



Review

Dynamic Role and Importance of Multi-Kingdom Communities in Mediterranean Wood-Pastures

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Abstract: Wood-pastures are among the most valuable types of farmland for ecosystem services, including biodiversity, landscape, soil protection, water management and cultural values. This paper reviews the scientific literature regarding the dynamic role and importance of plant, fungal and ruminant communities in Mediterranean wood-pastures and assesses the favorable and unfavorable aspects of their occurrence through grazing management. The grasslands of the Mediterranean region play an important role both in forage material production and the conservation of biodiversity in plant communities and at the landscape level. These two management purposes are not conflicting but complementary when the management is based upon the knowledge of the effect of grazing on the ecology of these ecosystems. Conclusively, vascular plant, fungal and ruminant communities have a strong influence on ecosystem structure and functioning and they play a key role in many ecological services. Hence, integrated studies which combine multi-level ecological research are essential in order to identify regional and/or national needs in terms of biodiversity, genetic resources, sustainable rural development and conservation policies.

Keywords: flora; fungi; ruminants; grazing; pastures; ecosystem services; ecology; utilization; Mediterranean



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1. Introduction

Wood-pastures are essential elements of landscapes and are recognized for their significant ecological value worldwide. Wood-pastures occupy around 20.3 million ha in the 27 EU member states, which represents around 4.7% of European land, with the area of grazed wood-pasture estimated to be 15.1 million ha [1]. In wood-pastures, livestock grazing co-occurs, with scattered trees and shrubs constituting the most valuable types of farmland for biodiversity [2]. It is widely accepted that there are many ecological and economic interactions among flora and fauna (e.g., fungal, nematode and ruminant communities, etc.) in these landscapes. The interactions among species are often complex and they may exhibit numerous positive or negative effects which are not easily noticed, observed or measured. Human activity is linked with the delivery of goods by the ecosystems; often, the survival and well-being of rural people is based on the production of the “ecosystem goods” [3,4].

Either due to the increased farming intensity or land abandonment during the last few decades, some major threats for the biological activity of several ecosystems have

emerged [5,6]. Therefore, recently developed conservation management strategies emphasize biodiversity conservation and ecosystem multifunctionality. The concept of agroforestry has evolved during the last few years, and under this concept, many different approaches are integrated into management practices in order to enhance the sustainable production of ecosystem goods (timber, food, medicinal plants, animal production, etc.) and balance productivity with environmental protection (enhancement of biodiversity, reduction in nutrient losses, pest and disease control, etc.). In many regions, such agroforestry systems were traditionally used for decades and consisted of important elements of rural landscapes (forest land, coppice forests and orchards) [7].

Wood-pastures are typical examples of successful agroforestry systems (multifunctional land use). By definition, wood-pastures are landscapes which are covered by a combination of a tree and a pasture cover and are regularly grazed by natural large grazers or by domestic livestock or both [2,8]. The structural diversity of wood-pastures varies considerably across Europe [8]. This variation is mainly attributed to the grazing intensity and tree thinning (selective logging), two practices which substantially determine the vegetation structure and dynamics in those ecosystems [2,8,9]. Wood-pastures are valuable elements of socially, ecologically and economically important landscapes in Europe, and their traditional management has been practiced for centuries [10] often, wood-pastures are regarded as forms of cultural heritage in Europe [10]. Mediterranean oak woodlands, Montados in Portugal and Dehesas in Spain have long been acknowledged as potential land-use systems of high nature and social value providing relevant ecosystem services and biodiversity conservation [11]. Cultural services (particularly the aesthetic and recreational values of the landscape), supporting services (biodiversity maintenance) and some regulating services (particularly fire risk prevention) were clearly recognized by both farmers and citizens, with different degrees of importance according to their particular interests and objectives [12]. The diversity of production is characteristic of these systems, and the long-term ecological sustainability derives from the sub-optimization of the resources for many centuries [13]. However, wood-pasture ecosystems in most European countries have been noticeably degraded during recent decades, and therefore, they are considered as threatened landscapes which need to be protected and conserved [1,10].

According to Bergmeier et al. [10], there are twenty-four types of wood-pastures which are categorized based on the following geobotanical criteria: (i) region, (ii) structure, (iii) land use and (iv) species composition. Moreover, they are categorized according to the different bioclimatic zones in Europe as boreal, nemoral, meridional, hemiboreal and submeridional [9]. Because of their dynamic nature (spatial and temporal variations due to climatic events, traditional management, pests, herbivores, etc.), all of these different wood-pasture types exhibit exceptional ecological values; they provide an important habitat for a wide range of different organisms and are therefore considered important for regional biodiversity; they pose important restoration possibilities for the maintenance and conservation of genetic resources [2,10].

