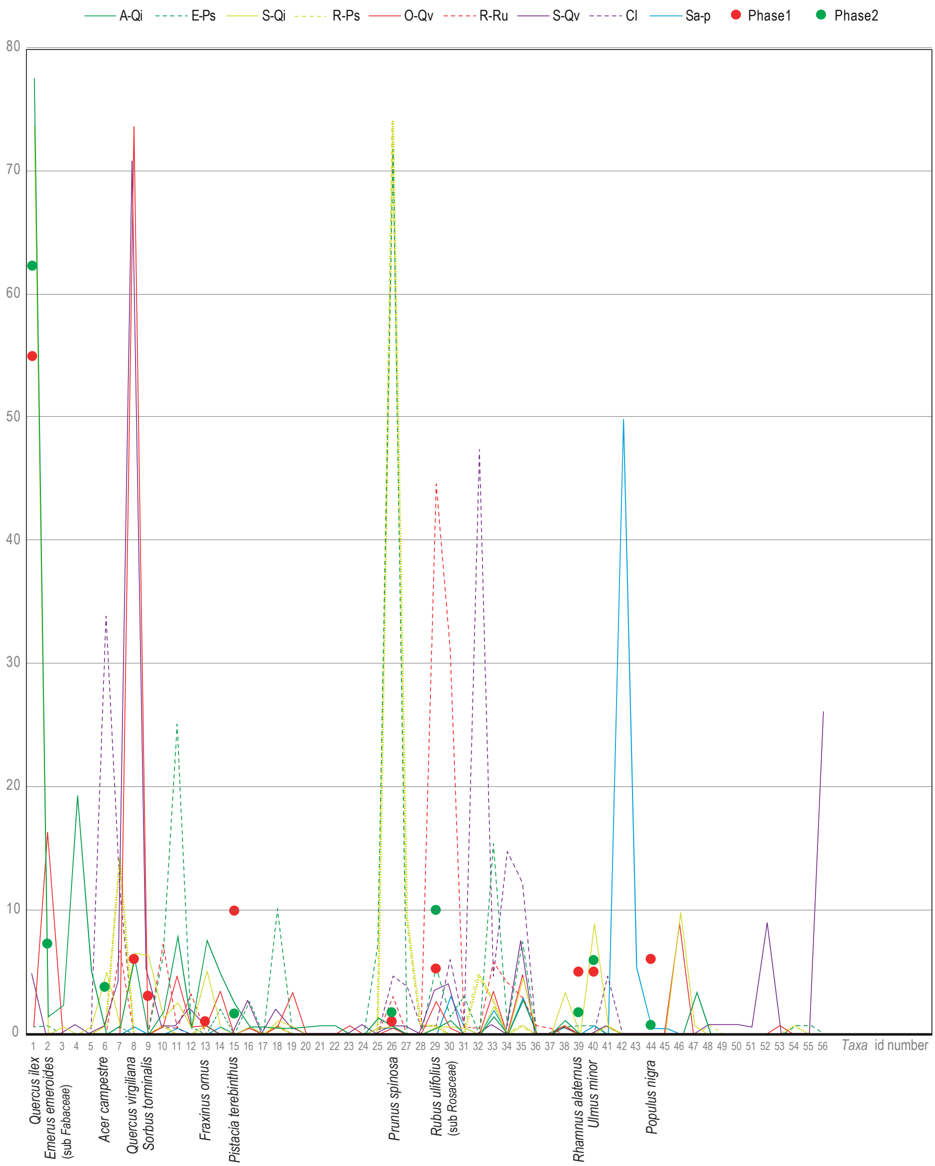

Figure 5. Mean coverage curves of the associations of Sicani Mountain forests and shrubs. The same color indicates associations belonging to the same vegetation series. The points show the incidence of identified taxa in the total volume of medieval wood charcoals (Phase 1: late 8th–9th century AD; Phase 2: 10th–11th century AD). In the x axis, the numbers indicate the taxa of Table 2 (phytosociological record) and the names are related to the taxa of Table 3 (archaeobotanical record).

4.2. Medieval Landscape: Anthracology and Wood Species

The preservation of the samples is quite good. Wood charcoals are from 1 mm^3 to about 1.5 cm^3 but on average quite small (3–4 mm^3). The volume of each stratigraphic unit in relation to the density of identified wood charcoals is quite similar (therefore the density is on average the same for all soils), with the exception of a burnt layer connected to the fuel of the kilns (US 43) in which the density is strongly higher, some stratigraphic units (US 12, 13, 49, 52 and 61) in which it is higher and other stratigraphic units in which the density is clearly lower (US 36, 37, 1 and 2).

From the comparison with modern vegetation, nine species were identified (Quercus ilex, Quercus cfr. pubescens Willd., Pistacia terebinthus, Rhamnus alaternus, Fraxinus ornus, Ulmus minor, Acer campestre, Ostrya carpinifolia, Populus nigra); the identification rate reached the detail of genus or subfamily in four cases (Phillyrea sp., Sorbus sp., Prunus sp., cfr. Rosaceae, Pyrus sp., cfr. Fabaceae Hippocrepis emerus subsp. emeroides/Anagyris foetida). The arboreal vegetation is therefore represented by evergreen oaks, semi and deciduous oaks, maples, ash, and it is associated with riparian species such as elm, poplar and hornbeam and with shrubby species such as alatern, terebinth, rowan, plum.

In the phase of the late 8th–9th centuries AD, Holm Oak prevailed with 35% of the samples and, together with the other oaks, it made up 48% of the total. The terebinth followed with 9% and all other species exhibited between 1% and 5% of representativeness. In the furnace, many wood charcoals were mixed with ash concentrations at various densities; some of these fragments bore traces of strong distortion due to combustion processes. It is also interesting that, in this context, most of the species represented were Holm Oak and terebinth, with a very low percentage of other species.

In the second medieval phase (10th–11th centuries AD), the variability seemed to be slightly wider with 11 species/genera but with a clear preponderance in the representativeness of Holm Oak, which in terms of volume represented 49% of the total, followed by lower percentages of unidentified oaks, terebinth, poplar, elm and a leguminous plant perhaps identifiable as *Anagyris foetida*.

The relative frequencies were calculated by excluding the data on the unidentified samples and on those oaks that were not better identified (that is, they were not recognized either as deciduous or evergreen) and which therefore could not be placed more precisely within the series. The frequencies are quite similar in both phases, with a slight deviation in the incidence of Holm Oak (which increased in phase 2) and the absence of deciduous oaks in the more recent phase (Table 3).

The frequencies in the anthracological record were overlapped to the mean coverage of taxa (Figure 5). This overlapping has shown the correspondence between the species recorded in archaeobotanical samples with forest or preforest associations detected in the current area.

5. Discussion

This work compares the vegetation pattern of two anthropized landscapes in two specific temporal frames: the medieval period and the present day. The archaeobotanical data are an important source for understanding the effective use of wood resources in a specific place (Contrada Castro site) and time (Middle ages). However, these anthracological data need to be contextualized in a landscape model. The phytosociological approach has allowed us to model the plant communities as associations (depicted as tables) for creating a comparative reference for the archaeobotanical data.

In this way, the occurrence of species in the archaeobotanical record—in terms of charcoal volumes (Table 3)—could be related to the mean coverage of woody species in the association (Table 2) which indicated the probability of finding the species. Then, each association has been assigned to a specific vegetation series that is geographically spatialized in the current landscape.

The intersection between the frequency data of the archaeobotanical record and the phytosociological analysis of current vegetation—in terms of vegetation series—have firstly confirmed the maintenance of the same plant communities over the last millennium. In fact, the identified species in the anthracological sample have shown a coherent fitting with the data of current vegetation. Wood charcoal assemblage is not "anomalous", because all the species identified are present today in the case study area. Furthermore, the correlation of the archaeobotanical data with the plant associations and the related series (Figure 5) have provided ecological and environmental information.

This consistency between the occurrences in the archaeobotanical record and the vegetational pattern is linked to the fact that, over the last millennium, no radical changes occurred, and so the ecological patterns of the vegetation series have not changed. In fact, this ecological pattern is determined by environmental or abiotic factors (e.g., climate, lithology, landforms) that change only over a long period of time [68] which is measurable on the scale of geological eras.

This long continuity in the vegetation pattern is also highlighted by the presence, as dominant species in these forest formations, of oaks, which are secular trees as regards their own physiology, as testified by the widespread presence in the Sicani mountains [69] of numerous enormous individuals with biological cycles of 400–500 years.

The archaeobotanical record has indicated an exclusive use of wood (as building materials or fuel) from the spontaneous plants specific to the natural vegetation of this area; no wood charcoals undoubtedly connected to cultivated tree plants have been found at the current stage of the investigation. Furthermore, according to the preliminary study of the seeds, the presence of fruits from fruit trees was not identified, apart from a single grape seed [70].

Previous analysis carried out on the catchment area of the Contrada Castro site by Bazan et al. [71] showed a 90% correlation with the distribution area of the Downy Oak series, which in Sicily is agriculturally suitable for arable land. The remaining 10% of the total catchment area of the site falls on the surface covered by the Holm Oak series. Holm Oak, according to the archaeobotanical record, is the most exploited species with percentages ranging between 30% and 50%. The massive use of wood species from different stages of the Holm Oak series clearly indicates an exploitation of the range of this series for forestry.

The high frequency of Rosaceae, which are typical of the secondary aspects of the forest (Figure 5, dotted line), is an indicator both of human activities of wood cutting and the use of this spiny rosacea species for combustible material for kilns and hearths, as identified in the archaeological excavation.

The use of the Monte Barraù area for wood exploitation for forestry, at least during the medieval period, is also attested to by a Latin parchment from AD 1428 from the *Tabularium* of the monastery of Santa Maria del Bosco di Calatamauro, which has owned the area of Barraù at least since the Late Middle Ages [47]. Preliminary data on the zooarchaeological sample from the excavation in Contrada Castro [72] have revealed, within a greater attestation of domestic species, a sporadic presence of wild taxa such as deer (*Cervus elaphus* L. 1758) and wild boar (*Sus scrofa* L. 1758). In particular, deer are no longer present in Sicily and appear to have become extinct between the 17th and 19th centuries [73]. By examining the ecological habits and habitat preferences of deer in Mediterranean areas where the species is still present, such as in Sardinia [74], the range of browsing activity of this animal during autumn, winter and spring is concentrated in the tall scrubwood area, and during the warm season, it moves to areas characterized by riparian vegetation, low scrubwood and oak woods. The presence of this animal is so strictly linked to its specific habitat that it allows us to hypothesize an extension and continuity of the wood to a relevant degree which is higher than currently.

The low percentage of wood elements attributable to the Downy Oak series indicates the scarce use of this type of wood resource, which is probably due to the fact that the Downy Oak area was intensely deforested in order to make way for arable lands. The agricultural exploitation was also documented by the discovery of charred seeds—still under study—which are similar, as can be seen from the medieval layers of Contrada Castro, to varieties of cereals and legumes connected precisely to the cultivation of the surrounding territory.

6. Conclusions

We believe that it is possible to reflect on the potentialities of this type of approach in the interpretation of current High Nature Value (HNV) farmlands.

In fact, the knowledge of the historical modes for the selection and exploitation of forest resources turns out to be a fundamental element in validating the characteristics and potentialities observable in the current landscape from geobotanical and phytosociological perspectives. It is necessary to return to the concept of the series of vegetation as an indicator of the dynamics of human–environment interactions. The passages between different stages of the succession of a series are, as a matter of fact, a direct effect of anthropic activities (the cutting of the forest, fires, exploitation of pastures, agricultural activities). The comparison with the archaeobotanical data not only confirms various types of exploitation of wood resources but provides an insight into the past associations of plant communities and dynamics of the anthropic impact, which is observable even today. Basically, the window on the past opened by the archaeobotanical record allows us to envision a dynamic relationship between the suitability of this territory and the sustainability of its effective anthropic use into the last millennium. In this area of the Sicani Mountains, the anthropic exploitation has not altered the composition of the plant communities, maintaining a high degree of biodiversity, which favors the conservation of this landscape and therefore its designation as HNV farmland. For the designation of a certain landscape within the HNV farmland category, we believe it is necessary to evaluate its historical value, which is only defined by an integrated approach of historical ecology and environmental archaeology and can help us to identify the maintenance of geobotanical characteristics, biodiversity and the sustainability of exploitation of environmental resources over the long term.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/8/3201/s1, Table S1: Phytosociological tables of associations of Sicani Mountains used as a data source.

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sustainability

Article

Contingency and Agency in the Mountain Landscapes of the Western Pyrenees: A Place-Based Approach to the Long Anthropocene

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Abstract: Regional- and biome-scale paleoecological analyses and archaeological syntheses in the mountain landscapes of the western Pyrenees suggest that the Long Anthropocene began with agropastoral land use at the onset of the Neolithic. Historical and geographic analyses emphasize the marginality of the western Pyrenees and the role of enforced social norms exacted by intense solidarities of kin and neighbors in agropastoral production. Both are satisfying and simple narratives, yet neither offers a realistic framework for understanding complex processes or the contingency and behavioral variability of human agents in transforming a landscape. The Long Anthropocene in the western Pyrenees was a spatially and temporally heterogeneous and asynchronous process, and the evidence frequently departs from conventional narratives about human landscape degradation in this agropastoral situation. A complementary place-based strategy that draws on geoarchaeological, biophysical, and socio-ecological factors is used to examine human causality and environmental resilience and demonstrate their relationship with the sustainability of mountain landscapes of the western Pyrenees over medium to long time intervals.

Keywords: Basque; Neolithic; Western Pyrenees; mountain agropastoralism; historical ecology; land-use change

1. Introduction

We focus in this article on contingency and agency in the “Long Anthropocene” in the Soule Valley of the western Pyrenees, where the Neolithic onset to agropastoral land use during the Middle Holocene marks an important transition in human-environment relations. Whereas the Anthropocene as a unique geological period concerns the sum total of human impacts on the whole earth as a complex system, the Long Anthropocene focuses on spatially heterogeneous shifts in localized human behaviors that ultimately lead to human dominance of the Earth System. An important shift in these localized behaviors is the domestication of plants and animals during the Neolithic and the concomitant transformation of landscapes. Significant effort among proponents of the Anthropocene has gone to identifying a “golden spike” in geophysical archives that would denote the punctuated on-set of human dominance of the earth as a whole, such as the abrupt transition to industrial forms of production, fossil fuels, and intensive global trade networks in the 18th century [1–3]. Long Anthropocene proponents have placed more attention on discovering the deep roots of human influence, progressively moving back through time in some instances into the Plio-Pleistocene, while giving attention to social in addition to geological dimensions of the relationship between humans and the earth (e.g., [4–6]). Proponents of both approaches have at times formulated deterministic accounts that capture the imagination, and the polemics between them may stem from what is in fact a paradigm shift between environmental science and earth system science [7,8]. We view the approaches as necessary complements and take a Long Anthropocene position in this article to draw attention to the complex dynamics of human-environmental interaction across the temporal and spatial scales at which the relationship unfolds in the western Pyrenees.

The Soule Valley is not a specific locus of plant or animal domestication, yet the localized deployment of agropastoral land use by Neolithic people has had long-term co-evolutionary consequences for both landscape and society. This paper presents a synthesis of our work in the Soule Valley that takes the long-term processes of human-landscape co-evolution as its main subject. The Neolithic transition in the Western Pyrenees is frequently termed a 'conquest' [9–14] and pastoral activities, including cutting, burning, and shepherding, are said to 'penetrate' the land so that the Neolithic is the first step on the orthogenetic path to becoming a global geological force [2]. This narrative of prehistoric land conversion (i.e., "anthropization" in the Pyrenean literature) is closely associated with the presumed inevitability of the degradation of nature brought about by the interaction of humans and environment [15]. By contrast, cross-disciplinary findings presented in this paper indicate that landscape "domestication" in the Soule Valley was not a unidirectional, imperious transformation of mountain landscapes, but an asynchronous, complex, multiscale process associated with individuals as operational change agents. These results are illustrative for research on the Long Anthropocene because they show how a place-based, cross-disciplinary approach can more accurately capture complex dynamics surrounding issues of socioecological sustainability.

Simplistic assumptions about the past trajectories and sustainability of mountain landscapes are not unique to disciplines such as palynology and archaeology. Historians in France have traditionally ignored mountain areas because " ... above 1000 m, there is no history" [16]. When mountains have been recognized they are examined indirectly from observations on the plains that surround them [17], resulting in a "quasi-immobile history" [18]. As a consequence, European mountain landscapes and their human inhabitants are perceived as spatially, politically, and economically marginal, which is a conclusion seemingly confirmed by the progressive abandonment of mountain landscapes and the pastoral lifestyle in the 20th century. Whether abandonment is due to marginality or ever-more specialized land-use policies and regulations (e.g., classifying the millennial practice of pastoral fire as irresponsible land stewardship) remains an open question [19–22]. We argue that speculation of a different kind simply substitutes for understanding of discrete vs. continuous components of a pastoral lifestyle and the nature of human-environment interactions across time.

Pastoralism is a production strategy in which sheep consume grass and transform it with the assistance of a herder into diverse commodities, while enmeshed in a complex interaction between broad-scale drivers, local resources, institutions, and individual agency [23–25]. This means that people, place, and history are inextricably linked, while land-use change unfolds as a multi-stranded process of intensification and dis-intensification related to generation-by-generation means and variance in individual reproductive success [26]. Any given household pedigree that holds, transfers, or abandons a portfolio of land parcels is but one realization or historical sample from the full constellation of pathways expressed in a particular population. While convenient to assume equilibrium between reproductive success and migration or between death and survival, to do so obscures the lived reality of agropastoralism that must be apprehended in order to explain how and why change happens.

Our overarching hypothesis is that anthropogenic land transformation in the Long Anthropocene was predominantly a long-term, spatially heterogeneous press dynamic [27] resulting in the sustainable coevolution of land use, socioeconomic intensification, and landscape change, rather than an intentional, uniform wave of agropastoral land conversion. Numerous studies now confirm that European mountain landscapes are the result of climatic and anthropic pressures exerted and interrelated in a variable manner over the course of the Holocene [28–32]. This means that factors of change cannot be separated from factors of location, duration, and intensity [33]. Cultural landscapes such as those in the Soule

Valley provide a rare opportunity to examine the origin of structural legacies (long-cycle) and signal processes (short-cycle) that link the past to the present in the anthropogenic transformation of mountain landscapes. We do so by examining the boundaries, scale, and flow in the response diversity of human agents operating under the changing circumstances within a complex adaptive system.

Geographic and Cultural Context of the Western Pyrenees

Our research is centered on the commune of Larrau in the Soule Valley in France (Xiberoa, in Basque). However, the contingency and agency characteristic of agropastoralism has required us to place Larrau within the Soule Valley and the larger Basque region (Euskal Herria) in the western Pyrenees spanning the French-Spanish border. Soule is the smallest of the seven Basque Provinces, and is centered on the Saison River in the French department of Pyrénées-Atlantiques that borders the autonomous community of Navarra in Spain. Despite the modern border between France and Spain, archival research gives evidence that individuals and institutions from both the north and the south slope of the Pyrenees have used its high elevation pastures since at least the High Middle Ages. Indeed, high elevation pastures at the head of the Soule Valley are still used by members of communities outside of Soule, notably Barétous to the east in France and Roncal to the south in Spain (Figure 1).

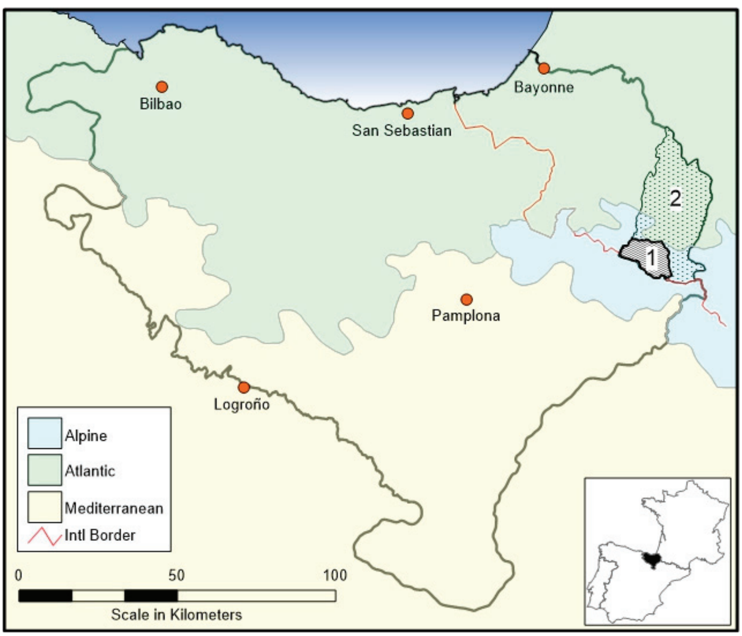

Figure 1. Location of Larrau (1) and the Soule Valley (2) relative to Euskal Herria and biogeographic areas in the western Pyrenees on the border between France and Spain.

At the European scale, the Pyrenees Mountains form a continuous barrier to atmospheric circulation [34,35], resulting in strong west-to-east and north-to-south gradients in climate, environment, and human use (See Supplementary S1, Figure S1.1, in Supplementary Files). The western Pyrenees receives significant precipitation (circa (ca.) 1500 mm/y) under the influence of the North Atlantic Oscillation (NAO) and the humid air masses of the north/northwesterly winds. The eastern Pyrenees, by comparison, are much drier (ca. 500 mm/y) and under the influence of a Mediterranean-like climate in which moisture is negatively correlated to the NAO [36,37]. The northward draining watersheds ("north slope") in France are wetter than the southward draining watersheds ("south slope") in Spain.

The latter borders the Ebro River basin subject to a Mediterranean climate under a strong continental influence with hot summers and cold, dry winters (ca. 300 mm/y) [38]. Consequently, Soule Valley exists at the convergence between the Atlantic, Mediterranean, and Alpine bioclimatic regions and abuts the political border between France and Spain.

Soule as a community is also part of Euskal Herria, where Euskera (Basque), the last non-Indo-European language in Europe, is still spoken as the first language by some 1,300,000 individuals [39]. Archaeological sites from the terminal Pleistocene through the early Holocene within Euskal Herria (Supplementary S1, Figure S1.2) speak to the debated origin of the Basque that are commonly said to have lived in the area bounded by the Adour and Ebro rivers since 'time immemorial'. Mounting evidence indicates that Euskera is linguistically related to Caucasian languages [40–42], suggesting that inhabitants of Iberia and Aquitania adopted the language from the carriers of the 'Neolithic package' as they moved up the Ebro Valley. Genome-level evidence suggests that the Basque are close to other Europeans, and even though they display unique Y-DNA and mtDNA lineages, their continuity as a biological population is only detectable back to the Neolithic/Chalcolithic period [43–46]. The most comprehensive human genetic study for the Franco-Cantabrian region to date [43] identified six unique mtDNA haplogroups autochthonous to the region and estimated that the separation of the Basque-speaking populations from the pan-European gene pool took place ca. 8000 calibrated years before the present (cal BP). The results further suggest a female genetic contribution distinct from other European areas. The implication is that the 'Neolithic package' does not indicate demic replacement as some advocate [47], but rather an extended coexistence of Epipaleolithic and Neolithic populations [48,49].

Despite the linguistic and genetic implications of occupational continuity, there are currently no known archaeological sites in the Soule Valley between ca. 14,700 cal BP and 9700 cal BP. However, it seems likely that hunter-gatherer populations residing in the low- and mid-elevation zones of the upper Ebro Basin used the uplands intermittently depending on weather conditions. Agropastoralism in the western Pyrenees and its continuation into the Cantabrian Range dates to the initial Neolithic expansion around the Mediterranean Basin ca. 7500 cal BP [50–53]. We examine the local socioecological dynamics of the Neolithic expansion and the Long Anthropocene in the headwaters of the Soule Valley in the administrative territory of the commune of Larrau.

2. Materials and Methods

2.1. Soule Valley and Larrau

Over the course of the last decade (2009–2019), we conducted interdisciplinary fieldwork in the communal territory of Larrau, in the Department of the Pyrénées-Atlantiques, France. Larrau has a surface area of 12,680 ha and contains most of the high-elevation pasture used by the 47 communes that presently comprise Soule as a territorial community. Elevations in the commune of Larrau range from 300 to 2000 m above sea level (asl), which is characterized by a cool and humid climate with an average precipitation of 1600 mm/y and average daytime temperature between 1.4 °C (winter) and 13.3 °C (summer) (data available, Météo-France). Land use in the lower elevations corresponds with private household farmsteads, that can either be consolidated or scattered landholdings, depending on the household. Forests below 800 m asl are dominated by oak, which transitions to beech and fir (*Abies* sp.) between 800 and 1300 m asl. These are predominantly communal woodlands with scattered private "inholdings" representing the upper limit of the privately owned hay meadows. Alpine and subalpine grasslands and heaths with patches of mixed pines dominate elevations above 1300 m asl. These high-elevation grasslands form the bulwark of the communal summer pastures accessed by herders from throughout the Soule Valley.

Landscape within the Soule Valley can be divided into a hierarchical set of socially and ecologically significant spatial units: valley, commune (a village and its territory), quartier (a topographically defined neighborhood), etxe (a household-level farm production unit), parcel (a spatially circumscribed, discrete unit of land use), a borde (an independent cluster of parcels surrounding a barn, often located in the mid-mountain within or between communal and private lands), and a cayolar (collectively owned pastoral inholdings within communal lands) (Figure 2). A valley is comprised of many communes, a commune is comprised of several quartier, a quartier consists of a number of etxe households, and the landholdings of an etxe consist of topographically arranged parcels that provide the unit with diverse resources across the annual production cycle. Pastoralists are often seen as having a separate, peripheral, and marginal existence vis-à-vis sedentary farmers [25]. In the case of the western Pyrenees Mountains this view translates into a perception of the Basque as spatially, politically, and economically marginal since at least Antiquity by comparison to surrounding areas. This view is closely associated with the 'valley republic' phenomenon common across the Pyrenees among Aragonese, Basque, Béarnaise, and Gascogne groups (e.g., [54,55]), of which there are approximately 15 among the Basque in the Western Pyrenees. Briefly summarized, these are ethnic enclaves organized by their dependence on agropastoralism and frequently described as systems in existence since time immemorial.

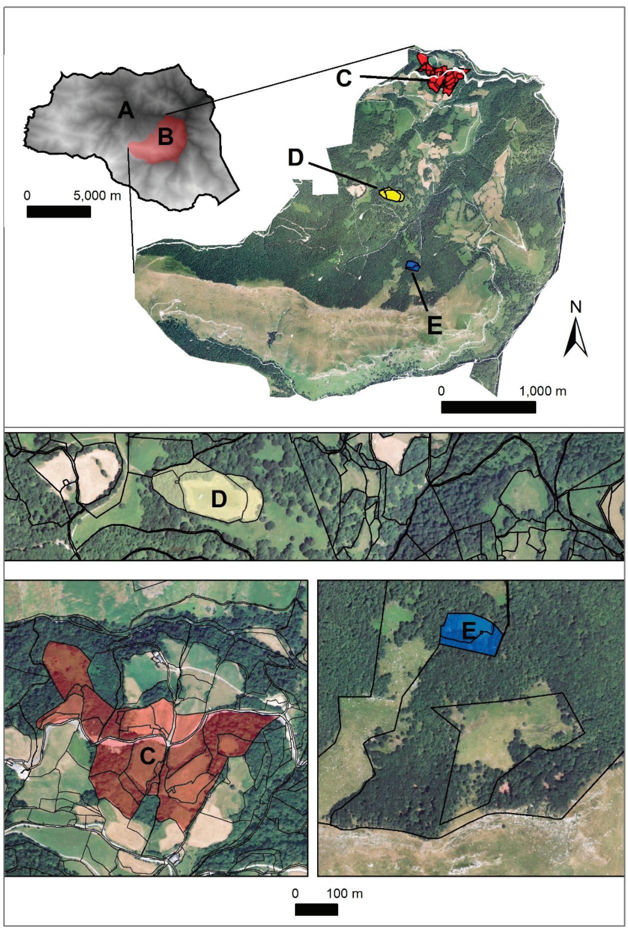

Figure 2. Cartographic depiction of the hierarchical spatial units of the landscape, (**A**) the commune of Larrau, (**B**) a quartier within Larrau, (**C**) an etxe and its parcels, (**D**) a borde and its parcels (an annex portion of an etxe's landholdings), (**E**) a cayolar inholding.

There are two types of land in Soule and the Basque region of France and Spain generally [56–58]: (a) parish-community lands belonging to the individual inhabitants of a village "since time immemorial", and (b) common lands belonging collectively to all parish-community residents in a defined region. In Soule, parish-communities re-defined as communes in the Napoleonic Cadaster of 1830 have been stable since at least AD 1377 based on the first tax-census of the valley [59], and at least five parish-communities have existed since the 11th century [58,60]. This division of the land and its associated administrative and economic autonomy includes diverse aspects of livestock management and provides the holders vis-à-vis a central authority with various rights recognized in customary documents called coutume (French) or fuero (Spanish).

The oldest surviving examples of such documents in the French Pyrenees, e.g., Coutume de Soule, date to the early 16th century [58]. In the Spanish Pyrenees, the Fuero de Jaca is the oldest such document, dated AD 1077, and elements from it were incorporated into a regional management document called the Ordenanza de Pastos, dated AD 1457 [61,62]. Coutume and fuero in the Basque region are anchored in an oral customary tradition termed the Derecho Pirenaico that circumstantial evidence suggests either draws from and/or is influenced by older legal frameworks from the 6th–8th century, if not 1st century Roman code from Gallia Aquitania. The groups of parish-communities who invoke a particular coutume or fuero are historically and colloquially referred to, even at present, as a "country", "republic", or "valley", e.g., Soule. This is a tacit recognition of the shared history, language, culture, and geography that gives identity to parish-communities and residents of a valley. Parish-communities are important at a certain scale, but historical and ethnographic evidence identify the etxe household as the principal locus of production and decision-making [26,63,64].

2.2. Research Design and Synthetic Framework

The overarching goal of our research on the Long Anthropocene in the commune of Larrau and the Soule Valley was to integrate diverse place-based observations to understand the co-evolution of pastoralism and landscapes scaled to the decision-making units responsible for activities on the land. Larrau provided us with a unique opportunity to assemble a long-time series on diverse dimensions of mountain pastoralism. Our approach combined multiple methods and data sources, including qualitative and quantitative analyses of historical archives, geospatial mapping and modeling, ethnographic participant observation and interviews with livestock raisers concerning historic and contemporary grazing and burning practices, archaeological survey and excavation of high-elevation pastures, dendrochronology of forest-meadow edges and ancient coppice woodlands, and paleoecological investigations of sedimentary archives. We used our findings to generate highly resolved chronostratigraphic sedimentary profiles for change in discrete landscape units for the entire Holocene (past 11,700 years), that we related through geospatial analysis to grassland pasture flammability, parcel use, and household abandonment. Since our purpose in this paper is to provide a synthesis of our various analyses, we provide only a summary of our methods below. For full methodological and analytical details, please see our various publications [26,65–70].

Humans have unparalleled behavioral plasticity and occupy many habitats that ecologists and development experts would term "marginal", even if a precise definition of marginality is rarely provided (e.g., [71,72]). Being marginal does not mean an area is uninhabitable or uninhabited, it implies that human culture and technology are unable to buffer against environmental or sociopolitical stressors [73]. In the case of mountains, such a determination cannot be made either by assuming there is no history above 1000 m asl or by inference from the more easily accessible plains that surround them. It requires us to examine system behavior itself and arrive at an understanding of the thresholds, alternative steady states, adaptation, contingency, and feedback that allow and determine the nature of the human relation to the environmental setting in which it is expressed [74–78].

Response diversity or how individuals differentially respond to their changing circumstances is an important component of the central tendency of any described behavior [79]. It is anchored in human agency, that nominally includes intentional, self-aware choice [80,81]. The existence of choice does not imply that human agents are aware of the reasons for their choices, or that they think in terms of costs and benefits regarding fitness or other such measures. Yet, people do make choices expressed in their agency that consider their circumstances and their preferences, and which derive from a developmental process inclusive of inheritance and learning. The weight of pastoral activities expressed in the geoarchaeological record is concentrated on places—a cabin, a corral, etc. However, these places are mere gateways distributed across a pastoral landscape to the exploitation of grass, the key, and almost invariably common resource that is exploited by livestock with the assistance of herders [82]. The implication of this characterization of mountain pastoralism is that to understand the system we must reflect on the boundaries, scale, and flow of the response diversity of the human agents operating within it, while addressing how response diversity can promote stability without resorting to a claim for exceptionalism:

- Boundaries—identity groups operating within defined territories called 'valley republics' that cannot simply be characterized as closed corporate communities, since they coexist within a regional system; these boundaries to pastoral activities must be evaluated as to their closed vs. open, flexible vs. inflexible nature.
- Scale—members of a herding cooperative (a cayolar) are bound by valley-wide 'rules of use' containing multiple levels (e.g., individual, etxe, cayolar, commune, valley) on a scale that must be considered for a proper understanding of system function.
- Flow—livestock are the means for exploiting the resources, and understanding their flow from/to places is central to evaluating the differential pressure and cumulative effect that stocking rates, for example, can have over time on the structure of archives at places across the landscape. We exemplified these aspects of response diversity during the Long Anthropocene by summarizing paleoecological, archaeological, and historical evidence for upland forest to pasture conversion and land use transition and persistence in Larrau.

2.3. Examining Forest to Pasture Conversion

In the absence of agropastoral land use and management, subalpine forest should cover all but the exposed rockfaces of the highest and steepest peaks in Larrau. Today, very little of the landscape above 1200 m asl is forested (Figure 3). Forest to pasture conversion is the fundamental process for domesticating landscapes in agropastoral systems and fire is the primary tool [65,66]. To examine forest-pasture conversion as a socioecological process in Larrau, we combined archaeologically derived chronologies of agropastoral occupation and colluvial stratigraphic archives of "legacy" sediments from zero-order hollows at locations along the top of the Pyrenean divide. We auger-sampled continuous profiles of colluvial slopewash sediments eroded from zero-order watersheds in 5–10 cm contiguous intervals. We used a multiproxy approach to analyze these sediments, examining charcoal, magnetic susceptibility, sedimentation rates, and phytoliths to characterize the differential onset of anthropogenic burning and forest-pasture transition across individual catchments [69,70,83].

We complemented each colluvial sample with systematic pedestrian archaeological survey of the surrounding catchments. We also conducted ground-penetrating radar surveys at and adjacent to 11 of the archaeological sites we located and followed this with subsurface auger testing [67]. For seven archaeological sites located beneath or adjacent to our zero-order colluvial catchments, we auger-sampled stratigraphic profiles at 5 cm contiguous increments and collected archaeologically-deposited wood charcoal for radiocarbon dating. Additionally, French colleagues conducted excavations of two sites a short distance (<10 and <100 m, respectively) from two colluvial sample sites [68]. Charcoal from these excavations were radiocarbon dated as well.

Figure 3. Typical upland pastures in Larrau showing treeline around 1200 m asl.

2.4. Analysis of Land Use Transition and Persistence

Regional studies suggest landscape transitions are primarily driven by "exogenous innovations that originate outside the boundaries of the local system" [84]. However, this approach necessitates that the motivations, decisions, and actions of individual land managers are derived from inferences about the group to which individuals belong, rather than the action of individuals themselves.

In Basque society, etxe households are social and economic reproduction units resulting in the demographic conditions that make the spatially- and historically-contingent economic decisions responsible for local patterns of land use change [85–89]. The etxe is more than just a smallholder family farm. It constitutes a spatially fixed property conceptually independent from a family. This means that normatively, an etxe can be abandoned while the family continues, or a family bloodline can die out while the etxe continues to bring in a new inheritor [63]. Etxe inheritance norms include ambilineal primogeniture and impartibility of the estate of land and buildings [26,90], i.e., the eldest male or female child inherits the entire estate and the right to form a family. The inheritor's younger siblings stay on as productive yet celibate members of the etxe household, who are beholden to the decisions of the inheritor [63]. Documents from the private archives of etxe in Larrau suggest that a least some of them were established prior to the 16th century.

We developed a geodatabase of fiscal land records from 1830 to the present that covers the entire commune of Larrau. We additionally compiled archival records from household and regional repositories that date back to ca. A.D. 1000 and provide information ranging in scale from the etxe household to the valley level. For one quartier in Larrau, we conducted field- and cadastral-based reconstructions of etxe and parcel-level infrastructure and land use from 1830 to the present. To confirm historical parcel boundaries for the quartier we matched the 1830 cadastral maps with current and historical air photos and conducted pedestrian surveys of parcels, hedgerows, and trails that access them. We additionally conducted a dendrochronological sampling program in the woodlands and hedgerows between communal lands and etxe private parcel holdings of the quartier. Using communal birth records from 1790 to 1950, we reconstructed household-level demographic histories and linked these to our geodatabase of etxe abandonment and parcel-level land use change in the same quartier. Using event-history analysis [26], we examined how agropastoral-focused etxe move at any point in time among a finite and theoretically meaningful number of states (e.g., 'occupied', 'abandoned') and how parcels flow in and out of dynamically-scaled etxe in response to time-constant or time-dependent factors [91,92].

Above the etxe landholdings (>800 m asl), are lands held in common by the members of a valley republic [93] and used by etxe as summer (May–September) pasture for their livestock [94,95]. Within these communal lands are small, collectively owned inholdings that typically contain a cabin and milking grounds, that together form a traditional grazing cooperative known as an olha (Basque) or cayolar (French) [94]. Ott [94] and others [56–58] have described in detail the historical and legal precedents of the cayolar institution, the roles and responsibilities of herders, and the economic and social imperatives of participation.

While extensive archaeological survey of Larrau's high elevation pastures allowed us to confirm the spatial and functional accuracy of cayolar infrastructure depicted within the 1830 cadastral maps, it did not provide adequate information on the social interactions that define the institution and link resources to etxe households. Thus, our analysis of pasture land use drew on an addendum to the 1830 cadaster that lists indivisible inholdings in Larrau's communal pastures that correspond with cayolars. The addendum notes herder names, the number of shares they hold in the cayolar, and their village of origin. We additionally relied on household archives, agricultural census data, and household-level tax and subsidy records from the 1970s onward to understand more recent land uses changes. To relate our understanding of the socioeconomic aspects of the pasture land use to the question of socioecological sustainability, we reviewed evidence of landscape resilience toward grazing and burning. These included: (1) visual and analytical characterization of soil horizons from excavated soil pits in paired forest-pasture sites at similar landscape positions [60], and (2) ethnographically informed Bayesian models that backcast the relationships between landscape topography, pastoral fire use, and land use change [65,66].

3. Results

3.1. Forest to Pasture Conversion

Log distributions of sedimentary charcoal accumulation (CHAR) revealed that fire was uncommon until the early Neolithic, and results from colluvial records that began between ca. 18,000 BP (Mulhedoy) and ca. 14,000 (Ihitsaga) indicated that CHAR values were not detectable (<0.0001 mm^2 cm^{-2} yr^{-1}) at two locations (Ihitsaga, Mulhedoy) until the Middle Holocene (between 6 and 7000 BP). Sporadic fires were evident prior to 9500 BP at a third location (Ibarandoua), yet appeared insignificant until ca. 8000 BP. The evidence suggests that low-severity burning activity progressively increased over several millennia and a human grazing-fire regime was not established in all catchments until about 6000 BP. The site of Mulhedoy registered the earliest CHAR peak ca. 3850 cal BP (middle Bronze Age), followed by the site of Ibarrandoua some 1550 years later at ca. 2280 cal BP (late Iron Age), while the site of Ihitsaga ended with a subtle peak ca. 1900 cal BP (Antiquity). We suggest that the cycling between pronounced peaks and declines in CHAR levels indicate the transitional tipping points between forest and grassland states at a landscape scale (Figure 4).

Archaeological survey located over 100 prehistoric/early historic sites and nearly 200 features (i.e., hunting blinds, cabins, corrals, tumulus). There are only six archaeological radiocarbon dates earlier than 3000 BP from sites discovered in Larrau previous to our own research. CHAR peaks at the sites of Ibarandoua and Mulhedoy fell within the confidence intervals for two early composite archaeological radiocarbon distributions (Figure 4). While suggestive of an association between burning activities and human occupation of upland areas, the highest density of archaeological radiocarbon dates occurred in the last millennia following a 1000-year decline in CHAR values. Thus, while burning and human presence are circumstantially related, the evidence is not sufficient to confirm or deny associated land use, much less social and economic organization.

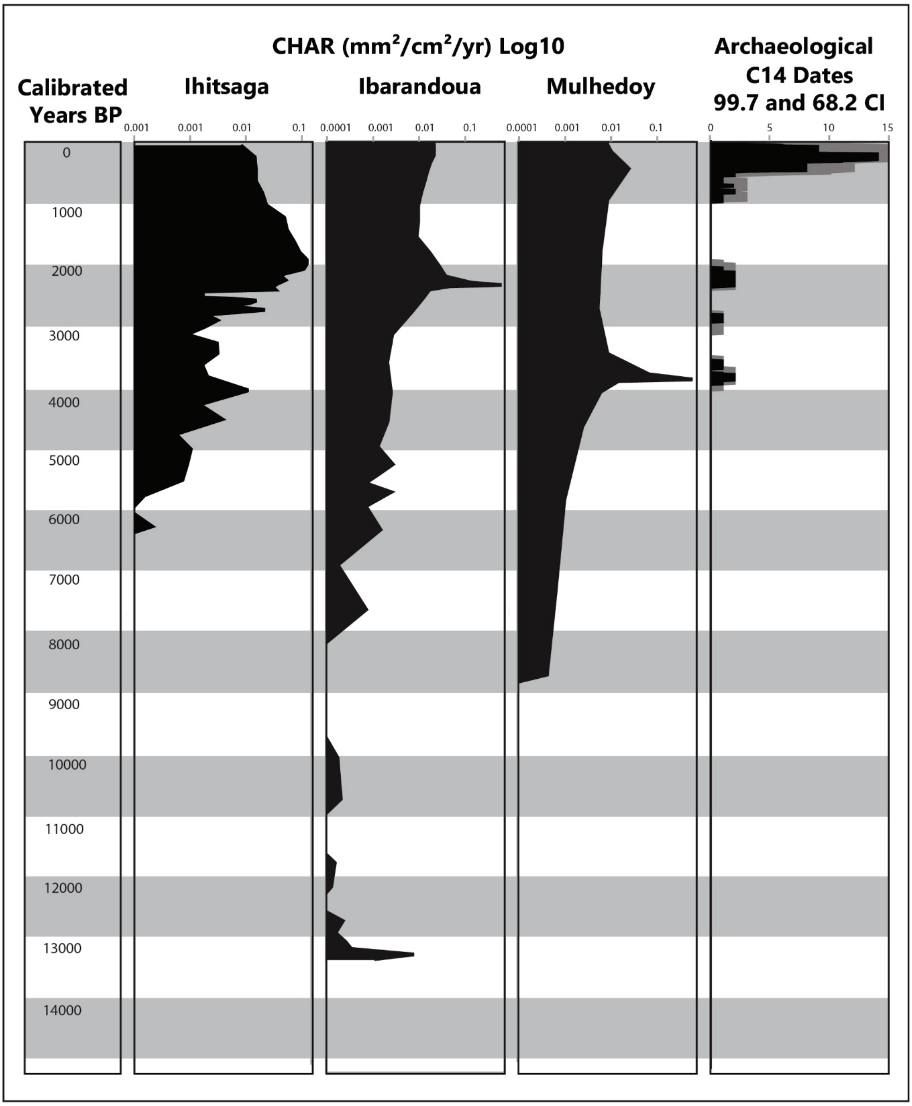

Figure 4. Charcoal accumulation (Log scale) for the Holocene period with the number of radiocarbon dates from archaeological contexts by probability distribution [83].

3.2. Land Use Change

Event analysis of parcel- and etxe-level land use change between 1830 and 1950 showed a pattern of increasing farm size, decreasing land use intensity, in tandem with household abandonment. About 50 percent of parcels that started in etxe that were abandoned ended up transferring to etxe that increased their landholdings. Yet, etxe that expanded their farms did not display preferences for particular parcel qualities, rather, they opportunistically absorbed (or invested in) adjacent parcels following the abandonment of neighboring farms, maintaining their own previous capacities for crop production (Figure 5). However, parcel quality (based on its 1830 land use tax value) did statistically buffer against etxe expansion. In other words, some etxe with a relatively small amount of high-quality, arable land remained tied to more traditional subsistence strategies and did not seize opportunities to expand or specialize in market-oriented production. Etxe with lower quality farmland either invested and expanded their estate, or abandoned farming altogether.

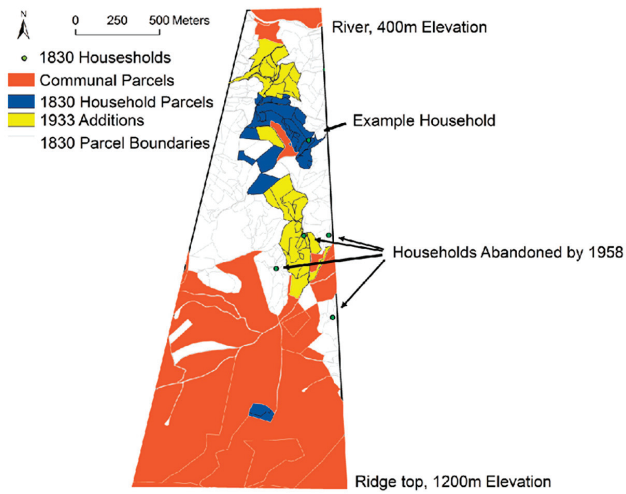

Figure 5. Etxe household estate expansion 1830–1958. Example of investor household, blue landholdings 1830, by 1933 expanding to adjacent yellow landholdings.

Results also indicate that the specific nature and location of land use change was directed by etxe-specific demographic cycles and was contingent on the pre-1830 composition of the etxe estates and the estates they subsumed. Considering that plowing, planting, and harvesting crops is the most labor-intensive component of the farming system, the areal proportion of an etxe's crop fields to hay meadows, pastures, and woodlots was constrained by its labor capacities. These, in turn, were determined by household demographic cycles in the ratio of consumers (young children, elderly, and infirm) to producers (workers). In a system where etxe farm sizes were fine-tuned to demographic cycles from at least the 15th century, the absorption of a neighbor's parcels entailed the transition of parcels to less labor-intensive uses, i.e., crop fields to hay meadows, hay meadows to pastures, and pastures to woodlots.

This transition of etxe land use was not as significant for the communal high-elevation pastures. Many of the currently extant pastoral syndicates were indicated as active cayolar on the 1830 cadaster. Others were abandoned and consolidated or re-located as roads were constructed during the mid- to late-20th century. Post 1830 construction efforts (mostly carried out after the Second World War), elaborated on existing infrastructure and provided cheese makers with modern sanitation equipment. Our cadastral data for 1830 show a total of 329 cayolar shares (where 1 share is equal to between 45 and 60 ewes) were held by etxe households for communal pastures in Larrau. Thus, we estimate that in 1830, the minimum stocking rate in the communal pastures of Larrau ranged between 14,805 and 19,740, depending on share/ewe equivalency. Agricultural subsidy records for the commune of Larrau show that the average etxe milch ewe herd size increased from 49 in 1975 to 160 in 2010. Agricultural census data from 1984, 1993, 2000, and 2008 for Larrau's pastures show an annual average of 22,422 sheep (including ewes, rams, and lambs). Thus, in spite of increasing etxe herd size, we suggest the total number of sheep has stayed relatively stable over the last 200 years.

Our examination of ecological components of the system also lends support to the hypothesis that grazing pressure has remained stable over the past few hundred years. Paired forest-pasture soil pits revealed that pasture A horizons exhibit three times the thickness in comparison to forested soils.

They have higher concentrations of organic matter and significantly lower bulk densities than forests soils. Indeed, when compared with the soils of forested slopes of similar degree and aspect, soils in pastures appear more resilient to ecological disturbances. Our studies on pastoral fire use also revealed a pattern of persistence without negative impacts to forests. For example, evidence of fire scarring in tree trunks at treeline was relatively scant. Dendrochronological dating of trees cored along two pasture edges confirmed that those woodland-pasture ecotones have been relatively stable over at least the last ca. 200 years, in spite (or because) of the regular use of pastoral fire (Figure 6). Lastly, Bayesian modeling of the interactions of fire use suitability and land use change from 1830 to 2003 suggested that although areas that are the least suitable for fire management experienced the highest afforestation on privately held lands, pasture commons used and managed by cayolars appear to have buffered against the afforestation.

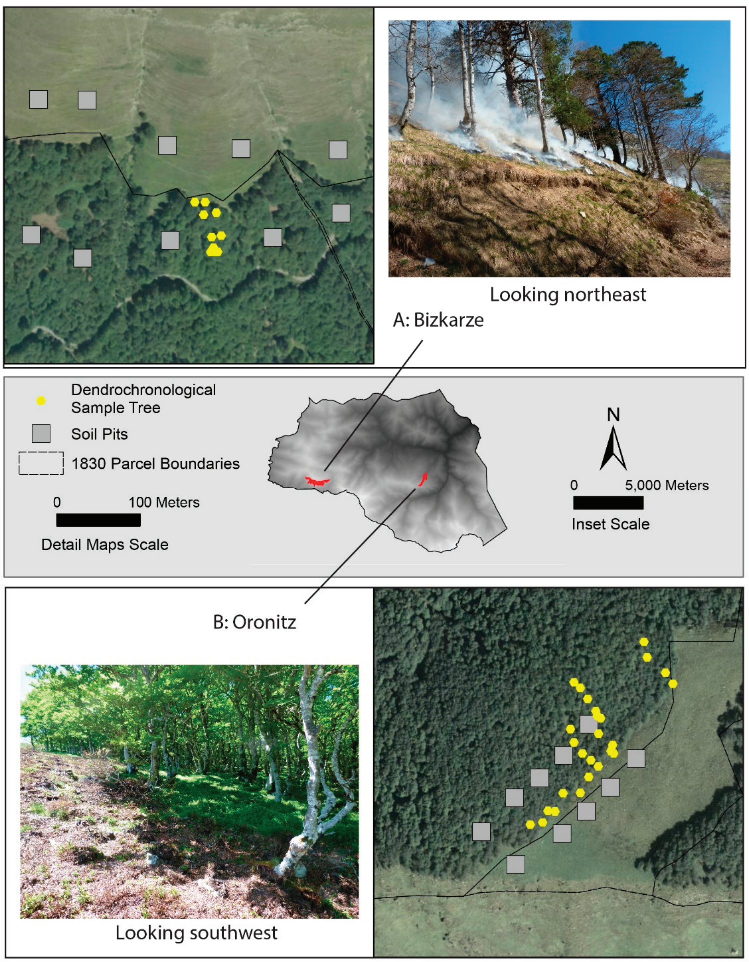

Figure 6. Map and photos of pasture treeline study sites showing dendrochonological sample trees and pair forest-pasture soil pits [60]). (**A**) Bizkarze, a south-facing slope. Photo of pastoral burns in April, 2011, near location of sampled treeline. (**B**) Oronitz, a north-facing slope. Photo of recently burned heath, May, 2012, along sampled treeline.

4. Discussion and Conclusions

4.1. Cause and Effect in Forest-Pasture Conversion

Archaeological results for the Ibarrandoua colluvial site provide a good illustration of the difficulty of empirically establishing cause-effect generalizations, even from the place-based pairing of archaeological and paleoenvironmental archives. Ibarrandoua is close to four major prehistoric mortuary sites, of which two (Amelstoy and Milgate) are ca. 750 m away. Amelstoy is a mortuary cave on a steep slope to the south of the colluvial catchment [96] that yielded human bone dated to ca. 3632-3514 cal BP. CHAR for this period registers around 0.014 $mm^2 cm^{-2} yr^{-1}$—well below the Holocene average, yet suggestive of some anthropogenic burning. Milgate is a large, multi-component cromlech-tumulus site located on an exposed east-west ridge overlooking the Ibarrandoua colluvial site from which two features (Milgate 4 and 5) were excavated and dated by a previous investigator [97,98]. Milgate 5 (ca. 2872-2764 cal BP, late Bronze or early Iron Age) coincides with an uptick in CHAR ca. 2877 cal BP, while Milgate 4 (ca. 2292-2001 cal BP, late Iron Age) overlaps with the steep CHAR peak ca. 2283 cal BP. Another site, Behastoy, is on the flanks of Pic d'Orhy opposite the Ibarrandoua colluvial site distant ca. 4.6 km, and it overlaps with the peak in CHAR as well. We interpret this peak as marking the forest-pasture transition point at Ibarrandoua that was followed by a greater than 1000-year decline in burning. CHAR values are sustained from 950 BP forward to the present and coincide with the establishment and use of three dated archaeological features (most likely representing seasonal pastoral shelters) directly down slope from the colluvial sample site (99.7% CI range: 905 to 0 BP [post 1950 common era]).

These results speak to the onset of anthropogenic burning without directly addressing the origin of the so-called 'Neolithic package' giving rise to the pastoral economy in the mountains. From the point of view of archaeological evidence, the most intensive and clear use of the area follows well after forest-pasture conversion of the catchment. Nevertheless, the evidence for land clearance and erosion processes in Soule during the Long Anthropocene indicate heterogeneous, non-synchronous outcomes at the landscape level [70]. We are beginning to resolve some aspects of the source area for the herders and livestock using the upland pastures for periods prior to 1000 CE from our examination of land use change in Larrau and the Soule Valley.

4.2. Land Use Change

Our event analysis results are consistent with the assertion that land use change between 1830 and 1950 in the Soule Valley was driven by the opening of dairy markets through improved transport and industrial creameries [55], as well as by outmigration that constrained locally available labor. For example, in 1902, Roquefort established a cheese facility in Tardets, the market town at the center of the Soule Valley, thus creating an annual market for ewe's milk and coinciding with the demise of long-distance transhumance beyond the confines of the Soule Valley, as historically described [17]. Many etxe began specializing in the production of ewe's milk, while their strategic response entailed abandoning traditional mixed-intensity agropastoralism, increasing the size of sheep herds, expanding hay meadows (thus, augmenting the capacity to stall-feed ewes over the winter), and collectively improving infrastructure surrounding seasonal transhumance between etxe and communal mountain pastures [55].

Our analysis revealed that the importance of the hay meadow contribution to etxe landholdings increased relative to the contribution from crop fields, but this shift in land use was not accomplished through a simple replacement of an etxe's crop fields with hay meadows. Instead, event analysis revealed that market-oriented etxe increased their hay production by increasing in size (land area) as other etxe were abandoned [26]. Thus, at the local level, the pace and character of land use change was significantly constrained by the social and spatial relationships between etxe [26]. In concert with the results of our soil and dendrochronological investigations, we suggest that institutional persistence in Larrau has buffered against degradation and constrained land use at a sustainable level.

Adaptation to a novel socioeconomic opportunity did not result in abandonment and collapse of the system, but a shift from a mixed-intensity agropastoralism to a more specialized pastoral land use. Such flexibility may be inherent to the system of agropastoral households in the Pyrenees, enabling the system to persist through centuries of shifting socioeconomic and environmental change. While not all etxe were equally able or willing to meet the diverse opportunities they encountered, the response diversity of their decisions facilitated the persistence of the remaining etxe and the institution itself. In Larrau, etxe that increased landholdings during the 19th century and maintained high fertility into the 20th century were more likely to persist beyond 1958 than those etxe that experienced an earlier transition to lower fertility and did not reorient production toward emerging markets. The local historical and spatial contingencies in Larrau mediated the influence of exogenous forces and guided the direction of change taken by individual etxe.

4.3. Boundary, Scale, and Flow in Agropastoral Response Diversity

Agropastoralism has deep roots in prehistory and much of the focus to date in the western Pyrenees has been on the regional onset of the Neolithic rather than the socioecological process of anthropogenic landscape transformation. Transitions are not enforced; they vary in rate and character through time and across space, because the cycle of households and the rhythms of the landscape are dynamically linked. A comprehensive consideration of the Long Anthropocene must contemplate how livestock management strategies and pastoral response diversity help to explain the place-specific trajectories of landscape transformation. Mobility and exchange are critical to pastoralism, yet also do not typically leave behind material signatures, since they are highly variable over time and across space and occur between rather than at places. A pastoral landscape includes various types of sites and features, e.g., cabins, pathways, and corrals, along with natural features such as caves, springs, and overhangs. It is these places and the relationships between them that structure pastoralism and serve as the arena in which repeated circulation and activities produce meaningful material patterns [99,100]. The multi-sited nature of pastoralism thus defines the spatiotemporal distribution of movement and settlement at varying social scales [101].

Pastoralists and agriculturalists, rather than forming divergent groups, may constitute sub-communities within the same identity group in the Soule Valley. Members of each group effectively retain the flexibility to shift between productive sectors over time, a trait that appears to be associated with pastoralism generally [102,103]. This suggests that assumptions about the pastoral lifestyle must be tempered by understanding response diversity among pastoralists who sometimes behave like agriculturalists. There is clear evidence for coexistence of divergent groups in Soule by AD 750, as Basque members of the valley republic coexisted with religious communities from Leyre and Sauvelade, and noble houses associated with various princes and monarchs. Pastoralism may not be, as often portrayed, an adaptation to a marginal environment, but a flexible adaptation to a shifting political-economic landscape resulting from the rise and fall of states and empires [104].

The second half of the 20th century witnessed a rapid disintegration of smallholder farming systems across European mountain landscapes [21] closely associated with rural population decline, agricultural industrialization, participation in non-local labor markets, and reforestation of abandoned lands [105–107]. In France it is referred to as the post-World War II rural crisis [108,109], which implies a change in lifestyle with implications for the future. Reforestation, for example, encroaches on continuing agropastoral land uses [110,111], reduces biodiversity, and leads to other conditions that threaten the future availability of ecosystem services [112,113]. There are serious efforts in Europe to preserve the pastoral lifestyle [114], even though there is still only a rudimentary understanding of the interplay between households as the fundamental unit of production and the forces responsible for disintegration of smallholder systems.

The boundaries, scale, and flow of the response diversity of human agents in pastoralism relate to differences in herd composition and labor availability. While the livestock portfolio of an etxe may change in response to environmental stochasticity, they also express preferences derived from experience, knowledge, and contingencies. As a consequence, individual herders representing the interests of their etxe household differentially evaluate the risks and opportunities they confront. Some etxe may follow an aggressive herding strategy, while others may follow a more cautious strategy, minimizing their exposure to risk. Response diversity is thus a multi-level undertaking within and among individuals, households, and villages [79], and the effects of response diversity at one level might act synergistically with or counter those at another level. Places and the relationships between them define the spatiotemporal context of pastoralism, while response diversity translates into the manifest consequences for a landscape [115,116].

4.4. Finding Sustainability in the Long Anthropocene

It has been suggested, with some finality, that the expansion of mountain grasslands and the creation of new upland pastures occurred through intentional landscape conversion and degradation (e.g., slash-and-burn practices [9,117]). While a plausible explanation, this rests on the search for a "golden spike" that could mark an abrupt transition in land use that aligns with conventional archaeological periodization schemes [118]. It assumes, a priori, that land use transitions represent stepwise intensification of human penetration and conversion of pristine landscapes that, in combination, represent an unsustainable trajectory of degradation. The contemporary conversion of tropical forests into degraded rangelands is a clear example of unsustainable anthropogenic landscapes that can influence how the past is interpreted from an Anthropocene position that rests on total human impacts on the whole earth system, while eschewing social, temporal, and spatial aspects of human-environmental interaction.

While one could argue that specialization and intensification of pastoral land use explains the motives for intentional forest to pasture conversion in the Pyrenees, our radiocarbon dating of charcoal from seasonal livestock cabins in Larrau suggests that intensive agropastoral land use followed only after forest to pasture conversion rather than vice versa [65]. Florescu et al. [119] identified a similar pattern in the Carpathians. In their study, charcoal and pollen archives derived from lake sediment showed an increase in subalpine and treeline fire activity between 8000 and 5000 BP that declined with the increase in the archaeological evidence for settlements. Indeed, as settlement and land use intensified after 2000 BP in lower elevation coniferous forests, fire activity remained low in the subalpine because forests were already transitioned to grasslands.

Given our analyses of the interplay between demography and agropastoral institutions in the Pyrenees [26,66], it seems difficult to imagine that mixed agropastoralists would intentionally invest the time and effort to convert forests to pasture in areas that are difficult to defend and ultimately served only as one component of agropastoral livelihood activities. In any case, agropastoral societies known to have inhabited the western Pyrenees could not have mounted the surplus labor required to intentionally convert forests to pastures in the rugged terrain of the region. Even under market pressures and technological enhancements of 20th century specialization and intensification in the use of mountain pastures, household-level labor and scheduling constraints continued to depend on collective efforts to support transhumant grazing. Furthermore, aside from the pooled labor efforts of the cayolar (and, post-1950s, the modern grazing syndicate), labor-saving management activities such as the application of pastoral fires are necessary just to retain existing pastures even in the face of continued grazing pressures [65].

As discrete events, pastoral fires are antithetical to converting forests to pastures. They are low-severity fires spatially confined by topography and previous burning activity that are set in winter or spring when soil moisture is high [65]. However, when set repeatedly, but with varying frequency, over decades and centuries, they may, unintentionally, tip the balance from relatively closed canopy forests with grass-dominated gaps to open canopy forests with grass understory, and finally, to open grasslands [83]. Over centuries, such processes could have transformed an entire landscape, perhaps without significant degradation of ecosystem services. In fact, the persistence of agropastoral practices over the long-term would suggest a sustainable co-evolution of land use and landscape.

The Pyrenees show little evidence of significant degradation and are better described as productive and predictable rangelands, and the hypothesized socioecological arrangements responsible for the conversion of upland landscapes are still under debate [120]. Our multi-proxy evidence does not empirically support the notion of agropastoral "impacts" and degradation. In the French Alps, Doyen et al. [121] explained the intermittent "intensification" of tree clearing from about 6000 BP onward as a function of creating and then abandoning arable and pastoral landscapes, perhaps as a way to avoid degradation. This and other evidence suggest that the construction of the agropastoral niche across Europe was a long-term, non-linear process of slow, cumulative change, a persistent ecological press, largely devoid of ultimate human intentionality [122,123]. Elsewhere in Europe, the temporal resolution of burning, soil loss, forest clearing, and agropastoral infrastructure (e.g., [124–126]) have made it difficult to distinguish between cause and effect. Yet, these and other studies do show that the evolution of agropastoral landscapes were regionally and locally asynchronous, and while ultimately giving rise to the Anthropocene, the phase shift cannot be independently explained or understood outside the details of the Long Anthropocene.

Deterministic narratives about human landscape transformation can be satisfyingly simple, while failing to explain the process itself. Human-environmental interactions and landscape history are not merely a function of population size, reducible to the insights afforded by a single archive or the opinion of a single agent. By examining the boundaries, scale, and flow of the response diversity of human agents to the contingencies they confront, it becomes possible to supersede the limitations of quasi-immobile history, as well as answer questions about desirable future end-states about rural lifestyles [127–129]. For places like the western Pyrenees, research that focuses on the how and why of the complex co-evolution of anthropogenic landscapes could be the key to understanding the nature of sustainability in the Long Anthropocene.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/9/3882/s1, Supplementary Materials S1: Geographic and temporal sketch of the Pyrenees. Figure S1.1: Relief, average temperature and average precipitation across the Pyrenees Mountains and surrounding area. Figure S1.2: Distribution of key paleoarchives for the western Pyrenees-Cantabrian mountain belt and dated archaeological sites by major periods from the LGM through the Middle Holocene.

Author Contributions: This was a collaborative effort, we contributed equally in conceptualizing the research, seeking funding to support the research, and directing different aspects of the research. We most often worked together in the field and assisted each other with lab work, while simultaneously discussing our findings and the direction in which we wanted to take the research. T.L.G. carried out the original field assessment of the Soule Valley, and conceptualized the initial research project. M.R.C. carried out extended on-site research on fire and settlement, and in conjunction with T.L.G. carried out the pedestrian archaeological survey of the commune of Larrau. D.S.L. identified colluvial and paired forest-pasture locales, and collected all sediment cores, then analyzed or supervised others, including T.L.G. and M.R.C., in analyzing the sediment samples. T.L.G. and M.R.C. collected documentary records from various local and regional repositories across France and Spain. M.R.C. performed the fire probability analysis, while T.L.G. performed the historical analysis of Basque land use; maps and figures were done by T.L.G. and M.R.C., T.L.G. drafted the initial text with substantial revisions by M.R.C. and D.S.L. All authors contributed equally to prepare the final draft. All authors have read and agreed to the published version of the manuscript.

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Ancient Environmental Preference and the Site Selection Pattern Based on the Edge Effect and Network Structure in An Ecosystem

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Abstract: Archaeological sites are facing serious threats from environmental changes in the background of urban sprawl. More efforts are needed to enhance the cognition of human–environment interactions for better conservation. Under the traditional geomantic view, the environmental preference involved was presented to guide ancient life. In this study, we analyzed the edge effect and network structure of two periods in an ecological transition zone where the ancient sites were located. From the cases of Gouzhang and Yinxian, the separability of edge intensity indicated the different site selection patterns because of the discrepancy of patch fragmentation and ecological structure. Additionally, the different trends of the edge effect were thought to be related to the complexity of the ecological network. Besides that, the ancient cities located in or around the high-centrality terrain in the network of closed space could have provided the convenience of accessing living materials from early ecosystems. In practice, the comprehensive methods based on geomantic and ecological analysis proved effective when used to explore possible areas of the undiscovered archaeological sites. What is more important is that traditional environmental perceptions could be integrated into a scientific system of the ecological landscape and contribute more to archaeological research and the study of ancient culture.

Keywords: site selection; archaeological sites; edge effect; ecological network; geomantic environment

1. Introduction

Archaeological sites provide a unique source for recognizing human–environment interactions and the ecosystems affected by differing degrees of human impact at a wide variety of temporal and spatial scales and thus both reconstruct past environmental conditions and reveal human behavior [1]. As early as 4000 BC, the ancient humans from the Banpo site had primary thoughts of utilizing the environment according to their residential locations along Weihe River [2]. With the increase of urban sprawl worldwide, archaeological sites are facing more threats from the shifting relationship between culture, climate, and land use changes [3], meaning that we need to re-recognize the various archaeological information and their cultural connotation under the human–environment relationship. Through the study of site selection pattern of archaeological sites, we can learn more about ancient environmental view and behavior patterns, which will help us with further archaeological research and in the conservation of cultural heritage.

Ancients' environmental preference was to select a site following basic principles, of which geomancy was one of the most classical theories in ancient life [4,5]. Geomancy claims to utilize nature to harmonize individuals or their communities at scales ranging from vast landscapes to houses and is indicated as the method and practice employed to guide site selection of a settlement, city, or tomb according to the surrounding natural environment [6–10]. It is necessary for us to learn this kind of site selection pattern in archaeological study. In the 1950s, this theory began to formally enter into the perspective of modern science. As a milestone event, Subai introduced geomancy into an archaeological study of the tombs from the Song Dynasty in the northern Paisha Town [11]. Thereafter, analysis based on geomancy rules gained extreme attention from modern scholars for its hidden scientific value [12–15]. Magli [16] discussed the cultural links between topography and traditional geomancy for studying royal mausoleums. Moreover, Gui [17] studied cultural landscape changes and site selection under geomantic principles in the Dongcun settlement of the Taihu Basin. Yang [18] further emphasized the function of geomantic evaluation in landscape and human–land relations. The significance of landscape ecology analysis was to explain the ancient environmental preference from geomantic theory, and it has facilitated some valuable research [19–23]. This was also the point of view we focused on in our study.

The ancient view on the geomantic environment is essentially related to the ecological landscape. Typical ecological characteristics are shown in the edge effect in ecological transition zones and the interaction of ecological units in an ecosystem. The edge effect plays a decisive role in the formation of ecological structure and dynamics of ecological patches. In a variety of applications, it has been used in the fields of microclimate, plant diversity, and bird communities [24–26]. In particular, in forest ecosystems, the impact of the edge effect has received universal attention [27]. Zhou et al. [28] focused on the boundary sensitivity, which is associated with forest ecotone types and exhibits remarkable habit heterogeneity at different scales. Yuan [29] and Chen [30] studied the coupling network of forest landscape patches and analyzed the characteristics of the edge effect in major forestry landscapes mixed with the arborous layer, shrub layer, and herbaceous layer. Although the edge effect and its scale problem have rarely been considered in spatial archaeology studies, it cannot be ignored in practice. In our study of edge effect, we did not focus on biocenosis specifically but put emphasis on the syntagmatic relations of ecological patch to look for site selection patterns. Therefore, the calculation of edge effect was different from previous studies. However, we still considered the factors of shape and size of patches and the quantified form in the established model, as mentioned in some other studies [31,32].

For the other ecological characteristics, the internal relations of different units in the ecological network was proposed in cultural landscape analysis in this study. The ecological network provides an operational methodology in the practices of studying ecological structure that relies on the concept of connectivity included in landscape graphs [33,34]. In recent years, there has been a rapid increase of studies that advocate network analysis to ecologically manage landscapes that suffer from fragmentation and loss of connection [35]. The focus is on the aspects of establishment and evaluation of networks. For example, habitat networks were constructed to assess how climatic variability influences potential connectivity for water organisms in the Murray Darling Basin of Australia by Robbi et al. [36]. Andrea et al. [37] proposed one methodology to build a network with the patch's area as the weight index of nodes for landscape planning in the peri-urban and urban areas of the town of Nuoro (Italy). When evaluating the network, connectivity metrics of landscape graphs have usually been applied to reflect a basic form of interaction between species and their environment [38–40]. Beyond ecological processes and social issues, network analysis is also meaningful in terms of cultural landscape perspectives. For instance, Agnieszka et al. [41] studied sustainability in terms of a cultural landscape service located in Malopolska Province (Poland) by quantitative assessment and qualitative categorization based on landscape diversity and connectivity. In fact, successful cases like this are rarely presented, except for the most qualitative discussions about network characteristics which are difficult to explain the internal mechanism of ecological structure [42–44]. In this study, we tried to build ecological networks to quantify the site selection pattern based on the connections between the ecological landscape and geomantic environment.

By both the edge effect and network structure in the ecosystem, the ancient site selection pattern and the scientific basis could be discussed according to the discovered archaeological sites in the study area. Multi-source remote sensing data in two times phases were used to reflect the changes of ecological structure. It could help us to speculate the major ecological structure and reveal the human–environment relationship in ancient times.

2. Methodology

2.1. Geomantic Environment

The geomancy derived from traditional environmental preferences leads to a highly developed cultural synthesis between the social and natural environment to a certain degree and emphasizes finding auspicious site locations with a favorable ecology and aesthetic perception [9]. Its continuing popularity in practice is used to promote harmonizing with ecological equilibrium [45–47]. This theory is useful to study ancient site selection patterns. However, we have to emphasize that we do not utilize the whole complex theoretical system of geomancy but are only concerned with the method of choosing a good environmental layout in relation to mountains and river.

Mountains, which embrace a site (usually with a river flowing through them), have been inspected to identify an enclosed space for living and justify whether they are beneficial for settlement development [48,49]. The optimal position of a mountain group is presented by Shang [50] as in Figure 1. Mountains behind the site stretch from near to far along the central axis. On the left and right sides, the mountains protect the site area. There are still mountains guarding the exit out of the closed space across the river in a certain distance. This spatial arrangement of mountains can provide a secure and stable environment. Besides that, it also blocks the cold monsoon from the north in winter and gain more warm sunlight in the south. It is conducive to the formation of a warm and humid microclimate. Moreover, the river can be examined to locate a relatively optimum position. A water city is an ideal site location embraced by a river on three sides. This situation is generalized as three kinds of positional relations, as in Figure 2. The inner side of the river bend, which is called the embraced side, is preferred, in contrast to the reserve side [51]. We can conclude that an auspicious water position has great influence on the residential area for the convenience of water supply and traffic [52,53]. It is also beneficial for forming a closed area for defensive purposes and a moderate microclimate in local environments [54,55]. Additionally, in an ideal landscape, forests are routinely considered to be involved in biological diversity, ecosystem service, and spiritual expectations [6,56,57]. Especially in this study, bamboo forest, which covers almost the whole mountainous area, is the main ecological type in the geomantic environment [58,59].

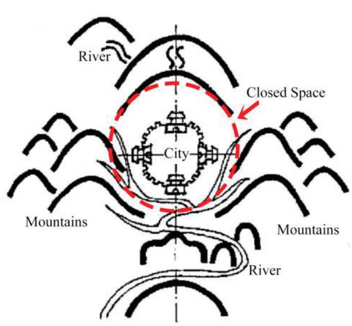


Figure 1. Schematic diagram of geomantic analysis. The closed space is circled by mountains and a river under ideal conditions for site selection.

Figure 2. Schematic diagram of the auspicious position of a water city. Positions (**a**,**b**) represent the place of the river bend with branches converging, while position (**c**) refers to the bay of the river.

In conclusion, the ideal location of the closed space consisting of mountains and a river lies back on a mountain and faces water toward the south [60]. It is the optimal geomantic environment appreciated by ancient peoples [61,62]. This environmental preference is of universal significance for the application of geomantic theory. We aimed to further study the ecological basis of site selection behind this environmental view and the behavior patterns in ancient times.

2.2. Edge Effect

The regular law of site selection was mostly studied based on the geospatial distribution of archaeological sites [63]. For example, many researchers focused on the slope, aspect, proximity, etc. [64,65]. However, selecting living environments was more complicated for ancient peoples. The edge effect was rarely considered by researchers. It is widely believed that the differences and interactions of ecological variables in transition zones of two or several different ecosystems may lead to the gradients starting at patch borders and proceeding along the edges [66]. The edge effect is a conspicuous consequence of the interactions between ecological units. The shape and size indices of a fragment patch, as well as the population structure, are widely used variables in edge effect calculations conducted by quantitative measurement [25,67,68]. In our study, we tried to organize the effective variables to describe the edge intensity in the locations of archaeological sites in the ecological transition zone. Even though we could not access the missing or not preserved sites, we focused on the general analysis of the known archaeological sites.

In the square buffer zone that is built with the edge width as its size for an archaeological object, the perimeter of each patch inside represents the actual contact interface used to exchange materials or energy with its neighboring patches. In this study, the fractal dimension index (FRAC) was used to reflect the edge complexity of each patch. In addition, the weights of different ecotypes (W) were defined according to their contributions to the environmental structure and resource utilization in terms of the nature status in ancient times. With the descending importance of forest, water, farmland, bare land, and settlement, the weights were set to 2.00, 1.75, 1.50, 1.25, and 1.00, respectively. To quantify the edge effect, the edge intensity was expressed as follows:

$$E = \sum_{j=1}^{n} \frac{P_j}{L} \cdot FRAC_j \cdot W_j, \quad (1)$$

where j represents one of the independent patches and n is the total number of patches in the square buffer zone. E means the edge intensity in a square buffer zone whose total length of the four edges is indicated with L, and the perimeter of an independent patch inside is P_j. P_j/L refers to the relative edge size. $FRAC_j$ and W_j are the multiplicative factors of each patch.

Edge effects usually show significant variations at different spatial scales [30,69]. They are influenced by the transferring patch number and ecological constitution, as well as the interface size, shape complexity, and the weight of each component patch. Therefore, the scale problem is non-negligible for edge effect analysis. In this study, six edge widths of 100, 200, 400, 600, 800, and 1000 meters were selected to evaluate the changes of edge intensity. We aimed to test scale validity for analyzing the environmental preference of ancient sites. What was more important for us was to explain the site selection pattern based on the discrepancy of the edge effect in different scales among the archaeological sites in ecological transition zone.

2.3. Ecological Network

The ecological network can be built based on the interactive relationship between ecological patches that serve as network nodes connected by links that indicate the potential exchange of materials and energy between neighboring patches within an organism [35]. In network analysis, we use network properties and centrality measures to reflect the accessibility and the flow of energy, matter, or species to patches where archaeological sites are located. The general network is evaluated with circuitry (α), the node/line ratio (β), and network connectivity (γ), as presented in Table 1. The well-structured network represents the less possibility of ecological changes and the variation of edge effect. It can be used to measure the general stability in the geomantic environment of closed space. In fact, the centrality importance contributes more to the specific site selection pattern based on the analysis of every patch in the network.

Table 1. General descriptions of the ecological network [70–72].

Equation	Description
$\alpha = \frac{e - v + p}{v - 5p}$	*α:* the ratio of the number of links in a network to the maximum number of links possible. $\alpha = 0$ means no loop circuit in the network, and $\alpha = 1$ means the maximum possible number of loops in the network.
$\beta = \frac{e}{v}$	*β:* the average connections of each vertex. When $\beta = 0$, there is no network connection between nodes; when $\beta < 1$, it represents incomplete structures of the network; $\beta = 3$ means the best network structure.
$\gamma = \frac{e}{3(v - 2p)}$	*γ:* the ratio of the number of links in a network to the maximum number of possible links. The condition $\gamma = 0$ occurs when no vertex is connected, while $\gamma = 1$ occurs when every vertex is connected in the network.

Note: e means the number of connections, v means the number of nodes, and p is the number of disconnected subgraphs ($p = 1$ in this studied ecological network).

The centrality metrics are popular indices used to describe the importance of local patches in a network, which mostly include the degree, betweenness, and closeness [37,73,74]. In this study, we wanted to assess the comprehensive importance of each patch in the ecosystem. Therefore, the centrality importance (*CI*) index was defined as

$$CI = Be + Cl, \tag{2}$$

where the *Be* (betweenness), characterizing the importance of a patch by the number of times the information passes through the shortest path between two nodes, and *Cl* (closeness), describing the central rank of a patch by measuring the total sum of the minimum distances from the given node to all other nodes, are deemed to have the same importance, with weight coefficients of 1. The relationship between the locations of ancient cities and high *CI* of a patch was constructed in this study to indicate superior status for getting more resources in network. It may represent one aspect of ancient site selection patterns.

2.4. Materials

In this study, Landsat images and the Digital Elevation Model (DEM) were used for analyzing the ecological landscape. Google Earth provided higher resolutions to recognize the local environmental features and help extract the historical environmental features in the Corona images. The remote sensing data are listed in Table 2. Because the city outskirts where the archaeological sites are located were less affected by urban sprawl before 1995 and have changed a lot under urbanization in recent years, as referred to in some other studies [75,76], we chose the phases of 1995 and 2017 for comparison. It is important to note that these images cannot reflect all the ecological information in the past. However, the multi-source remote sensing images in early time and variance analysis of two periods can help us learn the ecological characteristics in history combined with some documentaries.

Table 2. Remote sensing images used in this study.

Data	Landsat OLI	Landsat TM	SRTM DEM	Corona	Google Earth
Time	24 August 2017	12 August 1995	2003	21 December 1964	21 December 1984

The data sets of Landsat and DEM were provided by the Geospatial Data Cloud site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn).

3. Study Background

From 7 to 5 ka B.C., the plain of Ningbo was rarely influenced by marine corrosion except for three rising sea level events caused by the combined effects of regional tectonic subsidence and climate changes [77]. The relative variation of sea level did not cause cultural decline for a long period. The local culture flourished again with the retreat of the coastline, according to the historical changes map of Hangzhou Bay [78]. This area had been a continent of lakes for a long time after that, inferred by the strata information and the changes of paleovegetation composition [79]. Ningbo, with an age-old agricultural civilization, has been proven to have originated as early as 5.8 ka B.C. [80]. The area with a network of rivers and a humid subtropical monsoon climate provided a suitable environment for the development of civilization. This is supported by the evidence of archaeological excavations and the site distribution in early times [81].

At present, Ningbo a fast-developing city that is experiencing the universal problems of urban sprawl and population growth, which generate challenges for the conservation of archaeological sites, especially the early relics of important historical value. As shown in Figure 3a, all the archaeological sites are located in the transition area between the mountainous area and plain on the outskirts of Ningbo in Zhejiang Province. According to the FAO 1990 system of soil classification, all the sites are mainly on the boundaries of Humic Acrisols (ACu) and Cumulic Anthrosols (ATc), as in Figure 3b. The soil is the synthesis of physical, chemical, and biological characteristics. It is closely related to the ecological service system and human activities. Especially the presence of anthrosoils can be used to detect historical human habitation. It was formed due to long-term human activity, such as irrigation or anthropogenic organic matter [82,83]. Humus is the colloidal part of soil organic material with the nutrients and water molecules retained between cosmids [84]. The two types have a significant effect on promoting the formation of an ecosystem and settlement by ancients. Besides that, elevation and proximity to a river are also the important factors for ancient living (Figure 3c,d). Most of sites distribute in the gentle slope of the piedmont area or the river terrace with a certain altitude to avoid flood risk. At the same time, the proximity to rivers ensured adequate water supply for agricultural irrigation and daily life. These integrated demands for living environment causes that the archaeological sites almost locate in the transition of ecological environments. There are 158 archaeological sites from the Han–Jin Dynasties (206 B.C.–420 A.D.) located in this study area. Only three ancient cities named Gouzhang, Yinxian, and Maoxian (currently undiscovered) have been documented as the earliest cities in the basins of Yuyao River, Yinjiang River, and Yongjiang River, respectively [85]. The other sites are ancient tombs. This research focused on the site selection pattern of the three ancient cities compared with other tomb sites at the same time.

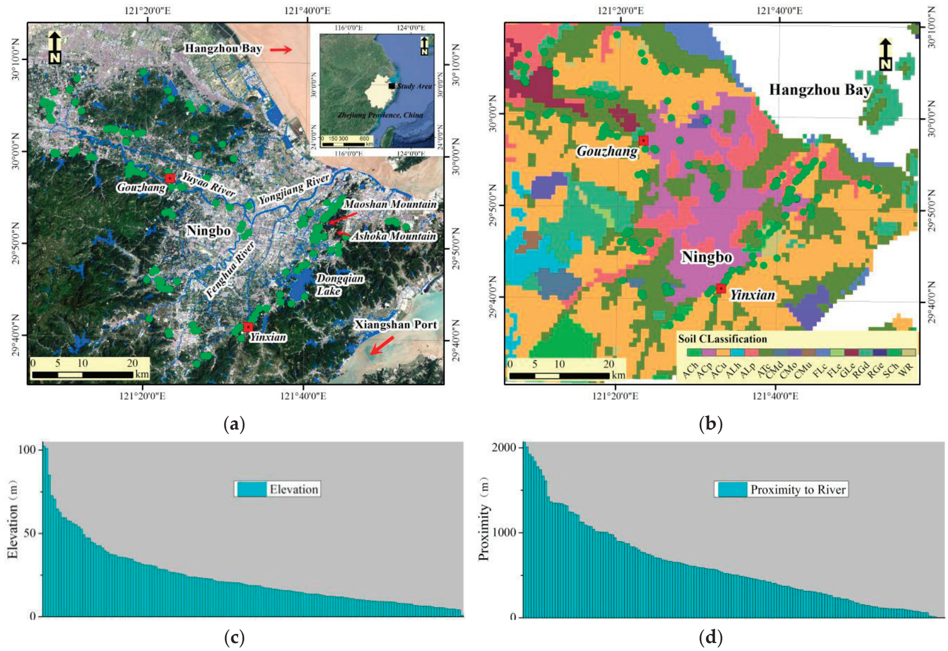


Figure 3. The spatial distribution of archaeological sites in (**a**) a remote sensing map and (**b**) a soil classification map based on the FAO 1990 system (provided by Cold and Arid Regions Sciences Data Center at Lanzhou (http://westdc.westgis.ac.cn)). The spatial characteristics were analyzed based on (**c**) the elevation range of archaeological sites and (**d**) the proximity to the river.

The ancient city of Gouzhang was discovered in 2004–2012. Its surface is covered with farmland and settlement (see Figure 4). After archaeological excavation, the profile was found to be an irregular rectangle with a 1200 m perimeter and 100,000 m^2 area, whose culture accumulation was from the Warring States Time (475–221 B.C.) to Jin Dynasty (265–420 A.D.) [86,87]. The location of Gouzhang is circled by the Yuyao River in the south with mountains in the east and west. Another ancient city of Yinxian was discovered in 2015~2018. It was inhabited for nearly more than 800 years from the Qin Dynasty (221–206 B.C.) to early Sui Dynasty (589 A.D.) [88]. Yinxian is situated on the mountain of less than a 50 m height in the transition zone between the mountainous area and residential area, with encircling rivers. The site's perimeter is about 760 m, and area is more than 38,000 m^2. Its internal residential zone is mainly located in the mountain (see Figure 5). The Yinxian site has convenient transportation in terms of both land and water ways because it is next to the Ningbo Plain in the north and connects to the Xiangshan Port in the south. In terms of the last undiscovered city with the longest documented history, ancient Maoxian should be situated between the east of Maoshan Mountain and west of Ashoka Mountain [85,89], according to the records, which are mostly from the Song–Ming Dynasties (960–1644 A.D.). An ecological structure analysis was applied to discuss the possibility of exploring its site location under the impact of urban sprawl. Because of the ubiquitous ecological transition zone, the methodological application can also be tested in other areas.

Figure 4. The scenery of the Gouzhang site (photographed in December 2018) and the ancient port discovered by archaeologists [87].

Figure 5. The western wall ruin of the Yinxian site and its classic unearthed relics [88] in the Han and Jin Dynasties.

4. Results and Discussion

4.1. Ecological Pattern Analysis

The ecological environment in the study area was classified in Landsat images. As the results show in Figure 6, the urban sprawl ratio changed from 14.42% in 1995 to 30.73% in 2017 by calculating the settlement area. In contrast, the ratio of the forest area dropped a little, but stabilized at a higher equilibrium of more or less 50%. Generally speaking, the urban sprawl is marked by the tendency of multiplying human activities, but the geomantic environment made up of forest, mountains, and river remains basically invariant. Considering the locations of archaeological sites at the edge of mountains and the stable mountainous environment in early times, we assumed that the major environmental constitutions did not substantially change in ancient times compared with early remote sensing images. This has been proven by archaeological excavations [84,85].

The pattern of patches in an ecological service is helpful for analyzing the location preference and ecological changes of ancient sites. As shown in Table 3, most ancient sites were located in forest and farmland in 1995. After the extension of the settlement area, some locations of sites transferred to patches of settlement. However, the forest is still the major ecological type preferred by ancient sites. With long-term urban development, patches have gone through fragmentation, which is revealed by the greater number of patches and smaller area of each patch. The shapes of forest patches became more complicated due to the increasing mean perimeter but declining mean area at the same time.

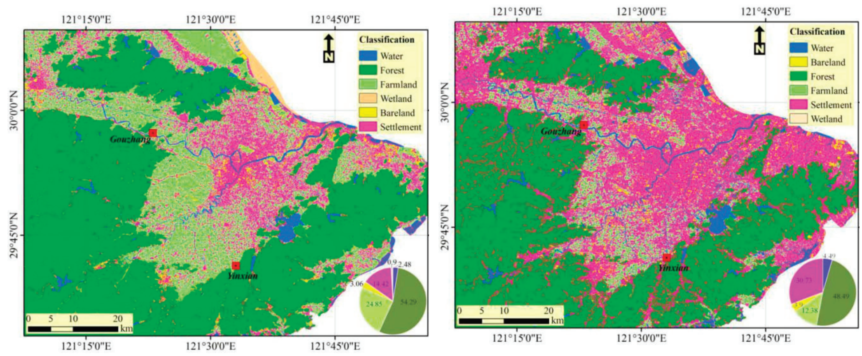


Figure 6. The ecological classification based on Landsat images in (**a**) 1995 and (**b**) 2017.

Table 3. Classification statistics of the patches where the relics are located.

Classification	Relics Number		Patch Number		Mean Perimeter		Mean Area	
	1995	2017	1995	2017	1995	2017	1995	2017
Bare land	9	7	7	7	977.14	1474.29	1.62	5.57
Farmland	39	20	30	20	61,046.00	5946.00	412.76	35.24
Forest	96	66	19	25	244,812.63	413,988.00	12,128.98	8092.58
Settlement	12	61	11	54	15,027.27	6907.78	73.04	33.04
Water	2	4	2	4	510.00	3345,00	1.17	33.23

As demonstrated by the analysis of shape metrics in Figure 7, high values of fractal dimension index (FRAC) that reflect high shape complexity of patches occur at several large patches of forest in both 1995 and 2017. The CONTIG index demonstrates the high spatial contiguity for most of the forest patches, representing strong ties in the ecosystem of 1995, but they decreased to a certain degree in 2017 due to the occupation by the settlement patches. The results of edge effect analysis depend on the ecological pattern.

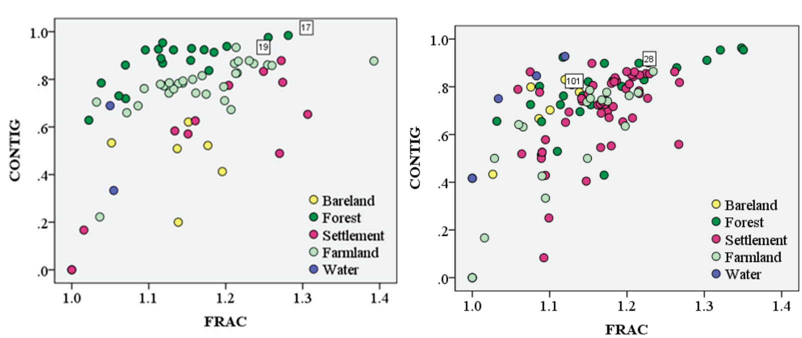


Figure 7. Ecological metrics analysis of 1995 is shown in (**a**), thereinto, the patch number 17 is the location of Yinxian and 19 represents the location of Gouzhang. Ecological metrics analysis of 2017 is shown in (**b**), in which patch number 28 is the location of Gouzhang and 101 is the location of Yinxian.

4.2. Edge Effect of the Ecological Transition Zone

In the study area, the archaeological sites are located along the border of the mountainous area in the ecological transition zone. Therefore, we tried to quantify the edge effect in the ecotope according to their spatial positions. Six scales were tested to discuss the edge effect changes with the varying edge width from 100 to 1000 m, which represented the buffer size for each site. Among the 158 sites, only the two ancient cities of Gouzhang and Yinxian are presented as an example in Figure 8.

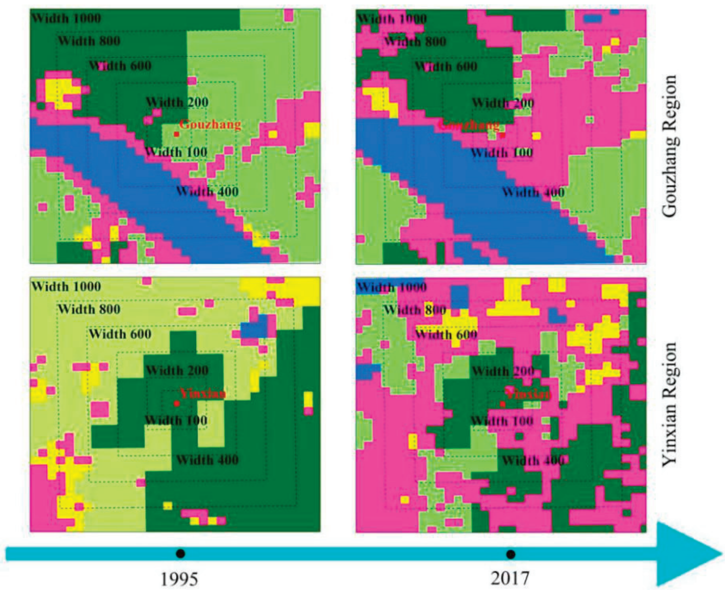


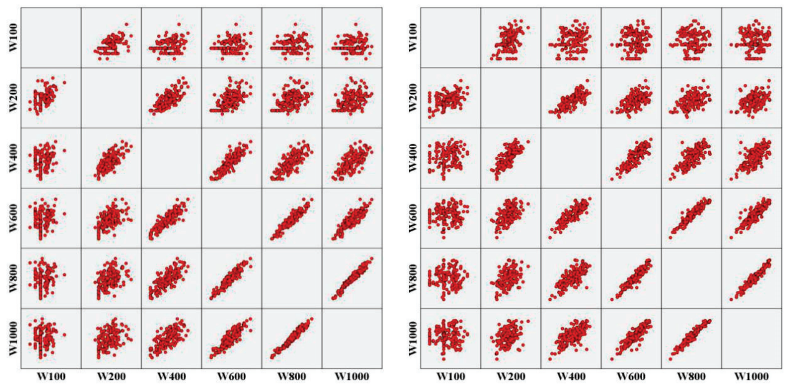
Figure 8. Ecological patches distribution of Gouzhang and Yinxian sites. Edge effects with six edge widths (100, 200, 400, 600, 800, and 1000 m) were calculated.

The edge intensity of different ecological types in which the archaeological sites are located are shown in Table 4. Most of the edge intensity increases as the scale also increases, because of more edge complexity and constitutions in the higher scope of the edge width. Considering the different ecological types that existed in 1995 before extensive urbanization, the forest-domain area had few patches and simple shapes, and thus had a weak edge effect compared to other types of farmland, bare land, and settlement area. In general, the ecological types of forest and water make the edge effect more positive to be distinguished. Things are different in 2017, when all ecological types have a basically equivalent edge intensity for the ancient sites on any scale but a higher value than in 1995. This is the result of universal fragmentation along the edge of the forest and river. Therefore, the ecological structure (the constitution and fragmentation of different ecological types) is the reason for the edge effect discrepancy of ancient sites. It could have an effect on the site selection pattern.

Table 4. Comparison of the edge intensity for different ecological types the ancient sites are located in.

Year	Mean Edge Intensity in 1995						Mean Edge Intensity in 2017					
Scale (m)	**100**	**200**	**400**	**600**	**800**	**1000**	**100**	**200**	**400**	**600**	**800**	**1000**
Forest	2.26	2.98	4.32	5.92	7.74	9.03	2.50	3.48	5.36	7.63	9.96	11.61
Water	2.46	5.69	7.1	6.65	8.93	9.78	2.27	3.88	5.76	8.07	10.01	11.54
Farmland	2.2	3.50	5.55	7.54	9.52	10.99	2.41	4.06	6.47	8.37	11.01	12.78
Bare land	2.67	4.26	5.97	8.20	10.30	11.84	1.76	2.73	5.47	8.22	10.24	11.50
Settlement	2.16	3.33	5.02	7.10	9.36	10.85	2.05	3.72	5.73	7.82	10.22	12.03

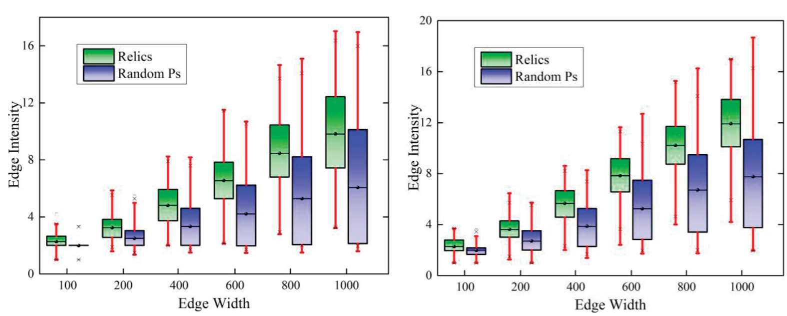
From the matrix scatter graphs (see Figure 9), all the sites have no obvious relation with the low scale of 100 m, but the edge intensity shows approximate linear growth between adjacent widths with the augmentation of scales. The linearity becomes distinct, gradually referring to the R^2 values of 0.242, 0.591, 0.768, 0.889, and 0.944 from the scale of 100 to 1000 m in 1995 and 0.179, 0.564, 0.696, 0.881, and 0.920 in 2017 with the same order. In practice, considering the redundant information which results from the linear relation of the neighboring scales, one optimum scale can be selected from the edge effect analysis at a medium or large scale. In the next step, we want to discuss how to choose the best analysis scale to recognize a site location using edge effect and further distinguish the ancient cities from other sites.



(**a**) (**b**)

Figure 9. Edge effect relationship between neighboring scales in (**a**) 1995 and (**b**) 2017.

In order to validate the method of edge effect when distinguishing between a relics area and a no relics area, 158 relics and random points with an equal number were compared at six scales (see Figures 10 and 11). In general, the separability aggrandizes based on the growth of average values and the enlarged difference between relics and random points as the scales increase. Moreover, the separability was more prominent at large scales in 2017. In Figure 11, the ancient cities of Gouzhang and Yinxian show the different degrees of separability among all the relics. The edge widths of 200 and 400 m are the scales that could be used to separate Gouzhang from most of the sites through the edge effect of 1995. After the ecological structure changes in 2017, the separability of Yinxian is better obtained through edge effect analysis at medium and large scales from 400 to 1000 m. The separability of the edge effect in the transition zone is helpful for differentiating the ecological patterns of ancient sites.



(**a**) (**b**)

Figure 10. Comparison of the edge intensity between the locations of relics and random points in (**a**) 1995 and (**b**) 2017.

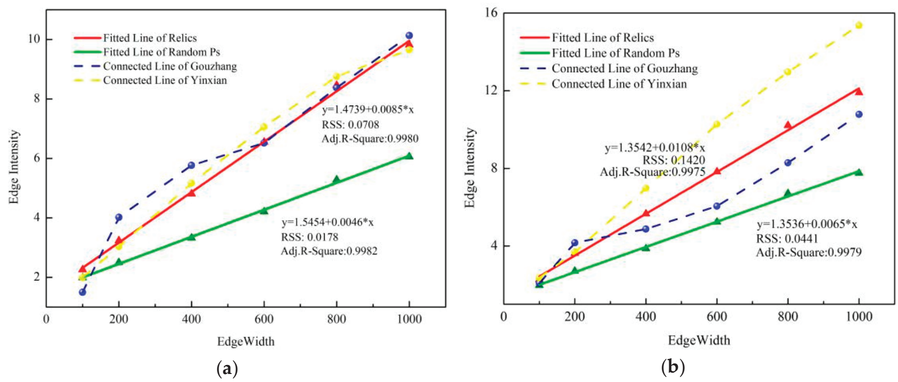
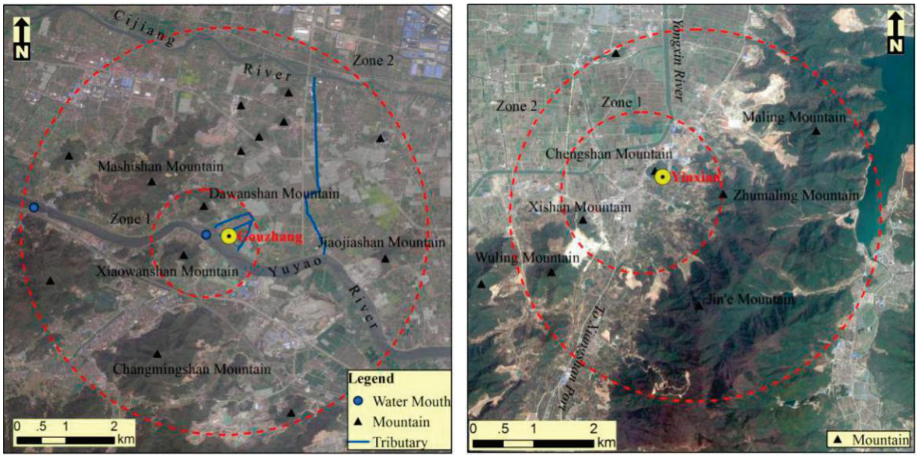


Figure 11. The separability of the ancient cities of Gouzhang and Yinxian based on the average edge intensity in (**a**) 1995 and (**b**) 2017.

By the analysis above, we could conclude that the different variation tendency of the edge effect was based on the discrepancies of the ecological structure for the locations of ancient cities. This manifested in different site selection patterns by ancient peoples. In this study, two patterns were recognized. One is the ecologically balanced pattern that the preferred living environment was constituted of mountains, rivers, and other ecological types. Edge effect shows a unique trend of changes in low–medium scales in the processing of urbanization. Because of rich ecological types and a strong edge effect in the early ecosystem, ancient peoples could access abundant resources and materials. At the same time, the ecological environment remained stable and reduced the influence of patch fragmentation to some extent. Therefore, the growth of edge effect is slow in certain scales under the background urban sprawl. The ancient city of Gouzhang is the representative of this pattern. The other site selection pattern is shown from the preference of the mountainous (also the forest-domain pattern in this study) ecological environment. The variations of edge effect are basically consistent with the fragmentation of the transition zone in front of the mountain. The main ecological constitution is simple and not stable with low resistance to environmental changes in general. Therefore, the edge effect changed a lot during the settlement expansion in this area. However, this could help us highlight the edge effect of the ecological transition zone and separate the important but unremarkable environment in the early ecosystem. The site selection of ancient Yinxian is this pattern. The edge effect in the ecological transition zone was found to have some relevance in terms of ancients' environmental cognition. Then, we aimed to discuss the two site selection patterns further with the ecological network method in a geomantic environment of closed spaces.

4.3. Ecological Networks and Centrality Importance

The geomantic analysis of site locations is concentrated on closed spaces, which are the minimum circles constituted of mountains and rivers. The internal closed area labeled as Zone 1 is the minimum circle consisting of the circling mountains, while the external closed space Zone 2 consists of mountains stretching far away. Both the spaces are traversed through by the flowing river. As an example, for Gouzhang City (see Figure 12a), we can identify the core geomantic environment of Zone 1 surrounded by adjacent mountains of Dawanshan and Xiaowanshan and some river branches, and the external closed space of Zone 2 is comprised of the mountains of Mashishan and Changmingshan in the distance. This site location may be selected by referencing both the landform and water position in the geomantic environments, as shown in Figures 1 and 2. About 35 km away in the southeast is the ancient city of Yinxian. The closed spaces can also be constructed by the minimum and maximum closed circles (see Figure 12b). The Yongxin River runs through the spaces and approaches traffic corridor to the Xiangshan Port in the south.



(**a**) (**b**)

Figure 12. Geomantic analysis of the ancient cities of (**a**) Gouzhang and (**b**) Yinxian as shown in Google Earth images from 31 December 1984.

As shown by the geomantic analysis above, both sites of Gouzhang and Yinxian generally follow geomantic principles and also acclimatize to local circumstances. Of course, this landscape of mountains and rivers usually restricts the desirable location to the ecological transition zone, thus causing the edge effect, as we analyzed. Furthermore, additional ecological meanings behind the geomancy in terms of site selection were discussed by network analysis in wider ranges of Zone 2.

For the network constructed by ecological patches and links between neighbors in the geomantic environment of closed space, Gouzhang has a higher density of vertices and edges than Yinxian, as demonstrated in Table 5. Its circuitry reaches 0.91, indicating a higher number of loops in the network, and the connectivity is 0.94, which shows that most of the vertices are well-connected in the network. It can be concluded that the ecological network is more stable, with a real benefit for the long-time exchange of material and energy, than that of Yinxian. In addition, the high ratios of edge to vertex show that the network structure is more complicated and complete. The network complexity of Yinxian rises up with the ecological fragmentation. It can be concluded that the complex and stable ecological network will bring small changes in the closed environmental space.

Table 5. Network analysis of Gouzhang (GZ) and Yinxian (YX) regions.

Holistic Evaluation	GZ 1995	GZ 2017	YX 1995	YX 2017
Area, a (km^2)	47.76	47.76	25.83	25.83
Vertex Number, v	81	125	32	68
Edge Number, e	223	346	79	182
Circuitry, α	0.91	0.91	0.81	0.88
Ratio of Edge to Vertex, β	2.75	2.77	2.47	2.68
Connectivity, γ	0.94	0.94	0.88	0.92

In order to quantify the importance of each patch in the ecosystem, centrality importance was introduced in our study (see Figure 13). In the network of the closed space in the Gouzhang region in 1995, the vertex of V5 representing the patch where the ancient city is located has the highest centrality of 1.10. It reflects that the selected location plays an important role in the ecological network. The adjacent patches of V54 (Mashishan Mountain) and V80 (Yuyao River) also have high centrality or closeness. It increases the importance of this site location. Although the patch number rises significantly in 2017, the centrality of the site location (V33) is still high, and the neighboring vertex of river patch

V124 and forest patch V102 retains the high centrality. The river and mountain (covered with forest in the study area) always play important roles in the network, as in the geomantic environment. For the Yinxian site, its location of forest patch V26 (the Chengshan Mountain) had very high centrality in 1995. Until 2017, the centrality importance of Chenshan Mountain reduced to 0.40 at the medium level. However, the neighboring patches of V66 and V31, with high centrality, could make up the loss of its importance. We can conclude that the mountain and river patches play important roles in the geomantic environment and ecological network, and the locations of high centrality had important ecological meanings for site selection in ancient times. The site locations have the advantages of accessing the life necessities in ancient times because of their high centrality importance in the ecosystem.

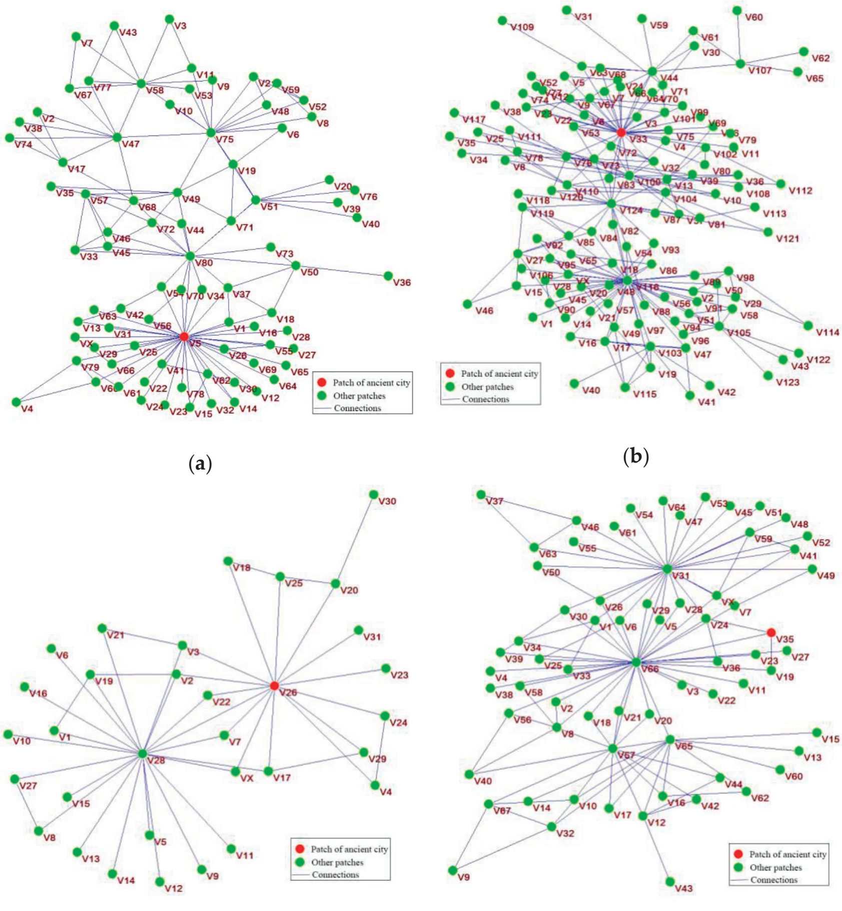


Figure 13. Ecological network analysis of Gouzhang in (**a**) 1995 and (**b**) 2017, as well as Yinxian in (**c**) 1995 and (**d**) 2017. The red dots represent the patches where the two ancient cities are located.

Based on the above analysis of the edge effect and ecological network, some interrelations between the ecological structure and environmental preference were explained. In ancient times, the site location may have been selected for its complexity and diversity of ecological types (for example, the balanced portions of mountain, river, farmland, and others), which would have presented a stable ecological and geomantic environment for long-term occupation. Even though there has been an appreciable impact of urban sprawl in the whole area, large variation of the ecological structure would have not taken place. People could have accessed enough goods in the ecosystem to maintain their life, supported by its strong edge effect and high centrality. The waterborne and land transport also permitted them to settle there. As for another classic site selection pattern, few ecological types and a simple structure usually lead to a relatively weak stabilization in the local environment. At the same time, the strong edge effect represents the high possibility of energy flowing to anthropological needs in the ecosystem. Therefore, the regional environment is susceptible to change, especially in the background of resource shortage and population swell in the process of urbanization, sometimes accompanied by the growth of the settlement area and edge intensity. It also proves that a large edge intensity is the indicator of a high possibility of environmental satisfaction for site selection, whether in ancient or modern times. In addition, the preferred mountain-domain area can provide not only an auspicious living space in geomancy but also a defensive fort and energy hub. The study cases of Gouzhang and Yinxian correspond to the above two patterns, respectively. To some extent, the ecological significance behind ancient site selection pattern can help us to learn more about human–environment relationship in ancient times.

4.4. Exploration of Undiscovered Archaeological Site

The environment of Ningbo is classic for its mountainous area and dense network of rivers. It provides suitable locations for ancients' settlement, which has been proved by the analysis of ancient site selection patterns in this research. The ecological method to recognize the environmental preference of this region is also applicable to other similar regions in the middle and lower reaches of the Yangtze River. Although the cultural and historical background varies along the Yangtze River, there are some universal environmental views shared among the local ancient people about how to utilize natural conditions and select site locations. Therefore, the site selection pattern may have a certain degree of similarity. For methodological validation of edge effect and ecological network, and a deeper revelation of cultural landscape in the Ningbo Plain, we analyzed the ecological structure and geomantic environment in the area of Maoshan Mountain in the basin of the Xiaojiajiang River. This comprehensive analysis was also used to find the new clues of the lost city of Maoxian.

There are 29 ancient sites in the transition zone around Maoshan Mountain, of which 16 were located in forest patches, three in settlement patches, and 10 in other patches in 1995. Until 2017, 14 were situated in forest patches, 13 in settlement patches, and only two in other patches. Therefore, the forest always provides the major environment for site locations. As the settlement region increases during urbanization, it plays a more important role in the ecological environment where the relics are located. The ecotone between the forest and settlement has significant meanings for ancient living. Although Maoxian has not yet been discovered, we can speculate its possible location around Maoshan Mountain in the basin of the Xiaojiajiang River, according to archaeological discoveries [68,69]. To narrow the scope further, the suspected zones of MX1~MX6 were divided by geomantic analysis and regarded as advantageous environments for ancients selecting a residential location through the systematic evaluation of the constitution of the mountain, water, and orientation in these closed spaces. The ecological transition zone was built to explore the ancient Maoxian, as demonstrated in Figure 14.

We divided this transition zone into 214 grids with a 400 m width. The edge effect analysis was conducted to reflect the edge intensity of each central point in a grid with the scales of 400, 600, 800, and 1000 meters. From the scatter diagram presented in Figure 15, the edge intensity of neighboring scales had a significant linear relationship in both 1995 and 2017, which coincides with the previous analysis results displayed in Figure 9. When considering the enlarged disparities of the edge effect on a large scale, a 1000 m scale was chosen for further analysis.

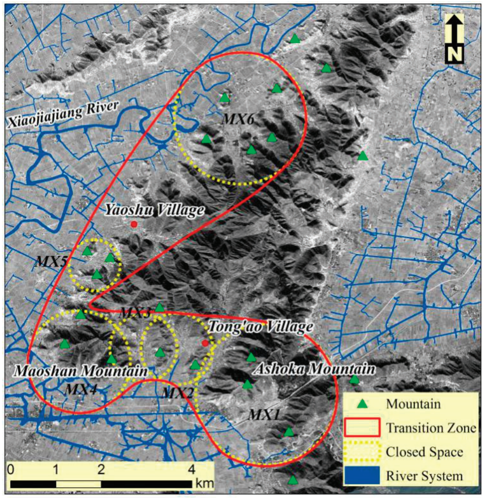


Figure 14. Geomantic analysis of the possible location of the Maoxian site. The river system was extracted from a Corona image of 1964 and partly refers to the Google image of 1984. The closed spaces of MX1–MX6 are mainly constituted of mountain and water with a suitable orientation.

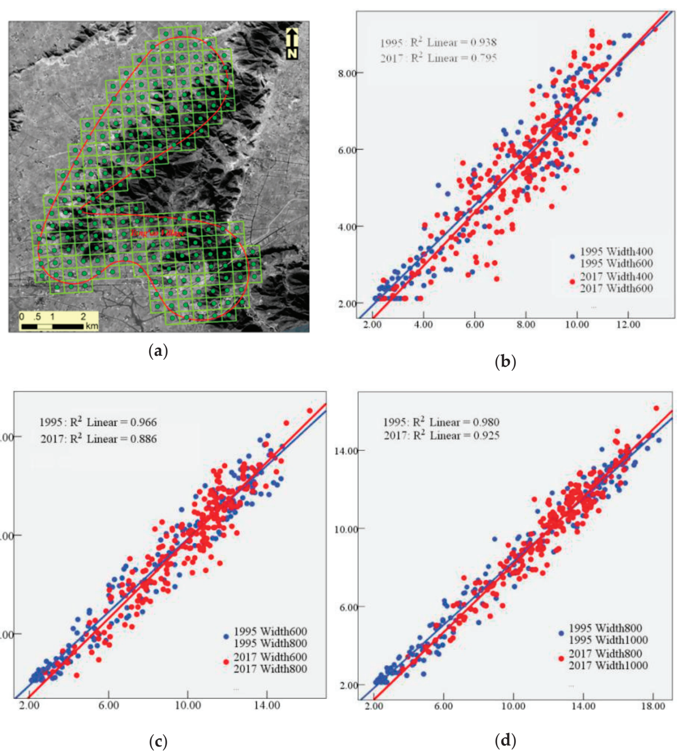
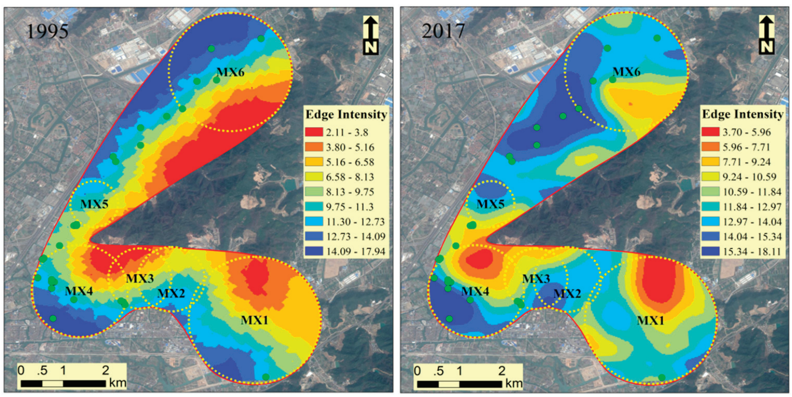


Figure 15. Edge intensity calculation with different scales in the transition zone around Maoshan Mountain: (**a**) the evenly distributed sampling points for edge intensity computing, and (**b**–**d**) the edge intensity relationship between different neighboring edge widths.

As shown in Figure 16a, Maoshan Mountain is composed of homogeneous forest patches and thus has a low edge effect. All the archaeological sites are located in this median zone of edge intensity, which imply that they had a similar ecological structure in early times. In Figure 16b, the medium zone appears differentiated for the ecological structure changes under the influence of urbanization development. The ancient sites are generally distributed in high-value regions in the ecosystem of 2017. These high anomaly regions signify the changes of ecological structure from patch fragmentation. In terms of the proximity of the environmental pattern and nearness of the spatial position, Maoxian might have similar high separability of edge effect as the ancient city of Yinxian. Therefore, the regions of MX2–MX5 with high edge intensity in front of mountains should be focused on when exploring the ancient site of Maoxian.

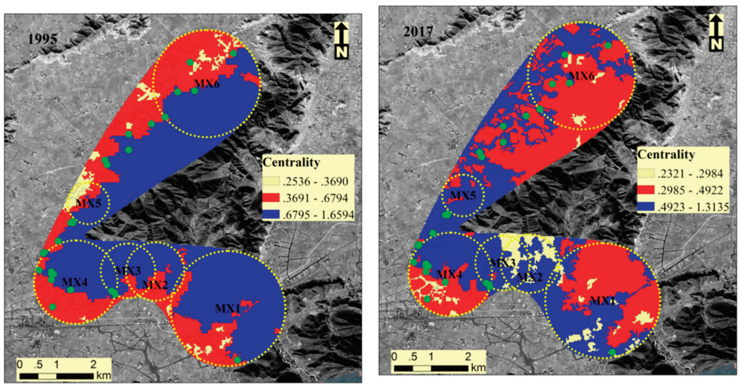


(**a**) (**b**)

Figure 16. Regional edge effect distribution obtained by the Kriging interpolation method for (**a**) 1995 and (**b**) 2017.

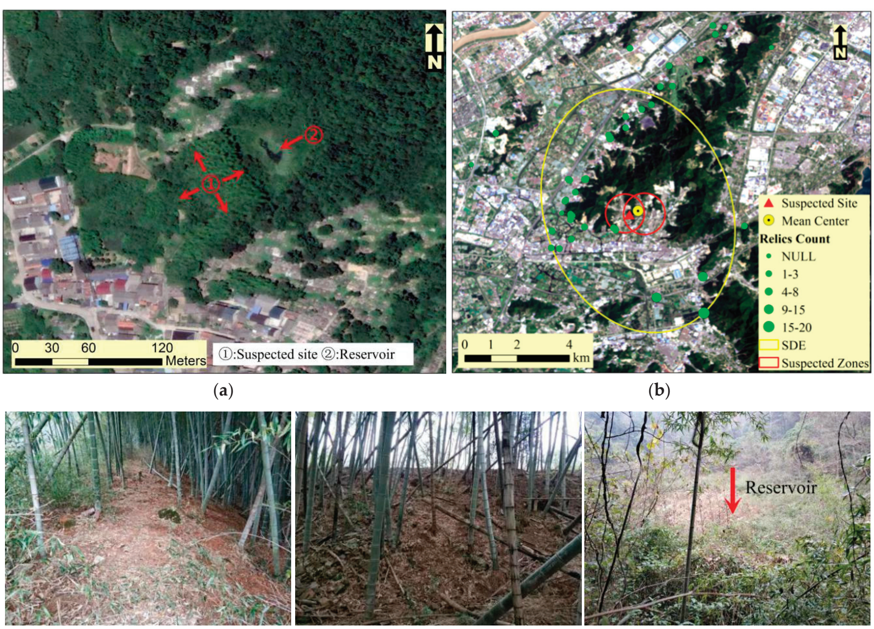
In the ecological network, the central patches play the role of connecting medium and interchange hubs in the network. In this transition zone along Maoshan Mountain, the ancient sites are distributed in the range of centrality transition from high to medium, as shown in Figure 17. What is different between the two periods is that the forest patches comprise the major part in 1995, with high values, but settlement patches have a central role in the ecosystem for urbanization in 2017. This change reveals that centrality transfers from the natural domain to human domain in the ecological network. Like Yinxian, the undiscovered city of Maoxian may have displayed a high centrality in the natural ecosystem, and with patch fragmentation under settlement sprawl, its central status may have decreased in the network for the unstable ecological network. The regions of MX2 and MX3 match this condition on the basis of the edge effect analysis result. The suspected area can thus be narrowed down to a smaller space.

By further interpretation of Google Earth images, some suspected archaeological features were extracted explicitly in the suspected zones of MX2 and MX3, as shown in Figure 18a, including the possible city walls and the reservoir nearby, but these were not found in other places around Maoshan Mountain. The size of this suspected area is 80 × 60 m. The reservoir might have been part of the city used for daily life and irrigation. Spatial analysis with the ArcGIS tool was used as an auxiliary method to confirm the importance of this location. The tomb groups in the target area around Maoshan Mountain in the basin of Xiaojiajiang River are concentrated in the standard deviation ellipse (SDE) and encircle the mean center, which was computed by the weight of relics count in the spatial analysis tool of ArcGIS and represents the residential center or high hierarchy position that may have some links with the ancient city of Maoxian. This result shows that the suspected site next to the mean center may have a central status among the contemporaneous sites in Figure 18b. Therefore, it seems that the site selection of ancient Maoxian may also emphasize the ecological structure, as analyzed by the edge effect and network structure. More important for us, this suspected site has been affirmed to have been built in a very early time, following a preliminary field investigation (sees Figure 18c–e), though we will not know more details before archaeological excavation. However, this methodological application demonstrates that the edge effect and ecological network are worth applying when trying to find the location of an ancient site.



(**a**) (**b**)

Figure 17. The centrality distribution in the ecological network of (**a**) 1995 and (**b**) 2017.



(**a**) (**b**)

(**c**) (**d**) (**e**)

Figure 18. Suspected archaeological target from remote sensing interpretation and a field investigation, (**a**) the interpretation of archaeological features in a Google image, (**b**) the centrality analysis of tomb groups in the same period of ancient Maoxian in ArcGIS, (**c**,**d**) ancient wall of the suspected site, and (**e**) the reservoir next to the suspected site now covered with dense grass.

5. Conclusions

Ancient environmental preference is rooted in the primary perception of nature and living practice when selecting a residential location. As the most popular method of site selection for ancient peoples, geomantic analysis was applied to find an auspicious environment based on constructing the closed space circled by the mountains and river, which illustrated that environmental utilization was focused on optimizing the overall layout of the living space from early times. As a matter of fact, it is only one aspect of the complicated environmental preference. The ecological meanings behind ancients' behavior of site selection deserve universal attention. The methodologies of the edge effect and ecological network are helpful for further recognizing the ancient site selection pattern.

Many ancient sites are distributed in the ecological transition zone, with an obvious edge effect. By the analysis of edge effect at different scales, it has been shown that the edge intensity grows linearly between neighboring scales as the edge width increases. The effective scales were found at a medium and high level to separate the preferred locations of archaeological sites from the surrounding environment and the ancient city from other archaeological sites. The separability of edge effect shown up in the medium level under the ecologically balanced pattern in the ecosystem with various ecological types and an equilibrium constitution, while the optimal separability in the largest scale is useful to extract the high-value anomaly of edge effect to recognize the mountain-domain (or the forest-domain) environmental preference, especially after ecological fragmentation during urbanization with the transition from forest-domain ecology to settlement-domain ecology. Therefore, the edge effect can be used to reflect the site selection patterns. Its high-value region can be considered as possible locations with more chances of exchanging resources and energy with the neighbor ecological units to provide the basic material basis of ancient life. From the perspective of the ecological network, it is possible for a complex ecological structure to form a stable environment. This is reflected in the less frequent transfer of ecological constitutions in the network and changes of the edge effect in the ecologically balanced ecosystem. Significant variations of the edge effect are related to the simple network structure of the mountain-domain ecosystem. As for the centrality of patches in the ecological network, the river and forest patches have the highest centrality importance and play the vital roles in the regional environment. They also constitute the main part in the closed space in geomancy. That is an important reason why a geomantic environment was preferred by the ancients. In addition, the ancient sites are located in or next to the high-centrality terrain for accessing sufficient raw materials for ancient life. Of course, the site selection patterns are localized in a similar environment in the middle and lower reaches of the Yangtze River and may be widely applicable. They are also helpful to discover the unknown location of ancient cities. In practice, one suspected site was found through an analysis in the geomantic environment of closed space and its ecological characteristics, though more archaeological details are needed to confirm this speculation. However, a comprehensive analysis of the geomantic environment and ecological structure has been proved effective for research on ancient site selection and exploring undiscovered sites. The results were validated by the spatial analysis in ArcGIS and the field investigation.

In short, we have attempted to discuss the ecological significance of ancient site-selection patterns with the background of fast urban development. However, it is not enough to explain the individual behavior pattern and the rich meanings of sociology and culturology under environmental preference. Further work will be conducted to take archaeological sites as important carriers to extract more scientific information in order to reveal the inner connection between humans and the environment from multi-disciplinary perspectives. If traditional cultural perceptions can be integrated into a scientific system of ecological landscapes, it would contribute more to the conservation of archaeological sites and the study of ancient cultures.

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Review

Archaeogenetics and Landscape Dynamics in Sicily during the Holocene: A Review

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Abstract: The Mediterranean islands and their population history are of considerable importance to the interpretation of the population history of Europe as a whole. In this context, Sicily, because of its geographic position, represents a bridge between Africa, the Near East, and Europe that led to the stratification of settlements and admixture events. The genetic analysis of extant and ancient human samples has tried to reconstruct the population dynamics associated with the cultural and demographic changes that took place during the prehistory and history of Sicily. In turn, genetic, demographic and cultural changes need to be understood in the context of the environmental changes that took place over the Holocene. Based on this framework, this paper aims to discuss the cultural and demographic dimension of the island by reviewing archaeogenetic studies, and lastly, we discuss the ecological constraints related to human peopling in times of change in landscapes that occurred on the island in various periods. Finally, possible directions for future archaeogenetic studies of Sicily are discussed. Despite its long human history, Sicily is still one of the world's biodiversity hotspots. The lessons we learn from the past use of landscape provide models for sustainable future management of the Mediterranean's landscapes.

Keywords: ancient DNA; population genetics; anthropology; historical ecology; paleobotany; past vegetation; potential natural vegetation

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1. Introduction

The emergence and spread of human populations in Italy have been reconstructed over the course of many years via archaeological and paleontological data. However, these approaches alone are insufficient to map and quantify the actual historical/evolutionary relationships between different ancient populations or groups of people. Archaeogenetic studies, together with the development of appropriate inferential and statistical methods, have provided a powerful tool to assess human demographic history and population dynamics [1].

Sicily offers the ideal context for the analysis of modern and ancient genomic data because it has always represented, since its first colonization, a crossroads of several human groups who visited and settled on the island (Figure 1). The oldest human remains in Sicily are dated to about 16,000 years ago [2]. Since then, Sicily has been settled by Neolithic peoples, Italics, Phoenicians, Greeks, Romans, Byzantines, Arabs, and Normans [3]. These complex demographic and cultural dynamics must have affected the genomic structure of the Sicilian population to different extents at different times, but the actual relative genetic impact of these migrations remains largely unknown. This is not to say that at the present time our understanding of the genetic history of Sicily is a *tabula rasa*; on the contrary, as this article documents, in the past 40 years, Sicily has been the focus of many important archaeogenetic studies. It is precisely by capitalizing on these past efforts, as well as on the latest developments in genomic sciences, that we can reasonably hope to disentangle the as-yet-unknown layers that make up the genetic palimpsest of the Sicilian population.

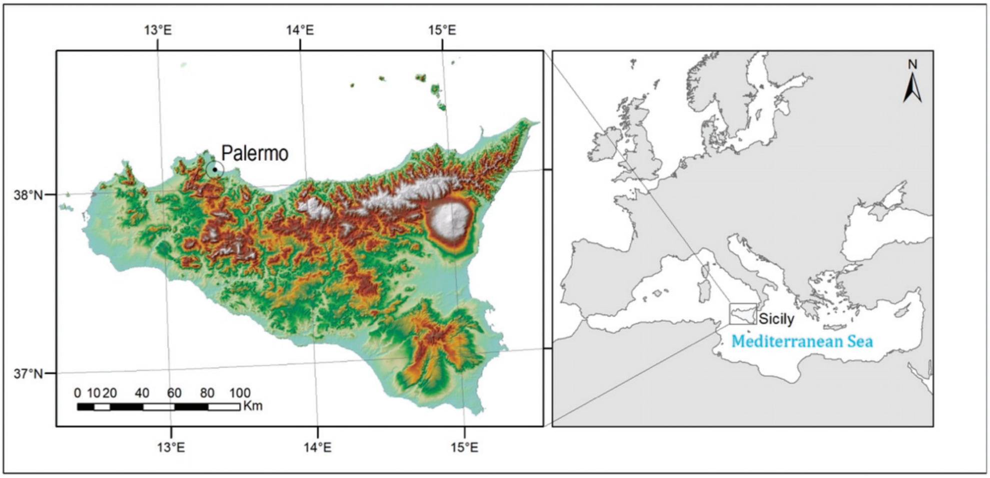

Figure 1. Map showing Sicily, the largest island of Mediterranean Basin. Due to its position in the center of the Mediterranean, Sicily has represented a crossroads for migrations of flora, fauna, and human populations, which has made it a hotspot of biodiversity.

The international workshop, "Genetic and population history of Sicily" held at Oasi Institute in Troina (Sicily, Italy) in June of 1998 was the first and—to our knowledge—the only workshop to focus on the archaeogenetics of Sicily [4]. This was an important scientific event that offered a unique opportunity to reduce the gaps among specialists studying the history and prehistory of Sicily from different research perspectives.

Several important messages were delivered in that meeting, some of which are still relevant today and, therefore, worth recalling briefly in this paper. One message concerned open questions related to the prehistory and history of Sicily. When was the last time that Sicily was entirely de-populated? Assuming that this time was mid-Paleolithic, was there a continuity of population from the Upper Paleolithic onwards? For different historical periods, the difficulty of translating information from the large repertoire of remains ("the material culture") made available by archaeological research, and the consultation of classical literary sources in terms of demographic dynamics, were discussed. For example, to what extent did ideology influence the accounts of the classical authors? Were the Sicels and Sicans really two distinct groups? How many Greeks stably settled in Sicily, and were they a genetically homogenous group? These questions are of remarkable relevance for population sampling and genetic analysis. The participants to that meeting have empathized that such genetic analysis should be directed towards the detection and interpretation of existing patterns of internal genetic differentiation and genetic affinity with other European and Mediterranean populations. In particular, the combined analysis of modern and ancient genomic data was considered an important step to help answer these questions. At the same time, it was stated that effort should be spent in the collection of more ancient and modern DNA samples, based on precise archaeological and historical criteria. Regarding DNA analyses, it was agreed that they should be carried out with highly polymorphic (molecular) markers, both nuclear (autosomal and Y-linked) and mitochondrial. On the other hand, the potential interest in ancient DNA from the pre-classical period was also emphasized. At the time of the meeting, ancient DNA (aDNA) analysis was still an emerging technology. As for the collection of samples, the discussion led to the decision to use a specific sampling strategy that takes into account the geographic distribution of historical, proto-historical, and pre-historical settlements on the island, as well as the subdivision of the island into dioceses.

Paleobotanical (and archaeobotanical) data, through a deductive approach, may also help to understand genetic, demographic, and cultural changes that occurred in the Sicilian population over the Holocene. However, archaeogenetic and paleobotany (more generally paleoenvironment) studies have followed parallel lines of development without any contact. The cross-disciplinary approach of historical ecology that includes human populations as a component of ecosystems [5] may allow us to understand the deep relationships between biodiversities and history.

Based on this framework, this paper aims to discuss the cultural and demographic dimension of the island by reviewing past archaeogenetic studies, and we then discuss the ecological constraints imposed by the peopling of the island in relation to changes in landscape that took place in Sicily in various prehistorical and historical periods by reviewing past paleobotanical studies. Finally, possible directions for future archaeogenetic studies of Sicily are suggested.

2. Ethnic and Demographic Dynamics of Sicily: From Prehistory to History

In the absence of circumstantial evidence of a presumed Middle-Pleistocene human colonization of Sicily [6], the human prehistory on the island presumably begins with the arrival of the Epigravettian hunter-gatherers during the LGM (Last Glacial Maximum, from 22,000 to 17,500 years ago), who came from the Italian peninsula via a land bridge connecting, at that time, the two shores of the Messinian Strait [7–9]. These are the early people who sporadically settled the large territories of the island and with whom the Early Holocene hunter-gatherers of continental origin overlapped and mixed [10–12]. After these, came the great Neolithic movement of settlers ("Neolithic" comprises a succession of different cultural traditions). The spread of Neolithic farmers to the West from the Near East reached southern Italy ca. 6000–5800 BCE [13], and was followed by large Metal Age migratory movements [14] (Figure 2a–e).

Following the successive migratory waves of continental peoples on the island—who created the heterogeneous indigenous genetic substratum of Sicanians, Elimyans, and Sicels—and the strategic presence of Myceneans, the first great historical colonization brought about the territorial division of the Phoenicians/Punics [15] and the Greeks [16] (Figure 2f,g). This "colonization" presumably consisted of a migration of males who quickly mixed with the indigenous population. We then have to consider the phenomena of migration, deportation, and colonization operated on the island, by Republican Rome after the Punic Wars (264–146 BCE), but, above all, by Imperial (27 BCE to 284 CE) and Late Imperial Rome (284 BCE to 476 CE). In this period, we should consider the introduction of slaves for agriculture, or movements of peoples due to trade [17], with the intermittent arrival of people attracted by the economic prosperity of the country or looking for a safe place, as in the case of the diaspora of the Jewish in Late Imperial Sicily [18]. The Late Antique/Byzantine period (4th–9th c. CE) is also very significant as regards the political, cultural, and genetic relationship of the island with the Near East and Byzantine rule, and the repeatedly arising influence of barbarians such as the Vandals [19]. The long-standing (heterogeneous) and culturally intense Islamic influence, from 827 to 1061 CE, left deep cultural, and presumably genetic, footprints [20]. After 827 CE, towns and villages gradually developed in the coastal areas of Sicily, which led to a process of integration between Muslim and Jewish–Christian communities [21]. For example, Sciacca (*Al Shāqqah* in Arabic) became a flourishing center of commerce, as described by al-Idrīsī, a geographer at the court of Roger II: "Sciacca is a small town located on the shores of the western sea. There are public buildings, markets and many houses. It is currently the capital of various districts and surrounding dependencies. Its port is constantly in good repair, with ships coming in from Tripoli and (elsewhere) from Africa all the time" [22].

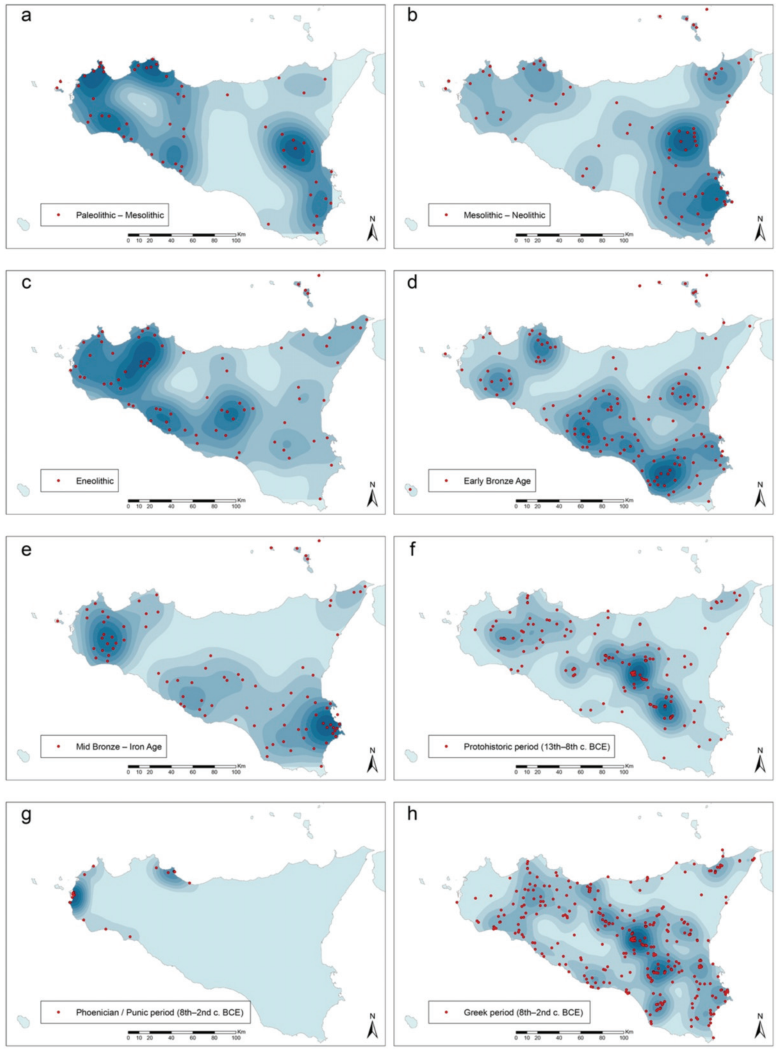

Figure 2. Distribution of archaeological sites in Sicily. Source data from Paleolithic to Iron Age (**a**–**e**) by Tusa [23]; Protohistoric period (**f**) and data for transition from Phoenician/Punic (**g**) to Greek domination (**h**) by Regione Siciliana [24]. The density of settlements was mapped using the Esri ArcGIS Kernel Density tool. The kernel density analysis was performed only to graphically highlight the areas of the highest concentration of sites, and it does not have any predictive meaning on the distribution of the sites.

Soon after the Islamic period, Sicily was ruled by Normans and Swabians. These rulers promoted the occupation of internal Sicily by people from the Aleramic lands of north-western Italy, or from the Lombard territories. Later, Sicily was the final destination of people escaping from Albania, under Ottoman rule, who were present in several areas of southern Italy between the 14th and 16th centuries. As for the Modern Era, while the Angevin domination was short-lived but significant, the Iberian contribution—first made by the Aragoneses and then by Imperial Spain—was long and very deep. In this context, it is worth remembering the socio-political role played by the Church of Rome in disrupting the Spanish cultural penetration of the island, and its historical consequences. The Jews, expelled from Spain by the Inquisition, found refuge, and were forced to convert to Catholicism, in Sicily. This also had its own cultural and microdemographic consequences. Finally, in contemporary Sicily, economic immigration has created clear genetic enclaves, such as the settlements of North African fishermen in Mazara del Vallo [25]. Taken together, all the above archaeological and historical data can be summarized in a single sentence, i.e., Sicily is, in all respects, an ante litteram melting pot. In this context, aside from the Spanish domination cited above, the problem of the colonists' heterogeneity also applies to East and North African Berber and Islamic settlers. For earlier periods, we might mention the stream of very heterogenous peoples (and genes) slowly—albeit continuously—flowing into the island from the surrounding Mediterranean regions, including the Punics of North Africa, the Iberians, and the Italics.

Archaeogenetic studies in recent years [26–50] have investigated on the actual demographic/genetic impact of this melting pot. The approaches that have been used include the following:

(i) The application of genomic technologies to the analysis of ancient samples and extant populations;
(ii) The selection of samples based on the careful integration of data from the material culture, literary sources, linguistics, and historical demography;
(iii) The ascertainment of the place of birth of ancestors of blood/DNA donors from a given rural site (village, town) for at least three generations;
(iv) The use of robust statistical techniques for data analysis.

One indirect indicator of the intensity of human occupation and landscape transformation can be found in the archaeo- and paleo-botanical records, which provide information on climate fluctuation and the exploitation of wild and cultivated plant resources.

3. The Archaeogenetics of Sicily: A Long Journey Lasted Forty Years

Colin Renfrew offered the first definition of archaeogenetics: "Applying molecular genetics to questions of early human population history, and hence to major issues in prehistoric archaeology, is becoming so fruitful an enterprise that a new discipline has recently come into being" [26]. Remarkably, population genetic studies in Sicily date back to at least the 1970s, and since then, they have made major methodological and conceptual developments, from classical markers to genomics, and from studies on extant populations to the more recent paleogenetic analyses. This has been an exciting undertaking involving many Italian and international researchers and scientific collaborations. In what follows, we present an extensive review of archaeogenetic studies on Sicily published over a period of nearly 40 years.

The genetic structure of Sicily was initially investigated using classical genetic markers (blood groups, proteins, and HLA) [27,28]. These studies indicated a large division between the Eastern and the Western parts of the island that, according to the authors, may reflect the demographic impacts of Greek and Phoenician colonization. A similar regional differentiation was also observed via studies on surnames [29,30]. A study on the genetic frequencies of enzyme systems and blood groups indicated a close relationship between Sicily and southern Italy. Moreover, it revealed a genetic similarity between the Sicilian and Middle Eastern populations, in accordance with the historical contribution of Islamic expansion on the island [31]. By analyzing 13 genetic markers of western Sicily, Vona et al. [32] detected a genetic variation within the island. The results also showed a Greek influence in the Sicilian and southern Italian gene pool, consistent with the Greek colonization of southern Italy and in line with a previous work by Piazza [33].

A significant development in population genetic studies came with the advent of uniparental (Y-chromosome and mtDNA) and biparental markers. Uniparental markers have been proven to be an extremely useful tool in population genetic studies. However, each of these single-locus markers offers only a partial perspective compared to genomic studies. In the last few years, advances in high-throughput SNP genotyping analysis have allowed for a more complete description of the overall genetic variation, overcoming some of the limitations of single-locus markers.

Calì et al. [34] investigated the diffusion pattern of the IVS10nt546 mutation in the phenylalanine hydroxylase gene in several Mediterranean regions, including Sicily. This mutation is the main cause of phenylketonuria (PKU) in southern Europe. PKU is an inborn dysfunction of the metabolism causing mental retardation. These authors showed that the ancestral gene bearing this mutation probably originated in Anatolia, and then spread westward to southern Italy, Sicily, and Spain. They also interpreted the geographic pattern of diffusion as the result of the expansion of Neolithic farmers, thus suggesting the onset of this mutation to have begun at least 10,000–5000 years ago.

The first study reporting the analysis of mtDNA polymorphisms in Sicilians was that of Semino et al. [35], who typed six restriction enzymes in a sample of 90 individuals. A finding of particular interest in this study was that the HpaI-3/AvaII-3 complex (a polymorphism of the mtDNA), which is unique to groups of African ancestry, was found in Sicily at a frequency of 4.4%. Thus, for the first time, an estimate of the volume of gene flow from African Blacks to the Sicilian gene pool could be obtained. The existence of a genetic differentiation between the western and eastern parts of Sicily was then confirmed by two different studies conducted using mtDNA and microsatellite [36,37] markers.

A world-wide mitochondrial DNA database and a geographical information system (mtRadius) were used to identify the regions of the world with the highest frequencies of matching HVR1 mtDNA types [38]. The analysis identified western Sicilians as "Europeans", while a few types were found to be typical African (2%) or Asian (5%) sequences. In this study, the ancestry of typed individuals was traced maternally to the province of Agrigento for two or three generations. In a subsequent analysis performed on the mtDNA sequences of 1082 Sicilians, 17 (1.6%) were found to have Sub-Saharan African mtDNA types, belonging to various African L lineages. These lineages stand out clearly among the mainly European mtDNA lineages of Sicily. Strikingly, the African lineages were observed predominantly along the Sicilian coast, on average, only 3.3 miles (5.4 km) inland, i.e., generally within one hour's walk from the gently sloping seashore (Forster and Romano, unpublished).

Romano et al. [39] analyzed the mtDNA haplogroups and autosomal microsatellite frequencies of 465 Sicilians (Figure 3). Their results were consistent with those for settlements of people that occurred at different times. In particular, the divergence times inferred from the microsatellite data seem to suggest that the genetic composition of the town of Sciacca is mainly derived from settlements after the Roman conquest of Sicily (First Punic war, 246 BCE), while all the other divergence times occurred between the second and first millennia BC, and, therefore, seem to backdate to the pre-Hellenistic period.

In order to investigate the population structure across the Mediterranean, Capelli et al. [40] investigated Y-chromosome variation in a large dataset of Mediterranean populations. Their analyses identified four main clusters, labeled North Africa, Arab, Central–East, and West Mediterranean. In particular, the relatively high frequencies of Y-chromosome haplogroup E-M81, as well as a subset of J1-M267-derived lineages, found in Sicily are consistent with the long-term Muslim expansion across the Mediterranean.

The study of Di Gaetano et al. [41], performed using the combination of Y-chromosome haplogroups and short tandem repeats from several areas of Sicily, has shown that traces of genetic flow in the island, still visible on the basis of the distribution of some lineages, are likely due to ancient Greek colonization and a northern African contribution. The genetic contribution of Greek chromosomes to the Sicilian gene pool has been estimated to be about 37%, whereas the contribution of North African populations is estimated to be around 6%.

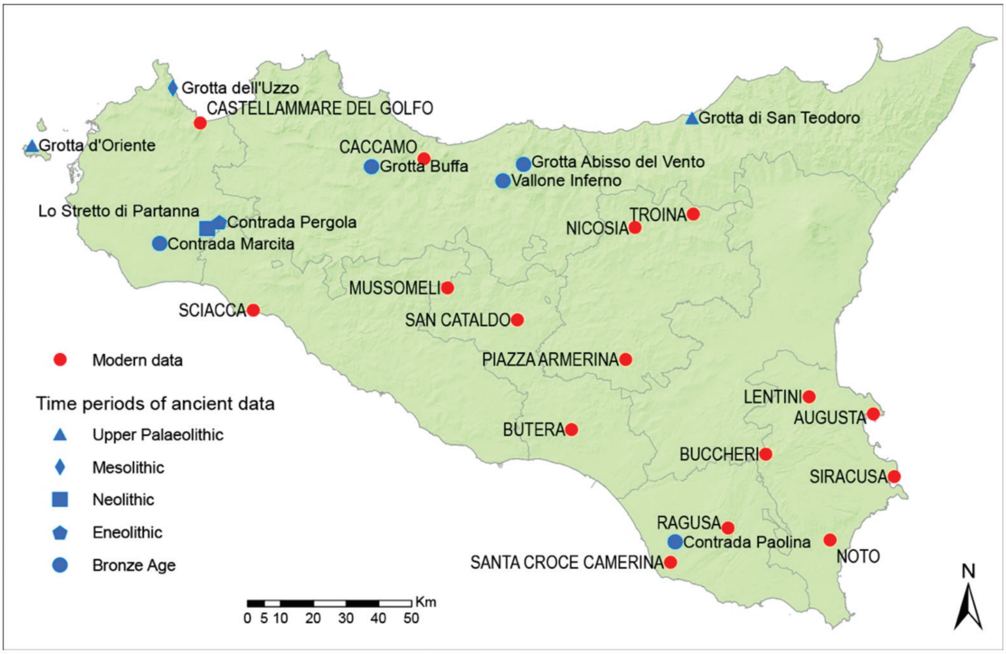

Figure 3. Geographic distribution of sites sampled for ancient genome analysis (blue symbols) and DNA analysis of extant Sicilians (red symbols).

The genetic history of Sicily was also investigated by Sarno et al. [42] through the analysis of Y-chromosome and mtDNA genetic markers. Their results showed a significant genetic homogeneity within the island, as well as between Sicily and southern Italy, thus suggesting different demographic patterns for the maternal and paternal lineages. In particular, while mtDNA genetic variability seems to be linked to pre-Neolithic and post-glacial migration events, the Y-chromosome results reveal a tight connection with the Balkan Peninsula dating back to Neolithic and post-Neolithic times.

A study investigating the proportions of admixture among present-day Europeans has shown that the Sicilian population, as well as Maltese and Ashkenazi Jews, have a strong affinity with the populations of the Near East [43]. These data are consistent with the abundant archaeological evidence of long and intense relations between the island and the Near East in the prehistoric and protohistoric periods.

In a recent paper, Busby et al. [44] estimated the different ancestral contributions of source groups to western Eurasian populations. Their results showed that southern European groups, including Sicilians, derive their ancestry from African and Near Eastern regions. Interestingly, they showed evidence of a specific West African genetic contribution to southern Italians and Sicilians dating back to 882–1250 CE, which is consistent with the Arabic conquest of the Mediterranean.

Tofanelli et al. [45], by analyzing both the Y-chromosome and mtDNA haplotypes, detected the contribution of Greek colonizers to present-day southern Italian and Sicilian communities. They observed a clear signature of Greek ancestry in East Sicily, consistent with the settlement from Euboea during the Archaic Period (1000–400 BCE). They also suggested that the colonization process was driven by a few thousand breeding men, with a minor contribution of Greek breeding women.

More recently, a genome-wide study based on the comparison between modern and ancient populations provided evidence of a "Mediterranean genetic continuum", extending from Sicily to Cyprus [46]. Furthermore, admixture analyses showed that modern Sicilians harbor a predominant genetic Neolithic-like ancestry, as well as significant contributions from post-Neolithic Caucasian and Levantine-like ancestries, with lower frequencies of the European hunter-gatherer component arising. These findings corroborate the idea that Sicily and southern Italy have long represented one of the most important Mediterranean crossroads in the peopling history of Europe.

Starting with the pioneering studies performed in the 1980s [47,48], the field of ancient DNA (aDNA) is now able to explore many aspects of human genetic history better than ever. The development of next generation sequencing (NGS) technologies, along with the application of sophisticated bioinformatics pipelines, has enabled the generation of an unprecedented quantity of genomic data from past populations [14,49,50].

A paleogenetic study by Mannino et al. [51] on the Mesolithic Oriente B individual, restricted to the mitochondrial DNA (mtDNA) HVR1 region, assigned the specimen to the HV1 haplogroup, and suggested that early Holocene Sicilians might have descended from the Late Epigravettians who migrated from the Italian Peninsula around the LGM. Recently, two genome-wide analyses reported a U2′3′4′7′8′9 mtDNA haplogroup for the Upper Paleolithic Oriente C individual, suggesting that the "Western Hunter Gatherers" were a genetically homogeneous population widely distributed between the Atlantic seaboard of Europe in the west and Sicily in the south, and the Balkan Peninsula in the southeast [10,11]. More recently, Modi et al. [12] also categorized the Mesolithic Oriente B individual into the U2′3′4′7′8′9 mtDNA haplogroup, estimating the emergence date of a "Sicilian clade" to 23,248 years BP. Interestingly, new ancient sequences from a Paleolithic individual in Grotta di San Teodoro and from two Early Mesolithic individuals in Grotta dell'Uzzo seem to corroborate the idea that U2′3′4′7′8′9 was the only mitochondrial lineage in Sicily during the Late Pleistocene and Early Holocene [49,50]. Taken together, all these findings are consistent with the hypothesis of a genetic continuity between Paleo-Mesolithic hunter-gatherers in Sicily.

In a study focusing on the spread of the Bell Beaker cultural complex across western Europe, Olalde et al. [52] also obtained genome-wide data from Early Bronze Age individuals associated to the Bell Beaker culture. They found that Sicilian individuals showed low proportions of ancestry derived from populations related to Early Bronze Age Yamnaya pastoralists from the Eurasian steppe. More recently, Fernandes et al. [14], in analyzing genome-wide data from ancient Sicilians from the Middle-Neolithic to Late Bronze Age, detected evidence of early European farmers' ancestry in Middle-Neolithic individuals. They also identified signs of steppe pastoralist ancestry in Early Bronze Age individuals who arrived in Sicily around 2200 BCE, mainly from Iberia. Furthermore, they found an Iranian-related ancestry associated with the Minoan and Mycenaean cultures in Middle Bronze Age (1800–1500 BCE) Sicily, which could have reached Sicily before the Greek period. Their results also showed, in extant Sicilians, a significant presence of North African-related ancestry, which probably spread onto the island in the Iron Age and afterwards.

The genetic reconstruction we have discussed does not currently allow us to define exhaustive scenarios. However, the prospects are very promising and are still based on the definition of targeted sampling, especially in the case of the analysis of aDNA. The demographic dimension of human events can potentially be reconstructed, but the big interpretative problem remains. A paleoenvironmental analysis that aims at the discovery of anthropization markers could provide further important insights in this sense.

4. Past Vegetation, Climate and Landscape Dynamics during the Holocene

The Holocene landscape of Sicily is the result of a long history of paleogeographic and paleoecological events that, together with human actions, have shaped the distribution of flora and phytocoenoses. The geographical position and bioclimatic conditions of this part of the Mediterranean allowed the survival of many species during the LGM, including many remnants of the "palaeotropical geoflora" [53,54], and the permanence of some species known as "glacial relicts" [55]. During the Late Pleistocene, the Italian Peninsula and Sicily were a refuge area for many plant species (e.g., *Fagus sylvatica*) and allowed post-glacial recolonization [56]. The first hunter-gatherers that arrived on the island with the LGM had a very limited impact on natural ecosystems. The causal relationship between humans and their environment is the consequence of the ecological transition that starts with the end of the Würm.

The evolution of vegetation throughout the Holocene in Sicily since 11,750 cal yr BP (9700 BCE) has been reconstructed using different paleoenvironmental records, such as pollens, charcoals, and isotope analysis of lacustrine deposits. Lacustrine deposits are crucial in both the understanding of paleobiogeography and the identification of human ecological prints, and intensity. In Sicily, lacustrine sediments have been investigated at different sites, such as Lago di Pergusa [57–63], Gorgo Basso, Lago Preola, and Biviere di Gela on the southern coast [64–66], and Gorgo Tondo, Gorgo Lungo, Urgo Pietra Giordano, Gorgo Pollicino, Marcato Cixè, and Urio Quattrocchi in the northern mountains of the island [67–69] (red dots in Figure 4).

The Early Holocene (11,750–8200 cal yr BP; 9700–6250 BCE) was characterized by a climatic trend toward warmer and wetter conditions than the Younger Dryas. This climate change favored the transition from steppe-like or grasslands to Mediterranean broadleaf forests, which reached their maximum expansion between 9000 and 7000 cal yr BP (7050–5050 BCE) [70,71]. The most profound changes in vegetation occurred in the Early Holocene as a result of insolation, temperature, and rainfall increases [56]. Sadori and Narcisi [57] reconstructed the paleoenvironmental evolution that took place between the Last Glacial period and the Holocene at Lago di Pergusa (670 m a.s.l.). The pollen data records from 10,000 cal yr BP (8050 BCE) indicate the presence of xeric steppes in the glacial period, dominated by *Artemisia* sp., Chenopodiaceae, and Poaceae. In the Sicilian inland region, wetter conditions arose after 9000 cal yr BP (7050 BCE), which allowed the beginning of the afforestation process. The transition from herbaceous plants to the woody vegetation of the Early Holocene was synchronous throughout Sicily. However, while the hilly interior and the mountains were colonized by mixed broadleaved forests, the southern coast was covered with maquis formations [64].

In coastal areas, postglacial afforestation started later than in other areas of the Mediterranean Basin [71]. At Gorgo Basso (6 m a.s.l.), the pollen record shows the predominance of grasslands populated by *Urtica dioica*, Poaceae, Brassicaceae, *Peucedanum*, Cichorioideae, and *Artemisia* up until 9750 cal yr BP (7800 BCE) (Figure 5) [63]. After this period, herbaceous communities were replaced by Mediterranean shrublands dominated by *Pistacia* sp. and *Phyllirea* sp., as well as *Tamarix* sp., *Chamaerops*, *Juniperus* sp., *Erica* sp., *Ephedra* sp., and *Cistus* sp. Since 9500 cal yr BP (7550 BCE), *Pistacia* shrublands have colonized the coastland as a consequence of increases in environmental moisture and related reductions in the occurrence of natural fires. The palynological record from Gorgo Basso also reveals an expansion of *Olea* woods between 8400 and 8200 cal yr BP (6450–6250 BCE), followed by a reduction [65] that is probably related to the 8200 cal yr BP (6250 BCE) dry/cold event [72]. About a thousand years would pass before the evergreen forests returned to the area.

At higher altitudes, in the Urio Quattrocchi area (1044 m a.s.l.), open forest ecosystems dominated by deciduous and evergreen oaks (today growing at lower altitudes) appeared at ca. 10,250 cal yr BP (8300 BCE). Since 10,000 cal yr BP (8050 BCE), the forests have begun to close and became more mesic, reaching maximum coverage at 9700 cal yr BP (Figure 5). The general increase in environmental moisture in this phase of the Holocene allowed the spread of broadleaved forests of *Quercus cerris*, *Fagus sylvatica*, *Quercus ilex*, and *Fraxinus* spp. [68]. The same transition from open communities to *Fagus* and *Abies* forests was observed at Urgo di Pietra Giordano (1323 m a.s.l.) in ca. 10,000 cal yr BP (8050 BCE) by Bertolani Marchetti et al. [67]. ca. 10,000 cal yr BP (8050 BCE).

The Mid-Holocene (ca. 8200–4300 cal yr BP; 6250–2350 BCE) was a period of climatic instability and intense cultural change in the Mediterranean region [71]. A warming period, which characterized the Holocene's optimum climate, occurred from approximately 7500 to 5500 cal yr BP (5550–3550 BCE), which was immediately followed by a dry/cold event, peaking at 4200 cal yr BP (2250 BCE) [73]. These climate oscillations had an impact on the plant landscape of Sicily and presumably reduced the efficacy and demographic expansion of pre-Neolithic peoples.

Paleobotanical records from Lago di Pergusa by Sadori and Narcisi [57] have revealed changes in floristic composition taking place after 8000 cal yr BP (5950 BCE). The pollen of *Olea* and Mediterranean trees increased after 7200 cal yr BP (5250 BCE), reaching their maximum expansion at around 3200 cal yr BP (1250 BCE). The Mediterranean plants' pollens (*Olea* sp., *Phillyrea* sp., *Quercus ilex*-type, *Rhamnus* sp., *Cistus* sp., *Pistacia* sp., etc.) increased in accordance with the attainment of an optimum climate.

The end of the Mid-Holocene was characterized by increases in *Olea* vegetation cover (4300 cal yr BP; 2350 BCE), despite the lower temperature (Figure 5). Wild olive is one of the dominant elements of the xerophilous forests in Sicily [74,75], and is a component of thermophilous oak forests, both semideciduous and evergreen [76]. The increase in *Olea* incidence is an indicator of the anthropogenic perturbation of forest cover, which then led to vegetation rich in sclerophyllous. *Olea* growth may also have been facilitated by humans, because archaeobotanical data confirm the use of olive tree wood [77], and probably its fruits, during the Bronze Age (ca. 4300–2900 cal yr BP; 2350–950 BCE) [78] (Figure 2d,e).

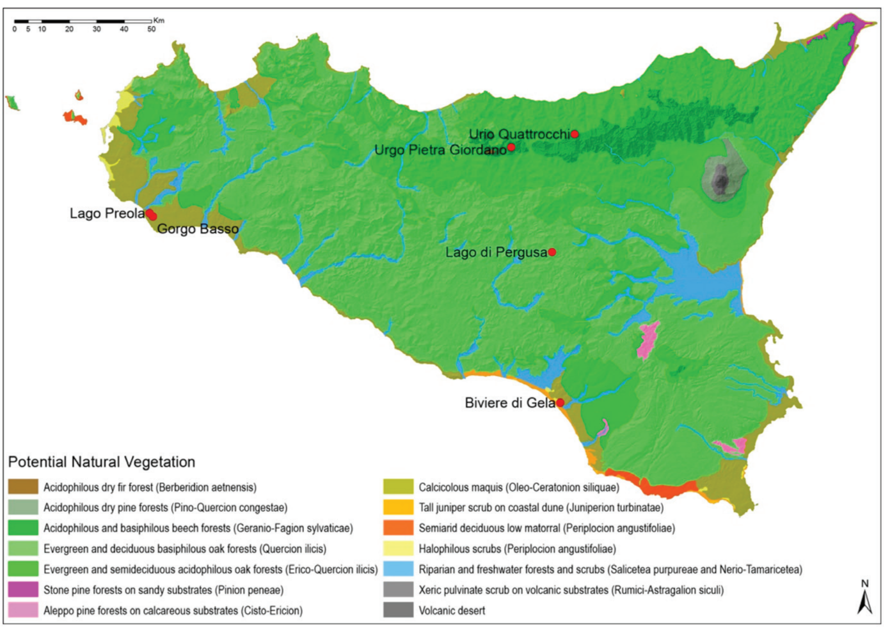

Figure 4. Potential Natural Vegetation of Sicily and locations of paleobotanical sites that have been surveyed in the literature. Vegetation types are indicated at the level of phytosociological alliances (see Bazan et al. [76]).

On the southern coast (Gorgo basso), there was also an expansion of *Quercus ilex* and *Olea* forests in ca. 7000 cal yr BP (5050 BCE) that replaced the open environments (grasslands, shrublands), probably resulting from the warmer/wetter conditions and related reductions in natural fire events [65]. After the afforestation of this period, the woods maintained their structure more or less consistently throughout the whole Mid-Holocene. Tinner et al. [65] argued that the climatic conditions of the Sicilian coast between 7000 and 2000 cal yr BP (5050–50 BCE) were similar to those found today. Consequently, the natural vegetation that could have grown is also similar to that seen in the present day (Figure 4). The landscape of the costal belt was dominated by evergreen oak forests, primarily of *Olea* sp., *Pistacia* sp., *Phillyrea* sp., *Chamaerops* sp., *Juniperus* sp., *Tamarix* sp., *Erica* sp., *Ephedra* sp., and *Cistus* sp. [64]. Paleobotanical indicators (*Ficus carica* and Cerealia-type pollens) and archaeobotanical remains (wheat, lentil, and fig) at Lago Preola and Gorgo Basso suggest timid farming activities in the Neolithic period (prior to 7300 cal yr BP; 5350 BCE) (Figure 2b), which had a smaller impact on coastal forests than it had inland [65].

At the beginning of the Mid-Holocene, on the northern mountains of Sicily, according to paleobotanical records, dense forests were widespread, indicating a period with less human disturbance [69]. In the Madonie mountains, around Marcato Cixè (1200 m a.s.l.) and Urgo Pietra Giordano (1323 m a.s.l.), forests of *Fagus sylvatica* (dominant), *Quercus pubescens*, *Q. petraea*, *Ilex aquifolium*, and *Abies nebrodensis* were present [65,67]. At Gorgo Tondo (783 m a.s.l.) and Gorgo Lungo (877 m a.s.l.), the forests were dominated by mesophilous species, such as *Quercus cerris* and *Q. pubescens* [68], which were in catenal contact with the thermophilous wood of the deciduous and evergreen broadleaf trees of the hilly belt [61,69]. From 7000–6500 cal yr BP (5050–4550 BCE) (data from at Urgo di Pietra Giordano), forest coverage began to thin out, and grassland (Poaceae, Cichorioideae, *Achillea*, *Aster*) took its place [69]. According to archaeological evidence, the transformation of the landscape took place at the same time as the first Neolithic crops were established in coastal northern Sicily (Grotta dell'Uzzo), dated to 5711–5558 BCE [78] (Figure 3). Animal husbandry (bovids, sheep, and goat) was introduced in the area of Grotta dell'Uzzo around 6000 cal yr BP (4050 BCE) [79]. According to Bisculm et al. [68], in the Nebrodi mountains (Urio Quattrocchi), due to anthropogenic fires, the forests also began to decrease after 7000 cal yr BP (5050 BCE) (Figure 5).

The Late Holocene (after 4200 cal yr BP; 2350 BCE) was an epoch characterized by significant human-induced landscape transformations related to the cultural transitions of human societies. The Middle–Late Holocene boundary has been placed at 4200 cal yr BP (2350 BCE), corresponding to an aridification event (the so-called "4.2 ka event") that may have played an important role in the decline of major ancient civilizations in the Mediterranean area [73]. According to recent temperature reconstructions spanning the past 10 millennia, the Mid-Holocene was followed by a progressive cooling period, culminating in the Little Ice Age, around 1550–1800 CE [80,81]. However, the influence of the climate trend on landscape transformation in this last period has been masked by anthropic processes. Human-induced landscape transformation is not necessarily the symptom of an increased demography but is rather an indication that humans began the process of sub-intensively cropping and burning.

In central Sicily, landscape changes began in 3200 cal yr BP (1250 BCE) with the increase in olive formations and continued in the following millennia. The increase in sclerophyllous Mediterranean taxa (*Olea* sp., *Pistacia* sp., *Phyllirea* sp., *Quercus ilex*) compared to the drop in mesophilous species indicates that opening up and structural degradation occurred in forest formations, and these were related to human disturbance. Even today, the main potential natural vegetation (Figure 4) that can grow in the central clayey soils of the Sicilian countryside is mixed wood (*Oleo-Quercetum virgilianae*), mainly thermophilous oaks and a variety of Mediterranean species (*Olea europaea* var. *sylvestris*, *Pistacia lentiscus*, *Phillyrea angustifolia*, etc.), which indicate a degree of environmental xericity [76] as a consequence of forest canopy openness. Another interesting aspect of the palynological data offered by Sadori et al. [61] is the development in 2600 cal yr BP (650 BCE) of certain anthropogenic taxa (Caryophyllaceae, Urticaceae, Asteroideae, Cichorioideae, Pooideae, *Papaver* sp., *Plantago*, *Polygonum*, *Rumex*, *Vitis* sp., etc.). The paleobotanical data are in accordance with the archaeological evidence. During the Iron Age, between 3200 and 2700 cal yr BP (1250–750 BCE), the area around the Lago di Pergusa was strongly exploited and disputed by Sicels and Sicanians [82] (Figure 2f).

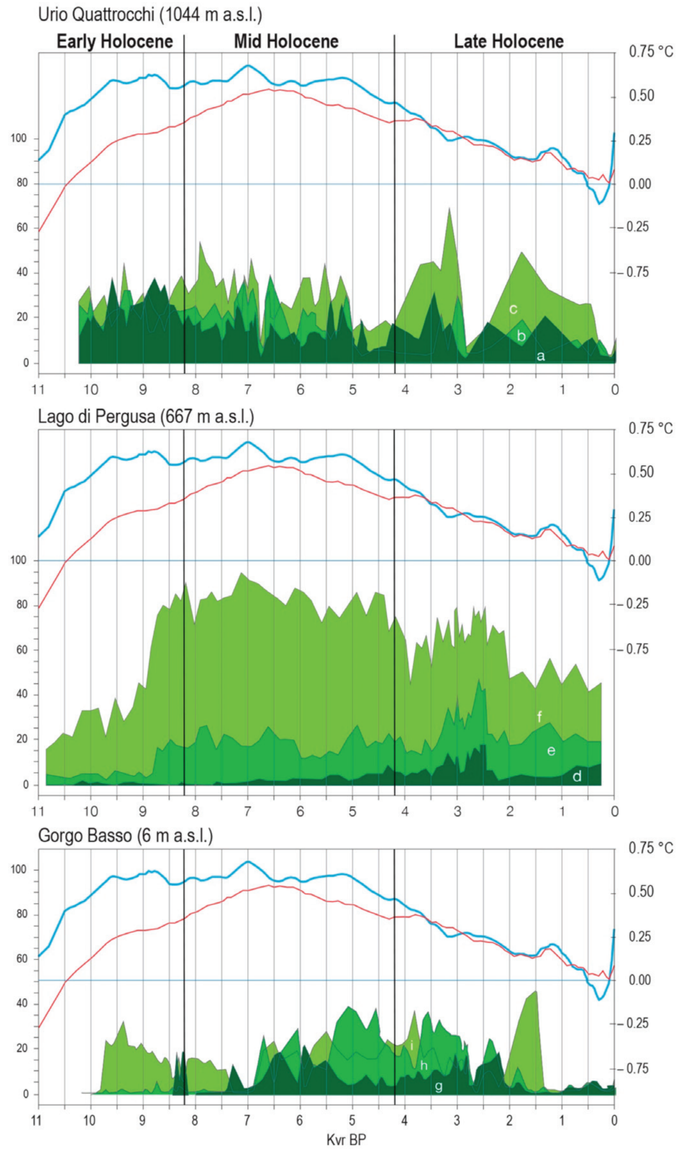

Figure 5. Schematic trends of pollen percentage: Urio Quattrocchi (a—*Quercus pubescens*; b—*Q. ilex*-t; c—*Q. cerris*) within the Evergreen and semideciduous acidophilous oak forests *(Erico-Quercion ilicis*) PNV (see Figure 4); Lago di Pergusa (d—*Olea* sp.; e—Mediterranean vegetation; f—Arboreal pollen) within the Evergreen and deciduous basiphilous oak forests (*Quercion ilicis*) PNV; Gorgo Basso (g—*Olea* sp.; h—*Quercus ilex*-t; i—*Pistacia* sp.) [59,65,68] within the Calcicolous maquis (*Oleo-Ceratonion siliquae*). Trends of average temperature variations by Marcott et al. [80] (red line) and Kaufman et al. [81] (blue line) during the Holocene.

During the last 2000 years, according to Sadori et al. [83], farming has been practiced continuously, as recorded in lacustrine sediments. Fluctuations in the concentration of pollen from species related to cultivation indicate changes in the productivity of agricultural system. For example, cereal pollens peaked during the Byzantine period (fifth and seventh centuries CE) [83] as an effect of temperature and humidity increases, which favored the late Roman economy of intensive grain production. This period was followed by a cooling that may have been important in determining the collapse of Byzantine society in Sicily and favoring the success of the Arab conquest, which spread new agricultural techniques on the island. During the Islamic domination, irrigated agriculture was widespread all over the island, and was integrated with non-irrigated agriculture and husbandry as part of a complex productive system. The great novelty of the medieval "Arabic agricultural revolution" concerned the new techniques, new species, and new social and economic conditions that all came together. In fact, the "green revolution" may have had such a huge impact on the agricultural landscape thanks not only to new agricultural and technical innovations, but also to the fact that these developments were rooted in innovations and improvements of agronomic techniques inherited from the Greeks, Phoenicians, and Romans [84]. Archaeobotanical and archaeozoological evidence from the medieval site of Contrada Castro in Monti Sicani (late 8th to 11th CE) showed that the transition between the Byzantine and Arab periods manifested no radical change in agricultural strategy, wood exploitation, or the management of animal resources [85]. Recent papers by Bazan et al. [86,87] highlight the *Long-Durèe* of the landscapes of the Sicilian rural countryside, which have displayed strong continuity throughout the last millennium.

The drastic reduction in evergreen forests (Figure 5) on the coastland between Gorgo Basso and Lago Preola have been dated back to ca. 2700 cal yr BP (750 BCE) by Tinner et al. [65] and Calò et al. [66], corresponding to the period of Greek colonization, which started in 734 BCE (2684 cal yr BP) [78] and which had a demographic impact on Sicily [27,28] (Figure 2h). This is evident in the first increase in *Pistacia* shrublands that was followed in subsequent centuries (after 1500 cal yr BP; 450 CE) by a drastic reduction in natural vegetation due to human-caused disturbances in the period of great prosperity in nearby Selinunte [88]. Since the Mid- and Late Holocene (6000–2600 cal yr BP), the climate conditions and potential natural vegetation present on the coastlands of Sicily have steadily evolved into those seen today (Figure 4) [64,65].

Beech and mesophilous forests have maintained their potential range since the Late Holocene in the mountains of northern Sicily [69]. The mountain forest ecosystem of Sicily has shown remarkable resilience against past climate change and increasing human pressure (burning, cutting, or overgrazing).

Paleoecological studies have shown that different climatic fluctuations caused no significant changes in the ecological setting of Sicily, demonstrating the high adaptability of natural ecosystems and human societies. On the other hand, the long-term agrosilvopastoral exploitation of land since the Neolithic period has transformed the natural ecosystems into agroecosystems that have played an important role in maintaining biodiversity and endemic, rare plant species [89–91]. In general, the Neolithization of Sicily led to the development of the first agroecosystems, which evolved in tandem with the introduction of new species that accompanied human migrations. New populations brought with them new domesticated species (even in areas where wild varieties were present) and new cultivation practices. An important role in the domestication of landscape was played by the spread of the three "key stone species" of the Mediterranean agroecosystems: wheat, olive, and grapevine.

The archaebotanical remains of the first Neolithic phase from Grotta dell'Uzzo (5711–5558 BP; 3751–3608 BCE) (Figure 3) have documented the exploitation of wheat (*Triticum aestivum* and *T. compactum*), fava bean (*Vicia fava*), bitter vetch (*Vicia ervilia*), pea (*Pisum* sp.), fig (*Ficus carica*), wild olive (*Olea europaea* var. *sylvestris*), etc. [78]. The oldest olive oil production, however, has been dated by Tanasi et al. [92] to the end of the third and beginning of the second millennium BCE, in the Early Bronze Age settlement of Castelluccio (Noto), while the earliest attested presence of winemaking was identified at the Copper Age site of Monte Kronio (Sciacca). The presence of wine was indicated by the presence of tartaric acid and its sodium salt in storage jars, which dated to the third millennium

BCE [93]. Therefore, archaeobotanical findings have confirmed that, in the Early Bronze Age, the cultivation of wheat, olive, and grapevine were already well-established practices.

These agroecosystems and associated agrobiodiversity have changed over time, starting with plant selection processes (agrarian archaeophytes) and changing in relation to migrations, commerce, and the introduction of new species (agrarian neophytes). Co-evolution processes between human culture and cultivated plants have favored symbiotic growth and mutual expansion [94]. These changes are evident in the first agricultural revolutions, which occurred during the Neolithic period, during the medieval "Arabic agricultural revolution", and at the end of 15th century AD. The "discovery of America" and its extraordinary richness of species introduced new species (at that time Sicily was under the Spanish Imperial Rule) that changed the agrobiodiversity of the Old World. In many cases, plant crops coming from other continents became very important beyond their places of origin, and even shaped the landscape in areas where farming has been affirmed to have taken place (e.g., the prickly pear in Sicily). Therefore, the landscape of Sicily has been profoundly shaped by the cultural transformations and stratifications that occurred during different historical periods with similar climate settings, which have in turn defined its identity.

5. Discussion

The extensive survey of the archaeogenetic studies of Sicily since the Troina meeting presented in this paper verifies that many of the predictions and plans made at that meeting have been realized. Nevertheless, it is worth remembering that the reconstruction of the genetic history of the island is a growing field of investigation, and this survey of the published efforts clearly indicates that there are many difficulties that remain. This is somewhat inevitable, given that the analyses conducted thus far have only involved a small part, perhaps not even representative, of the extensive archaeological and historical evidence pertaining to the island, containing (by a previous outdated prediction) over 3000 registered sites. This contrast is better illustrated by comparing the map of archaeological sites surveyed to date (Figure 2) and the map of sites sampled for DNA analyses (Figure 3).

The new NGS technologies will undoubtedly have important effects. As a first step, it is necessary to increase the coverage of ancient genomes by focusing on the cultural and bio-demographic processes that have shaped the current genetic landscape. In our opinion, the extent of the genetic contribution made by Iron Age indigenous peoples is a highly debated issue that needs to be addressed (Figure 2e), as this contribution may have been masked by subsequent migration events.

Another fundamental area of focus will be forming a better understanding of the impact on the present-day Sicilian gene pool of Greek and Punic colonizations, beginning with the founding events of the eighth and the sixth centuries BCE (Figure 2g). The evaluation of the demographic dimension of colonization may be indirectly inferred through changes in vegetation cover recorded by paleoecological analyses. The movement of people and the effective genetic impact of their settlements is tied to ecological and environmental factors. The evaluation of the ecological and paleo-botanical characteristics of the territory is thus important, as this helps in reconstructing the diffusion and demographic repercussions of the different Holocene human flows.

In our opinion, it is necessary to proceed, with reinvigorated effort, with the integrated study of modern and ancient genomes, in order to achieve a completer and more accurate picture of the population history of Sicily. We would like to mention here the research project AGED "1000 Ancient Italian Genomes: Evidence from ancient biomolecules for unravelling past human population Dynamics", begun in 2020, which aims to study the dynamics of population that have characterized the Italian peninsula via a multidisciplinary approach based on the paleogenomic, isotopic, and radiometric analysis of ancient biological samples from the Paleolithic to Middle Age. As far Sicily is concerned, the AGED project aims to provide an interpretation of genetic data for Sicily via a detailed examination of the population dynamics associated with the cultural, demographic, and environmental changes that took place during the prehistory and history of the island. In turn, the genetic, demographic, and cultural changes need to be understood in the context of the environmental changes that took place over the Holocene.

6. Concluding Remarks

While, on one hand, the literature surveys on the three themes (ethnic/archeological, archeogenetics, past vegetation/landscape) discussed in this review were intended to offer the reader a systematic knowledge about the state of art of studies performed on various aspects of the prehistory, protohistory, and history of Sicily, on the other hand, we wish to suggest here a few ideas for future studies on Sicily, hoping they will serve as a useful general theoretical framework. First of all, we underscore the importance of pursuing an interdisciplinary approach to gain a deeper understanding of the complex dynamics that have characterized the past timeline of Sicily. More specifically, we think that the most effective and appropriate way to implement such an interdisciplinary approach is to undertake a systems level analysis of Sicily by which to investigate the many crosstalk events that have occurred between the cultural and biological evolutions during the Holocene. Indeed, as it was extensively discussed in the landscape section of this review, the two types of evolution have interacted and influenced each other at different periods and places within the island. Moreover, we propose that such evolutionary changes would be better understood if they are considered in terms of the changes in biodiversity and sustainability of the Sicilian ecosystem. Here, the term biodiversity is used to include the genotypic as well as phenotypic changes of the humans, animals, and plants that have lived in the island throughout this time frame. From this perspective, changes of sustainability can be causally linked to changes in biodiversity of the Sicilian ecosystem. In turn, such changes need to be studied as a response to natural (e.g., climatic, geological) and cultural (e.g., transition from a hunter-gatherer to agricultural economy) influences. Within this framework, the contribution of archaeogenetic studies will help to reconstruct the dynamics of human populations. Throughout the Holocene, these dynamics have constituted the main driver of the prehistoric and historical changes of Mediterranean landscapes. Despite its long human history, the Mediterranean is still one of the world's biodiversity hotspots and Sicily is one of its important areas [95]. The lessons we learn from the past use of landscape provide models for the sustainable future management of the Mediterranean's landscapes.

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The Monumental Olive Trees as Biocultural Heritage of Mediterranean Landscapes: The Case Study of Sicily

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Abstract: Monumental olive trees, with their longevity and their remarkable size, represent an important information source for the comprehension of the territory where they grow and the human societies that have kept them through time. Across the centuries, olive trees are the only cultivated plants that tell the story of Mediterranean landscapes. The same as stone monuments, these green monuments represent a real Mediterranean natural and cultural heritage. The aim of this paper is to discuss the value of monumental trees as "biocultural heritage" elements and the role they play in the interpretation of the historical stratification of the landscape. We present the results of a survey of the most significant olive trees growing in Sicily. The selection was based on the "monumentality" aspects of trees, taking into account dendrometric parameters and environmental contexts. The collected dataset constitutes a heterogeneous sample of 367 specimens of considerable size that, in some cases, reach a circumference of about 19 m. Starting from the data presented here, the whole Sicilian territory shows a historical relationship between human and olive. The presence of these plant monuments is, therefore, evidence of long-term, often centennial, landscapes as a result of sustainable use of the territory.

Keywords: agrobiodiversity; ancient trees; biocultural diversity; biodiversity; heritage trees; historical ecology; long-lived trees; *Olea europaea*; veteran trees

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1. Introduction

The olive tree can be considered the most symbolic tree of civilization and a part of the anthropized Mediterranean landscape [1]. Exploited at least since the Mesolithic [2] and cultivated for the production of oil at least since the Bronze Age in Sicily [3,4], it has a wide distribution in all countries bordering the Mediterranean, with around 800 million individuals [5,6]. Evidence of mythology, history, and literature attest to the great importance of the olive tree and its oil in the trade, food, and customs of Mediterranean populations, starting with the olive tree as the protector tree of the city just founded by Athena and mentioned among the most precious trees by numerous Jewish, Greek, and Roman sources [6]. It is a very long-lived plant, with very slow growth, able to bear fruit for several hundreds of years, assuming extraordinary shapes and sizes over time and contributing to modern genetic diversity [7].

The use of the wild olive dates back to the Israeli region in the Epipaleolithic [4]. It is probably from primitive cultivation located in the west of Iran and the south of the Caucasus that the irradiation to other geographical areas and the differentiation of the different cultivated varieties began [5]. It is believed that the cultivated olive tree (*Olea europaea* L. var. *europaea*) is derived from the refinement of the wild one (*Olea europaea* var. *sylvestris* (Mill.) Lehr), which is spontaneous throughout the Mediterranean basin [8] and with which it retains considerable genetic affinities [9], although its origin is still much debated [10]; however, it is no coincidence that the aspect of the abandoned olive tree tends to regress toward that of the wild olive tree [11]. The distribution of the olive tree, in fact, is almost superimposed on that of its wild ancestor, representing one of the characteristic elements of Mediterranean sclerophyllous vegetation [8]. According to Zohary and Hopf [9], within the Mediterranean countries, the olive tree was one of the first fruit plants to be domesticated, perhaps as early as the 5th millennium BC, as evidenced by the several structures for the pressing of olives found in the Chalcolithic age in the Jordanian area [12].

The olive varieties we know today would therefore be the result of an ancient selection process [13] by Syrian and Palestinian farmers and probably also those from the vast area extending from the Southern Caucasus to the Iranian highlands, starting from the wild olive tree, widespread in that time period but not very usable for food purposes due to the spinescence and small drupes and their being poor in oil, to cultivars rich in oil and without thorns [14–16].

The relation between humans and olive trees in Sicily has a long story. Beyond the previously cited remains from Grotta dell'Uzzo, olive tree wood has been exploited in Eastern Sicily since the end of the Paleolithic [16]. According to the natural sequence of Pergusa lake, *Olea* sp. experienced an expansion starting from 7200 BP (Middle Neolithic) [17], but it is unlikely that it was due to its early cultivation. Archaeobotanical data confirm that olive tree wood and probably its fruits were used during the Bronze Age, 2nd millennium BC, despite missing carpological data [18–20]. For the Greek colonies such as Selinunte (7th century BC), the olive tree was considered a symbol of peace, wisdom, and prosperity for the various uses to which the oil was intended. Carpological data are scarce, probably due to the extremely low record of archaeobotanical remains for these phases; the only exception is the city of Camarina [21]. According to literary sources, the farmers of Selinunte became a point of reference in the oil trade in the Mediterranean. They cultivated and propagated the olive tree in the valleys and in the fertile lands of the hinterland, producing oil, as evidenced by the findings of rudimentary mills dating back to the fifth century BC [22] and exporting it, as the city of Akragas, to the Phoenicians colonies of Northern Africa [23].

It is evident that this tree constituted a preponderant and highly characterizing element of the ancient Sicilian agricultural landscape, also according to the literary sources. Thucydides (Book VII, 81, 4), speaking of a village south of Syracuse, called the Polizelo enclosure, where the Athenians stopped briefly in retreat, gives us the opportunity to imagine the olive fields delimited in "enclosures" by low walls of dry stones, as they are still today for the needs of sheep farming. One significant document with some valuable information on the olive tree in antiquity is the Tabulae Halaesinae, a Hellenistic description carved on two stone tablets of the land of Halaesa, an ancient city near the modern village of Tusa (Messina). Ancient olive trees are raised to the role of natural monuments through the marking of the Halaesian monogram engraved on the bark as a marking boundary sign [24]. In the Tabulae, the importance and predominance of olive cultivation for the economy of that territory come out, also supported by the presence of special "nurseries" (*elaiokomion*) [25]. During the Roman Empire, the exploitation of Sicilian oil together with other food resources was slowly replaced with the use of the island as a bridge for the import of Northern African products [26]. Finally, during the Middle Ages, its presence in the hilly Sicilian landscape seems quite spread, with some exceptions, especially in the Islamic areas [27–29].

Today the olive tree, together with wheat and vines, represent the "Mediterranean triad" of traditional agriculture [30]. In the Sicilian agricultural landscape, dry (non-irrigated) olive groves are widespread in pure plantations, with more or less irregular spacing, or in "mixed cultivation" systems, together with carob and almond trees.

The centuries-old olive trees and, more generally, all monumental trees, with their longevity and considerable size, certainly represent a sign that is not negligible for the purposes of a better understanding of the territory that hosts them and of the society that wanted them to be preserved. The attention to monumental olive trees is linked to the most up-to-date concepts of "istorical ecology" for the interpretation of the traditional rural landscape, in which the historical-anthropological components are intimately connected to the natural ones. As a matter of fact, as cultivated plants, olive trees are anthropogenic elements of the landscape, and, thanks to their longevity, they have become a source of historical information on the use of the territory. They are the only cultivated plants that tell the story of the Mediterranean landscapes through the Anthropocene and represent a "cultural heritage", like some stone monuments. Having evolved over the centuries, the olive tree landscapes represent a tangible example of sustainable land use [31]. The recognition of ancient and notable trees and historic orchards as elements of cultural heritage is widely accepted (see, e.g., www.english-heritage.org.uk), although, as they are living monuments, we believe it is more appropriate to consider trees as elements of the "biocultural heritage" [32].

While some research has focused on the role of olive groves in the Mediterranean landscape e.g., [33–35], less emphasis has been placed on the cultural/biocultural value of single monumental olive trees that dot the landscape.

Considering the importance of secular olive trees not only from a cultural, environmental, and scientific point of view, as well as for the precious genetic heritage of which they are depositories, in 2003, a survey project was started in Sicily in order to acquire significant elements for the documentation, protection, and enhancement of this plant heritage [36,37].

This work reports the results of the survey of monumental olive trees conducted in Sicily and discusses their value in terms of "biocultural heritage" and the importance they play in the interpretation of the historical stratifications of the landscape.

2. Materials and Methods

2.1. Study Area

Sicily is the largest Mediterranean island, with an area of approximately 25,500 km^2 and about 1000 km of coastline. The island has different geological characteristics, which have shaped different landforms with an elevation ranging from sea level to 3340 m (Mount Etna). The territory is hilly in the central and southwestern parts (approximately 61.4%), mountainous, especially in the northern and eastern parts (24.5%), and 14.1% consists of alluvial plains [38].

According to Bazan et al. [39], Sicily is divided into 25 bioclimatic belts (thermotypes and ombrotypes) from thermomediterranean semiarid to cryo-mediterranean hyperhumid. This great variety of environmental conditions and its complex paleo-geographic and human history make the island one of the Mediterranean biodiversity hotspots.

Agricultural systems are widespread and are structured as highly diversified landscape mosaics (arable lands and extensive herbaceous crops, vineyards, olive groves and dry cultivation mosaics, orchards, built-up areas, etc.), which are significant containers of agrobiodiversity.

Olive groves create diffused semi-open landscapes compared to other tree crops, especially along the marginal hilly areas and at the base of the mountainous areas [40]. The cultivation of the olive tree currently has about 18 million plants in Sicily and contributes considerably to the characterization of the physiognomy of the region's agroecosystems, with particular reference to the hilly ones, where 65% of the olive groves exist, and to the mountain ones, where the traditional olive groves represent 17% of all groves [41]. With an area of 157,891 ha [42], equal to 6.1% of the regional territory, this cultivation plays an important role.

2.2. Data Collection

The survey covered the entire Sicilian regional territory and the selection of the most significant specimens, chosen for their "monumentality" aspect, mainly took into account the parameters inherent to the measurement of maximum circumference, measured at 1.30 m from the ground (for appropriate comparisons with other individuals), height, development, crown width, and presumed age. This information was also integrated by considerations relating to the historical, naturalistic, and landscape value of the individual plants.

For the survey, the research group also made use of the collaboration of the technicians of the Operational Sections of Technical Assistance (SOAT) of the Regional Department of Agriculture, Rural Development, and Mediterranean Fisheries, located in the territory, which helped to report to the authors the presence of individuals with the characteristics of monumentality.

The research methodology was chosen in order to maintain the methodological continuity with previous surveys on monumental trees carried out in Sicily [25,36,42,43]. For the survey of monumental individuals, the survey form proposed by Schicchi and Raimondo [25] was used; it is made up of various items, listed below and contextually explained to summarize the methodology used for the acquisition of the information data:

1. Identification refers to the scientific binomial (or trinomial) of the taxon to which it belongs, to the vulgar name, to the local name, and to the family of reference;
2. Location, with reference to the surveyed sample, indicates the municipal area, the province, the IGM Italian Map Sheet, at scale 1:50,000, and the section of the Regional Technical Map at scale 1:10,000. This item also shows the geographical coordinates in UTM WGS84 format, information about the ownership of the area in which the monumental tree stands as well as the path to access it. The geographic coordinates, latitude and longitude, were identified by GPS (global positioning system). Mapping and spatial analysis were carried out using ESRI ArcGIS 10.2;
3. Stational parameters show the altitude expressed in meters above sea level (m asl), the exposure, the position, the nature of the substrate, the vegetation context of which the surveyed tree is a part, and any existing protection measures, with particular reference to the Regional Parks and Regional reserves;
4. Main morphological features concern the structure and habit of growth, the circumference of the stem measured at 1.30 m from the ground, the maximum circumference of the trunk, the width (length and width) of the foliage, the height of the plant, and the presumed age. The circumference was measured, using a measuring wheel, at the point of maximum development, generally coinciding with the basal part of the stem or with the part below the insertion of the branches, and at a predetermined height (1.30 m from the ground) for appropriate comparisons between individuals belonging to the same species. In the case of plants located in areas subject to steep slopes, the measurement at 1.30 m from the ground was carried out in an intermediate position, between the upper and the lower part of the trunk, following not the line parallel to the ground but the one perpendicular to the trunk. The width of the canopy was measured differently: in the case of foliage with a basically circular base, the diameter of the projection on the ground was measured; in the case of irregular foliage, the greater length and width of their projection on the ground was measured. The height was measured using a hypsometer, a laser distance meter, metric rods, etc. The age estimation represents the closest approximation, as it is very difficult to determine. In fact, in centuries-old olive trees, the trunks are hollow and do not allow the use of classical methods of dendrochronology. Therefore, an age range was derived from an "expert-based" estimation [25] based on the growth rate of 1.5 mm/year by Michelakis [45]. This methodology, compared to the growth rates proposed by Arnan et al. [46] and Camarero et al. [47], is more suitable for the comparison with the growth measure carried out 25 years after some sampled trees. Age estimation was made at the root collar because many trees are branched at a height of less than 1.30 m.

In the attribution of age, both the growth features of the species and the fertility conditions of the site where the monumental olive trees were found were considered.

5. The condition of the specimen concerns the vegetative and health state (pathologies in progress, organs affected, the type of damage, the extent of damage, etc.), threats to its conservation, and any proposed conservation interventions. The vegetative and phytosanitary state is synthetically expressed on the basis of evaluations referring to a qualitative scale of the appreciated condition (excellent, good, fair, mediocre, and poor);
6. Notes and distinctive traits are reserved for all other possible information regarding the tree and/or the station in which it stands, including historical references, legends, etc.

3. Results

The collected dataset represents a heterogeneous sample for dendrometric parameters and environmental contexts. There are 367 specimens, 364 of which are *Olea europaea* var. *europaea* and 3 of which are *Olea europaea* var. *sylvestris*, of considerable size found in different Sicilian provinces (Figure 1). Of these, a significant part is located in the provinces of Agrigento, Messina, Palermo, and Syracuse. The collected data were computerized to facilitate its management, consultation, and implementation over time. A significant example of the surveyed specimens, divided by regional province and referring to 50 individuals, is reported in Table 1. Of 367 specimens, 74 are part of the province of Agrigento, 73 are of Messina, 64 are of Palermo, 56 are of Syracuse, 30 are of Trapani, 21 are of Ragusa, 20 are of Catania, 16 are of Enna, and 13 are of Caltanissetta (Figure 2).

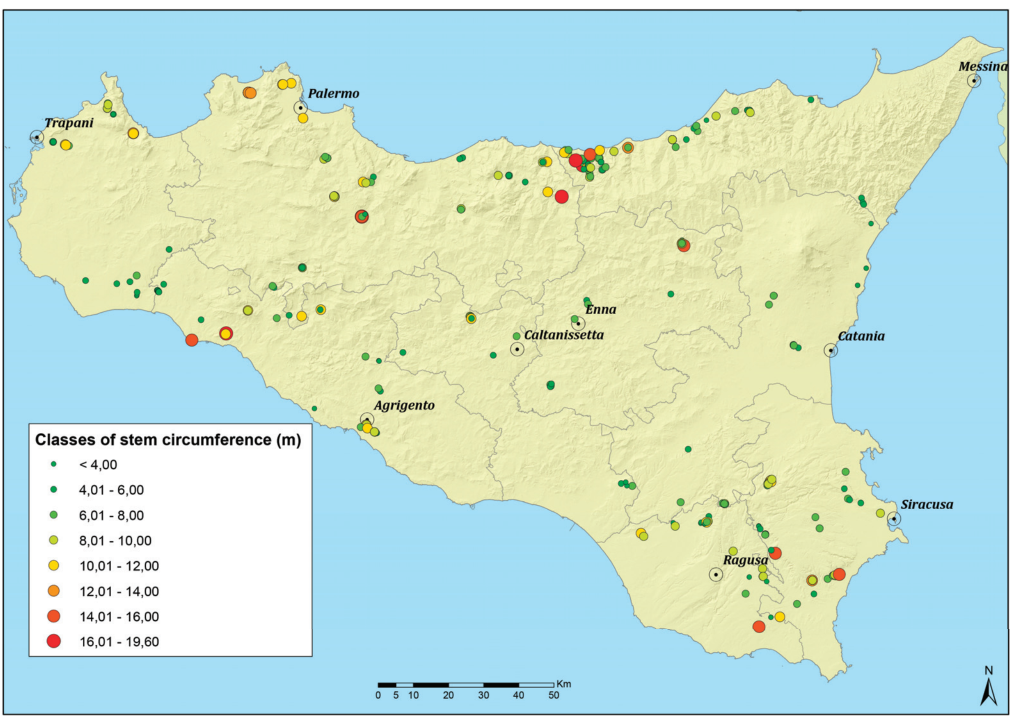

Figure 1. Distribution of 367 monumental olive trees of Sicily represented by classes of stem circumference (at root collar).

Table 1. Sample of the 50 most significant monumental olive trees. The complete list of specimens is given in the supplementary materials.

Name	Municipality	Province	Circ.	Age
Olivo di Innari 1	Pettineo	Messina	19.60	2081
Olivo di Vallefonda 4	Vicari	Palermo	19.00	2017
Olivo di Calabrò	San Mauro Castelverde	Palermo	18.00	1911
Olivo di Fontana Calda 1	Sciacca	Agrigento	17.00	1805
Olivo di contrada La Gebbia	Avola	Siracusa	15.50	1645
Olivo di Feudo Vassallo	Sciacca	Agrigento	15.20	1613
Olivo di Palazzelli	Modica	Ragusa	15.10	1603
Olivo di Fraginesi 1	Castellammare del Golfo	Trapani	13.00	1380
Olivo di Predica 1	Caronia	Messina	12.90	1369
Olivo della Contemplazione	Carini	Palermo	12.70	1348
Olivo di Busulmone	Noto	Siracusa	12.60	1337
Olivo secolare di Troina1	Troina	Enna	12.10	1284
Olivo di Cattiva 4	Alessandria della Rocca	Agrigento	11.40	1210
Olivo secolare di Mokarta 2	Erice	Trapani	11.30	1199
Il Patriarca della Favorita	Palermo	Palermo	11.10	1178
Olivo del Cinghiale	Agrigento	Agrigento	11.00	1168
Olivo di Maviti	Pettineo	Messina	10.80	1146
Olivo di Fontana calda 2	Sciacca	Agrigento	10.50	1115
Olivo di Muti 4	Chiaramonte Gulfi	Ragusa	10.50	1115
Olivo di Scorsone 3	Ispica	Ragusa	10.50	1115
Olivo di Lippia	Acate	Ragusa	10.30	1093
Olivo di Pullicia di Sopra	Palazzo Adriano	Palermo	10.10	1072
Olivo di Verdesca 1	San Vito Lo Capo	Trapani	10.00	1062
Olivo di Zocco-Vernera 4	Buccheri	Siracusa	9.70	1030
Olivo di Castelluzzo 2	San Vito Lo Capo	Trapani	9.50	1008
Olivo di Misilmeri	Misilmeri	Palermo	9.50	1008
Olivo di Centunzi	Caltavuturo	Palermo	9.10	966
Olivo Grande di Bonamorone	Agrigento	Agrigento	9.10	966
Olivi di Acquedolci	Acquedolci	Messina	9.00	955
Olivo di Sacramento 3	Buccheri	Siracusa	8.50	902
Olivo di Santa Tecla	Capri Leone	Messina	8.20	870
Olivo di via dell'olivo Millenario 1	Motta Sant'Anastasia	Catania	8.00	849
Olivo di Nicoletta	Enna	Enna	7.80	828
Olivo di via dell'olivo Millenario 5	Motta Sant'Anastasia	Catania	7.60	807
Olivo di Milo 2	Trapani	Trapani	7.50	796
Olivo di Piraino	Licodia Eubea	Catania	7.50	796
Olivo di S. Maria di Licodia	Santa Maria di Licodia	Catania	7.50	796
Olivo di Fontecà	Pettineo	Messina	7.40	786
Olivo di Sugherazzo	San Fratello	Messina	7.40	786
Olivo di Tardara	Tusa	Messina	7.40	786
Olivo di Contonaro-Lavanche 1	Caltabellotta	Agrigento	7.20	764
Olivo di Vituso 2	Niscemi	Caltanissetta	7.20	764
Olivo di Falabia 3	Palazzolo Acreide	Siracusa	6.90	732
Olivo di Contonaro-Lavanche 2	Caltabellotta	Agrigento	6.80	722
Olivo di Rastello	Pietraperzia	Enna	6.70	711
Olivo di Monaci	Caccamo	Palermo	6.50	690
Olivo di Seggio	Castelvetrano	Trapani	6.40	679
Olivo di Garofalo	Canicattini Bagni	Siracusa	6.30	669
Olivo della Madonna del Piano	Grammichele	Catania	6.00	637
Oleastro di Inveges	Sciacca	Agrigento	5.20	552

With reference to the maximum circumference value of the stem (measured at the collar), 11.4% of them have circumference values equal to or less than 4 m; 30.5% have values between 4 and 6 m; 31.3% have values between 6 and 8 m; 14.2% have values between 8 and 10 m; 7.1% have values between 10 and 12 m; 2.7% have values between 12 and 15 m; 2,7% have values greater than 15 m.

Considering the age of the surveyed plants, 7.1% of them are between 200 and 400 years old, 26.4% are between 400 and 600 years, 33.5% are between 600 and 800 years, 15.3% are between 800 and 1000 years, and 17.7% over 1000 years.

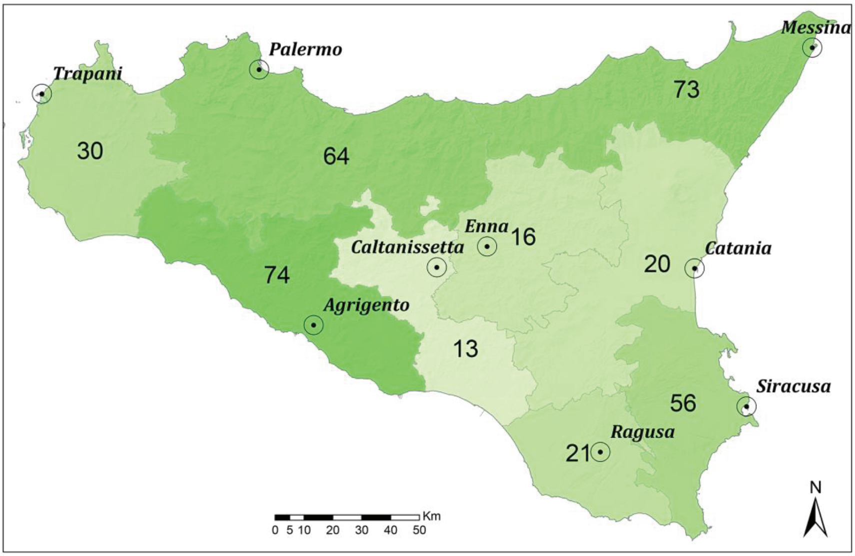

Figure 2. Distribution of monumental olive trees in the Sicilian provinces.

In particular, examining the data relating to the aforementioned sample, it is possible to argue that, in the province of Agrigento, there are several extraordinary olive trees among which, in addition to the very suggestive ones of the Greek Valley of the Temples, there are some plants of about 800–1100 years present in the municipalities of Agrigento (Figure 3a), Caltabellotta (Figure 3b), and Sciacca, with circumference values ranging from 6 to 17 m. Additionally noteworthy is the Olivastro di Inveges, located in the Sciacca area, full of history and legends, with a stem of about 5 m in circumference.

In the province of Caltanissetta, the largest olive trees are found mainly in the territory of the chief town, in the Canalotto-Mimiani, Vituso, and Bugini districts. These are ancient specimens with maximum circumference values between 5 and 11.40.

In the province of Catania, among the most beautiful monumental olive trees, there are specimens along the millenary olive tree road, in the municipal area of Motta S. Anastasia, with specimens up to 8 m, while in the province of Enna, there are ancient specimens with a maximum circumference between 3.40 and 14.1 m.

Among the most noteworthy olive trees in the province of Messina, aged between 414 and 2081 years, we can mention those present in the Nebrodi mountains territory, with particular reference to the area between Tusa, Pettineo, Acquedolci, and Caronia. In particular, the Predica area of the latter municipality contains one of the most relevant examples (Figure 3d). It has a maximum circumference of 12.9 m at the stump and a monocormic stem of 9.30 m at breast height, with various ribs with rounded edges, cavities, and grooves that, from the insertion of the crown, reach the ground. This specimen, over 1360 years old, can most likely be considered one of the largest olive trees in Sicily and Italy.

Among the numerous other notable specimens for age, shape, and size, we remember those of the Maviti and Innari areas in the territory of Pettineo (Messina): the first (Figure 3c) consists of a large stump of about 10.8 m in circumference, surmounted by two trunks of particular beauty, for shape and bearing, of 6.30 and 4.50 m in circumference to breast height; the second has a large stump of 19.60 m in circumference surmounted by three trunks with a breast height circumference of 4.60, 2.90, and 2.40 m, respectively.

Figure 3. Some of the monumental olive trees of Sicily: (**a**) Olivo grande di Bonamorone (Agrigento); (**b**) Olivi di Caltabellotta; (**c**) Olivo di Contrada Maviti (Pettineo); (**d**) Olivo di Predica (Caronia); (**e**) Olivo di Calabrò (San Mauro Castelverde); and (**f**) Olivo di Busulmone (Noto).

Several olive trees in the province of Ragusa, distributed in the municipalities of Chiaramonte Gulfi, Acate, Modica, and Ispica, are striking for their bizarre shapes and sizes. In the territory of the latter municipality, there is an extraordinary olive tree of Scorsone of about 1115 years, with a maximum circumference of 10.5 m at the collar.

In the territory of Siracusa, extraordinary olive trees can be found in Buccheri, Noto, and Avola. The most representative are certainly those of the Busulmone district (Noto), which, with a circumference of 12.60 m at the level of the stump and 7.20 m at breast height, are probably 1338 years old (Figure 3f), and those of the area La Gebbia (Avola) with a circumference of 15.50 m at the collar and 10.10 m at breast height.

In the territory of the province of Palermo, considerable olive trees are found in the municipalities of Caltavuturo, Carini, Misilmeri, Palermo, Pollina, San Mauro Castelverde (Figure 3e), and Vicari, where several individuals with very large stumps show maximum circumference values of up to 19 m.

In the province of Trapani, worthy of consideration are several ancient olive trees present in the municipalities of San Vito Lo Capo, Castellammare del Golfo, Castelvetrano, and Trapani, which have maximum circumference values between 3.5 and 12 m.

The secular olives are located at an altitude ranging from 24 to 841 m asl, showing a distribution with an average value of 304 m and a standard deviation of 175 m. The distribution of olive trees across soil types shows no significant effect of substrata, indicating the plasticity of the species. A total of 267 specimens grow on basic lithotypes (limestone, dolomite, marl, gypsum, and calcarenite), and 94 grow on acid lithotypes (vulcanite, flysch, and quartzite).

Only four trees fall within the regional natural reserves, eight are located in Madonie Natural Park, and five are in Nebrodi Natural Park.

Concerning the structure and habit of growth, the tree crown diameter varies from 7 to 15 m and, in the case of irregular shape, ranges from 5 to 13 m in the N–S direction and from 4 to 15 m in the E–W direction. The height of the surveyed plants changes between 5 and 15 m, in relation to the different techniques of pruning or in relation to the state of cultural abandonment or in order to maintain the foliage at a level that allows the grazing of livestock without damaging plant production.

Vegetative and health conditions are excellent in 4.9% of specimens, good in 24.8%, fair in 53.7%, mediocre in 14.4%, and poor in 2.2%.

4. Discussion

The olive tree is a rustic species able to live on different types of soil. Over the centuries, it has been widely spread in all of the provinces of Sicily, from sea level to wherever the climatic conditions have allowed it (about 900 m asl). It has become, over time, the tree that dominates and is one of the most expressive, if not the most expressive, tree of the Sicilian agricultural landscapes, together with the marginally determined manna ash (*Fraxinus angustifolia* Vahl), another species of the same family [48,49].

Traditional olive groves with monumental specimens host a high number of varieties. The importance of this latter genetic resource and the potential it holds for agriculture is also a common element in other European and Mediterranean contexts, as shown by the recent studies on centenary olive trees conducted in several Mediterranean countries [50–55]. The cataloging, characterization, and in situ conservation of secular olive trees is, in fact, a priority to safeguard their genetic, natural, and agricultural value and to protect ancient genotypes threatened with extinction [56,57].

The varietal diversity of olive germplasm in Sicily is represented by 25 cultivars with different features in terms of the morphology, production, and quality of the oil [58].

The surveyed monumental olive trees belong to 11 different cultivars, including the cv. Fastucara, Biancolilla, and Cerasuola in the province of Agrigento, the cv. Ogliarola Messinese in Caltanissetta, the cv. Santagatese and Nocellara Etnea in Catania, and mainly the cv. Moresca in Enna.

In the province of Messina, the monumental specimens mainly belong to the Santagatese cultivar and, to a lesser extent, to the Ogliarola Messinese. In the province of Palermo, in addition to cv. Ogliarola Messinese and Santagatese, there are also some individuals belonging to the cv. Nerba. In Southern Sicily, monumental olive trees are of cv. Tonda Iblea and Moresca in the province of Ragusa and cv. Virdisa or Pizzuta in the

Syracuse area. In the western sector of the island, in the province of Trapani, in addition to the Nocellara del Belice, there are olive trees of cv. Cerasuola, Santagatese, and Tonda Iblea.

These are ancient cultivars grafted onto the wild olive trees that have given rise to irregularly planted olive groves, favoring the natural lay of the soil; several centuries-old plants still survive, cultivated extensively, with generally hollow trunks or with numerous cavities, which constitute microhabitats for vertebrate and invertebrate fauna. To preserve these trees in the best vegetative condition, as far as possible, it is necessary to ensure adequate crop care, including rational pruning, aimed at removing dying branches and aerating the foliage, monitoring and fighting against the agents of wood decay, and contrast, in some cases, to attacks by harmful insects and fungi. For some specimens, located in the Nebrodi mountains, it is also necessary to proceed with the removal of *Viscum album* L. and *Loranthus europaeus* Jacq., two semi-parasitic species that often develop abundantly on the canopy of centuries-old olive trees causing a vegetative decay and subsequently a worsening of the phytosanitary conditions

However, *Olea europaea* is a species characterized by remarkable longevity and by an extraordinary resistance to drought, due to different forms of anatomical and physiological adaptation, so much that it can survive and provide a certain fruit production even in conditions of low rainfall. It also resists fires very well due to its remarkable ability to emit vigorous suckers from the buds present on the stump after the passage of the fire. Therefore, the olive tree can be defined, with good reason, as "a plant that never dies". In this regard, Morettini [59] assigns the qualification of perennial species to the olive tree, observing that "the aerial portion is not perennial [, but] the underground portion it is; it is the base which, expanding into the bases formed by the new trunks that have succeeded over the centuries, replacing [. . .] the oldest ones, retains the vitality and a set of generations of other younger olive trees".

The antiquity of olive growing in the Sicilian territory is testified by several archaeological and historical finds, artifacts, laws, deeds, and inventories, as well as by the numerous toponyms of various places that recall the olive tree (Ogliastro, Marcatagliastro, Alivazza, Ogliastrillo, Madonna dell'Olio, etc.) and, above all, from the discovery of ancient plants and/or stumps. The oldest olive trees found in the Sicilian territory are spread within the areas where the wild variety of the olive tree lives or can potentially live. The latter is an important element of the Mediterranean scrub of which it constitutes particularly expressive formations, settled on the semi-rupestrian stations, both on calcareous and quartzarenitic soils, along the coasts and in the hinterland where the temperature almost never drops below 0 °C [11].

In Sicily, as it is in the rest of the Mediterranean, olive trees are relevant landscape elements because of their considerable economic, cultural, and environmental roles. According to Cancila [60], in the fourteenth century, the olive trees, with the exception of the provinces of Palermo and Catania, did not constitute wide groves; they were spread elements of a mixed agricultural system, very common in the island country. At the end of the fifteenth century, olive growing was also quite widespread in the province of Messina, and considerable development began in other areas of Sicily in the sixteenth century.

Currently, the island's olive trees are mainly grown in semi-intensive or traditional dry systems, both in specialized and mixed cultivation. The landscapes characterized by the olive tree are widespread and diversified in the regional territory in relation to the history of the places and the pedological and microclimatic characteristics and, above all, to the position, which also influenced the cultivation methods (Figure 4).

In hilly and coastal areas of Western and Southern Sicily, in favorable geopedological conditions, specialized olive groves are widespread and, until the mid-twentieth century, constituted a real cornerstone of the rural economy of the island. In addition to having considerable importance for production and a strong identity value for the landscape, the olive grove plays a fundamental role in protecting the soil, especially in areas with higher slopes where older plants are present. It is in these areas that most of the monumental olive trees surveyed in this work have been preserved.

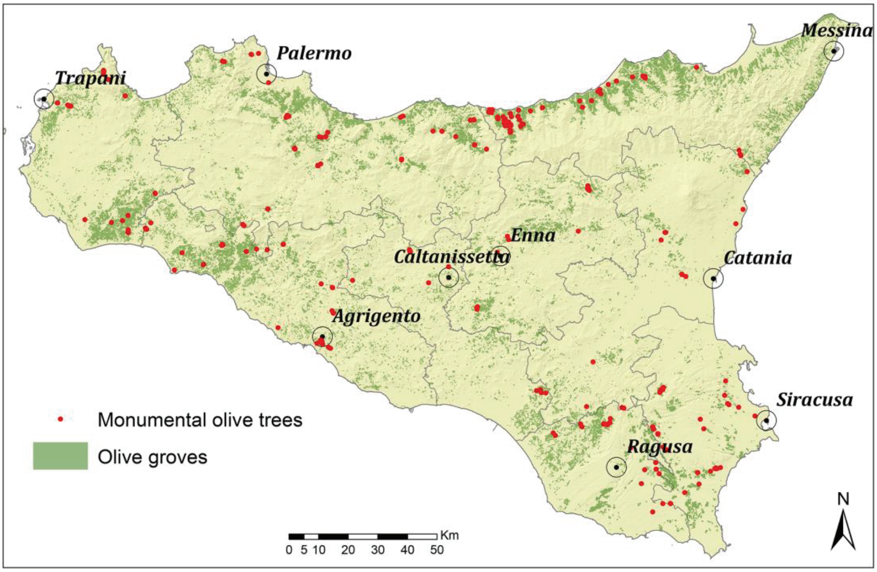

Figure 4. Distribution of the monumental olive trees in the olive Sicilian landscapes.

In coastal areas, especially in Southern and Eastern Sicily, the olive tree represents a characteristic element of mixed agricultural systems together with the carob, almond, and pistachio trees. These systems have been maintained in marginal areas, with often uneven morphologies, where the olive trees are unevenly distributed in the plots. In the traditional groves of the foothills, the individual trees are sometimes protected from erosion thanks to drystone lunettes. In other areas (e.g., in the Etna area), the olive tree can also be found within terraced polycultural systems.

Many olive groves in Northern Sicily, located in the province of Messina and Palermo, within the ancient marquisate of Geraci, date back to the early sixteenth century when the Marquis Ventimiglia allowed the farmers to graft the wild oleasters that grew spontaneously in his fields, letting them become owners of the single trees: this gave origin to a promiscuous property, as the land, where the inhabitants could exercise civic uses, remained in the hands of the feudal lord [60].

Cases of mixed ownership, although less frequent than in the past, are still known both on the Madonie mountains, especially in the territory of Castelbuono, and on the Nebrodi mountains, in the municipality of Tusa. A tangible sign of this anachronistic form of ownership is the engraving on the stem of the initial letter of the tree owner's surname (Figure 5), often highlighted in recent decades with a red painting [43]. The promiscuous property in Sicily concerns only the olive tree and no other cultivated tree species; as a matter of fact, because of its longevity, the olive tree is considered as real estate and therefore transmissible by inheritance.

Furthermore, on the northern side of the Madonie mountains, there is an extraordinary landscape created by the promiscuity of ancient olive trees within the relict manna ash tree grove. In this context, there is no lack of fruit species, such as pear, almond, fig, rowan, apricot, and plum.

In Eastern Sicily, on the slopes and on the Iblean plateau, olive trees spot the fields of wheat or pastures. The landscape of this arbored arable land is marked by an extensive system of fences built with dry stone walls. Inside these, there are ancient and isolated olive, almond, and carob trees, many of which are of extraordinary size and with limited productivity. In this context, the presence of several monumental olive trees is very frequent.

Figure 5. The Olivo di Zimmari (Tusa) engraved on the stem of the initial letter of the tree owner's surname is different from the landowner.

The traditional olive agroecosystems with monumental olive trees constitute peculiar tiles of the expressive Sicilian landscape consisting of a heterogeneous mosaic of agricultural systems and semi-natural systems, more or less fragmented and interspersed with hedges, dry stone walls, and narrow bands of forest species, which result in a high taxonomic and landscape diversity. The presence of monumental olive trees can be considered an indicator of the high biocultural diversity in the landscape and its agroecosystems. These last ones, given their diffusion in Sicily, define territorial mosaics with a high "widespread naturalness" [61], in which extensive agricultural practices are applied with a low environmental impact, compatible with the sustainable management of natural resources. They host rather diversified residual habitats, characterized by species of high conservation interest (e.g., [62–67]) and by a rich flora of ethnobotanical interest that is used for food purposes by local populations [68,69] or for its dyeing properties [70]. Along the margins, there are frequent residues of the ancient *Rhus coriaria* L. cultivation, recently re-evaluated for the antioxidant properties of the fruits [71]. According to Blasi et al. [72], the olive grove is a cultivation that maintains a dynamic link with potential natural vegetation.

The recognition of the value of these landscapes in terms of biodiversity conservation has led Biondi et al. [73] to suggest their inclusion in Annex I of the EEC Directive 92/43, called "Centuries-old olive groves with evergreen *Quercus* spp. and arborescent mattoral" (code 6320), as a priority habitat, considering them peculiar to the Mediterranean region.

The olive tree, with its unmistakable persistent foliage, glaucous green on the upper page and silvery-gray on the lower page, gives itself and its landscape a particular and unusual beauty. In this context, numerous monumental specimens, with their particular shapes and extraordinary dimensions, testify to the slow passing of the centuries and the succession of human generations. For this reason, monumental olive trees can represent the destination or one of the major attractions of naturalistic itineraries within agroecosystems and the "oil routes". These green patriarchs, in fact, can alone constitute the reason for a trip, since they always have something special to offer: their shape, their size, and their age make each of them unique, and visitation of them is a memorable event [44].

From the data reported in this work, it emerges that, throughout the Sicilian territory, the relationship between man and the olive tree is historicized, as can be inferred both from the different signs of material culture, of which centuries-old olive trees constitute an extraordinary testimony and from the historical sources. Their longevity, the longest among cultivated plants, allows for a stratified reading of the contemporary landscape in which these "plant monuments" are the silent witnesses of the transformations of the environment that characterized the Anthropocene.

The monumental olive trees represent the bulwarks of a Mediterranean agricultural landscape that, over the last millennium, in many parts, has undergone limited alterations, at least up to about 60 years ago. In recent decades, this precious heritage, of incomparable historical, landscape, and scientific value, is seriously in danger of disappearing due to the abandonment of cultivation, especially in the hilly and foothills areas on sloping soils and by fires. Therefore, a renewed attention and protection toward these monuments of nature is crucial.

5. Conclusions

The Mediterranean agricultural landscape expressed by the olive tree has unique features, and it is still possible to find numerous monumental individuals in it, extraordinary for their age, shape, and size. They constitute authentic milestones both for the expressiveness they impress on the agricultural landscape, of which they are the significant elements and for the conservation of the precious germplasm of which they are custodians. The monumental olive trees represent, in fact, a reservoir of genetic diversity, which includes characteristics associated with resilience and adaptation to specific environmental conditions and which has allowed for resistance for several centuries, some for over a millennium, to the action of climatic agents, parasitic and anthropogenic activities, and the passage of fire. Therefore, they constitute the best guarantee for the future of olive growing, a sector of agricultural production that is fundamental for maintaining the Mediterranean identity, from an environmental, food, and social point of view.

The survey of secular olive trees, in addition to the considerable interest it holds in the context of the characterization and typification works of the olive-growing heritage, is also important from an eco-touristic point of view, being able to represent the destination or one of the major attractions of naturalistic itineraries within agroecosystems.

On the basis of the results of this paper, the following general recommendations should be taken into account for the conservation of monumental olive trees:

- Start long-term conservation projects beyond the horizon of European Community Policy, aimed at tangible results and more efficient use of financial resources. Monumental olive trees are biological entities depending on human care, and post-project abandonment would undermine the conservation effort;
- Establish a field collection of the germplasm of the Mediterranean monumental olive trees both for conservation purposes and with the aim of coping with climate change due to their extraordinary resilience;
- Promote on-farm germplasm conservation of monumental olive trees, which is an appropriate conservation strategy for this type of biodiversity that is strictly linked to the environmental and cultural contexts of origin;
- Recover and enhance traditional agricultural systems of olives. This approach preserves both agrodiversity and landscape, enhancing rural contexts' tourism attractiveness;

- Recover traditional agricultural knowledge (TAK) in management of secular olive trees, so preserving the associated biocultural heritage;
- Acknowledge monumental olive trees as cultural heritage under UNESCO's normative framework.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13126767/s1. Table S1: List of the 367 monumental olive trees sampled in Sicily.

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sustainability

Article

Transition and Transformation of a Rural Landscape: Abandonment and Rewilding

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Abstract: The concepts of slow environmental change through evolutionary processes associated with ordinary artefacts from Central European rural life as part of biogeographical morphology was studied in Goričko Landscape Park, northeastern Slovenia. The research was based on field observations, including the recording of a former aristocratic dwelling and two small rural farmsteads, all abandoned. An analysis of the extant residual artefacts, their in situ placement and their former utility was undertaken. The value of residual items in ascertaining local perceptions, occupations and utilizations of landscape resources, from various viewpoints, was discussed in relationship to the surrounding landscape. The authors found that the abandoned rural buildings are now utilised as a faunal habitat, and the ruins were reincorporated into the wider landscape. The study sites represent empty places in the process of returning to nature after the retreat of human activities. The research examined the transition and transformation of biodegradable/non-biodegradable components within a rural landscape.

Keywords: abandonment; decay within the rural environment; artefacts; cultural landscapes; landscape transformation; rewilding; human–environment interaction; Slovenia

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1. Introduction

Landscape is defined as "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" [1]. Accordingly, landscape is the interaction of people and the environment, and every landscape, not just the outstanding ones, frame people's lives and define their identity, at local, national and European levels [2]. Therefore, historic natural and cultural features within the landscape can be identified through the cultural meaning features of past human presence and even the ecological remains of past land use.

The majority of European landscapes, particularly rural landscapes, have a cultural origin inextricably linked to agriculture, forestry and livestock [3]. The current socio-economic trends favour land abandonment, industrialisation and conservation policies that support and encourage restoration [4]. As a result, European landscapes have undergone rapid transformation [1]. The marginalization of agriculture and the abandonment of arable land is one of the most important transformations of landscapes in Europe [5]. In many rural areas of Europe, the process of marginalization is of a long duration, and has led to the abandonment of rural settlements and activities [6]. The landscape is transformed into something else, but records the movements and events that pass through it [7]. The different stages of abandonment and post-abandonment sequences reveal complex anthropogenic and natural influences that complicate spatio-temporal concepts of cultural practice within a rural setting [8].

Utility, significance and associations, coupled with generations of experience with familiar landscape features, can be used to capture the ecological and cultural significance of a place in the wider environment. Geographic data with contemporary landscape influences and memories incorporating local experience is fundamental to defining and describing landscape transformation, and can be a good way to synthesise analysis and interpretation.

Although Brook [9] and Given [10] have philosophically explored the complex interaction of biogeographical and cultural elements, this study is possibly the first to attempt an integration of philosophical, socio-cultural and environmental concepts at the landscape level. In this context, a number of concepts have been accepted: 'transition' as the slow act of change through evolutionary processes of use, wear, abandonment and decay, and 'transformation' as the process of physical change and reintegration of materials into the ecosystem within the landscape setting. As environmental evolution under natural conditions is a slow process of transformation, the distinction between interior and exterior boundaries can become blurred as the exterior overlays the interior through structural collapse, and protected objects can resist decay for a period of time, not in the sense of museum curation, but as succinctly described by DeSilvey [11] as in situ "arrested decay". The impacts on rural biodiversity due to land use change, aging populations, and demographic shifts may provide an opportunity to improve habitat availability over past species fragmentation, although this remains a topic of debate, particularly with the anthropogenic maintenance of grasslands and low-intensive agriculture [5,12].

Brook [9] perceived that those who manage the land have an intimate knowledge of their landscape as a co-operative creativity over generations. In order to identify the aspects of historical and social values held locally over generations in the Goričko landscape in northeast of Slovenia, cultural meaning elements were identified as evidence of past human presence and ecological evidence of past land use, according to the concept of landscape. The value of residual items in determining the local perceptions, occupations and use of natural and anthropogenic resources is discussed in relation to the Goričko landscape. The transformation from anthropogenic use to an ecological habitat was explored through socio-economic and environmental changes, and the establishment of new relationships as ecological processes unfolded, particularly the complexity of fluid anthropogenic and faunal relationships either 'in place', i.e., domestication, such as cattle in a barn, or 'out of place', e.g., household-dwelling vermin such as rodents, nesting pine martins and birds [13]. As described by Brook [9], the historical tradition of the landscape can be linked to cultural heritage, and the inhabitants of Goričko value the preservation of traditions and cultural patterns associated with the local landscape [14]. Goričko is a vernacular landscape that has been shaped over millennia by anthropogenic and natural interactions to serve its agricultural purpose. Through this process, one can see in miniature in Goričko the complexity of anthropogenic environments determined by geographic features that have evolved throughout human history.

The research question here aims to explore the intrinsic value of the landscape, including the transformation of dwellings as they transition from anthropogenic use to an ecological habitat and eventually re-enter the environment. This process of creation, use and decay is presented as a cyclical and natural consequence, through material use, occupation, abandonment and reuse. In understanding historical geographies and their relationship to current land use practices, one should remember Darby's words, "the different elements that make up a landscape do not change at the same rate nor at the same time" [15].

2. Materials and Methods

2.1. Study Area and Study Sites

The Goričko Landscape Park was chosen as the study area because it is an example of the landscape characteristics of Central Europe [16–20], an area dominated for many centuries by anthropogenic development for housing, commerce, industry and intensive agriculture, such that the landscape reflects multiple uses, and consequently land use conflicts. Therefore, this typical Central European rural landscape has been formed from several mosaics patterned by the historical and cultural traditions of its inhabitants, local geographical factors and political interventions. The Goričko Landscape Park covers the hilly sector of north-eastern Slovenia, which has developed over a millennium an individual form of land use [14]. In the landscape of Goričko there are seasonally interwoven areas of small orchards, pastures and meadows, vineyards and pumpkin fields fringed by forests, where subsistence agriculture prevails [21]. This landscape is maintained by geopolitical, economic and sociological factors of marginality (i.e., in the Hungarian–Slovenian border region) [22]. In Goričko, most villages are located on hill tops or along ridge lines. The rural architectural style of Goričko, known as 'Pannonian', demonstrates domestic construction dominated by the use of abundant local clay, kneaded between timber planks, used as rammed earth walls, abode and field-fired bricks, although hidden beneath layers of plastering and paint [23]. The older homesteads were either one long, narrow building with adjacent out houses, or 'L' shaped [24,25]. Some were of red brick construction, while others were a mix of brick and abode. Many barns had an intricate open work pattern for cross ventilation. This is indicative of a long cropping tradition in the region. This vernacular architecture is extant in the Goričko landscape, but it is no longer constructed due to modern municipal planning codes.

Within the study area, three sites representing abandoned buildings in the area were selected by the director of the Goričko Landscape Park. These study sites are located in two villages, Ratkovci (Sites 1 and 2) and Prosenjakovci (Site 3) (Figure 1), within the Municipality of Moravske Toplice, which borders Hungary and is an area known for its ethnic Hungarian communities. In Ratkovci, the small population of 54 [26] is scattered along the valley of the Ratkovski potok stream and the road linking Prosenjakovci with the Križevci villages. The shallow valley is dominated by meadows with fields on gentle, sunny slopes and forests at higher elevations. The agricultural holdings are small, with honey production and dairying being the main economic activities. Most villagers are employed in the Prosenjakovci village [27]. The roadside village of Prosenjakovci, lying in the valley of the Ratkovski potok stream, is a larger, closely settled, bilingual village located near the Slovenian–Hungarian border at a significant road junction [27], with a current population of 163 [26]. The surrounding area is cultivated, the fields are dominated by wheat and corn, and livestock breeding is highly developed; the southern slopes are planted with vineyards and the northern portion is covered by forest [28].

Sites 1 and 2 (Figures 2 and 3, respectively) were representative of numerous abandoned farm dwellings built in the Pannonian style, while Site 3 (the Matzenau Manor) represents a feudal recreational residence of the early 19th century ([29] Figure 4) which, through altered use into a working farm and later being socialised, created an alternative perspective of landscape interaction. Rural buildings in Goričko are oriented in the same direction and they are arranged in a row along one or both sides of the road; however, they do not border it and stand equidistant from it [30]. Visually, there has been a natural continuation from earlier centuries as described by Maučec [31], in whose house description there was usually a courtyard, garden, vegetable garden, well and corn rack. Maučec [31] defined Pannonian houses (Sites 1 and 2) in the Prekmurje region as a result of centuries of development, reflecting historical events, social occasions and anthropogenic endeavour in aspects of material and spiritual culture. The Matzenau Manor (Site 3) was constructed in the first third of the 19th century [32] as a seasonal and hunting lodge set in 150 hectares of park and rural land [29].

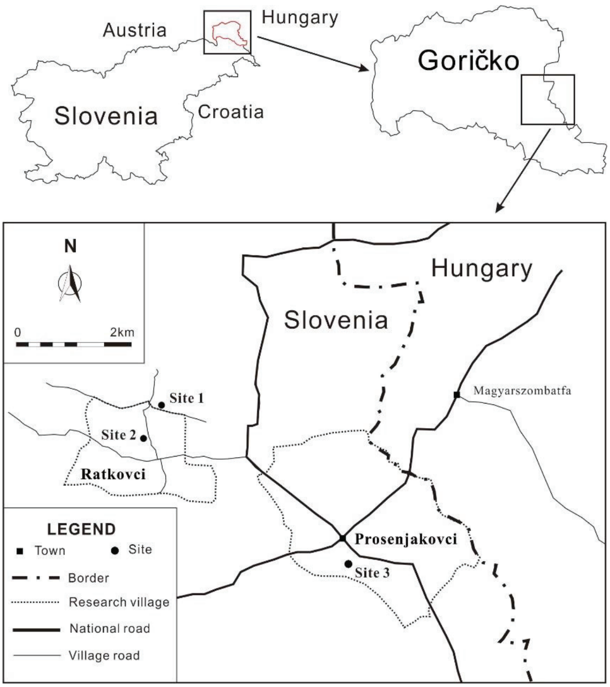

Figure 1. Location of the study area (Goričko Landscape Park) and study sites (Sites 1, 2 and 3).

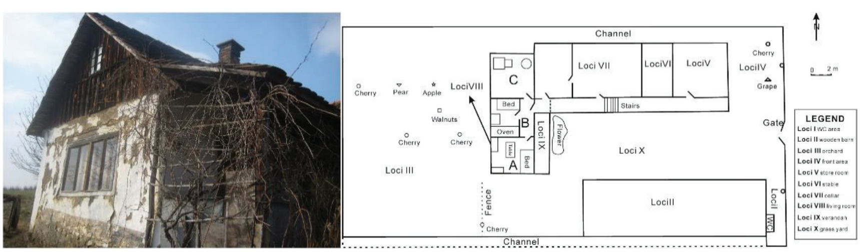

Figure 2. (**Left**) The condition of the abandoned Site 1 (Photograph: Wei Liu). (**Right**) The plan of the farmstead at Site 1.

The farmstead and barn belonging to Site 1 (Figure 2) are clustered and oriented north–south, with an eastern aspect. The kitchen is the central room, with a brick and tiled fireplace occupying almost the entire length of the southern wall. A single window is located in the center of the west wall, providing a view of the orchard. The southern room is a day room/dining room with simple, rustic furniture and utensils. A large window faces south and a smaller window opens onto the eastern veranda. The northern room is partially below ground level, and has an earthen floor and a small east-facing window. The room was apparently a wine-making and storage cellar. A ladder leads to the attic area above.

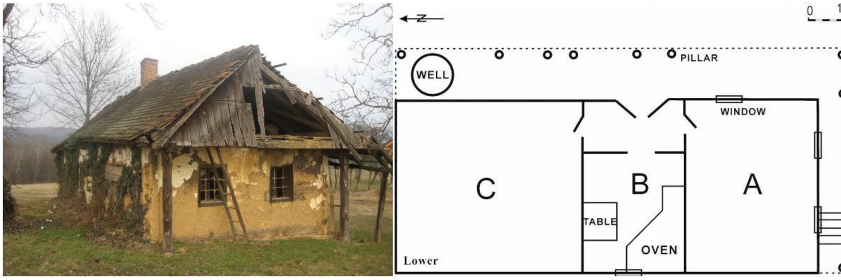

Figure 3. (**Left**) The condition of the abandoned Site 2 (Photograph: Wei Liu). (**Right**) The plan of the farmstead at Site 2.

The farmstead of Site 2 (Figure 3) consists of three rooms: a centrally located kitchen with a very low doorway, to the south a square room with two windows to the south and one to the east, and a northern cellar/storage or workroom with a very small, light opening without glazing in the eastern wall. All of the floors are of beaten earth with an irregular surface. It has a low gable roof with an attic, which previously had two small north and south windows, the remains of which are in the attic. A veranda runs along the eastern side of the building with roughly carved veranda posts and finer carved roof beams. A lintel light is positioned above the twin-paneled wooden front door. The horizontal wall planks had been filled with abode, a clay-water-straw mixture, and covered thickly with the same material and painted with lime paint. An outside ladder leading to the attic is attached to the south wall. A covered well is located under the veranda roof at the northern end.

Figure 4. (**Left**) The condition of the abandoned Site 3 (Photograph: Wei Liu). (**Right**) The plan of the Manor at Site 3.

Double-panelled wooden doors lead into an entrance hall at Site 3. Six ground floor rooms face the front of the building. At the eastern end of the ground floor is a doorway directly facing the well. A wide central hallway with marble terrazzo flooring runs through the middle of the building, separating the reception rooms from the living quarters [33].

2.2. Data Collection and Analysis

The fieldwork was conducted in order to test for the presence or absence of items considered household artefacts (evidence of former human presence), the intrusion of wildlife into residential buildings abandoned by human inhabitants (ecological evidence of former land use), and the rate of reintegration into the wild environment (transformation from anthropogenic use to an ecological habitat).

Firstly, the three abandoned buildings selected in the Goričko Landscape Park (Sites 1, 2 and 3) were assessed, recorded and described in order to identify aspects of their use within the landscape associated with their previous former use, abandonment and re-use as faunal habitats. For this, a combination of visual recording, detailed field notes, building measurements, descriptions and photographic analysis of the three sites was undertaken in the context of their immediate surroundings and the practices of the different land uses. A standard recording form, used for field notes, was developed with the following parameters: site location, site code, geographic description, type of site, salient features, description, and space for a site plan. A second artefact location form with key information for the site was designed, including: the artefact type, material(s), use, condition, signs of use, photographs, damage, mend, patina, artefact location, secondary use, proximity, heirloom, and space for a detailed description. The artefacts were counted and recorded. No artefact was removed from its in situ position, with the exception of the objects excavated from rodent burrows in a 1-m square quadrat. The information collected in the field, using the two forms, was then compared to anecdotal and published sources in order to determine the accuracy of the field observations. A recorded interview with the last member of the Matzenau family, Karolina Zrim, conducted as part of a larger study [33], provided additional information on the historical development of the abandoned Site 3. The data collected was then interpreted in order to provide a conceptual analysis, related to the acceleration of decay due to natural and human interventions, and the establishment of new relationships as an ecological process. Special importance was given to the comparison between the two contrasting environments within the Goričko landscape: the two abandoned farmsteads (Sites 1 and 2) and the ruined Matzenau Manor (Site 3).

3. Results and Discussion

The processes of abandonment defined by Papadopoulos [8] were developed with the unique spatial and temporal conditions of Goričko in mind, rather than as a secondary role in the environmental assessment. It is relevant to note that in this study, the artefacts fell into two distinct categories: farm implements that have received considerable care and long-term use, and family documents that span at least three generations. Within these categories, four types of artefacts were identified: clothing, agricultural equipment, household items (e.g., furniture, pottery), and documentation. For different families (different studied sites) the retention of some items was more highly valued than others. In particular, the mended hay rakes with a high patina from long use were both simple in design and construction, and were also everyday items. The artefacts recorded at both farmsteads (Sites 1 and 2) contrasted significantly. The three sites studied represent different abandonment and post-abandonment sequences. Matzenau Manor was the site that is most consistent with the literature [8]. Both farmsteads were closed on abandonment; the building fabric was decaying. The Site 3, with the surrounding gardens, is an example of a landscape that became, in a sense, common property through serial ownership and utilisation until its final abandonment and subsequent ruination. The long-term environmental impact of all three abandoned sites will depend on the percentage of non-biodegradable material used in their construction and the building's location in the landscape, with slope degree and aspect being of considerable importance.

3.1. Evidence of Former Human Presence

Descriptions of Pannonian houses in much of the literature by Slovenian and foreign recorders differ from author to author (e.g., [21,25,31,33–36]). The two farmsteads recorded (Sites 1 and 2) are closely correlated to the historical descriptions collected by Vugrinec [36]. The dichotomous nature of the recorded artefacts between Sites 1 and 2 was notable, albeit that both sets of artefacts pertained to land use and long-term land tenure. Several features emerged that could prove to be of ethnological value, regarding the psychology of elderly landholders, their value judgments regarding personal items retained over long time periods and physical retraction into rooms occupied at the time of death, landscape transition and cropping characteristics compared with tilling and harvesting techniques, and perceived attitudes to the cultural significance of landscapes. At Site 3 the extant orchards, avenues and fields constituted a record of land utilisation, but no artefacts were found.

3.1.1. Items Considered Household Artefacts in Site 1

Eighteen baskets constructed from corn stalks and leaves, together with willow baskets and a woven willow cart tray, suggested part-time basket manufacturing, possibly a winter season activity conducted with osier willows and crop residues; several chickens were cooped at elevation, indicating local fox predation; three individual pig pens; two donkey carts; cows; sheep or goats were housed in the lower barn compartment, hay loft and hay rakes; and extensive wine making equipment suggest subsistence farming. However, ploughs, scythes or other metal tools were not observed, nor were oil spots on the floors from mechanical machinery. The homestead was situated on a land area of approximately 0.25 ha, but the tools and artefacts observed suggested that formerly a vineyard, crop land and pastures were utilised (Figure 5). Two wine barrels were recorded in the farmstead. The maize residue baskets, pig pens and trugs for feed mixing suggest cultivated fields, while the hay loft, ladder, hay rakes and donkey carts suggest annual hay making, most probably from adjacent grasslands.

Figure 5. Some household artefacts recorded in Site 1. (**Left**) A wine barrel, suggesting a former vineyard use. (**Right**) The treasured hay rake with a high patina on the handle and use wear mends (Photographs: Wei Liu).

The collection of agricultural implements was decayed and worm eaten, and generated—through erasure—a different kind of understanding [11]. One item, however, stood out from the others: a long handled wooden hay rake (Figure 5, Right; Table A1 VI:1), with a polished patina through long use and repeated use wear mends. It was an everyday, common farm implement that had apparently been treasured over a considerable period of time. It was an ephemeral object hanging on a wall nail while the other items were moldering into biodegradable forms of wood rot and dust on the earthen barn floor.

3.1.2. Items Considered Household Artefacts in Site 2

Almost all of the furnishings had been removed from Site 2, leaving only a kitchen table and broken kegs; however, in the context of this site, the extant documents were treated as important artefacts due to their historical richness and time span (Figure 6, Left). Careful excavation of the rodent burrows within a one meter square was conducted in a central area adjacent to the south room's northern wall, which would have been warmed by the kitchen oven and possibly occupied by a bed. From the five entrances, 46 buttons of various sizes, four coins (three Hungarian and one Slovene) (Figure 6, Right), a full plastic envelope of medicines, the rusted top from a kerosene lamp, metal shoe fittings, and a broken belt with small buckle attached were recovered.

Figure 6. Some household artefacts recorded in Site 2. (**Left**) Wind-blown documents and photographs on the kitchen floor. (**Right**), buttons and objects retrieved from rodent burrows in one metre square in the south room (Photographs: Wei Liu).

However, the documentary history of the farm holders, spanning three generations (circa 1906 to 1983), contained in a cardboard shoe box on the kitchen table were of particular value in understanding the former landholder's agricultural activities. The acreage of the land had been recorded and documented: 79 acres of grassland, 199 acres of woodland, 173 acres of cultivated fields, 44 acres of orchard and 9 acres of vineyard (Table A2, I:B xvi), comprising a substantial farm holding. The bean seeds, located in the kitchen table drawer, indicated vegetable cultivation, suggesting an agricultural landscape. The chains in the loft and hanging in the storeroom also suggested oxen-powered ploughing techniques.

The documents, including the prayer book (Table A2, I:A i), were damaged by rodent activity and weathering; however, most were legible. The family's business dealings with the agricultural cooperative, *Kombinat Pomurka*, a Slovenian agricultural cooperative for expensive equipment purchases and insurance cover, signifies a level of affluence not apparent in the abandoned farmhouse. The dichotomy of substantial landholdings and purchasing power in an impoverished homestead is hard to reconcile, unless a show of wealth would induce discrimination within the local socio-political situation.

The encounter of the disarticulation of these cultural artefacts dealing with taxation, births, deaths and marriages, land acquisition, tenure and cultivation engaged in the transition of boundaries [11], in that although they were of archival interest to the recorder, the documents lay outside a spatio-temporal context, without ownership and, therefore, do not pertain to memory or history as they have 'dropped out of social circulation'.

3.2. Ecological Evidence of Former Land Use

The human geography of the agricultural land abandonment in Goričko has opened habitat categories for a variety of expanding faunal geographies.

The dominant feature with regard to post-occupation at both Sites 1 and 2 was the significant presence of a beech marten (*Martes foina*). Beech martens frequently occupy rural areas, using farms opportunistically when they are available but avoiding arable land [37], thus—with the aging of the farmstead buildings—their presence can be assured, particularly in the sparsely populated rural landscape of Goričko. Seed-filled scats were evident and nests had been made in the bedding of the south room and kitchen of Site 1 (Figure 7, Left). Rodent activity was also noted, particularly at Site 2. Mouse traps were recorded in the cellar and rodent holes were observed in the barn rooms at Site 1. Mole (*Talpidae sp.*) mounds were observed in the orchard area and the mummified remains of two bee species, honey bee and bumble bee, were found on the kitchen window sill. Brightly coloured bird feathers, possibly from the European roller (*Coracias garrulus*), were also observed on the end of the single bed in the south room of Site 1.

Figure 7. (**Left**): Faunal presence observed on the bed in the south room of Site 1. (**Right)** Bird's nest on a shelf in the south room of Site 2 (Photographs: Wei Liu).

Many rodent holes at Site 2 had eaten walnut shells adjacent to them, and the leg of the kitchen table showed significant gnawing. Butterfly wings (blue- and black-coloured) were recorded on the kitchen windowsill; black and white bird feathers were found also in the kitchen, and a small bird's nest was located in the south room on the coat rack located behind the door (Figure 7, Right). Guano was observed on the floor below a nail in the ceiling beam. Birds' nests were located at all of the sites.

The Site 3 was rich in faunal evidence. Inside the ruined house, the scats of the European badger (*Meles meles*) were found. Owl pellets were noted in the ash at the bottom of the dining room chimney. The Eurasian wren (*Troglodytes troglodytes*) was visually seen inside the building, and a wasp's wax comb was found adjacent to the badger scat in the central hallway. Within the garden, ten bird species were determined visually or audibly, and the majority of the identified species use nesting hollows that are very common in the garden. Animal footprints and/or scats of the domestic cat, red fox (*Vulpes vulpes*) and European roe deer (*Capreolus capreolus*) were identified, and one European brown hare (*Lepus europeaus*) was visually identified. It seems ironic that three of the species known to be hunted recreationally in the early 19th century—the European badger, European brown hare and European roe deer [38,39]—were now closely associated with the ruins and surrounding parkland.

The orchard at the Site 3 appears to have covered an area of approximately 0.5 ha lying to the north of the building and down a gentle slope which appeared to have been terraced (Figure 8). Very few senescent trees were extant, although seedling plum trees were evident. The area has been heavily invaded by black locust and other forest species, closing the canopy cover and reducing light. The Matzenau estate was rich in both old mature and senescent trees of many species, including some now considered rare in Goričko, and older 'heritage' fruiting varieties within the orchard area that are no longer commercially available. The plane trees in the upper carriage drive have developed numerous hollows suitable for a range of bird species and small mammals. The complexity afforded by the forest encroachment to a range of species with varying maturation rates would attract and provide a habitat for a wide range of hollow-dwelling and nocturnal species. The senescent fruit trees still have limited windfall, but through decayed branches and boles they provide a significant habitat. Ivy-clad tree trunks afford additional small bird habitats and refuges, although the ivy impacts on the long-term viability of the tree species. The provision of habitat through the older tree maturation stages (old mature, senescent and stag) is critical in balancing the loss of these stages in the managed forests of Goričko.

Figure 8. Remnants of old fruit trees in the Manor orchard now invaded by various forest species (Photograph: Wei Liu).

A significant feature at all three sites, albeit on a small scale at the Sites 1 and 2, was the presence of old, mature and senescent trees, which provide invaluable food and habitats (tree hollows) that are not present in the managed forests of Goričko. Conservation efforts to preserve these trees are vital in ensuring ongoing ecological complexity.

3.3. Transformation from Anthropogenic Use to Ecological Habitats

The simplicity of Pannonian house design rests into the landscape rather than dominating it, and the largely biodegradable structural components of Pannonian houses (local clay and timber) facilitate their post-occupation transformation through dereliction and decay into new environmental elements.

Matzenau Manor (Site 3) has a specific ecological function as an island refugia, and it contributes significantly to the objectives of the European Landscape Convention [1], albeit as a relic of former land use. The natural value of the extensive orchard, former vineyards, gardens and avenues provides a diversity of wildlife habitats; these elements act as linkages within the wider landscape, and are of particular importance since the loss of the adjacent wet meadows and the introduction of broad-acre cropping.

The ecological function of the Matzenau Manor, through its sequence of abandonment, decay and collapse in connection with its immediate surroundings, enhances the biodiversity of its locality. There are diverse vegetation patterns with an abundance of mature trees and a complex faunal assemblage. The remnant structural remains function as a refugia and provide unique habitats. It also has a critical role as an adjunct to the adjacent woodland and the ecological corridor created by the tree-lined stream. It seems significant that the Matzenau Manor, orchard and associated avenues intersect the axes of monoculture–diversity and openness–enclosure, wherein a co-existence of ecological, cultural and social island interact.

The utilisation of these abandoned dwellings by wildlife indicated a material transition intrinsically linked to evolving ecologies, as described by DeSilvey [11]. The boundary between the faunal and human habitation of the sites is blurred; the rodent activity probably coincided with habitation, and the beech marten is also frequently associated with inhabited dwellings. Our results also demonstrate that boundaries, therefore, are constantly being redefined until human occupation ceases and the faunal presences animates the habitat through their own modifications, providing another perspective to material forms, as concluded by DeSilvey [11].

The studied landscape and the obtained results can be used for landscape planning purposes, e.g., they can be addressed as a historical landscape and historical landscape elements for management. Changes in landscapes, and thus their transformations, are a fact, and are related to the development of human societies, as Bastian and Walz [40] mentioned. Due to the current socio-economic trends, people are less connected to their land than they were in the past, leading to the abandonment of land practices in rural areas. Agnoletti [4] suggested that this process has also been favoured by agricultural policies, which have encouraged the gradual abandonment of traditional farming systems that are less important from an economic and productive point of view. On the other hand, it is interesting to observe the transformation and transition of former land uses in rural areas to the rewilding of these areas. This is still an under-studied topic. However, this leads to one question: is the revitalization of rural settlements in Europe in our interest, or is the support of nature conservation strategies and restoration of natural habitats? The future of traditional rural landscapes, such as the Goričko landscape, may depend on the answer to this question.

4. Conclusions

The landscape transition and transformation of Goričko Landscape Park is due, in part, to its endurance, the slow transition of evolutionary change over time, and the ecological transformation of materials, most of which are biodegradable, from one form to another. The biotic components of the landscape have blurred boundaries. Ecologically, the abandoned houses offer the possibility of habitat restoration for wildlife species. The social and cultural impact of objects, rural dwellings, or the items they contain is not limited only to their preservation or persistence, but also their destruction, which facilitates the circulation of matter through the energy pathways of ecosystems and landscapes. These natural processes dichotomise nature and culture as they decay, and can reinforce different associations through action, closure and continuity. The three sites studied represent empty places in the process of returning to nature after the retreat of human activities. No general conclusions can be drawn from these three specific cases, but they may provide suggestions for future research.

At the end of the 20th century, some of the world's most progressive environmental protection legislation was passed in Europe, based on the concept of human-induced environmental degradation and the need to restore a 'natural state'. This has led to a neglect of the diverse resources that rural landscapes provide. Although it is beyond the scope of this study, future studies could analyse the difference between the biodiversity of traditional rural landscapes (associated with agricultural biodiversity) and the biodiversity of abandoned rural landscapes. This would help to define the appropriate strategies for European landscape development.

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Appendix A

Table A1. The range of artefacts associated with Site 1.

Register Number	Artefact Type	Description
II:1	Trug	A movable wooden feed trough on runners in poor condition due to woodworm
II:4	Donkey carts (2)	One larger with willow woven tray, axles of both worm eaten However, the wheels (of beech or black locust) were in good condition
II:5	Wooden ladder	Extensive patina indicating long use, positioned to provide access to the hay loft
VI:1	Hay rake	Extensive patina, wear and mends indicated long use
VIII:1	Stool	Wooden stool with patina in fair condition
VIII:2	Amphora (2)	Pottery amphora simple external decoration, broken flange rims, internal glaze one minus handle and has string substitute
VIII:3	Copper bowl	Part of an alcohol distillation plant
VIII:4	Wine keg	Oak keg in good condition
IX:1	Wooden bench	Finely crafted pine bench with doweling joints, minor nail mends
IX:2	Oak chairs (2)	Hand crafted chairs in good condition

Table A2. The range of artefacts associated with Site 2.

Register Number	Artefact Type	Description
I:A i	Prayer book	An Evangelical volume with owners' signatures inside the front cover, dated 1906, eaten by mice
I:A ii	Religious calendar	An Evangelical calendar dated 1965
I:A iii	Religious calendar	An Evangelical calendar dated 1972
I:A iv	Coins	Three Hungarian coins and one Slovene coin
I:B i	Religious calendar	An Evangelical calendar dated 1974
I:B ii	Tax receipt	For the year 1924 addressed to Ivanševci 35
I:B iii	Photograph	Document size, male portrait
I:B iv	Doctor's notice (three)	Dated 1969 for a broken wrist. Three documents in total
I:B v	Income tax booklet	Dated 1951
I:B vi	Newspaper fragment	Dated 1983 very poor condition
I:B vii	Cash benefit	Dated 1969, kombinat Pomurka
I:B viii	Extract from Marriage Register	Dated 1913, Ivan Grabar married Franciška Hujs
I:B ix	Envelope	Notation, not dated
I:B x	Doctor's notice	Dated 1969 for a broken wrist
I:B xi	Co-operative pass	Dated 1946
I:B xii	Goods receipt	Dated 1969, kombinat Pomurka
I:B xiii	Tax receipt	Dated 1969
I:B xiv	Prescription medicine	Lanitop packet containing tablets
I:B xv	Tax receipt	Dated 1922, addressed to Ivanševci 35
I:B xvi	Land survey	Undated, written by hand a summary of agricultural land
I:B xvii	Tax receipt	Dated 1923, addressed to Lončarovci 48
I:B xviii	Tax receipt	Dated 1922, addressed to Lončarovci 48
I:B xix	Tax receipt	Dated 1924, addressed to Ivanševci 35
I:B xx	Tax receipt	Dated 1925, addressed to Lončarovci 48
I:B xxi	Tax receipt	Dated 1924, addressed to Lončarovci 48

Table A2. *Cont.*

Register Number	Artefact Type	Description
I:B xxii	Tax receipt	Dated 1922, addressed to Lončarvci 48
I:B xxiii	Official envelope	Dispatched from Murska Sobota, stamped, addressed to Josip Hujs
I:B xxiv	Document	Dated 1977, a decision on tax payments, eaten by mice
I:B xxv	Tax receipt	Dated 1921, for both addresses: Lončarovci 48 & Ivanševci 35
I:B xxvi	Goods receipt	Undated, for cellulose (plastic?), kombinat Pomurka
I:B xxvii	Tax receipt	Dated 1968
I:B xxviii	Contract	Dated 1965, kombinat Pomurka, an agri-industrial combine (purchase?)
I:B xxix	Tax receipt	Dated 1923, addressed to Lončarovci 48
I:B xxx	Tax receipt	Dated 1925, addressed to Ivanševci 35
I:B xxxi	Tax receipt	Undated, addressed to Lončarovci 54
I:B xxxii	Tax receipt	Dated 1922, addressed to Ivanševci 35
I:B xxxiii	Tax receipt	Dated 1923, addressed to Lončarovci 48
I:B xxxiv	Land survey	Undated summary of agricultural land
I:B xxxv	Death certificate	Dated 1961, for Ivan Grabar
I:B xxxvi	Instructions	Undated, in the case of natural disaster
I:B xxxvii	Cash benefit	Undated, kombinat Pomurka
I:B xxxviii	Account book	Undated, agricultural co-operative
I:B xxxix	Certificate	Undated, Agricultural producers' insurance
IB xl	seeds	Approximately 1000 been seeds, unviable

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Managing the Historical Agricultural Landscape in the Sicilian Anthropocene Context. The Landscape of the Valley of the Temples as a Time Capsule

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Abstract: The debate over whether we are entering the Anthropocene Epoch focuses on the unequal consumption of the Earth system's resources at the expense of nature's regenerative abilities. To find a new point of balance with nature, it is useful to look back in time to understand how the so-called "Great Acceleration"—the surge in the consumption of the planet's resources—hastened the arrival of the Anthropocene. Some particular places—for various reasons—survived the Great Acceleration and, as time capsules, have preserved more or less intact some landscape features that have disappeared elsewhere. How can we enhance these living archives that have come down to us? Through the analysis of the case study of the Valley of the Temples in Agrigento (Sicily, Italy), the article presents several initiatives that have tried to answer this question. For example, the pre-Anthropocene landscape of the Valley of the Temples has preserved rare specimens of some plant species from which living gene banks have been built for the propagation of species, such as the Living Museum of the Almond Tree. In addition, the Kolymbethra, an ancient example of a Mediterranean garden, has been brought back to life revealing finds related to Greek and Arab cultivation and irrigation systems. The research perspectives opened by the "disappeared landscapes" show that the knowledge of the historical landscape, in particular the mechanisms behind its resilience, is indispensable for countering the unsustainable voracity of the Anthropocene and rediscover a renewed synergy between humankind and nature.

Keywords: landscape; Anthropocene; Valle dei Templi; sustainable development; territorial planning; cultural heritage; archaeological heritage; local development; Agrigento; Kolymbethra

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1. Introduction

The debate about the consequences of entering the Anthropocene Epoch [1] is at the centre of the reflections of many researchers who have dedicated themselves to analysing the dynamics of humankind's use and consumption of resources at the expense of nature's regenerative abilities, adopting lifestyles that have long proved unsustainable. The landscapes of the Anthropocene are the product of the humankind's predatory attitude towards the environment [2] which, especially since the Great Acceleration [3], has broken the ecosystem's balance with nature and will eventually overwhelm the thresholds of the planet's limits, beyond which unforeseeable chain reactions and potentially catastrophic scenarios will likely occur [4].

As Barbera [5] states, it is possible to find answers to the questions of the Anthropocene by looking to the landscape. The analysis of human–landscape interactions in Anthropocene landscapes is an essential interpretative key for better understanding the evolution of our current environment and can provide useful information on the phenomena that gave rise to the Anthropocene. In this context, agriculture is at the centre of human interference in natural cycles; therefore, profound reforms in agriculture and food systems [6] will need to be achieved in the coming years if we want to live within the boundaries of the planet, acting within what Rockström defines as a "safe operating space for humanity" [4].

Finding a point of balance with nature does not necessarily mean returning to a pre-disturbance stage, but rather finding new ecosystem balances [7]. The study of traditional agricultural systems [8], the subject of disciplines such as landscape archaeology and historical ecology, is particularly useful in the search for principles upon which to establish new human–environment balances [9,10]. It might also be useful to look back to the past to understand how the Great Acceleration gave a boost to the Anthropocene. Evaluating the signs of our domination is already the beginning of change and, in this sense, reading the "vanished landscapes" can help us start this process.

This article describes one of the complex and multi-specific landscapes still surviving in Italy, recorded in the National Register of Historical Rural Landscapes [11]. Some landscapes, in fact, characterised by a fine-grained polycultural mosaic, constitute living archives of exceptional value for the conservation of biodiversity. Among these, just to mention the best known, there are the "Terraced and irrigated chestnut groves and vegetable gardens in Alta Valle Sturia" (Liguria, Northern Italy); the "Landscape mosaic of Montalbano" (Tuscany, Central Italy); the "Polycultures of Loretello" (Marche, Central Italy); the "Mixed hill cultures of the lower Irpinia", the "Terraced orchard-gardens of the hills of Naples" (Campania, Southern Italy); the "Polyculture on the slopes of Mt. Etna" and the "Mixed orchards of the Temples Valley" (Sicily, Southern Italy) [12].

The latter is an exceptional pre-Anthropocene landscape, that is, a case in which a particular regime of constraints has safeguarded a wide territorial environment, preventing its transformation precisely at the start of the period of the Great Acceleration.

The Valley of the Temples in Agrigento (Sicily, Italy) is an archaeological area subject to landscape constraints since the mid-1960s and which extends over an area of more than 1400 hectares. This area, removed from the transformation processes by these constraints, has remained marginalised from the general evolution of the local area. Thus, in this space, traces of dormant landscapes that have disappeared elsewhere have been preserved as real "reserves of history" which are an important point of reference for evaluating the effects of the Anthropocene. The environments that have been preserved allow both to bring back to life animal and plant species that are rare elsewhere, and to revive artisanal and pre-industrial agricultural production systems together with their internal eco-sustainability.

The case analysed makes it possible to critically rethink consolidated development paradigms and to search for new ways of using and consuming the territory's resources in terms of contents, values and potential. The landscape of the Valley has been enhanced as a natural and cultural ecosystem through a series of initiatives that constitute good practices in land management. The establishment of the *Living Museum of the Almond Tree* (a genetic bank for the conservation of the intraspecific biodiversity of the species), the restoration of the *Kolymbethra Garden* (an agricultural area that had been forgotten for over 50 years and, like a message in a bottle or a time capsule, survived through the years of the Great Acceleration in a state of apparent death) and other initiatives carried out in the Valley of the Temples, with the help of agricultural techniques which evolved over the centuries for the cultivation of this specific territory and which we have inherited from the knowledge of the local elderly farmers, have awakened the agricultural landscape from a long sleep.

Thanks to the extraordinary resilience of nature, supported by the historical explorations of 'placed environmental knowledge' [13], it has been possible to save rare plant species that enrich the biodiversity of the landscape from extinction. Through the analysis and comparison of the biodiversity of past and present landscapes, in the case in question as elsewhere in similar situations, specific sites are, effectively, archives that provide valuable information from the past that we must learn how to implement and update for a virtuous combination of human environmental transformation and sustainable ecological models of wise use of the territory.

2. Levels of Awareness of the Ecological Footprint of Humankind in the Anthropocene

The intense changes that humanity has imposed, and continues to impose with exponential speed, on the Earth system are pushing us to search for new models of interpretation of the reality that surrounds us and for different ways of using the planet's resources.

Climate change, famine and migration, pollution are the by-products of these changes that have now taken on an epochal dimension [14]. In this regard, Crutzen and Stoermer's [1] studies evaluating of the impact of human-induced transformations on global ecology are well known. In his article "Geology of Mankind" [15], Crutzen highlighted how the human species has become a geological force in the sense that the effects of its activities are comparable to those of natural processes, a thesis that has recently been confirmed and supported by others [16]. In view of these processes, Crutzen put forward the proposal to integrate the current geological epoch, the Holocene, with a new era which he suggested calling "Anthropocene", that is, a geological age dominated by humans. Currently, the *Anthropocene Working Group*—a group of experts appointed by the International Subcommittee on Quaternary Stratigraphy of the International Union of Geological Sciences—has been working since 2009 to gather scientific evidence in order to formally ratify the Anthropocene as an epoch within the geological time scale [17].

The studies by Steffen, Crutzen and McNeill, starting from the postulate that the industrial era (1800–1945) marked the first phase of the Anthropocene, identify a second phase marked by what is called the "Great Acceleration", that is, a rapid and pervasive change in human–environment relations that occurred after the end of the Second World War. To measure the phenomena of global change, the authors considered the following indicators: population, total real GDP, direct foreign investment, the damming of rivers, water use, fertiliser consumption, urban population, paper consumption, McDonald's restaurants, transport (motor vehicles), communication (telephones), international tourism [3]. All indicators recorded a dramatic surge in values starting from the 1950s.

A decade later, studies carried out by McNeill and Engelke [16] have reported the planet's resource consumption data since the Great Acceleration, figures that have increased ten-fold in just over half a century. Thus, an awareness has emerged that the consumption dynamics of the Anthropocene have definitively transformed the resources of nature into the limits of development.

The limits to Growth were announced in 1972 by the Club of Rome [18]. The group of environmental and Earth system scholars led by Rockström and Steffen added, in 2009, the "limits of the planet". Exceeding the thresholds could also affect mutually related parameters and trigger additive consequences, non-linear systemic feedbacks and unpredictable chain reactions [5].

The Great Acceleration cannot, and must not, last much longer. From this awareness—according to the interpretation of McNeill and Engelke [16]—began the third phase of the Anthropocene, around 2015, a turning point that has shaken our consciences towards the sustainable management of the planet's resources. We can trace the beginnings of this turning point to the 1960s, when environmentalism was born and then later, in the 1980s, when rising temperatures confirmed global warming as a reality.

In the third phase of the Anthropocene, it is universally recognised that human activities influence the structures and functioning of the Earth system as a whole (a vision that opposes the searching for solutions to environmental problems on a local or sectoral scale). Despite the general sharing of this dangerous drift of the current development model, state governments still do not prove themselves sufficiently committed to adopting measures to reduce, mitigate or offset the effects [19,20]. Rockström's studies highlight that it is very difficult to re-establish "a safe operating space" [21–23] for human activities due to the fact that prevailing economic and political paradigms do not pay adequate attention to environmental issues [4].

As Barbera has observed [5], due to the harmful effects caused by the Great Acceleration which had transformed nature from a resource to a limit, the sudden leap forward in human activities in the second half of the twentieth century led to many limits being surpassed, altering the planet's bio-geophysical processes and ecosystem relations. Faced with the complexity of the problem, Barbera indicates that we must seek solutions through an integrated multidisciplinary approach, hoping for the necessary convergence of scientific and humanistic knowledge, and address the issue in global and systemic terms, i.e., at the scale of the entire planet and referring to all its inhabitants (humans, plants, animals). In the systemic vision, says Barbera, the landscape is the set of characteristics of a territory, a meeting place between nature and history, an ecosystem capable of producing negative entropy and restoring order in the dissipative disorder of the Anthropocene.

3. Managing Anthropocene Landscapes

The increase in resource consumption during the Great Acceleration caused a progressive increase in intensive agriculture, industrialisation and urbanisation which transformed natural landscapes by changing the topography, vegetation cover, physical and chemical properties of the soil and water balances, thus inducing large changes in sediment and nutrient retention [24].

The analysis of human–nature interactions in Anthropocene landscapes is an essential interpretative key to better understand the evolution of our current environment [25]. In this context, agriculture is at the centre of human interference in natural cycles (phosphorus, nitrogen, water, etc.); it is therefore necessary to change agri–food systems in the coming years if we want to live within the boundaries of the planet [4].

Mick Lennon [7] warns that it is not possible to manage Anthropocene landscapes by returning degraded ecosystems to a pre-disturbance reference point [16]. The climatic, geological and ecological environments of ecosystems have profoundly changed in the Anthropocene. He therefore proposes the concept of "new ecosystems", that is, the composition of configurations of non-historical species that arise due to the environmental change of the Anthropocene, a self-evolutionary response of the biosphere to human influence [7].

Since species follow the mechanisms of the theory of evolution, we could extend the concept to agriculture, land cultivation techniques, land uses, production and resource consumption patterns; it will be necessary to select from the past which of these have proven to be the best in terms of sustainable development and review them to update them in new configurations.

The management of the agricultural landscape in its Anthropocene transition must also be considered, as Barbera [5] observes, on the basis of the multiple benefits it provides to humankind. The author therefore proposes to define the notion of landscape not in the sense of a set of interacting ecosystems, but in the sense of cultural landscape, that is, as a combined work of nature and human beings. The landscape, therefore, concerns not only the physical, chemical and biological aspects of the biosphere but also the culture of the populations, their needs—material and immaterial—meanings, symbols, artistic expressions, etc.

4. Materials and Methods

4.1. The Valley of the Temples of Agrigento as a Case Study

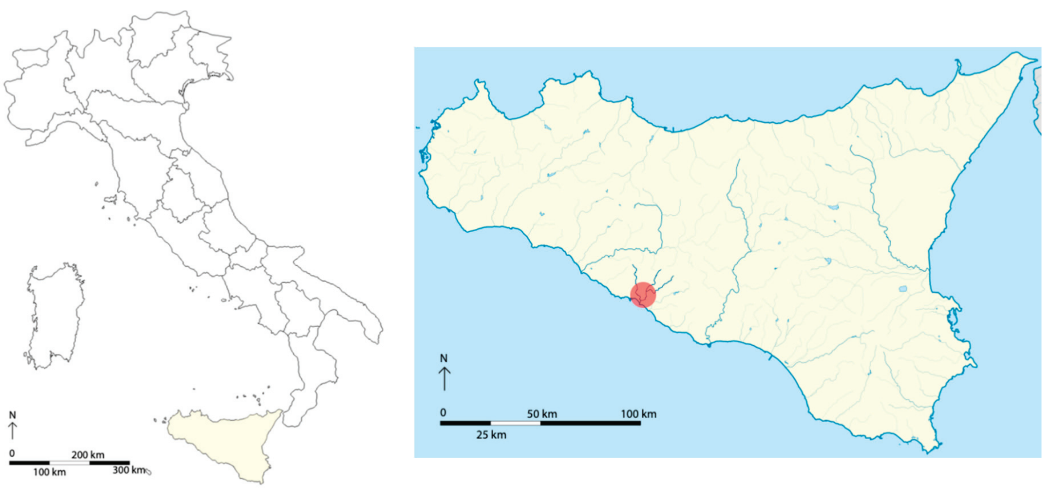
As an antidote to predatory Anthropocentrism, several authors have insisted on the urgent need to change current development models. Respecting the limits of the planet is the only way, according to Rockström, that we can enter what he calls "the good Anthropocene" [26].

"Neoanthropocene" is the term with which Carta proposes a new way of inhabiting the Earth, or a transition towards a new, more sensitive and responsible humanism based on the principles of social justice, coexistence of peoples and species, sharing, the circular economy, recycling and radical ecology [27].

Barbera uses the holistic interpretative categories of the landscape as a natural and cultural ecosystem to propose a radical transformation of our way of thinking and, consequently, of using the planet's resources. To address the issues of territorial development, he argues that "through the landscape (its government, its project) one can seek and find answers to the questions of the Anthropocene" [5], p. 11 (author's translation).

It might also be useful to heed the reflections of McNeill and Engelke [16], who suggest looking back to try to understand what brought us to the current situation and how the Great Acceleration gave a boost to the Anthropocene. A case study that allows us to analyse a landscape of the past is the archaeological site of the Valley of the Temples in Agrigento. This case study is reported because (unlike the contexts in which landscape archaeology or palaeobotany is practised) living ecosystems have been preserved there which have stratified over the centuries and have not been irreparably overwhelmed and devastated by the Great Acceleration.

The name Valley of the Temples indicates what was once the area of the Greek city of Akragas, founded at the beginning of the 6th century BC (581 BC) by Rhodesian–Cretan settlers along the southern coast of western Sicily (Figure 1), which extended for about 456 ha between the Girgenti Hill and Rupe Atenea to the north and the plateau delimited by the sacred road to the south, on a territory crossed by the two rivers, the Akragas and Hypsas.



(**a**) (**b**)

Figure 1. (**a**) Location of Sicily (Italy) in the Mediterranean Sea; (**b**) topographic map of Sicily with the hydrographic network. The archaeological site of Akragas, between the Akragas and Hypsas rivers, is in red.

The place where the city was founded was chosen based on political and landscape considerations. The site is located halfway between Selinus and Gela, colonies founded, respectively, by Greeks from Attica and Rhodian–Cretan populations. The two cities, both Greek colonies but enemies because they belonged to different lineages, were among the most powerful in Sicily in the 6th century BC, and they tended to expand their range of territorial influence more and more. The city of Gela founded Akragas to stem the expansionist aims of Selinus, but in a short time the subcolony became much larger, more populous, richer and more powerful than the mother city, experiencing its maximum splendour in the classical period (5th century BC) with an estimated population of 300,000 inhabitants.

From the landscape point of view, the site chosen for the foundation of Akragas has ideal morphological characteristics for the expansion of the city, for its defence and control of the territory (Figure 2). Most of the urban centre was built on a gently sloping southwestern plateau bordered to the south by a high vertical rock face rising from a plain at sea level. Six temples were built on top of the terminal edge of the plateau (including the monumental Olympieion which, with its 112.70 m at the stylobate, is the largest temple in the Hellenised world). The purpose of this placement of the temples on the edge of the rocky ridge was to show all the power and wealth of the city to intimidate any enemies that came from the sea (at the time the only access route to the territory) and to increase the monumentality and visibility of the temples.

Figure 2. Akragas: reconstruction from photointerpretation (Schmiedt and Griffo), published in *Urbanistica*, n. 48, 1966, tav. 4. The map is north-oriented.

The inclination of the plateau, on which the layout of the city was traced according to the "Hippodamian Plan", was favourable to the disposal of waters which, with an ingenious underground water system, flowed into a retention basin. The acropolis dominated the inhabited area, built on the Girgenti hill which, at 800 m above sea level, stood out on the plateau and on the marine horizon.

The city was close to the sea but at a safe distance that allowed the enemy to be seen in time to activate defences. The connection with the sea for the transport of goods to be marketed in the Mediterranean Sea was ensured by the two rivers that bordering the city, ensuring all the advantages of a maritime city.

An imposing circuit of walls surrounded the entire city; the walls were built using the southern rocky ridge, the Girgenti hill and the Rupe Atenea to the north, taking advantage of the natural gradients connected by massive walls.

The surface delimited by the walls thus built, about 456 ha, was not entirely occupied by buildings; in fact, the steeper or more peripheral parts were used for agriculture and arboriculture. A peri-urban landscape made up of cultivated fields and fruit orchards alternating with wooded areas was already present in the ancient polycultural landscape located in the peri-urban areas of the island of Crete—motherland of Akragas—during the 4-3 millennium BC [12]. Furthermore, the presence of centuries-old olive trees within the city and next to the temples (Figures 3 and 4) can, most likely, testify to the sacred character attributed to the tree as a divine gift to humanity [28].

Figure 3. Archaeological Park of the Valley of the Temples in Agrigento. Remains of the Olympieion mixed with the vegetation. The most represented tree species are the olive, almond, carob and pistachio.

The presence of a rock sanctuary dedicated to Demeter, goddess of nature who presided over the crops and harvesting, testifies to the cultivation of cereals, a characteristic of ancient Greek food traditions. The agricultural landscape in classical Greek times also included grazing areas; the decorations of numerous vases found at the site depict horses, and the breeding of horses for military and sporting purposes (participation in the Olympic Games) is also referenced in numerous literary sources (Diodorus Siculus, *Bibliotheca Historica*; Virgilio, *Aeneide*; Pindaro, *VI Pitica* and *III Isthmica*).

The inclusion of the city of Akragas in the Sicilian coastal landscape reached admirable levels of harmony and integration with nature which testifies, once again, to the great sensitivity to the landscape and the technical skills achieved by the Greek colonists.

The city's heyday ended with its defeat inflicted by the Carthaginians in 406 BC. The city was almost completely destroyed and, in 339, was partially rebuilt and repopulated, without ever reaching the glories of the classical period. The history of the Greek colony ends in 210 BC with the Roman conquest during the second Punic War [29–34].

The city gradually lost importance after the Roman conquest until it was reduced, in the Middle Ages, to a small urban settlement perched on Girgenti Hill. The current urban settlement, Agrigento, is much smaller than the Greek city and has just over 55,000 inhabitants.

Figure 4. Archaeological Park of the Valley of the Temples in Agrigento. Stenopos between the agora and the sacred road. Remains of the forest of almond and olive trees.

After the fall of Akgragas, the history of the agricultural landscape of the Greek colony follows the fate of the Sicilian landscape. Having become the first Roman province in the 3rd century, Sicily was exploited for the production of extensive wheat-based crops, for the breeding of animals (and therefore large areas were set aside for grazing), for the production of wine. The region was heavily plundered as all these products were not intended for local consumption but were transported on ships to Rome. With the spread of extensive crops, the new agricultural landscape design was the "*latifundum*" (large estate).

A long period of increased humidity during the last centuries of the Roman period (IV-VI century) favoured the agrarian economy in Sicily until the late Roman–Byzantine period [35]. A sudden climatic shift towards aridity, which took place in 750 AD, caused a change in the hydrological conditions with a consequent general socio-economic decline. The consequent weakening of the Byzantine communities made them particularly vulnerable to the Islamic conquest, which took place between 827 and 878 AD. As Ferrara describes,

> "with the arrival of the Arabs on the island, an authentic agrarian revolution began: introduction of new crops, innovative soil improvement techniques and hydraulic systems which contributed to a better use of water resources, a temporal and spatial differentiation of production and a more integrated view of the agricultural system in all its components (irrigation, energy, micro-climate and aesthetic functions): a completely different approach to agriculture which, for its holistic nature, could be indeed defined as agroecology. Such structural revolution marked deeply the Sicilian agrarian landscape; it was the beginning of the *coltura promiscua* system, based on an authentic intercropping of the fruit trees" [35], p. 140.

The Arabs imported, in particular, citrus fruits which began to spread throughout the Mediterranean. Their presence contributed to the modification and enrichment of the characteristics of the Mediterranean landscape. The Arabs also introduced irrigation systems so efficient that they could greatly increase the irrigable land, replacing extensive cultivation with intensive cultivation. Even today in the Sicilian countryside, spared from the frenetic rush toward modernisation, there are remains of the ancient Arab irrigation systems that in Sicily have become so integrated into the local culture that they have also taken on names in various local dialects (*saie, cunnutti, gebbie*, etc.). Even today, some of the older farmers remember how they used to work.

The Norman conquest of Sicily and the subjugation of the Arabs led, starting from the late Middle Ages, to the feudal structuring of the society and, consequently, to the return to agricultural management based on the *latifundum*, marking a substantial regression in agricultural production compared to the Arab restructuring.

Mediterranean landscapes increased their biodiversity again when new species were introduced by the conquest of the American continent: the most important for its impact on the natural and rural landscape of Sicily was the prickly pear [12].

The structuring of agricultural production imposed on Sicily by the Romans with the large estates continued to persist until the 20th century, when agricultural mechanisation also began in Sicily. Immediately after the First World War, the Fascist regime tried to revive the ancient Roman concept of Sicily as the "granary of Italy", but the large-scale cultivation of wheat was not well managed and impoverished the soil [35].

The large estate system was officially dismantled after World War II, but the new land system, based on small private ownership, was unable to provide peasants with sufficient means. All this indicates that agriculture in Sicily, despite the good quality of its soil and the favourable climate, does not form a solid basis for economic development for individual agricultural entrepreneurs. Furthermore, after the abolition of the feudal system and the mechanisation of agriculture, civil uses and customary rights were progressively abolished and the common lands, which were used by the resident population for both grazing and wood harvesting and temporary cultivation, were sold to private individuals [36].

For centuries, the area occupied by the ancient Greek city of Akragas, the current archaeological area, was considered the land of the *civita*, that is, an area available to the citizens of Agrigento. The land, which in Greek times was occupied by residential and public buildings, was used for agriculture. This equilibrium was broken when the city entered the vortex of the Great Acceleration, that is, in the post-Second World War period when the predominantly agricultural economy of Agrigento, based on the cultivation of small plots of land by individual farmers, was supplanted by a form of development based mainly on construction, producing one of the riskiest situations in Italy due to unproductive, illegal and speculative land use [32,37,38].

In 1966 a landslide [39], which affected part of the historic centre of Agrigento, showed that the urban overload, in many ways illegal, carried out between the 1950s and 1960s [40] had exceeded the carrying capacity of the soil. This distorted form of economic development

> "has taken on the forms of parasitic speculation which have reached an aberrant extent in this city; the rights of nature and history have been trampled on, the physical and historical characteristics of our country have been ignored (. . .). The work was done in such a monstrous way that the landslide that engulfed a third of the City of Temples appeared as an inevitable, indeed coherent, reaction of nature (. . .) to the way in which its laws have been ignored or trampled on" [41], p. 58; author's translation.

The calamitous event, unexpected but perhaps foreseeable, changed the course of the history of the Valley: the Italian government subjected the area to archaeological and landscape constraints. The limitations on indiscriminate uses of the territory and construction have safeguarded the territory from the risk of succumbing to the speculative and dissipative uses of the predatory Anthropocene.

The constraints cover both the areas involved in the archaeological finds and the surrounding agricultural landscape for a total of approximately 1450 ha. The coexistence of the archaeological constraints with the landscape constraints affirms the unity of a cultural heritage in which art and nature are inseparably intertwined and recalls the need to safeguard and restore every historicised element of the territory as an inseparable whole.

In 1997, the Valley of the Temples was declared to be the cultural heritage of humanity and was included in the World Heritage List (WHL) of UNESCO; it is one of the largest archaeological sites currently registered, with a total area of 2803 ha (including boundaries and buffer zones) (Figure 5).

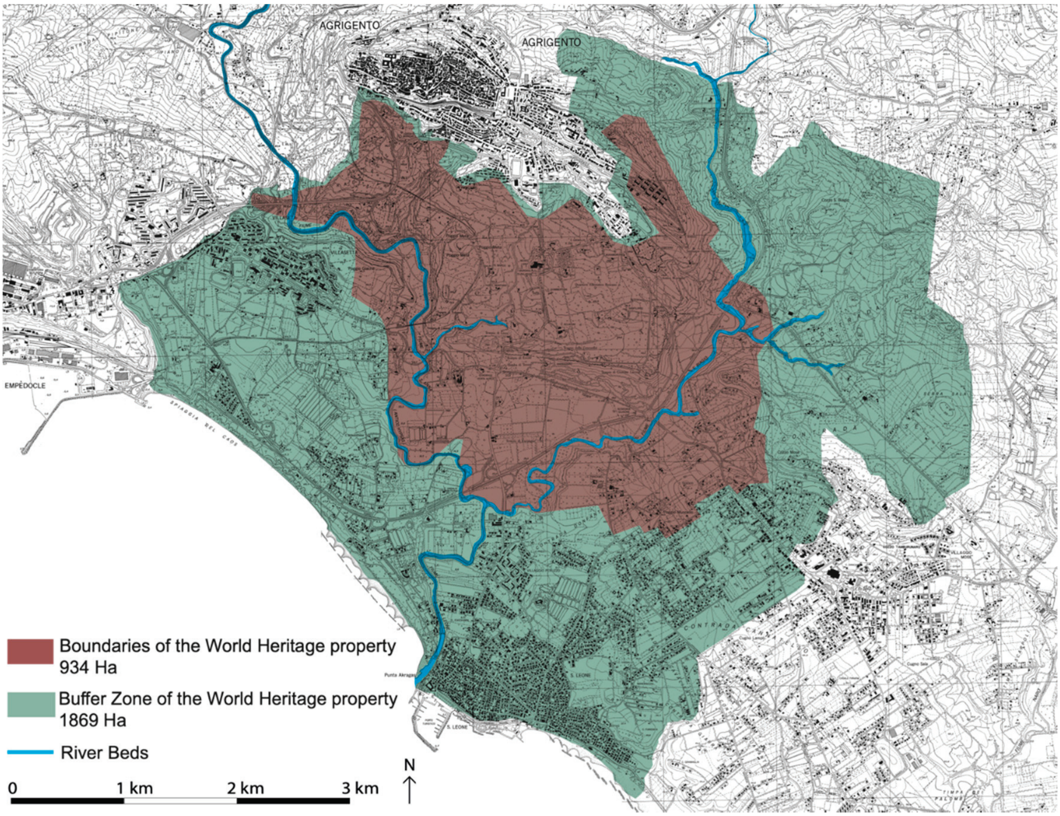


Figure 5. Boundaries of the area of the Valley of the Temples registered in the WHL of UNESCO and the buffer zone.

The effect produced by the constraints became evident in the long term, when the difference in quality between the protected area and the surroundings became visible. Outside the constrained area, the transformation processes continued to consume land and resources at breakneck speed without producing wealth. For over thirty years, the local population has refused the constraints because they were experienced as an imposition from above. Since the end of the 20th century, however, local institutions and the population have begun to manifest a desire to culturally re-appropriate the Valley, to take care of it as the noblest and most important part of the territory [42].

To promote the safeguarding, management, conservation and defence of its archaeological and landscape heritage and to promote better usability for scientific, social, economic and tourism purposes, the Region of Sicily enacted Regional Law n. 20/2000 for the establishment of the *Archaeological and Landscape Park of the Valley of the Temples in Agrigento*. With the establishment of the Park, an innovative form of cultural heritage management was inaugurated, experimenting for the first time with new methods of integrated enhancement of archaeological, landscape and agricultural heritage. The Archaeological Park Plan is the guiding tool for this process which aims to enhance the entire territory in its synthesis of archaeology and rural landscape [34,43–48].

The vast area of the Park today appears as a cultural landscape that has been stratified over the centuries, where archaeological finds mixed with pieces of agricultural landscape—

protected by the dense blanket of territorial constraints—have been largely spared from the Great Acceleration [49].

4.2. Change in Landscape Ecomosaics

During the preparation of the Park Plan, a study of the evolution of landscape ecomosaics was produced in order to identify the configurations of the most significant landscape elements for defining urban planning choices.

The evolution was evaluated on the basis of the comparison between the ecomosaics of the area in 1955 and in 2002. Territorial biopotentiality (or biological territorial capacity, BTC, which measures the degree of relative metabolic capacity and the degree of relative antithermal maintenance of the main ecosystems, expressed in Mcal/m2/year) [50] was used as an indicator for estimating the degree of equilibrium of the territorial areas, which allowed for the comparison of ecosystems and landscapes both qualitatively and quantitatively, favouring the interpretation of territorial transformations [50]. By relating biomass to the homeostatic capacities of ecosystems, BTC helps to measure the degree of metastability of the ecosystems themselves, or their ability to conserve and maximise the use of energy [51].

The evolution of its ecomosaics has clearly demonstrated that the territory of the Valley of the Temples still preserves ecosystems which, thanks to the constraints, were preserved in a phase prior to the Great Acceleration [52]. A testimony that confirms the authenticity of the landscape is the literary, iconographic and photographic documentation that accompanies the story of the rediscovery of the archaeological site of Akragas by lovers of the landscape and archaeology, starting from the 18th century [29,53].

5. Results

5.1. Different Degree of Transformation in Landscape Ecomosaics

The comparison revealed the different evolution/involution of the landscape and the different degrees of conservation and transformation that the Valley of the Temples, protected by constraints, has undergone compared to the parts of the Agrigento area not subject to specific constraints.

From the calculation of the average BTC of the study area in 1955—a period in which urbanisation had not yet spread in the municipal area of Agrigento—the entire territory under analysis showed a much higher value of metastability than the regional average for the period (1.76 Mcal/ha/year against 1.69 in the region in 1951). The mean metastability value, on the other hand, decreased in 2002 to 1.54 Mcal/ha/year, significantly lower than the regional average (1.73).

The decrease in the overall average BTC, over 47 years (during the Great Acceleration), was caused by the occupation of agricultural land by new urbanisations, by an increase in bare land (almost 25 ha) and by over 56 ha of specialised horticultural crops, often in greenhouses. In particular, the increase in built-up areas has gone from about 207 ha in 1955 to about 1321 ha today, with an increase of 1114 ha of new buildings; thus, the agricultural land lost almost 15% of its 7710 hectares. In the agricultural landscape, arable land has decreased by over 53%, as well as the almond and olive forest of over 260 ha. The territory has been transformed with a general agronomic intensification of the surfaces (greenhouse and horticultural crops, vineyards, specialised olive/almond groves); finally, there has been an increase of 310 ha of marginal crops (meadows, pastures and uncultivated areas covered in herbaceous plants and shrubs).

The decrease in average BTC due to the reduction in the area of traditional agricultural crops would have been considerably greater if it had not been offset, in ecological terms, by the more than 117 ha of new eucalyptus woods around the city of Agrigento. These new woods were planted after the 1966 landslide with the aim of hydrogeological protection and static soil consolidation [45], though the trees introduced are foreign to the original ecosystem.

The analysis of the ecomosaics of the 1450 ha of the Valley of the Temples, that is, the portion of the territory subject to restrictions, instead showed a much higher average BTC value in 2002 than the average of the entire territory (1.54 against 1.43). While in the rest of the territory those forms of territorial organisation that recall the landscape of the Mediterranean garden have almost disappeared, in the area of the Valley of the Temples, the mixed olive grove has been maintained, albeit with a modest reduction of 21% (from 519 to 410 ha). The mixed olive grove, the so-called "forest of almond and olive trees" typical of the Valley of the Temples, is a remnant of the traditional agricultural landscape of dry arboriculture; it is a cultivation of olive and almond trees in association with other tree crops, typically fig, carob and other fruit trees, and constitutes, together with the limited citrus groves present near the waterways, an element of very significant environmental, historical and cultural importance.

Within the Park boundaries, urbanised areas, although they have increased from 20 to 136 current hectares, still represent just over 9% of the surface. Finally, due to the progressive abandonment of direct cultivation of the fields, citrus groves have been halved and arable land has been reduced by 64%.

In the maps that represent the two landscape ecomosaics (Figures 6 and 7), it is evident how the mosaic tiles of the territory of the Valley that are subject to archaeological and landscape constraints (the so-called "heart of the park", which coincides with the area registered in the WHL of UNESCO, coloured in brown in Figure 5) have remained substantially unchanged. The parts of the territory outside the archaeological area and protected by landscape restrictions (coloured in green in Figure 5) have undergone a modest transformation. The tiles of the territorial context outside the restricted area have, instead, undergone profound and sometimes irreversible transformations. Table 1 shows the values (in square meters) of the surfaces of the landscape mosaic tiles by land use categories in 1955 and 2002. Table 2 summarises and compares the main transformations of the Agrigento landscape and the landscape of the Valley of the Temples in the period examined.

Table 1. Evolution of the landscape ecomosaic of the study area (Boundary of the Park, Regional Law 3.11.2000 n. 20) between 1955 and 2002, with the measurement (in m^2) of the surface of the tiles that make up the mosaic. Source: Politecnica, Map of the Archaeological and Landscape Park of the Valley of the Temples in Agrigento, 2003.

Land Use Categories	1955	2002	Variation
Dense inhabited area	106,581	749,240	+642,659
Sparsely inhabited area	100,620	387,292	+286,672
Industrial area, infrastructure	0	224,421	+224,421
Quarry, landfill	7278	13,952	+6674
Urban green (parks and gardens)	0	129,730	+129,730
Protected crops, vegetable gardens, plant nurseries	0	565,829	+565,829
Simple arable land	6,110,870	2,176,887	−3,933,983
Arable land planted with trees	700,750	965,314	+264,564
Vineyard	464,283	493,115	+28,832
Specialised olive/almond grove	299,540	1,073,318	+773,778
Citrus grove	285,714	132,150	−153,564
Almond and olive forest	5,193,362	4,104,387	−1,088,975
Meadow, pasture, uncultivated herbaceous	302,636	977,084	+674,448
Bushes, shrubs, overgrown shrubs	148,160	378,515	+230,355
Mediterranean bush	150,811	62,308	−88,503
Wood	0	1,168,487	+1,168,487
Archaeological area	169,450	262,659	+93,209
Riverbed	403,834	409,479	+5,645
Sandy beach	57,182	104,788	+47,606
Rocky outcrop	75,290	220,235	+144,945

Table 2. Main transformations of the landscape of the Agrigento area and the landscape of the Valley of the Temples from 1955 to the present.

Transformations of the Landscape of the Area between the City of Agrigento and the Coast	Transformations of the Landscape of the Park of the Valley of the Temples (Boundary of the Park, R.L. 3.11.2000 n. 20)
• very high urban growth with reduction in areas available for agriculture • reduction in traditional agricultural landscape: almond groves, olive groves and citrus groves • significant intensification of crops on the remaining agricultural soils • naturalisation of marginal land, even if of limited surface • large strip of reforestation around the city	• urban growth limited by constraints after 1966 • conservation of large portions (29% of the entire area) of traditional agricultural landscape: forest of almond and olive trees and citrus groves • not excessive intensive cultivation (plus 134 ha of intensive crops) • increase in 'marginal' land for agricultural activities (meadows, pastures, uncultivated shrubs and bare soils cover approximately 160 ha)

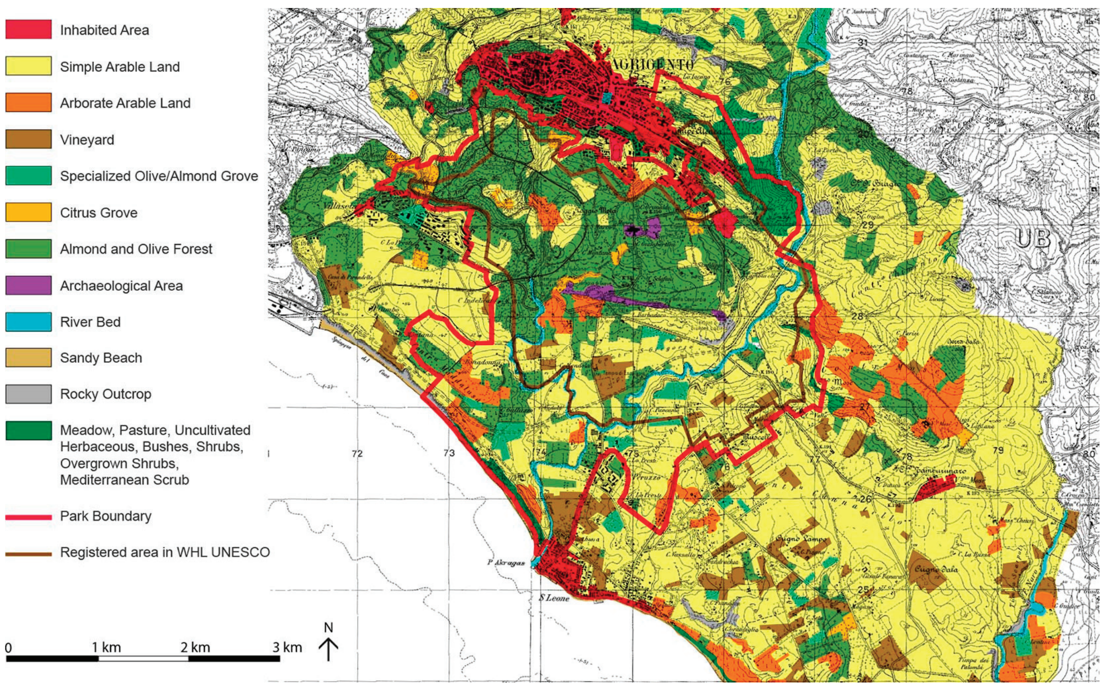


Figure 6. Ecomosaic of the landscape until 1955. Graphic reworking. Source: Politecnica, Plan of the Archaeological and Landscape Park of the Valley of the Temples in Agrigento, 2003. From the photo-interpretation of aerial photos (in black and white, scale 1:33,000 approximately) made by the Military Geographic Institute with the flight of June 1955, the Ecomosaic Charter was created, indicating the different categories of land use considered as tiles in the landscape mosaic.

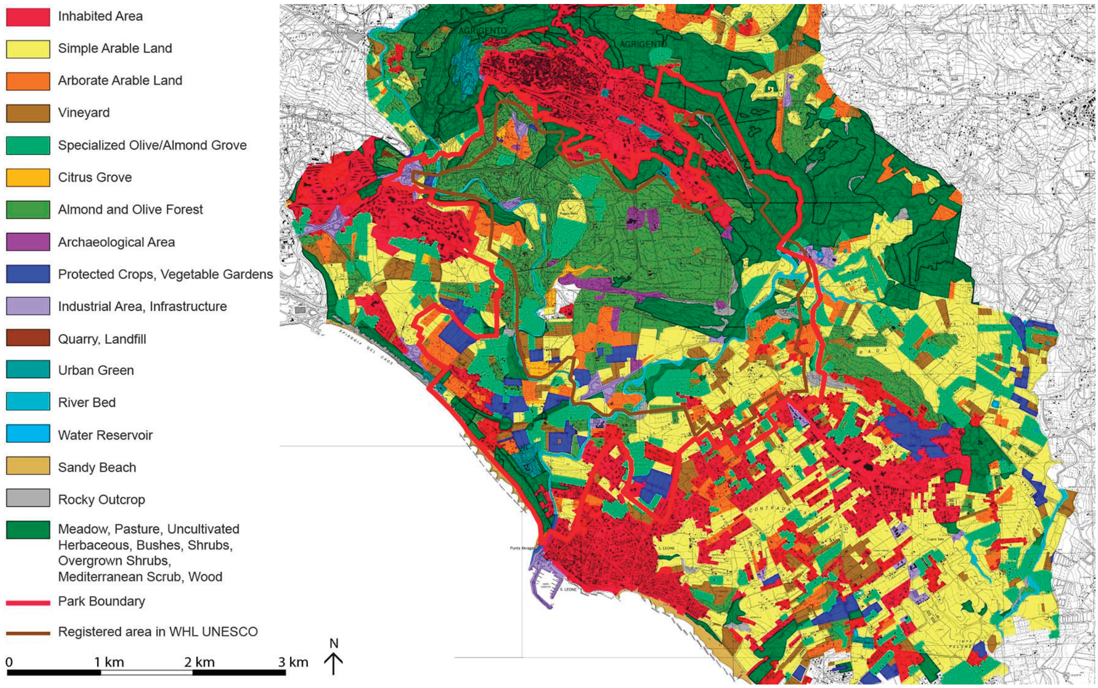


Figure 7. Landscape ecomosaic in 2002. Graphic reworking. Source: Politecnica, Plan of the Archaeological and Landscape Park of the Valley of the Temples in Agrigento, 2003. The map was drawn up following the photo-interpretation of the colour aerial photos.

5.2. Historical Iconography of the Agricultural Landscape of the Valley of the Temples

Travellers on the Grand Tour who arrived in Agrigento described a landscape characterised by the presence, among the archaeological finds, of fruit trees, vegetable gardens and arable land. The main travellers who have crossed, written on and drawn the Valley are: J.P. d'Orville, 1727; J.H. Von Riedsel, 1767-70; P. Brydone, 1767-71; M. J. De Borch, 1776-77; H. Swimburne, 1777-78;P. Hakert, 1777; C.S. Saint Non, 1778; J. P. L. Saint Non, 1778; F. Munther, 1785-86; H. Bertles, 1786; J. W. Goethe, 1786; F. L. di Stelberg, 1792; J. G. Seume, 1802; K. F. Schinkel, 1804; W. Wilkins, 1807; J. Russel, 1815; J.A. de Gambillon, 1820; A. E. De La Salle Gigault, 1882; A. Conte de Forbin, 1823; W. Light, 1823; O. Ormonde, 1832; W. H. Bertelett, 1853; F. A. Gregovius, 1853; G.F. Hoffwailles, 1870; G. Vuillier, 1897; E. Viollet Le Duc, 1836-37; Berenson, 1953. In the illustrations accompanying their reports, there are always farmers intent on cultivating the land adjacent to the temples and ruins of the city of Akragas (Figure 8). From their descriptions, it can be deduced that the presence of fruit trees was not only in the peri-urban orchards, but that it also extended into the hilly areas; here, the absence of irrigation water required the presence of dry arboriculture which, in the Mediterranean environment, sees olive and almond trees as protagonists, followed by carob and pistachio trees.

Among the testimonies of these travellers, each of which saw and described the temples and their landscape in their own way (for the interpretation of the different literary sources, which would require an in-depth study that goes beyond the purposes of this article, see Barbera, Di Rosa, 2000 [53]; De Miro, 1994 [29]), the richest in information are those left by Johann Wolfgang Goethe, who visited Agrigento in 1786. In his travel diary (*Italienische Reise*, 1816), he described the agricultural landscape with a list of the cultivated crops and noted all of the aspects of the agricultural techniques of the countryside in use at the end of the 18th century. The crops and techniques described by Goethe find a perfect match in the memories and agricultural practice of the elderly peasants who are still alive today.

Figure 8. Remains of the Temple of Vulcan, drawing and engraving by Jean-Pierre Louis Laurent Houël, 1787. Illustration extracted from De Miro [29].

What is relevant, through the reading of these memories (see Table 3), is the possibility of comparing the images of the landscape described and drawn with the existing landscape; from this comparison, it can be easily seen that the landscape of the Valley of the Temples (even though partially degraded by the abandonment of crops) has not substantially changed [54]. The countryside of the Valley of the Temples is a living testimony to the transformation of Sicilian agriculture which, between the 18th and 19th centuries, led to the spread of the cultivation of fruit trees in large areas previously dominated by pastures, bare arable land and Mediterranean scrub. The traditional agricultural crops which are still established in the countryside of the Temples saw, in the period between the 18th and 19th centuries, the moment of their affirmation as crops that define the historical Sicilian agricultural landscape.

On the basis of agronomic, forestry, agricultural landscape and literary sources analyses, the Park Plan has defined a specific model for the Valley of the Temples that makes historical-settlement peculiarities and aspects of Mediterranean scenography and rurality the strong point of sustainable development, able to guarantee its protection and reproducibility over time [45].

Table 3. Variety of crops cited in literary sources, divided by author and period.

Crops	Authors (Period)										
	Diodoro (1st cent. BC)	Idrisi (1138)	Riedesel (1767)	Brydone (1770)	Swinburne (1770)	Münter (1785)	Goethe (1787)	Stolberg (1792)	Seume (1802)	Didier (1829)	Laugel (1872)	Vuiller (1897)
Vineyards	•		•	•		•	•	•				
Fruit trees	•	•	•	•								
Pastures	•											
Olive groves			•	•	•			•	•	•	•	•
Wheat			•	•	•		•	•				•
Barley							•					
Vegetable gardens		•										
Gardens		•	•			•	•					
Almond trees			•	•	•		•	•		•	•	
Citrus trees				•								
Pomegranate trees				•				•				
Pistachio trees				•				•				
Table grapes							•					
Fig trees							•	•			•	
Carob trees							•		•	•		•
Legumes/broad beans			•				•					
Oats							•					
Melons							•					
Artichokes							•					
Broccoli							•					
Cabbages							•					
Forage			•				•			•	•	
Tumenia (soft wheat)							•					
Mulberry trees								•				
Prickly pear trees			•							•		
Aloe/Agave/Acanthus			•	•			•					
Ferula (giant fennel)			•	•				•				
Flax							•					

6. Discussion

6.1. Main Issues of Agricultural–Forest Management in the Valley of the Temples

The current economic–productive structure of the agriculture in the Valley of the Temples is rather particular compared to the other contiguous agricultural areas [52,53]. Changes in the ownership structure that have taken place in the last forty years (the state-owned areas of the Park) have upset the existing corporate structure. The land subject to constraints was acquired by the public domain, and its management was given in concession to the former owners who requested it.

Before the emergence of this new reality, the land was mainly concentrated in the hands of a few landowning families. Nothing remains of this production structure today. Instead, many families cultivate only small areas of land, given in concession, around their country houses. There are fewer and fewer small farms. The problem is that it is not possible to start a profitable agricultural business in such limited areas.

Among the causes of the abandonment of raising crops is the difference between the high cost of cultivation operations and the low value of the products. The production from the gardens is characterised by local and ancient varieties and is completely unsaleable. Though their cultivation may have important results from the point of view of landscape conservation [55], it has no value from a strictly productive one [56].

Other causes are: the obsolescence of production systems; the aging of the rural population and the abandonment of agricultural activity by elderly farmers; the loss of the technical knowledge of traditional agriculture, once handed down from generation to generation.

6.2. The Living Museum of the Almond Tree for Safeguarding Intraspecific Biodiversity

From the analyses of the historical iconography, travellers' testimonies and historical photographs, it is clear that the cultivation of the almond trees has taken on an important economic role since the 18th century. However, it was in the second half of the 19th century and in the first decades of the 20th century that a vast wooded area called the "almond forest" was formed in the Valley of the Temples.

In the 1950s, the surface of the specialised almond groves of the Valley was about 60 hectares, while that associated with olive trees (mainly) was almost 540 hectares. By the end of the century, however, due to the problems outlined above, the specialised almond groves were reduced to just over 10 hectares, while in association with the olive trees they were reduced to about 400 hectares.

Most of the residual areas occupied by the "almond forest" are now public property and in a state of decay; this was caused by the death of many plants and the thinning of the forest. The almond tree species, among all those cultivated in the Valley, is the richest in intraspecific biodiversity. There are numerous varieties that, over time, have been selected and consolidated in this campaign and are now at risk of extinction.

To address this problem, and in general to save the different varieties of Sicilian almonds from extinction, the Institute of Arboreal Cultivation of the University of Palermo, in agreement with the Superintendence of Agrigento and the Province of Agrigento, has launched a living collection of Sicilian almond varieties [57,58].

The Valley of the Temples was chosen as the ideal place to carry out the project. So, in 1996, a new almond grove, called the *Living Museum of the Almond Tree*, was planted on an area of about five hectares in the San Biagio valley, at the foot of the hill dominated by the Temple of Juno Lacinia (Figure 9). The new almond grove hosts over 300 varieties of almond trees from different places in Sicily: it is a genetic bank that holds the intraspecific varieties of the species. Four trees of each of species, specially grafted with branches taken from the trees of the Valley of the Temples, are cultivated for the purpose of studying and preserving their genetic heritage. Many varieties have been selected from plants born spontaneously and whose productive characteristics have been appreciated. The plantation has the appearance of a traditional almond grove where, mixed with the almond trees, there are olive, carob, pistachio, mulberry and rowan trees, as well as shrubs characteristic of the Valley's arboriculture [59,60].

The Museum is an open-air museum that has the scientific purpose of facilitating the study of the genetic diversity of the almond tree in Sicily, identifying those varieties that best lend themselves to maintaining the quality and excellence of the taste of the Sicilian pastry tradition. The Museum also has educational purposes because it exhibits the cultivation techniques of traditional agriculture of the Agrigento area and contributes to the conservation and enhancement of the centuries-old landscape of the Valley of the Temples, encouraging cultural, ecological and educational tourism [61].

The University of Palermo and the Valley of the Temples Park have collaborated together on the establishment of a laboratory for the categorisation and conservation of germplasm. The laboratory, set up inside Case Fiandaca (an old 19th-century farmhouse), is playing a fundamental role in the study of biodiversity and landscape restoration of degraded agricultural and natural systems for the protection and enhancement of the cultural landscape of the Valley of the Temples. A permanent exhibition on biodiversity and traditional agriculture, an iconographic exhibition of the landscape of the Valley, a permanent exhibition on traditional Sicilian almond-based pastries and, finally, specific tasting and sale stations for agricultural products from the Valley of the Temples are planned in the old rural house.

(**a**)

(**b**)

(**c**)

Figure 9. (**a**) The Living Museum of the Almond Tree with the old building destined for the "Ethno-anthropological Almond Museum". Francesco Sottile ph, published in Barbera, Monte, Sottile, 2005, https://www.researchgate.net/publication/228864141, accessed on 12 April 2021; (**b**) Case Fiandaca, headquarters of the laboratory for the categorisation and conservation of germplasm. Photographic archive of the Archaeological and Landscape Park of the Valley of the Temples, www.parcovalledeitempli.it/paesaggio/il-museo-vivente-del-mandorlo/, accessed on 12 April 2021; (**c**) Almond Tree Museum overview. Photographic archive of the Archaeological and Landscape Park of the Valley of the Temples, www.parcovalledeitempli.it/paesaggio/il-museo-vivente-del-mandorlo/, accessed on 12 April 2021.

6.3. The Mediterranean Garden

Among the most precious and appreciated resources of the historical–cultural landscape of the Valley of the Temples are the so-called *Jardini* (Mediterranean gardens consisting of fruit trees and irrigated gardens) [62]. In Mediterranean gardens, the main cultivation matrix is made up of citrus fruits (in different varieties), to which are added: persimmons, prickly pears, figs, peaches, pears, pomegranates, quinces, walnuts, apricots. The gardens, small in size and located near springs, constitute a particularly productive polycultural system throughout the year [63].

Unlike dry arboriculture, gardens need care and watering throughout the year [64]. These landscape tiles were the ones that unfortunately suffered the most damage due to the series of factors mentioned above.

One of the most significant Mediterranean gardens of the Valley of the Temples, and which miraculously survived the Great Acceleration, is located along the narrow valley of the Kolymbethra, located between the Temple of Castor and Pollux and the Temple of Vulcan (Figure 10). Literary sources describe the Kolymbethra as an artificial reservoir, an ingenious hydraulic work carried out by Theron in the 5th century BC; Diodorus Siculus describes it as "a large basin (. . .) with a perimeter of seven stages (. . .) twenty fathoms deep (. . .) where the Phaeacian Aqueducts, a nursery of refined flora and abundant wild fauna" (Diodorus Siculus, *Bibliotheca Historica*, book XI, 25, 1st century AD; author's translation).

Figure 10. Kolymbethra Valley. The garden, brought back to life and integrated by the FAI, is highlighted in colour. It is located within the archaeological area of the Greek settlement of Akragas, between the sanctuary of the Dioscuri and the Temple of Vulcan.

Having lost its original function as an artificial lake, the reservoir was subsequently transformed, with adequate terracing, into a Mediterranean garden. The French traveller Jean-Claude Richard de Saint-Non in his notes, published at the beginning of the 19th century (*Voyage pittoresque à Naples et en Sicil*, 1829), testifies that, already at that time, the valley had taken on the form of a luxuriant citrus grove (Figure 11).

The oral testimonies collected confirmed the presence of a Mediterranean garden which, already at the beginning of the 20th century, appeared very ancient, while none of the contemporary peasants recalled the initial plan or remembered who the architect had been. The garden was cultivated continuously until the 1980s. Subsequently, both due to aging and the lack of generational turnover of the workforce, and to the status of the archaeological area as state property, the garden was abandoned by the peasants. It has thus been transformed from a luxuriant place to a heap of brambles, also used illegally as a landfill.

Faced with the risk of forever losing this heritage of considerable landscape, genetic and cultural value, an initiative to start the process of recovering the ancient garden has been started [65]. The Superintendence for Cultural Heritage of Agrigento, the University of Palermo and the FAI (*Fondo Ambiente Italiano*) have been involved in support of the initiative.

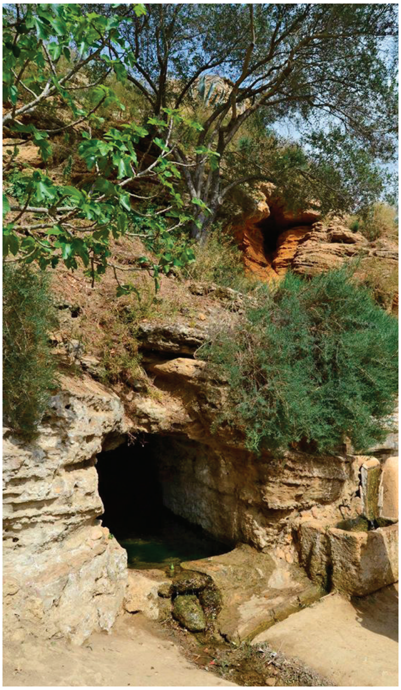
For the recovery of the Kolymbethra, the formula of the free concession of a public domain to a private body was used; in October 1999, the FAI was granted the management of the garden for a period of 25 years, dealing with restoration, maintenance, promotion, opening to the public and tourist use.

Figure 11. Panoramic view of the ancient Akragas water reservoir. Drawing by Ch. L. Chatelet. Engraving by P.E. The Epine. 1785. Illustration extracted from De Miro [29].

From 1999 to 2001, the garden was patiently rebuilt thanks to the collaboration between the Department of Arboreal Cultures of the University of Palermo, the FAI, the Agrigento Superintendence and the contribution of elderly farmers and labourers of the local area, custodians of the ancient and traditional techniques of cultivation, reproduction, pruning and collection and regimentation of the waters [66].

The garden was returned to the public in 2001, equipped with new routes, guided tours and a new outdoor dining area. The dry-stone walls that supported the terraces that shaped the valley floor have been restored (Figure 12), at the centre of which the waters coming from the numerous hypogea of Greek origin (Figure 13), still functioning today, are channelled. Through pruning, grafts and new plants, the Mediterranean garden has been restored with all its characteristics: on the slopes between the tuff walls and the valley floor, there are olive trees (*Olea europaea*) (Figure 14), almond trees (*Prunus dulcis*) and pistachios (*Pistacia vera*), the only species capable of producing in such inhospitable places. Everywhere, then, various fruit trees are used: from pomegranates (*Punica granatum*), located mainly along the edges of the river banks to myrtles (*Myrtus communis*), which today we find (in almost arboreal forms) cultivated on the terraces; fig trees (*Ficus carica*), pear trees (*Pyrus communis*), apple trees (*Malus domestica*), plum trees (*Prunus domestica*), apricot trees (*Prunus armeniaca*), medlar trees (*Eryobotria japonica*), persimmon trees (*Diospiros kaki*), quince trees (*Cydonia oblonga*), white mulberry trees (*Morus alba*), red mulberry trees (*Morus nigra*), prickly pear (*Opuntia ficus-indica*). The trees are seemingly distributed in no apparent order; in reality, they are distributed according to a practical criterion used by local farmers who, having identified the planting site, have chosen the most suitable plant to enhance its production potential [67].

Figure 12. Archaeological Park of the Valley of the Temples in Agrigento. Kolymbethra Garden. New visiting routes. Restoration of dry-stone walls.



(**a**)

(**b**)

Figure 13. (**a**) Archaeological Park of the Valley of the Temples in Agrigento. Kolymbethra Garden. Hypogeum dating back to the Greek era for the channeling of water, still functioning today; (**b**) *Cunnutti* for the canalisation of the water, an irrigation system of Arab origin, still functioning today.

Figure 14. Archaeological Park of the Valley of the Temples in Agrigento. Kolymbethra Garden. Secular olive tree.

A vegetable garden (Figure 15) has been created near a water collection tank where seasonal vegetables are grown in rotation. The traditional irrigation system of ancient Arab origins [68] has been restored and uses the water that still flows from the ancient aqueducts. It is a system based on the channelling of water which, made to flow through channels and controlled by the opening of special shutters (Figure 13b), reaches the fruit trees.

(**a**)

(**b**)

Figure 15. (**a**) Archaeological Park of the Valley of the Temples in Agrigento. Kolymbethra Garden. Garden maintenance; (**b**) portion of the garden grown with seasonal vegetables for educational demonstrations.

It should be emphasised that the restoration of the Kolymbethra garden is mainly for cultural and museum purposes. In fact, the visit to the garden is offered to tourists who visit the archaeological area of the Valley of the Temples with an integrated entrance ticket. As mentioned above, restoring a state of equilibrium in a pre-disturbance phase cannot be adopted as a generalisable method because the surrounding situations have changed. Even in the agricultural management of Kolymbethra, for example, the new technology of sub-irrigation was introduced to integrate the irrigation carried out with the Arab system. In this case, in fact, it was estimated that the climatic regime in the Arab era was much more humid and, therefore, there was abundant water available for irrigation. Today the climatic regime is more arid and, therefore, it is necessary to save as much water as possible. Subirrigation, by considerably reducing the dispersion of water by evaporation, allows significant water savings and produces better results for the trees.

One of the most important values of Kolymbethra is that it is a formidable source of biodiversity; of particular value is the genetic heritage that its trees preserve: the only species of orange is represented here by as many as nine ancient varieties, largely no longer cultivated (Figure 16). This garden also preserves the traces of traditional agricultural techniques, eliminated elsewhere by the modernisation process of agriculture which, in the last fifty years, has profoundly reshaped the Sicilian agricultural landscape. Furthermore, traditional agricultural landscapes preserve biodiversity in terms of flora, fauna and habitats [69]. The vegetation that grows spontaneously on the calcarenite steep slopes of the Kolymbethra is remarkable. It consists of Mediterranean maquis dominated by wild olive [70,71], in the sunny and xeric slopes, and laurel formations in the shaded part of the valley, which represent in Sicily a vegetation of particular phytogeographic interest [72].

Figure 16. Archaeological Park of the Valley of the Temples in Agrigento. Kolymbethra Garden. Variety of cultivated citrus fruits.

6.4. The Productive Dimensions of the Historical Landscape. The Landscape Regeneration Project

The Living Museum of the Almond Tree and the restoration of the Kolymbethra Garden were the first sprouting of a rebirth which blossomed after almost half a century of hostility towards the archaeological area of the Valley of the Temples, thanks to the collaboration between universities, the public administration, the third sector and private entrepreneurs. This effort represents a model of good practices for the enhancement of the archaeological and landscape heritage since, from a repressive model imposed by the State, we have passed to a collaborative and proactive model that also leaves room for private initiative.

Following the success of the two projects described above, the Archaeological Park Authority has undertaken other important initiatives to manage the 1400 hectares of land in a sustainable way. To actively safeguard the traditional agricultural landscape, productive functions have been associated with cultural, ethical, aesthetic and recreational functions.

The set of initiatives undertaken by the Park Authority gave life to the Landscape Regeneration project. Starting from the landscape as an element of creative inspiration, the project pursues the objective of keeping the historical memory of ancient production practices alive, proposing them for cultural and educational purposes. Some areas of the park, not containing archaeological finds have been used for organic farming, for the production of high-quality food and wine products, recovering and updating, where possible, the agronomic practices of the ancient Sicilian tradition.

To achieve these objectives, the Park Authority made use of the collaboration of the University of Palermo and leading companies in the agri-food sector. Other partners in the project are the Kaos Cultural and Railway Activities Association, for the reactivation of the railway line that crosses the Park, and FAI, which manages the Kolymbethra Garden.

The Landscape Regeneration project pursues four main objectives which are integrated with each other: appreciating the environmental heritage, agricultural production, environmental education, recovery and requalification of the landscape. For each issue, the project foresees specific actions, listed below.

6.4.1. Appreciating the Environmental Heritage

In addition to the integration of six hectares of irrigated orchards of the Kolymbethra Garden as an integral part of the use of the Archaeological Park, three other itineraries have been designed: a visit to the *Goethe Garden*, a vegetable garden created in the land around Casa Barbadoro, an ancient rural building at the foot of the Temple of Concordia, featuring the crops and agronomic techniques of the late 18th century, as described by Goethe in his travelogue; an *environmental itinerary*, almost four kilometres long, from the Temple of Vulcan to the Temple of Demeter, where the unique characteristic of the local ecosystems are illustrated; the *Vegetable Patriarchs* itinerary, to become familiar with the monumental centuries-old trees, including olive, carob, pistachios and myrtles trees (for the identification, cataloguing and localisation of monumental trees, and the cataloguing of plant and animal species, see Politecnica, 2003).

6.4.2. Agricultural Production

Since 2005, the Park Authority has registered the *Diodoros* trademark to identify and certify the quality of the agricultural production of the Park's land. The olive groves and vineyards have been granted, in concession to local agricultural companies, the highest quality profile which, with their methodological and production experience, have made it possible to recreate and revive high quality traditional products, exploiting natural resources hitherto unused. More than 152 hectares of land have been tendered for private bidding, and the use of more than 117 hectares has been requested by and granted to private operators. The basket of products under the Diodoros brand, initially consisting of oil and wine, has been enriched with products derived from the processing of almonds, *Sicilian black* bee honey and the milk of *Girgentane* goats, whose breeding has recently been reintroduced in the valley.

As Vesalon and Cretan observe [73], the function of the brand is, above all, to represent, innovate or construct a specific imagery for a place and to transmit it through new narratives. The power of branding is, above all, to create or reshape the image of a place. In the context of the Valley of the Temples, the Diodoros brand has worked very well in transforming the imaginary of Agrigento from a place of illegality into a territory of excellence which, in the shadow of the temples, produces organic products with eco-sustainable techniques inspired by the most ancient agricultural traditions whose origins date back to the ancient Greek and Arab cultures.

The initiative has received the appreciation and emotional involvement of the local population for the rediscovery of traditional production methods and local products; for private partners, the project represented an opportunity for investment and development, creating jobs and generating a new economy.

In 2014 the *Agri Gentium* project was launched in which more than 152 hectares of agricultural land in the Park were offered to three types of subjects to pursue differentiated purposes: social gardens to be allocated free of charge to citizens to promote socialisation processes and stimulate the sense of belonging; agricultural areas to be used for rehabilitation and social reintegration activities for disadvantaged people; new productive agriculture with products to be marketed under the Diodoros brand for the recovery of uncultivated or abandoned areas for production purposes.

6.4.3. Environmental Education

The Living Museum of the Almond Tree has been expanded with the planting of olive and pistachio varieties and has been transformed into the *Living Museum of Non-irrigated*

Fruit Species in Sicily. The museum has also been integrated with the *Laboratory for the Characterisation and Conservation of Almond, Olive and Pistachio Germplasm*.

The *Oliver: From Olive to Oil* environmental education program was developed, aimed primarily at school-age children; the children are directly involved in the production processes, from the harvesting olives in the field to the subsequent pressing in the mill.

6.4.4. Restoration and Requalification of the Landscape

In 2009, the *Thousand Almonds* project was launched which made it possible to plant a thousand almond seedlings in the Valley to contribute to the reconstruction of the damaged ancient heritage of almonds. The project was developed and implemented by the FAI, together with the Office for Infrastructural Interventions of the Regional Agriculture and Forestry Department, the *Feudo Principi di Butera* and the Department of Arboreal Cultures of the University of Palermo.

In collaboration with the Kaos Railways Culture and Activities Association, an alternative mobility project was launched through the recovery of the ancient railway line, dating back to 1874, which crosses the park.

Thanks to its holistic vision of the landscape as a natural and cultural ecosystem, the Landscape Regeneration project won the *Italian Landscape Award* in March 2017, assigned by the Ministry for Cultural Heritage and Activities and Tourism. The project was also nominated to represent Italy in the 5th edition of the *Landscape Award of the Council of Europe* for maintaining a harmonious interaction between nature and culture through the protection of the landscape.

7. Conclusions

According to Niles [73,74], traditional agriculture is usually considered a relic of the past, an inefficient way of farming the land. In reality, and this is amply demonstrated by the case of the Valley of the Temples, traditional agriculture is one of the richest testimonies of human environmental experience, one of the most successful ways to establish a relationship of collaboration with the nature that is transmissible and sustainable [13].

Similar observations are contained in the ICOMOS-IFLA *Principles Concerning Rural Landscapes as Heritage* (2017), which considers rural landscapes as a vital component of human heritage that includes technical, scientific and practical knowledge relating to human–nature relations. Rural landscapes and traditional agriculture also provide multiple economic and social benefits, cultural support and ecosystem services for human societies.

The case study of the Valley of the Temples in Agrigento was observed from the point of view of the study of the archaeology of rural landscapes, and it emerged that these landscapes are repositories of the ecosystem's values and the sustainability of the exploitation of environmental resources in the long term, values that have disappeared elsewhere.

The good practices analysed make it possible to evaluate how the results achieved are able to favour the dissemination and enhancement of the cultural values borne by the landscape. The best practices with the greatest impact concern: initiatives capable of keeping alive the historical memory of ancient production practices and using them as a basis for new creative products; saving plant species from extinction through germplasm banks and living collections of trees; appreciating the biodiversity of mixed crops (Mediterranean garden) as a value; facilitating cooperation between the public administration, private entrepreneurs and research institutes for the management of state-owned agricultural land while maintaining the diversity of the landscape and habitats; creating of economic opportunities linked to local products in harmony with nature and with the culture of the communities concerned [75].

The Park Authority, as the territorial body responsible for the planning and management of the Archaeological Park, has prepared projects and plans that involve top-down processes. However, it has also activated processes for the involvement of the local population, aimed at schoolchildren, entrepreneurs, farmers as well as B&B owners [61], with the aim of reaching the common citizen. It should be emphasised that these actions open up new and interesting research perspectives. Indeed, this process of involvement, referring to a territorial context that expresses a very strong identity value, could be channelled into the processes that lead to the formation of an ecomuseum, considered as a powerful tool for the participatory management of natural and cultural heritage [75,76]. To this end, it is necessary to create a community capable of recognising its territory as a living heritage, of identifying itself with it and of actively participating in its transmission, communication and enhancement.

We close these reflections on the trajectories of the landscape through the Anthropocene with the same authors with whom we opened this article. Crutzen and Stoermer seemingly expressed a prophecy when, in 2000 (long before we could have imagined the global pandemic that arrived in 2020), they claimed that:

> "without major catastrophes like an enormous volcanic eruption, an unexpected epidemic, a large-scale nuclear war, an asteroid impact, a new ice age, or continued plundering of Earth's resources by partially still primitive technology (...) mankind will remain a major geological force for many millennia, maybe millions of years, to come. To develop a world-wide accepted strategy leading to sustainability of ecosystems against human induced stresses will be one of the great future tasks of mankind, requiring intensive research efforts and wise application of the knowledge (...). An exciting, but also difficult and daunting task lies ahead of the global research and engineering community to guide mankind towards global, sustainable, environmental management" [1], p. 18.

As we have demonstrated, the context of the Valley of the Temples, spared by the Great Acceleration, is a historical landscape that contains a vast archive of practices, knowledge and living plant and animal species. This "fertile ground" is particularly suitable for the growth of new management models that prove to be truly durable and sustainable in the long term.

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Article

Neoanthropocene Raising and Protection of Natural and Cultural Heritage: A Case Study in Southern Italy

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Abstract: Analyzing the human history on the planet, a conflictual relation was raised when humankind had started destroying the natural ecosystem and biota, and consequently, a capacity to induce environmental change has increased throughout human history in the so-called Anthropocene age. A 'noosphere'-centered civilization could produce a non-disruptive new kind of anthropocentrism. This is becoming a new context to define Neoanthropocene based on a renewed homeostatic relationship between Earth and mankind. The potential application of this theoretical approach has been tested in drafting steps of Plan of Lucania Apennines, Valdagri, and Lagonegrese National Park, in southern Italy. Drafting the plan, the authors have applied a strategic approach based on environmental and cultural evidence and have drafted an interpretation plan for local growth, consistent with local resources. The result is a plan, shared with local stakeholders, in which the authors have proposed a multisectoral development plan based on a 'cluster approach' for regeneration: The main wild areas are reached through a visitor center or similar introducing facilities, and they are connected with historical centers, archaeological parks, ski areas, accommodation facilities, and other local services. The expected effect is the growth in number of chances to develop business in accordance with environment protection duty.

Keywords: Neoanthropocene raising; inner land; environmental protection

1. Introduction

In 2016, the Anthropocene concept [1] reached far beyond the traditional definition of a recent geological epoch characterized by human impacts on biogeochemical and biophysical processes, as notoriously defined by Crutzen and Stoermer [2]. The study of the Earth requires understanding of the system of human-derived forces and impacts on planetary processes. The Anthropocene essentially defines the growth of nested social-ecological systems where human–environment interactions are not bi-directional but reach across different spaces and times. In this sense, the relevance of 'Complexity' science to a new understanding of human–environment interactions become apparent. The first model formulation of the huge anthropic conditions and effects, and its interpretation, are now over 40 years old. It was born as the World3 Model and Limits to Growth research, promoted by the Club of Rome [3] not only for showing the horizon of crisis, but mostly for sketching the ground of action.

Recently, the International Geosphere-Biosphere Program (IGBP) community proposes a 'second Copernican revolution' in our understanding of the Earth [4], drawing upon 'Complexity' science to argue for a new generation of models that could simulate coupled human–environment relationships. In 2001, the Amsterdam Declaration extended these ideas to include the possibilities of threshold-dependent changes and tipping points.

Analyzing the human history on the planet [5], we can define an increasing conflictual relation in which humankind had started destroying the natural ecosystem and biota as far back as the Holocene (extending the spillover and opening our doors to COVID-19). The capacity to induce environmental change, however, has increased throughout the ages with a logarithmic–logistic function describing human population growth. Technology and socioeconomic conditions relate to this function and they are described in it. However, the 'noosphere' concept [6] could contribute to a new period where people carefully calculate relationships with the earthly universe in order to maximize the joined wellbeing of people and the environment.

A wide adoption of the 'noosphere' concept would be the inception of a non-disruptive new Anthropocene, that we propose to call Neoanthropocene, consistent with a radical innovation towards a renewed homeostatic relationship between Earth and mankind [7].

The Neoanthropocene age is announced by several worldwide avantgardes, and many ongoing experiments and consolidated practices are testing the necessary transition. The National Park of Lucania Apennines, Valdagri, and Lagonegrese in southern Italy, in the so-called 'Mezzogiorno', is one of the most relevant examples of the suggested transition from the Anthropocene (the Paleoanthropocene indeed) to the Neoanthropocene. In other words, the perfect example of a renewed circular alliance between Earth and mankind, ecology, and culture [8–10].

So, the Lucania Apennines Park's planning has been a fruitful occasion for investigating a new paradigm in a circular approach to nature preservation and territorial development, testing a new protocol based on the fertile relationship among multiple interests, stakeholders, and competences.

Starting from the theoretical framework adopted for the plan of the National Park, the paper describes the case study current situation and the adopted solutions to meet the challenge of a heritage based growth of a park in which the wilderness is functionally joined with the seminatural areas and anthropic land uses. The results are focused on planned solutions for a new alliance between man and nature in the Park. At last, the discussion focuses on how to balance environment preservation and community development: It proposes a solution for the integration of nature sanctuaries and human activities, as fully as possible.

2. Materials and Methods

2.1. Circular Development and Circular Metamorphosis: A Theoretical Framework for the Plan of the National Park

During the euphoria for the Anthropocene, some reflective and militant planners have taken up the challenge to develop an effective local sustainable growth based on community engagement, environmental regeneration, and integrated goals for a whole sustainable development, in terms of social, cultural, economic, and overall environmental point of view. Visionary and pragmatic at the same time, they are convinced that we need to accept the challenge to live in the Neoanthropocene, described as a 'good Anthropocene' [11]. Designing the transition to this new era and reactivating the traditional alliance between human and natural components as co-acting forces [12] is guided by the ethics of a responsible project to integrate people and nature, the human habitat, and the environment, as collective responsibility towards Global Change beginning with the huge and accelerated footprint of human habitat [8,13–16].

In order to achieve a Neoanthropocene strategy for Lucania Apennines, we worked on it as researchers, teachers, and planners, with a responsible and militant approach, for drafting the plan of the National Park, as a multidisciplinary workgroup.

Since 2012, the EU Commission has clearly stated that more intelligent, sustainable, and competitive development requires a paradigm shift in which the territory is construed as a primary resource, considered the holder of 'development cells', which are too often underused or mystified with regard to their real potential for use [17]. Cities designed and built on land rent—on which Italy set a benchmark—need to be replaced with cities of social and cultural profitability, value creation, and production of jobs, based on a renewed circular alliance between rural and urban resources [10] and therefore more responsible. In rural-urban growth strategies, new urban policies towards the lifecycle approach (life cycle assessment) are needed: From the procurement of raw materials to the end of the cycle using as little energy and resources as possible and, instead, reactivating latent energy.

Human habitat will have to act within a new evolutionary model, the result of innovation produced by the third industrial revolution and by start-ups, actions of makers, and energy generated by creativity and by metamorphosis of circular economy. This urban model could be more responsible and capable of reshaping the objectives of tangible and intangible asset production, of revising energy and mobility protocols, and above all, of rethinking the settlement model.

It is possible thanks to a new holistic way of thinking that elicits reuse, recycling, and creative evolution within a 'Capitalism 4.0' [18], which generates the next economy [19] created from the integration of renewable energies and circular economy, able to produce new value from the re-cyclical process of new urban metabolism. The economic model supporting the territories in the circular society must be able to generate local value, rather than an extractive economy that creates dependence on the exogenous strategies of large companies. We work on a regional economy guided by a social agenda.

The task of decision-makers, planners, architects, citizens, and enterprises is to work on rural-urban settlements characterized by cycle flows—some still vital, others produced by surplus, and by the overproduction of changing urban complexes. The circular approach needs also to work on the discontinued urban fabric and transforming infrastructure networks: They need to be addressed through their modification, removal, or reinvention, thanks to which the components are recreated, without destroying them, and by changing their functions in pursuit of a generative view and increasing their creative resilience. Recycling and changing the settlement structures will be the issue that guides rural-urban habitats more and more constantly fluctuating between conservation and transformation [20], identity and innovation, in an accelerated metabolism of lifecycles.

Recycling is not only one of the main keywords of the action of urban planning, architecture, and design [21], but is also one of the most powerful guiding thoughts in the transformation from a wasteful linear economy to a regenerative circular one for cities and territories that wish to pursue sustainability, quality, and creativity [22]. In the circular economy, there are two types of material flows: Organic ones, capable of being replenished in the biosphere, and technical ones, destined to increase in value in a system in which all activities, starting from mining and manufacturing, are organized so that the waste of one phase becomes a resource for the following one. According to the principles of the circular economy, nothing is waste and everything that is discarded from one production process is the raw material for another production process. Moreover, the very design of a product is based on the possibility of dismantling its parts and reusing them in subsequent production cycles, based on supply chain cooperation and new production networks: A more creative 'planned recycling' instead of consumerist planned obsolescence.

Furthermore, the circular growth movement aims to change the current linear system on which our industrial society is based, into a cyclical system, replacing the 'produce, use, and throw away' process with a more fertile one of 'produce, use, and reuse' [23]. The principles of the circular economy raise the fundamental question of how the recycling of materials, semi-finished products, scraps, products at the end of the cycle of use, and biomass could contribute to the growth of a more responsible and less erosive GDP; so that the production value would be maintained for longer through reuse and, where possible, up-cycling, triggering a new cycle of sustainable prosperity that generates new services in a fertile combination of new products, lower environmental impact, and the elimination of toxicity.

A more open and collaborative circular society based on sustainability and sharing is the catalyst that allows the economy to transfer its effects to the territory and lifecycles of the communities, activating and extending territorial dividend [24]. A circular society demands new political responsibility—mainly taking charge of urban planning—so that cities may once again be welcoming to people, attractive for ideas, generative for businesses, and supportive to the community archipelagos. It requires the implementation of concrete actions to guarantee a new balance between rural, urban, and developable, between landscape and infrastructures, not just placing limits on the indiscriminate use of land, but above all, stimulating, encouraging, and rewarding the reuse of already urbanized areas and the densification of functions. Planning cities, territories, and landscapes in the emerging Neoanthropocene means rejecting the complacency of a 'molecular' approach: We need a new long-sighted vision to look towards the innovation horizon by looking back and retrieving wisdom, rituals, and structurally self-sufficient circular practices not yet seduced by the demon of anthropic development.

We also need effective paradigms and concrete projects, or commitments, to serve a discipline of urban planning that knows how to influence the urban metabolism, reusing the local resources and flows to be put back into circulation. Although often fragmented or weakened, these flows are still able to generate new fabric if reactivated by the vital energy produced by the cycles of water, food, energy, nature, waste, people, and goods. Flows that have an impact on the daily life of cities, and that inevitably act on a large scale, contribute to the reticular connection of settlements. Reconnecting them with a holistic view of the metabolism is one of the greatest challenges for urban planners, designers, administrators, and citizens to give new impetus to the circular Neoanthropocene, connecting its technical components with its social and moral dimensions [25].

Finally, we need new types of urban and regional planning with localizing strategies rather than comprehensive planning, plans that work with simple and adaptive rules rather than masterplans, and generative settlement actions alongside regulatory plans [26].

2.2. The National Park of Lucania Apennines, Valdagri, and Lagonegrese: A Case Study

Dealing with the transition from the disruptive Anthropocene to the generative Neoanthropocene is not easy, but the strategy for the Plan of the National Park of Lucania Apennines, Valdagri, and Lagonegrese can be considered as a focused example to understand what the transition implicates. The National Park is in the center of southern Italy, in the Basilicata Region, and entirely included in the Province of Potenza.

The Park boundaries include three areas: Lucania Apennines in the north—very important mountain landscapes and protected habitat, listed in Natura 2000 project are the peculiarity of this area; Valdagri in the middle—along the Agri river, lakes, and wet habitats, has important archaeological sites, some relevant historical centers define a network of cultural and natural sites; and Lagonegrese in the south—focused on the Sirino Mountain, the area is the natural link between Lucania and Calabria Apennines. The Presidential Decree that established the National Park in 2007, focused the goals of the park on:

- Conservation species, plant associations, geological formations, paleontological singularities, biological communities, biotopes, natural processes, hydraulic and hydrogeological balances, ecological balances;
- Protection of the landscape;
- Application of land management methods suitable for promoting integration between man and environment by maintenance and development of traditional agro-forestry-pastoral activities;
- Promotion and development of traditional and organic agriculture through appropriate forms of incentives for the conversion of existing crops and technical assistance to businesses;
- Forest conservation and management of forest resources through interventions that do not change the fundamental characteristics of the ecosystem;
- Promotion of education, training, and scientific research activities;
- Compatible tourism and recreational activities;
- Support and enhancement of compatible production activities;
- Protection and enhancement of the customs and traditional activities, as well as the cultural expressions proper and characteristic of the identity of the local communities;
- Respect for the ‘open fields’ uses that are exercised according to local customs.

However, the general goals request a specific plan framework: In fact, the Park’s natural and cultural quality is dependent upon changing a 50-year inconsistent development, dominated by the crude oil extraction, storage, and transport through the oil pipelines.

In order to meet the challenges of a new growth for the Park community and for the protection of natural sanctuaries, the planning path is based on pre-planning, assessment, and synthesis, as below:

- A preliminary pre-planning step concerning statistical data and assessment of the related socio-economic condition;
- The assessment of the territorial structure of the Park concerning natural and cultural resources, historical centers and other heritage; (b) the ongoing projects and programs relevant in preservation and valorization of the Park heritage, as opportunities for further actions;
- The SWOT analysis that is the synthesis of pre-planning and structural assessment.

Sectoral analysis, such as habitat, ecosystems, wildlife, freshwater, cultural heritage, etc., were provided by the National Park Authority or by other experts in the workgroup as input to produce the maps with the overlay mapping approach [27], in ArcView GIS 8.x software environment.

As described in paragraph 3, the result of this analytic and interpretative path is the 'interpretation plan' structured as framework of strategies for local growth and below described.

2.3. Evidence in Local Context

The natural landscape of Lucania Apennines, Valdagri, and Lagonegrese National Park is the expression of the paleoclimatic events of southern Apennines that have enriched the flora of this territory with interesting species of considerable interest, as well as long historical relationships between man and nature that have created an inseparable link between biological wealth and cultural diversity in material and immaterial aspects. The result of this process is a floristic diversity with the presence of rare or very rare species. The variety of the environmental pattern also manifests itself on the vegetation, which diversifies in relation to the altitude and the different substrates: This territorial mosaic is also diversified in relation to the geomorphological characteristics that enrich a heterogenous landscape. In general, natural and semi-natural systems are the majority in the Park: Only 13% of surfaces are covered by artificial systems, such as agricultural surface.

Concerning the human settlement, strictly joined to the natural and seminatural environment, the National Park is composed of 30 municipalities with a very old population: The age pyramid of total population highlights a typical situation in Italian inner areas, and so a very small group of young people and a larger and larger group of old age people compose the local population set, as in Figure 1.

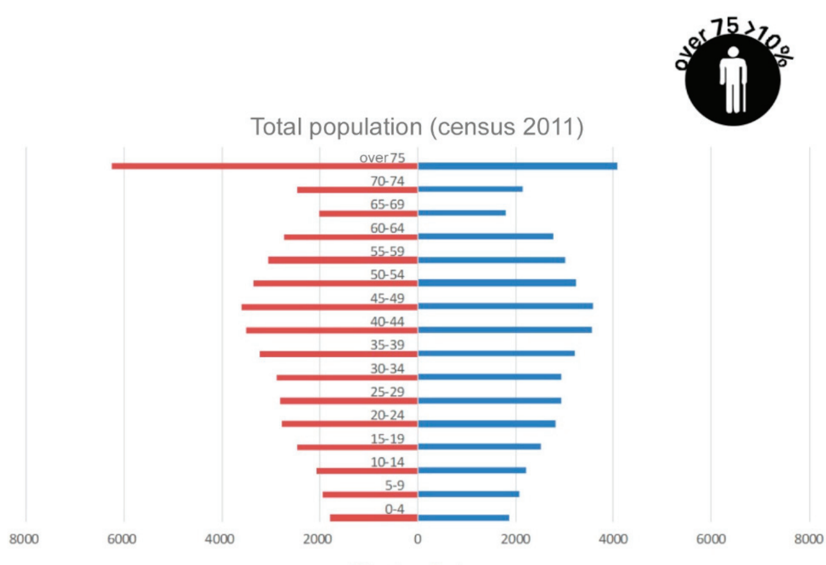

Figure 1. National Park municipalities' age pyramid. The strong incidence of the population in the older age groups, as a significant weakness for maintaining the social cohesion of Park territories, is evident.

This characteristic is going to produce depopulation in many little towns such as in Carbone where people who are more than 75 years old make up 75% of total population. Carbone is the maximum case of this faster and faster depopulation; furthermore, recent analysis of the social and sustainable assessment of Province of Potenza, in which the Park sits, has confirmed that in the Park, the population is old aged and accompanied by the relevant problem of employment ratio.

Apart from the depopulation described above, the general good quality of life is relevant in compensation of critical status of abandonment, thanks to landscape, environment, low pollution levels, cultural heritage, and quality of local facilities [28].

Furthermore, some historical-medieval and ancient origin-centers (Marsico Nuovo, Abriola, Anzi, Castelsaraceno, Gallicchio, Moliterno, San Chirico Raparo, Spinoso, Tramutola) are included in the Park boundaries: They are occupied, and this is a very important opportunity because nature and human history are connected in the Park interpretation and narrative for local population, tourists, and researchers.

However, some weaknesses and threats are related to anthropic activities, such as the crude oil extraction and production chain. If we consider the extraction sites, no oil field extends into the park boundaries, but its presence in the closer surroundings can influence the environmental quality of the Park. The local activists and ecologists fight against the crude oil extraction activities, and thanks to the establishment of the National Park, this activity was banned: To date, the oil extraction–production chain is entirely placed out of the Park boundaries, but the pipelines cross the park. The radical proposal by people, activists, and ecologists is focused on the banning of the crude oil production chain from Basilicata, assessed as inconsistent with the local natural and cultural heritage.

2.4. The Structural Analysis: Current Status and Ongoing Priority Projects

In order to assess the current situation and to check how many resources could be used to develop a protection and promotion of the Park, a specific analysis was drafted, called a structural analysis [29]. It is based on the overlay mapping technique [27] to assess the interactions among the natural and anthropic systems. Furthermore, the analysis goal is to define what natural and anthropic components identify the Park and can contribute to its circular development. To do so, the overlaid maps are divided in four categories corresponding to the main life cycles [30], as in Figures 2 and 3:

- The blue and green cycle, concerning the most relevant component of green coverage across the Park and the water, above all rivers, lakes, and freshwater springs, based on priority habitat map and on hydrographic network, as provided by National Park Authority and Regione Basilicata;
- The red cycle, concerning cultural heritage, its relations, and historical networks, provided by Regione Basilicata Geographical Information System, updated on field by the authors;
- The brown cycle, concerning local agriculture production system, high-sensitivity areas, and other sealed soils, based on CORINE map and updated at local level by Regione Basilicata and by the authors;
- The grey cycle, concerning infrastructure network, mainly roads and railways, used and abandoned, provided by Regione Basilicata Geographical Information System.

The research group has synthesized findings in the prevalence of wilderness. The National Park is composed of 69,000 hectares, 14 Natura 2000 sites recognized in regard to EU habitat protection policy [31] (12 Special Conservation Zones and 2 Special Protection Zones), 1 International Bird Area and 2 Important Plant Areas, 11 peaks over 1500 m high and 1 peak over 2000 m high, a hydrographic system composed of the Agri river and its tributaries that feeds Pertusillo artificial lake 75 square kilometres large, Laudemio lake, and a wide number of freshwater springs, geological sites, and singularities. Each habitat is composed of a higher and higher level of biodiversity, such as the old woods or the Apennine meadows.

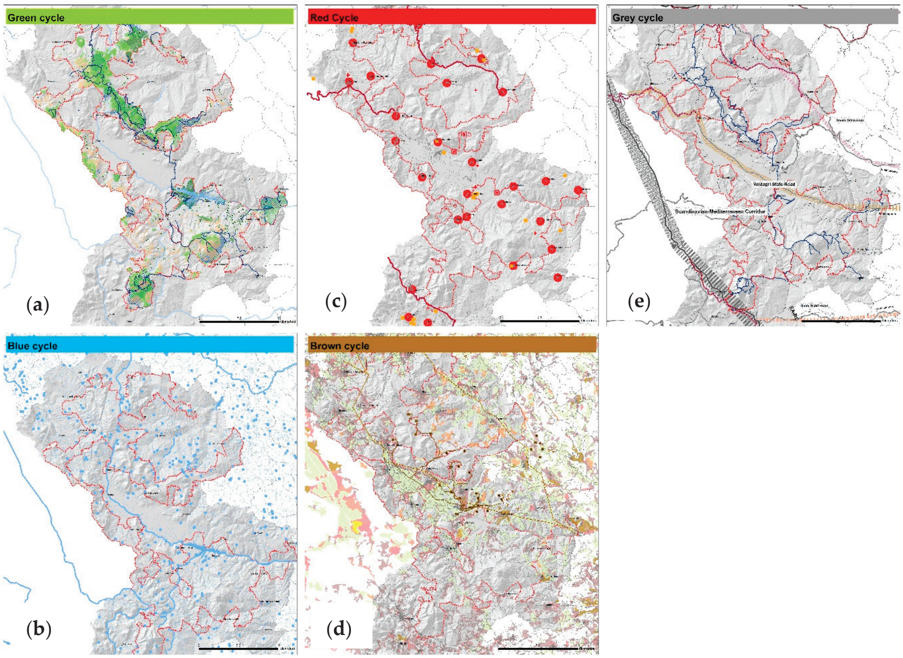

Figure 2. Five life cycles defining the backbone of Lucania Apennines National Park: From top to bottom, left to right, (**a**) green main components, (**b**) the blue network, (**c**) cultural networks in red cycle, (**d**) brown soils, and (**e**) grey infrastructural networks.

Regarding the cultural heritage, in the National Park, there is the Grumentum archaeological park—the most important Roman city in the area—many medieval castles and monasteries, historical centers, and sanctuaries, often in the mountains.

Regarding the immaterial heritage, food and art and crafts reveal a multifaceted use of local resources that has modelled the anthropic landscape in depth.

On the other hand, the research group focused on the ongoing transformations, mainly on EU structural fund granted projects that are the financial backbone of the conservation and promotion projects: The result is an amount of almost €40,000,000.00 for the realization of priority projects in the preservation and development of the National Park.

Table 1 shows the priority list for the protection and enhancement projects selected by the National Park Authority: It is clear that the primary necessity of protection is in Park natural capital (woods, planted areas, etc.), but it is otherwise clear that the park community is making a special effort to draft a new identity-centered development strategy.

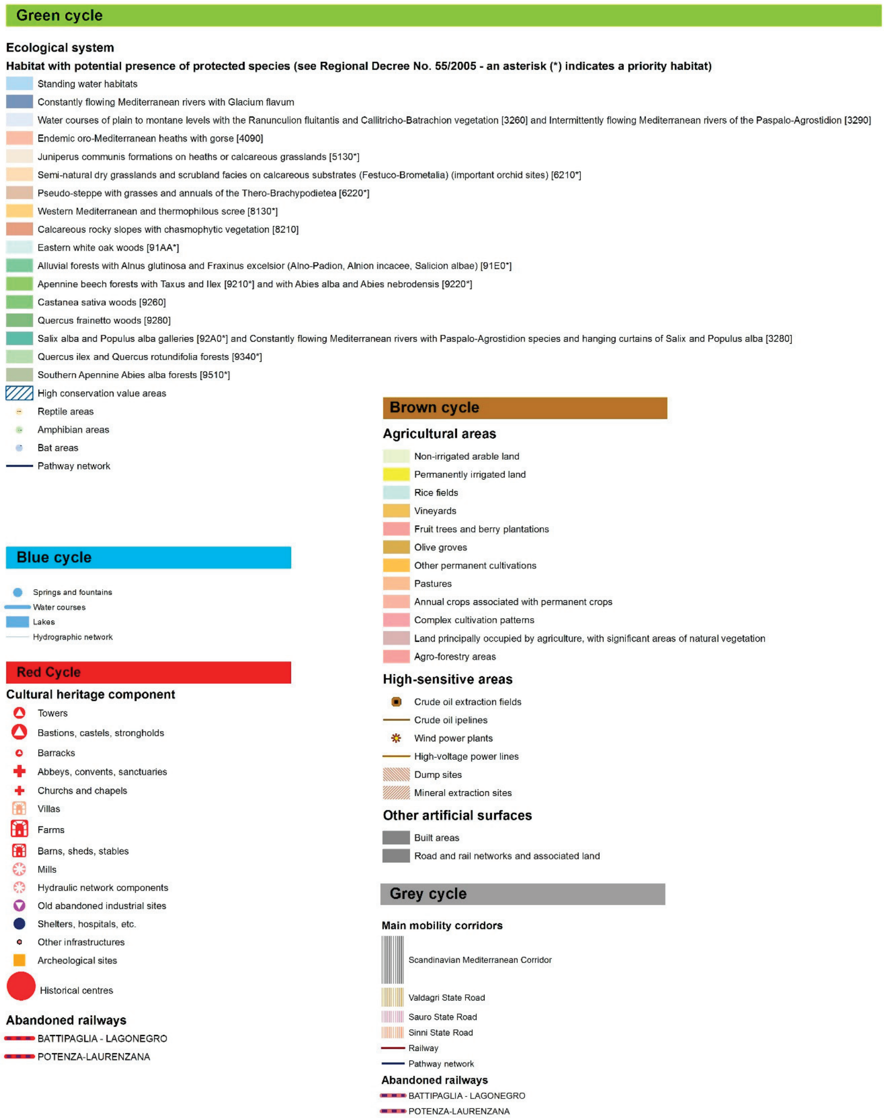

Figure 3. The structural components in life cycle analysis. The summary of information used in cycle definition enables the composition of a structure map of the National Park.

Table 1. Priority projects in National Park protection and enhancement.

Project Name	Local Resources			Economic Chain	Proposed Development Axis		
	Nature	Culture	Local Identity		Urban Metabolism	Interpretative Planning	Urban Smartness
1. New touristic signage	•	•				•	•
2. Reproduction environment for migratory fish protection activities	•				•		
3. 'Le porte del Parco' project	•	•				•	
4. Monumental trees GIS mapping	•		•			•	•
5. Orchid GIS mapping	•						•
6. New birdwatching stations	•					•	
7. Regional Ecological Network enhancement	•	•				•	•
8. Carnages and plant modules for habitat protection	•				•		
9. 'Fare Rete con il Parco'—project for local network enhancement	•	•				•	•
10. Local stakeholder digital platform for a new shared policy			•	•			•
11. Ski resort upgrading			•	•		•	
12. Communication and interpretation activities 'The Laurenza Beechwood'	•	•		•	•	•	
13. Communication and interpretation activities 'Sorgitora Park' and 'Agri Aqueduct'	•	•	•	•	•	•	
14. New Biodiversity Museum	•	•	•			•	
15. Touristic paths along the former 'Calabro-Lucana' railway, on the Padula MarsicoNuovo line and Pignola Laurenzana line			•		•	•	
16. Training for guides		•				•	
17. New National Park school		•				•	•
18. Planting species programme to attract wild fauna	•					•	
19. Environment quality monitoring	•						•
20. Water system monitoring	•					•	•
21. Boar production chain							
22. Wood certification project	•						
23. Forestry activities for reforestation	•				•		
24. Eco-functional monitoring system	•				•		

Source: High-priority project list. Lucania Apennines, Valdagri and Lagonegrese National Park Authority (2016).

2.5. The SWOT Matrix as Synthesis of Targeted Analysis

At the end of the structural analysis, the research group produced a SWOT matrix to select endogenous and exogenous resources. It is a widely used study undertaken by an organization to identify internal strengths and weaknesses, as well as external opportunities and threats, and it is focused on a non-neutral point of view: Our initial pre-planning idea and intended objective to analyze the emerging Neoanthropocene growth mirror the SWOT matrix items and shape up the whole plan.

In detail, strengths derive from a complex system of ecological, environmental, cultural, and settlement resources present in the National Park:

- Ecological continuity of the environmental system, despite settlement issues relating to crude oil extraction activities;
- Presence of a system of high-valued historical centers;
- Towns relevant to local urban facilities;
- Agricultural resources and 'niche' production (e.g., legumes).

Weaknesses derive from the presence of critical conditions, specific to the territory of the National Park, inherent to it or deriving from a consolidated tendency:

- Old-age population (peaks of the elderly population, over 75, in the smaller municipalities);
- The infrastructure network is exclusively based on the backbone of State Road Val d'Agri, and Naples, the nearest metropolitan context, is far from the Park because of the weak infrastructural connection;
- Economic dependence on the oil extraction chain and consequent weakness of the economic sectors connected to the protection and enhancement of the park's resources.

Opportunities derive from the ongoing projects driven by National Park, Regione Basilicata, and local rural development agents, in detail:

- Projects for enhancement of local resources, already authorized and activated with the support of the National Park Authority;
- Activities of GIS cataloguing for habitats, plant, and wildlife;
- New information and communication technologies and infrastructures for training and environmental dissemination;
- Projects aimed at promoting entrepreneurship centered on the local resources;

Threats derive from projects activated by territorial or extra-territorial stakeholders and which may cause a reduction in the environmental quality and resources present in the Park, mainly:

- Enhancement of the oil treatment plant with highly probable risk for biodiversity, soil and water quality, and human health.

3. Results

3.1. The Inner Area Policy as a Beacon for Development

The targeted analysis results enlighten the nature of Lucania Apennine peripherical and ultra-peripherical areas and focus on the relevance of the Park as a beacon in local development policies.

Distance far from metropolitan contexts, as a weakness, and high-level quality of life of inner areas, as a strength, are the main strategic resources for a disruptive and radical vision: In this context, a nature protection framework needs to connect to social and economic policies in order to innovate the approach to local development in the medium-long term, starting from innovative actions in a new—and sustainable—development chain composed by climate change response, rural economy, soil consumption reduction, and resilient approach [32–34].

The new vision implicates networking among the towns, update of infrastructures, re-negotiation of energy production model, as a more complete regenerative capacity for social, economic, and production tissues [35].

The Lucania Apennine Park can strive to [36,37] become an antifragile community, better and stronger than before the crisis, able to promote a non-dissipative circular metabolism, to climate change proof and maintain biophysical and socio-economic balances, alongside the urgent need to improve collaboration between users and supply chains, acting as a circular habitat instead of an unsustainable consuming one. The starting point is clear: People feel the ethical responsibility for protection and innovation, as in Figure 4.

Figure 4. A peculiar welcome to the National Park. A welcome to mountain lovers and an otherwise strong vade retro to its enemies: In a glance, for Lucania Apennine inhabitants, the mountain is a sacred place to be protected.

The Lucania Apennines Park Plan, therefore, manages the territory involved for long-term uses, facilitating the change of functions where necessary, as a more efficient alternative in terms of carbon emissions. A commitment is needed so that the extension of the life cycle of existing human and natural habitats becomes a new or renewed opportunity to strengthen the relationship between communities and territories through environmental sustainability and resilience.

3.2. Interpretation for Drawing a Regeneration Flagship Project

As a consequence of the new vision for the Lucania Apennines National Park, natural and cultural heritage promotion strategies have started selecting local resources relevant to promoting and enhancing the Park's identity. The interpretative relationships among the community, the park, and the experts are the basis to start a completely new regeneration process. However, the vision requires designing and implementing new flagship projects.

Therefore, the research group has drawn a development model, based on two widely known models:

- Interpretation planning framework [38] enables wider knowledge activities, planning, and communication;
- A landscape regeneration approach, based on the European Landscape Convention [39], in which the landscape is a new 'fundamental right'.

The result is an 'interpretation plan model' based on specific knowledge that divides the Park in landscape contexts, homogeneous in natural, historical, and urban aspects. The model is drafted through four steps:

- Recognizing the naturalistic, cultural, and landscape heritage framework as described in 'life cycle' analysis;
- Integrating the current protection rule framework, especially the regional plan for protection and enhancement of the landscape;
- Recognizing the landscape units, as required by national law n° 394/91 [40];
- Extracting enhancement and transformation strategies, consistent with the natural, cultural, and landscape resources, and shared with the local and external stakeholders.

The 'interpretation plan' is also a communication strategy, activated within the regulatory context: It constrains the existing naturalistic, cultural, and landscape resources, and proposes all the methods useful for valorization, such as communication strategy, educational activities, and structures capable of taking up the challenges of communication in the field of the protection of resources [41]. It is expressed as a methodology for making the strategic framework that contributes to the achievement of landscape quality objectives.

The core of the interpretation plan is the recognizing of landscape units: The landscape assessment has produced six landscape units, in which a specific identity typifies and distinguishes the places. These units are:

- High-mountain system of the Lucania Apennines, which is the wood and mountain Natural Park backbone;
- The Sirino mountain landscape that is the gate towards the Calabria Apennines, with lakes and peculiar geomorphology;
- The Raparo mountain with the historical Orthodox settlement;
- The Moliterno creek, with not very high mountains but with a peculiar Roman settlement centered in Grumentum. The unit is also characterized by a Medieval castle network;
- The Campania Felix and the 'Two Valley Principality' are composed of the wood at the west of Agri river;
- The Agri Valley, with Pertusillo artificial lake and 'Murge di Sant'Oronzo' clay landscape. The Valley is the main path for peoples who arrived and colonized Lucania while the ancient towns were settled in the hills around the Valley.

The landscape units include the whole Park, while the 'interpretation plan' needs otherwise to select some beacon landscapes that are selected places for promotion and regeneration activities, such as Brienza landscape hub, Pignola lake and wetland, Viggiano Holy Mountain, Laurenzana fir wood, Grumentum Archaeological Park, and Pertusillo Lake. They are not in hierarchical order with the six units but would represent relevant examples of the Park identity.

In accordance with the regulatory and zoning aspects aimed at the protection of National Park environment, this work step ends with the selection of an interpretation theme summarized in the expression 'wilderness': Actually, also where nature is 'artificial' as in the case of Pertusillo lake, it is capable of conceptually, perceptually, and structurally prevailing over anthropic presence.

The interpretation plan for the Park, therefore, is not sub-articulated into units, which could fragment and pulverize the interpretation theme, but aims at communicating and enhancing the landscape contexts defined and identified within a functional scheme in which the natural and cultural resources, the infrastructure network, and the leisure facilities are connected by slow mobility network.

4. Discussion: How to Balance Environment Preservation and Community Development? A 'Cluster Approach' for Circular Regeneration

The peculiar components in the National Park environment have created a deep reflection on the operative way to implement the development paradigm shift proposed in targeted research results, in discussions both with local communities, stakeholders, and national/regional government, in order to balance the preservation duty and the development opportunities.

This is more difficult if we consider the rub between preservation and crude oil extraction activities: In a simplistic view of development strategy, preservation and development are on opposite sides. According to circular metamorphosis paradigm, this is not true if we consider a development strategy based on the environment and cultural capital stock.

On the basis of current trends in the National Park and referring to the theoretical framework as above described, we are absolutely convinced that only a new approach can reset an effective social and economic development in Lucania Apennines.

The concept we have proposed to National Park Authority is a 'cluster approach' as in Figure 5: The metaphor, such as in UN and non-UN organization disaster response networks, means the necessity of an integrated approach to environment-based local development.

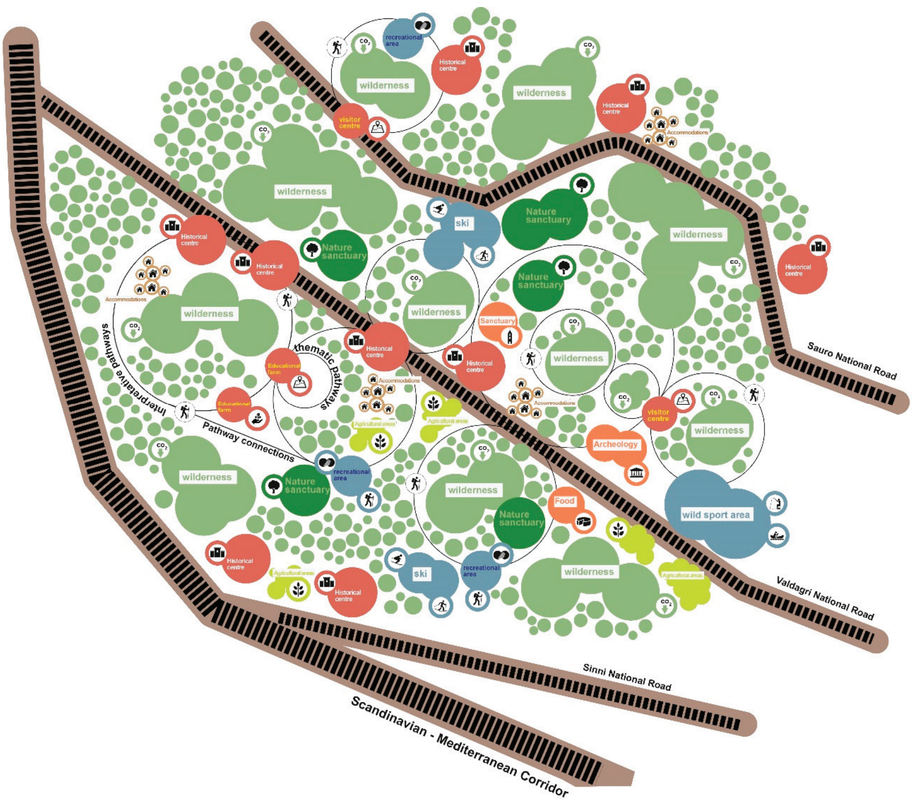

Figure 5. The 'cluster strategy' for environment-based local development. The nature sanctuaries and wild areas are reached through a door, often a visitor center, and they are connected with historical centers, archaeological parks, ski areas, accommodation facilities, and other local services.

In other words, one or a small group of local stakeholders has a chance to develop an interpretation plan, starting from a local cluster composed of some local components, updating it to the next level in a fertile circular process able to achieve transcalarity and reticularity.

Main resources are the wild areas—the A zones in National Park zoning map—where the plan decides upon the limited level of use, and accessibility is limited. Some of these areas have tourist activities or sanctuaries inside or in close proximity and, where it will be possible, the plan establishes places for interpretation and dissemination. These areas can be crossed and used in accordance with the Park regulations, but the mere experience of the place, through the paths, can guarantee the visitor will understand the experience of Wild Nature that the Plan is inspired by. Capturing CO_2 is the first strategic and interpretative mission of these areas.

In the field of the interpretation approach, we propose an action plan composed by a set of integrated policies and actions:

- Agricultural activities into the park are needed by a consistent and equilibrated land use: It is relevant for the purposes of preserving and spreading the sense of community and the traditional use of landscape, by the continuity of cultivation techniques and local productions;
- Accommodation and restaurant facilities in the park area make desirable (or even necessary) the development of food and wine supply chains;
- Traditional cultural activities, including festivals and religious customs (especially those related to traditional worship on the mountains) will aim at increasing the knowledge of the places and the vitality;
- Pathways and visitor centers are the core business of interpretation activities into the National Park: Dissemination activities centered on inhabitants and kids could improve the identity perception;
- Leisure, sport, and accommodation facilities ought to be integrated with protection and interpretation plan to avoid touristification effects. We are certain that the integration of these tourist activities within visitor centers and structures for active protection, such as in ski area and other sport facility areas, will become more and more economically sustainable and compatible with the nature protection.

In 2018 and 2019, the National Park Authority organized some engagement activities: A photo competition for kids and students to attract interest of young people, and three technical meetings with the local stakeholders to explain and amend the plan strategies and rules. During the meetings, the stakeholders were divided in five groups focused on the geographical areas of the National Park and their issues: The results of participation meetings more and more confirmed that the community is, and should continue to be, engaged in environment-oriented development in Lucania Apennines and now the Park is waiting for the official approval by National Park Community.

5. Conclusions

Our applied research demonstrates that National Park planning needs to be changed, facing the inconsistency of many aspects, both in national and in local framework:

- The national protection law is based on the total protection of sanctuaries, that are apart from anthropic transformation;
- The Natura 2000 sites request—often in natural sanctuaries—the presence of man to manage and to maintain alive the ecosystem, such as prairie or some types of woods; Local communities ask for a renewed strategy for growth in which they would feed a human–environment integrated development framework.

In comparison with traditional approach of separation between nature sanctuaries and human activities, the new plan produces a paradigm shift, to induce a fertile relationship among all the components of local communities and to define a positive environmental restoration.

Based on the plan scenario, we will wait for long-term consequences in planning and actions in both regional land use management and environment protection and raise the awareness of the advantages of a protection model based local resource development.

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How to Balance Environment Preservation and Community Development? A 'Cluster Approach' for Circular Regeneration, M.C. and D.R.; 5. Conclusions, M.C. and D.R. All authors have read and agreed to the published version of the manuscript.

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sustainability

Article

A Meaningful Anthropocene?: Golden Spikes, Transitions, Boundary Objects, and Anthropogenic Seascapes

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Abstract: As the number of academic manuscripts explicitly referencing the Anthropocene increases, a theme that seems to tie them all together is the general lack of continuity on how we should define the Anthropocene. In an attempt to formalize the concept, the Anthropocene Working Group (AWG) is working to identify, in the stratigraphic record, a Global Stratigraphic Section and Point (GSSP) or golden spike for a mid-twentieth century Anthropocene starting point. Rather than clarifying our understanding of the Anthropocene, we argue that the AWG's effort to provide an authoritative definition undermines the original intent of the concept, as a call-to-arms for future sustainable management of local, regional, and global environments, and weakens the concept's capacity to fundamentally reconfigure the established boundaries between the social and natural sciences. To sustain the creative and productive power of the Anthropocene concept, we argue that it is best understood as a "boundary object," where it can be adaptable enough to incorporate multiple viewpoints, but robust enough to be meaningful within different disciplines. Here, we provide two examples from our work on the deep history of anthropogenic seascapes, which demonstrate the power of the Anthropocene to stimulate new thinking about the entanglement of humans and non-humans, and for building interdisciplinary solutions to modern environmental issues.

Keywords: ecodynamics; historical ecology; Anthropology; archaeology

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1. Introduction

Nearly two decades ago, atmospheric chemist Paul Crutzen [1–3] quipped during an academic conference that we no longer live in the Holocene, but have entered the age of humans and are living in the Anthropocene. What began as an off-the-cuff remark has emerged as an innovative concept that has been quickly adopted by academic and public communities. As the political debates over anthropogenic climate change highlight, accepting that humans are altering global environments and influencing Earth systems forces a conceptual leap that challenges the foundations of the modern world. Even though there is broad consensus within the scientific community around anthropogenic climate change, there continues to be major points of contention and debate among scientists over how to define the Anthropocene, and even the usefulness of designating a formal Anthropocene epoch.

Earth scientists, for their part, have been the most vocal advocates for establishing a formal definition for the Anthropocene. To do this, they convened the Subcommission on Quaternary Stratigraphy to gather evidence and determine if we have entered a new geological age of our making, the Anthropocene (anthro for "human" and cene for "recent"). The Anthropocene Working Group (AWG) was tasked with deciding whether an Anthropocene signal has produced significantly clear and distinctive enough strata to make its formal designation scientifically justified, and whether the term would be useful to the scientific community.

Various members of the AWG have been especially prolific in their support of the concept and in the publication of proposed boundary markers, golden spikes, and hard rock criteria for designating the Anthropocene [4–15]. These authors have proposed a wide range of Anthropocene markers, including species extinctions, atmospheric gas, plastics, radionuclide accumulations, exploding human populations, fresh water diversion, landscape clearance and transformation, declining natural resources, and more. What these markers have in common is a post-Industrial Revolution (largely mid-twentieth century) start date, which the AWG and others have designated as "the Great Acceleration" [16–19].

This work, however, has sparked tremendous and wide-ranging debate that has gained momentum in recent years. Some have called for the rejection of an Anthropocene altogether [20–23], while others have proposed alternative terminology such as the "Capitalocene" or "Platationcene" to emphasize the social, economic, and moral dimensions of our current epoch [24–26]. The AWG argues that these "anthropocenes" discussed by non-geoscientists are fundamentally different concepts than their "Anthropocene" (lower-case versus upper-case), which is intended to be a formally designated unit of the geological time scale that must have a fixed point in time and be tied to hard rock stratigraphy or a golden spike [15] (p. 219). Debates over the Anthropocene, according to the AWG, should focus on the concept's "stratigraphic reality and distinctiveness", following traditions in the geosciences [15] (p. 219). A determination hinges, according to AWG's framing of the Anthropocene, on whether there has been a change in the Earth system sufficiently large enough and sharply enough defined to produce a distinct body of strata where natural geologic processes end and human-dominated strata begin. It is this kind of rigorous and precisely defined upper-case Anthropocene definition that, according to the AWG, will enable consistency in communication and a stable meaning. One danger of an approach framed as such is that there is little room or need for Anthropocene debates outside of the geoscientific community. The message is that, even though the "Anthropocene" suggests that humans are now a force of nature in the geological sense, its designation is the purview of Earth scientists, and they have the tools and techniques to provide a privileged, evidenced-based definition. Further complicating the debate is work by a variety of geoscientists showing the deep antiquity of human–natural entanglements that extend back millennia [27,28].

Thus, the Anthropocene, despite its common usage in academic publications and popular discourse, seems to divide and fracture the scientific community, across and within disciplines, while simultaneously unifying it around a common theme. There seems little chance of reaching a trans-disciplinary scientific consensus when the Anthropocene is being framed and defined differently across disciplinary boundaries. Despite these academic debates, the broader community of academics, policy makers, and concerned citizens seems to find value in recognizing that the relationship between humans and the biosphere has taken on new, and potentially, ruinous dimensions.

Here, we argue that the productive nature of the Anthropocene concept is that it attracts disciplines into dialogue, and rubs them together in ways that spawn innovative thinking. In many ways, the Anthropocene is a classic "boundary object," in that it is ambiguous, yet robust [29]. Below, we investigate how the Anthropocene illuminates previously undetected social-ecological dynamics by offering two examples from our own research, namely: one from California exploring the long history of red abalone (*Haliotis rufescens*) fishing and anthropogenic seascapes, and one from the Pacific Islands involving the sustainability of tropical coral reef seascapes. Our case studies demonstrate how the Anthropocene concept stimulates new lines of inquiry into the long, discontinuous, and complicated distribution and redistribution of human and non-human agencies; necessitates trans-disciplinary research agendas; and facilitates the communication of political and environmental management messages to the public.

2. An Anthropocene of Red Abalone Shellfishing

The story of California red abalone fishing offers critical lessons on the importance of time, history, human–environmental ecodynamics, and modern management in the Anthropocene. The Pacific red abalone fishery was once a thriving part of the California economy, with commercial and sport landings peaking in the late 1950s. By the 1970s and 1980s, however, serial overfishing, increased competition with expanding sea otter (*Enhydra lutris*) populations, and the appearance of Withering Syndrome (a deadly bacterial disease) took a dramatic toll on red (and other) abalone populations. A moratorium was placed on all red abalone fishing in 1997 south of the San Francisco Bay, leaving open only a highly regulated sport fishery in northern California. Red abalone was the last of California's abalone species to be closed to commercial and sport exploitation, as a moratorium had been placed on black (*H. cracherodii*), green (*H. fulgens*), pink (*H. corregata*), and white (*H. sorenseni*) abalone by the California Fish and Game Commission in the early 1990s [30,31]. Beginning only ~160 years ago with immigrant Chinese fishermen, the commercial harvest of abalone has evaporated in California, and the outlook for species' survival in the wild is abysmal [32]. Despite careful management and monitoring and nearly two decades of fishery closures, there have been little to no signs of improvement for most of California's abalone. Contrast this with the Native American harvest, which was intensive and continuous for at least 12,000 years [33].

Red abalone, however, may be the one bright spot for the recovery and management of the California abalone fishery. Unlike other California abalone species, such as whites, red abalone have expanded their numbers and range across much of coastal southern California, especially the Northern Channel Islands. San Miguel Island, the western-most of the Northern Channel Islands, has seen promising increases in red abalone densities, likely spurred by the strong upwelling and cold-water influx that made San Miguel Island red abalone the focus of commercial and recreational harvests before the 1997 closure. Commercial divers have argued for over a decade, citing an amendment of the California Abalone Recovery and Management Plan that allows for experimental harvests before stocks are fully recovered, that the California Department of Fish and Game (CDFG) should open a small test fishery along San Miguel Island. Debates over the feasibility of this proposal continue, and are entangled with deliberations over the reintroduction and expansion of sea otter populations. Traditionally, these debates have centered on understanding "A"nthropocene systems (human–environmental ecodynamics over the last half century), and the recovery and future management of California abalone can be accomplished by marine biologists and resource managers employing modern ecological data.

When the deeper history of red abalone fishing in southern California is considered, the processes that reconfigure and recombine human and non-human agencies over time are exposed. Combined archaeological, paleoecological, historical, and modern catch data demonstrate that the availability of red abalone has been discontinuous across the Santa Barbara Channel over deep time [34]. For millennia, red and other abalone were an important component of Native American hunting–gathering–fishing economies, along with other shellfish species, such as California mussels (*Mytilus californianus*) and sea urchins (*Strongylocentrotus* spp.) [33]. Shellfishing productivity was enhanced, despite intensive human predation pressure, by the anthropogenic restructuring of marine foodwebs, where humans replaced sea otters as the top shellfish predators (Figure 1). Archaeological and paleoecological data suggest that beginning approximately 8000 years ago, Native American hunters reduced sea otter populations in local watersheds, intentionally or unintentionally either through direct hunting or competitive exclusion, which resulted in exceptionally productive red abalone (and other shellfish) communities [35]. This pattern was especially true on San Miguel Island, where red abalone were available for millennia, regardless of fluctuations in the local water temperatures. Red abalone was only abundant on the other islands during optimal climatic conditions when sea surface temperatures were colder than normal along the channel [34]. This novel, human–ecological system was in place throughout much of the Native American occupation, until sea otters were extirpated from the Santa Barbara Channel during the historical fur trade in the 19th century [36].

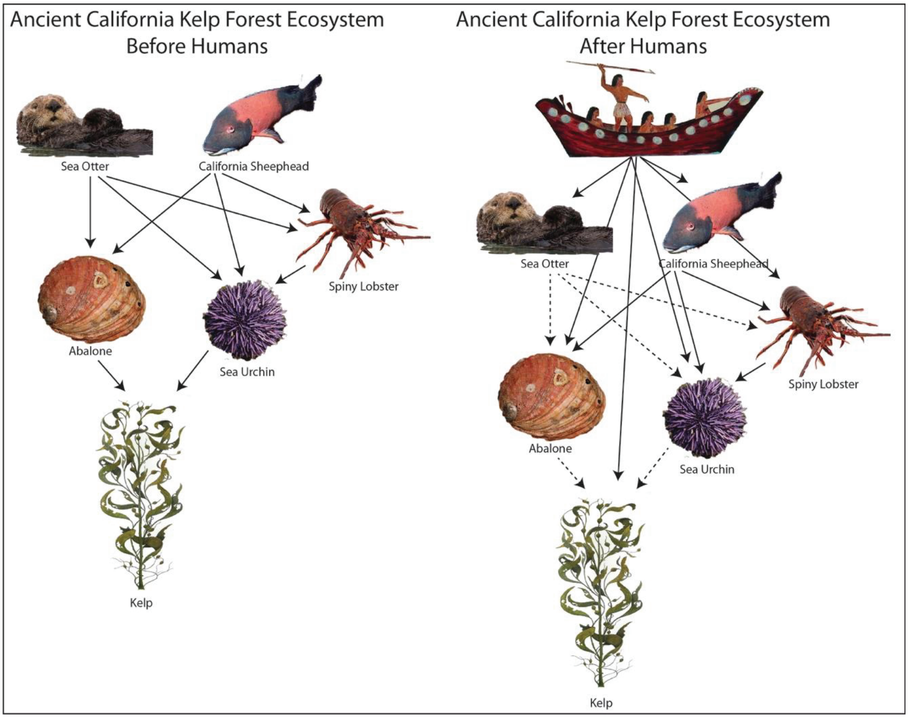

Figure 1. Simplified model of an ancient southern California kelp forest food web showing changes after the arrival of Native Americans. The food web on left depicts the ancient kelp–abalone–otter relationship prior to human arrival. The food web on right depicts the changes after human pressure on sea otters intensified, reducing their predation pressure on red abalone and other shellfish, creating a novel human–natural system that was in place until historical times. Note: solid arrows represent strong interactions, and dashed arrows represent weak interactions.

The modern implications of these findings are vital for the continued survival of red abalone in the wild and for the potential reestablishment of a California fishery. For at least 8000 years, the waters surrounding San Miguel Island maintained intensive red abalone fisheries and were a critical habitat for larval production and recruitment, which fed the larger Santa Barbara Channel during optimal sea surface temperatures [34]. With the closure of sport and commercial fishing since 1997, we would expect the first signs of red abalone rebound along the Santa Barbara Channel to occur in San Miguel Island waters. A better test of the channel-wide health and recovery of red abalone is their re-population along island shorelines to the east, where ancient fisheries flourished during optimal climatic conditions, and the modern fishery was robust but less productive than in San Miguel Island waters.

The lesson for the Anthropocene future of the southern California kelp forest ecosystems is that a sustainable red abalone fishery and the recovery of sea otters may be able to co-exist, if we use the deep past as our guide. The goal should not be to for a “natural” system that disconnects human agency from ecosystems. Rather, the long history of abalone fishing on the Channel Islands tells us that red abalone populations must be fully recovered, and sea otter populations must be reintroduced and controlled, recreating a human–ecological state that began at least 8000 years ago [37]. For millennia, the Northern Channel Islands can be characterized as a kelp–otter–abalone–human entanglement where the effects of each of these agents have dynamically shifted through time. Understanding these human and non-human processes are vital for effectively restoring and managing the contemporary ecosystem.

3. Managing Anthropocene Coral Reef Fisheries in Polynesia

Coral reefs represent some of most the complex and iconic of all ecosystems, yet they may be the first to be fundamentally transformed in the Anthropocene. Under current oceanic temperatures, coral reefs are transforming rapidly into novel ecosystems [38]. The 2017 mass coral bleaching of the Great Barrier Reef, for example, is expected to permanently shift the assemblage structure towards faster growing corals, the long-term effects of which are still unknown. Moreover, the frequency and intensity of bleaching is reaching a point where corals cannot recover to a mature state [39]. Even if we achieve the Paris agreement goal of maintaining sea-surface temperatures below a 2 °C increase, future coral reefs will be fundamentally altered from their Holocene state.

Changes to coral reefs are beginning to be felt by millions of coastal dwelling people who depend on them for their income, food, and cultural identities. In the Pacific region in particular, island people have interrelated with coral reefs for thousands of years for both food harvesting and cosmological inspiration. Islanders do not pit themselves against their marine environments or consider themselves outside of it. Their cosmologies consider corals, reef fish, families, chiefs, land, coastal streams, personal identity, and island mountains as intermixed. In Hawaii, for example, there were all-inclusive territorial units known as "ahupuha'a" [40], while in French Polynesia they were known as "fenua" [41]. In many Pacific Island contexts, however, colonialism precipitated an ecological–cosmological collapse of these territorial units. In their place, local resource exploitation has increased, and more recent climate change-induced ocean warming has accelerated the transformation of Anthropocene reefs into novel joint human–ecological systems [42]. As a result, effective site-specific management is paramount as both local livelihoods and reefs transform.

The coral reefs around the island of Moorea in French Polynesia present a microcosm of these Anthropocene colonial, ecological, cultural processes. This high volcanic island with a circumference of 60 km has barrier reefs, roughly one kilometer from the shore, that encircle a 29 km^2 coral reef–lagoon ecosystem. Located 25 km northwest of Tahiti, Moorea is densely populated with 17,000 people, has a disruptive colonial history, and has a number of major stakeholders who use or who have a vested interest in the lagoon. They include large hotel conglomerates, tourists, multiple conservation non-governmental organizations (NGOs), and two of the world's most important centers of coral reef research. Moreover, nearly 80% of Moorean households regularly fish the lagoon, for economic, food security, and cultural reasons [43,44]. The cooking, sharing, and eating of fresh lagoon fish is a fundamental expression of Polynesian identity. Notwithstanding, there is widespread acknowledgement and concern among the populace that the coral reef fishery is less productive than in the past.

Compounding the increasing fishing pressure, Moorea's reefs have experienced a number of climate change-related perturbations over the past decade, including a large hurricane, a crown of thorns seastar (COTS) outbreak, and a bleaching event, resulting in a steady transformation of the island coral reef assemblage [45]. The 2010 COTS outbreak, in fact, reduced coral cover on the outer reef slope from 95% to 5% [46]. The reefs, however, have so far shown resilience, and coral coverage has returned to pre-disturbance levels.

One promising strategy for the Anthropocene management of coral reefs in contexts like Moorea is known as adaptive co-management [47,48]. The central focus of this approach involves careful monitoring of resource conditions and then adaptation of the management strategies (e.g., gear use, size limits, and location of no-take zones) as resource conditions change. Rather than assuming that coral reef dynamics are known, adaptive management rests on the uncertainty principle, where surprise, non-linearity, and unknown tipping points are expected and managed rather than suppressed.

In addition to adaptively altering management, this strategy also involves joint governance among all vested stakeholders, as well as collaborative resource monitoring and knowledge production. Considering the magnitude and rate of Anthropocene change occurring to coral reefs, resource monitoring and governance must necessarily involve local resource users, scientists, policymakers, and conservation practitioners. It is by drawing on the knowledge and insights of all of the vested stakeholders that we have the best chance to grasp the changes to coral reefs and the communities that depend on them, as well as to devise iterative solutions to navigate through them [49]. New symmetrical approaches to knowledge, such as "bridging knowledge" and "citizen science", emphasize this style of open collaborative frameworks of knowledge production, where knowledge space is provided for multiple framings of problems, and possible solutions are assumed to be valid and jointly evaluated [50]. This process, however, is not assumed to be void of political positioning and contestation. Anthropocene research assumes that politics are an inherent and critical dimension of knowledge production, as stakeholders vie to influence decision makers. Moreover, some of the ontological suppositions of different stakeholder groups, especially in non-Western contexts like the Pacific Islands, may be incommensurable, and pose challenges for effective blending or meaningful co-production.

On Moorea, the management regime is shifting towards adaptive co-management [43,51]. To address the marine resource challenges on the island, a management regime known as Plan de Gestion d'Espace Maritime (PGEM) was established in 2004. In many ways, PGEM was conceived based on the principles of the "Holocene" coral reef management (Table 1); it emphasized biodiversity conservation over sustainable use, implemented rigid management rules (most notably the establishment of eight no-takes zones), decision making and governance were top-down, and scientific knowledge was privileged over all other forms of knowledge and understanding. The outcome of the initial PGEM project was turmoil and discontent among fishers who felt that their interests were not heard and that they were being disenfranchised from the lagoon. Moreover, several years after being established, marine science monitoring revealed little increase in fish stocks within the reserves, suggesting that compliance with PGEM was low. With PGEM struggling both ecologically and socially, a revision process began in 2016, and, although not yet finalized, it appears to be adhering more closely to the principles of Anthropocene-era adaptive co-management [43].

Table 1. Comparison of coral reef management principles during the Holocene and the Anthropocene.

Holocene Coral Reef Conservation and Management	Anthropocene Coral Reef Conservation and Management
Privilege biodiversity conservation	Manage for joint human–ecological wellbeing
Rigid and goal-oriented	Adaptive and process-oriented
Emphasize marine protected areas free of humans	Emphasize mix of managed fishing/harvesting areas and temporary, shifting no-take zones
Assumed predictably of social-ecological dynamics	Assumed uncertainty of social-ecological dynamics
Top-down governance	Shared stakeholder governance
Knowledge of western scientists privileged	Knowledges approached symmetrically
Knowledge production is black boxed	Knowledge production is open and deliberated
Political contestation is detrimental and should be avoided or suppressed	Political contestation is inherent and is managed
Impose foreign management strategies and reject traditional or non-Western strategies	Repurpose traditional strategies and mix with the contemporary strategies

One of the most challenging obstacles for more effective management is acute distrust between the scientific community and local fishers. Fishers perceive that the research centers on the island are extensions of post-colonial power, while many researchers assume that fishing communities are incapable of effective management and are too politicized. To overcome this, an effort is underway to bring fishers into the research centers, and to collaboratively research, monitor, and produce knowledge about the lagoon by drawing from both scientific and local knowledge. During these interactions, politics are not avoided, they are expected. Holocene management idealizes a decision-making space that is free of political positioning, where it is assumed that all actors can equally have a voice and contribute. Rather than attempting to eliminate power contestations and seek an apolitical space, anthropocene management assumes that all actors speak from a certain position (e.g., race, gender, or other structural inequalities), and attempts to make these positions explicit. This opens the possibility that strategies to address, manage, and potentially ameliorate power differences will emerge. Of course, Anthropocene era adaptive co-management is not a panacea, but because it is built around principles that do not neatly partition the social, political, or cosmological from the ecological, nor are certain kinds of knowledge production privileged over others, pathways to assemble mutually beneficial interrelatings become more achievable.

4. Nature, Culture, and the Anthropocene

These studies highlight how traditional lines of inquiry in the biological and social sciences that meticulously partition biophysical domains from social or cultural ones stifle our understanding of the key dynamics of these systems. Yet, much of the current debate over the Anthropocene centers around arguments that pursue either naturalistic definitions and explanations or sociological ones. The geoscience community, for example, searches for suitable global signals of human agency in stratigraphic records [15]. Where "natural" history was once the only player, humans are now agents of geological change.

Despite the centrality of humans in creating Anthropocene rocks, the AWG's descriptions tell us very little about the world or biophysical entities jointly constituted through human/non-human processes [52]. To explain the materiality of novel Anthropocene substances, such as radionuclides [53], plastiglomerates [54], or over 200 new Anthropocene minerals [55], many geologists explicitly express their bafflement when they put quotation marks around these types of "stone", or describe the minerals as "mineral-like compounds" or "human-mediated mineral-like compounds." In fact, Anthropocene minerals are not even formally recognized, as they do not adhere to their definition of a mineral, namely "a naturally occurring solid that has been formed by geological processes" [55] (p. 4). Because of geologists' classic line of inquiry to focus on identifying the boundary between humans and the natural, their objects of study, stones or minerals, are rendered anomalous and are no longer empirically describable as stones or minerals, but instead are human-made entities. Rocks can either be natural or human-made, but not both.

In much the same way, successfully protecting, restoring, and rebuilding red abalone fisheries in California requires an understanding of the joint human–biophysical processes that shaped the fishery for millennia. Rather than attempting to parse out natural or social drivers of ecosystem change, we must understand and describe the California abalone fishery as deeply intertwined systems that can never be successfully managed by pulling them apart.

Crutzen (one of the original Anthropocene authors) and Schwägerl succinctly express their adherence to the culture/nature dichotomy when they state that "(i)t's no longer us against 'Nature'. Instead, it's we who decide what nature is and what it will be" [56]. Their "A"nthropocene, then, redefines nature as a human enterprise, as if we have control over the planetary-level forces we have unleashed. Natural geological forces have crossed the threshold in the Anthropocene, and now geology is "human-dominated." We highlight this not to suggest that their framework should be rejected, but rather to point out that their approach does not deserve a privileged position of explanation, signaled by their insistence on the upper-case "A" of the Anthropocene over the so-called "anthropocenes." A formal "A"nthropocene definition with an associated GSSP or golden spike can be an important and valuable tool for the geosciences, but one that should not limit the broader uses of the "a"nthropocene concept.

On the other hand, advocates, mainly social scientists, of those "anthropocenes", push back against the AWG's Anthropocene concept by arguing that we have entered a thoroughly anthropocentric world structured not by some generic "anthropos", but instead a specific economic and political system—capitalism. For this reason, scholars argue that the current epoch is more accurately described as a "Capitalocene" or "Plantationocene", rather than an Anthropocene [24–26]. The Capitalocene concept, in particular, rightly focuses attention on the linkages between the rise of industrial capitalism and the rapidly expanded scale of human impact on planetary systems. Capitalism, however, can no longer be described without bumping into those non-human processes that were previously cordoned off as aspects of the "natural" world. When describing coral reef fisheries, for example, there are no neat dividing lines between human–virus infected coral, fish behavior, ciguatera fish toxicity, the rise of highly efficient fishing gear, fertilizer driven nutrient rich stream run-off, thermal stress on corals, profits made through the live-reef fish trade, and the implications of increasing global seafood consumption. In the same way that the AWG has trouble conceptualizing how human agents and geology jointly brought into existence Anthropocene rocks, advocates of the Capitalocene have trouble describing how non-human agents and capitalism jointly brought into existence contemporary coral reef fisheries.

Even though the notion of the Capitalocene correctly narrows the generic "anthropos" of the Anthropocene to focus attention on the fundamental role that capitalism and the elites have played in the current environmental crisis, it backgrounds the deeper point, that no single group of actors is exclusively responsible for the Anthropocene era. Even if the global elite have been the great beneficiaries of capitalism, their collective activities are not equivalent to a geologic force of nature. Rather, it was the industrial complex collectively (and increasingly the emerging economies of China and India) that constitute the force of nature that has altered the planet's chemistry. The planetary crisis cannot be reduced to capitalism, as, "unlike the crises of capitalism, there are no lifeboats for the rich and privileged" [57] (p. 221). The 2017 mudslides that devastated Montecito, California, one of the wealthiest towns in the United States, is a case in point. Moreover, the low income service worker living in a sprawling American city who has no alternative to driving an automobile to work every day will insist that s/he is not responsible for melting the polar ice sheets and burning up tropical coral reefs.

5. The Promise of the Anthropocene

In the search for and debate over Anthropocene definitions, we risk losing out on the real power and promise of the concept. The key conceptual productivity of the Anthropocene label is that it enrolls scholars across the natural and social sciences to collaboratively pursue research projects, while simultaneously destabilizing their objects of inquiry. It reconfigures what geologists thought was a unified nature, by bringing humans back onto the stage while simultaneously transforming what the social scientists demarcated as social, by recognizing the intrusion of non-human entities. More broadly, it dissolves the idea that the human species is a unified agent of history. It is the disruptive force of the Anthropocene concept that should be embraced and recognized as its most important unifying and productive effect. The construction of an "Anthropocene" for Earth scientists and an "anthropocene" for everyone else, and the rise of concepts of like the Capitalocene or Plantationocene undermine the unifying power of the Anthropocene, as they attempt to resolve its fragmenting effect through a well-worn, but flawed natural/cultural dichotomy.

The grand challenge, opportunity, and promise of the Anthropocene is that accurately studying, describing, and responding requires an extremely diverse group of actors—interdisciplinary scientists, resource managers, politicians, artists, activists, amateurs, and professionals. This necessitates "cooperation—to create common understandings, to ensure reliability across domains and to gather information which retains its integrity across time, space and local contingencies" [29] (p. 387). This does not mean, however, that scientific cooperation requires consensus [58–60].

As the Anthropocene concept has increasingly become interpreted more broadly across disciplines as a way of thinking about the current state of the world [15,61,62], we suggest that the Anthropocene has become and should remain a "boundary object"—facilitating communication across disciplines by creating a shared vocabulary, and acknowledging that no one discipline has a privileged framework for describing the current epoch. Of course, the precise definition and understandings of the Anthropocene across diverse actors and disciplines is not necessarily shared. As is a common problem with boundary objects, this can result in diluted and unclear meanings, obscure conflicts, and power struggles, and can create confusion about how to operationalize and apply the concept [29,63]. Yet these difficulties are precisely why boundary objects are productive. The conceptual ambiguity of the anthropocene concept rather than its precision is why a wide spectrum of academic disciplines, from the humanities to the physical sciences, have found it a meaningful line of inquiry, even without consensus about the aims and interests. Anthropocene research has generated a space for critical communication, reflection, and articulation across scientific disciplines and the science community, the public, and policy makers [63–65]. Acknowledging ambiguity also has the effect of acknowledging, rather than suppressing, the salience of politics and power inequities in shaping the future trajectories of social-ecological systems. This destabilizes the narratives and knowledge of privileged actors, and potentially opens space for oppressed or unrecognized modes of human or non-human knowing or being. By resisting encapsulation and assuming some fluidity, the Anthropocene term is able to enroll actors, while also compelling reflective deliberation and stimulating new thinking. This productive elusiveness stands to make the concept a continually successful socio-ecological gathering point for describing and understanding the proliferation of novel entities emerging at an ever-increasing pace, an understanding that may open up the possibility of developing future sustainable systems.

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