The degradation of biodiversity observed in wood-pastures during recent decades is mostly attributed to (i) abandonment, which leads to the formation of closed-canopy forests; (ii) intensification, that leads to the development of crop monocultures; (iii) failure of wood-pasture regeneration and woodland aging; (iv) management methods (overgrazing, tree thinning, etc.); (v) pest problems (devastating insects and/or diseases) [8,13]. Wood-pastures are still widely distributed in the Mediterranean and Balkans, areas where their traditional usage is still retained to some extent [8]. The conservation of wood-pastures in the Mediterranean is linked with the traditional practice and their appropriate management is very important for the maintenance of their biodiversity, ecological and economical value.

Hence, the present study aimed to investigate the dynamic role of vascular plant, fungal and ruminant communities in Mediterranean wood-pastures, as well as the favorable and unfavorable factors that influence their occurrence through grazing management. Moreover, it highlights how grazing is linked with animal welfare and can improve the quality of livestock products. This short review may be useful for future studies that seek to

expand the information regarding the dynamic role and importance value of biodiversity in Mediterranean wood-pasture landscapes.

2. Literature Review

A review of the scientific literature about the dynamic role and importance of multi-kingdom communities in Mediterranean wood-pastures (Figure 1) was conducted. The keywords used for the Boolean search [14] included words such as “flora”, “fungal”, “ruminant”, “grazing”, “ecosystem”, “ecology”, “pastures”, “utilization”, “services”, “landscape” and “Mediterranean”. A total of 320 articles and abstracts were identified through the database searches. After removing 122 duplicates, 198 records were studied based on the title and abstract.

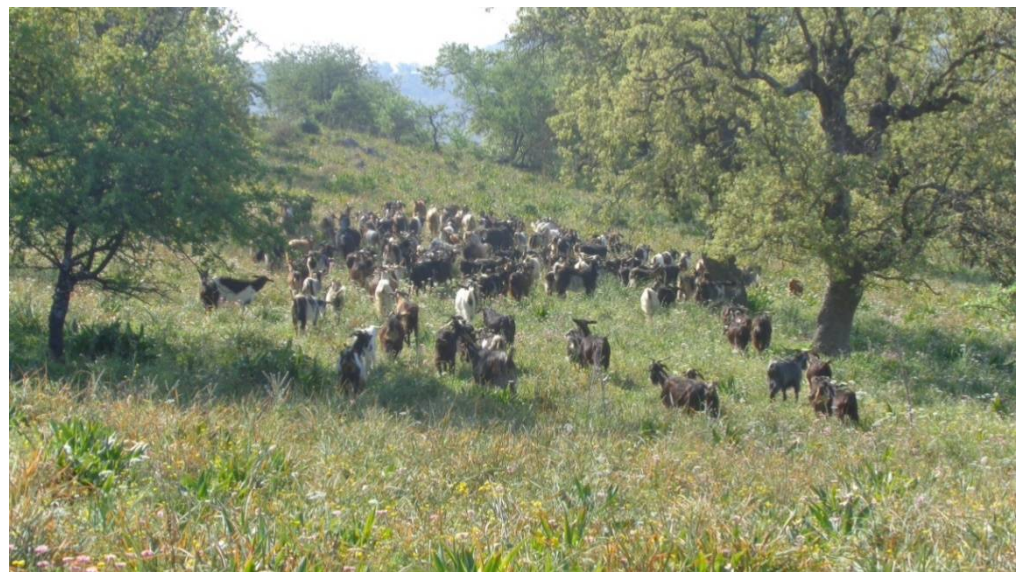


Figure 1. Example of a Mediterranean wood-pastures (the photo was taken at wood-pastures of Xiromero/Aetolia-Acarmania (38°35′00.43″ N, 21°13′21.56″ E) in western Greece by Dr. K. Mantzanas). The vegetation of Xiromero/Aetolia-Acarmania mainly includes valonia oak (*Quercus ithaburensis* subsp. *macrolepis*), in combination with phrygana and herbaceous plants.

The research studies were reviewed from 10 perspectives. These were: (i) general characteristics, (ii) Mediterranean basin, Mediterranean climate, (iii) dynamics of the communities in the wood-pastures of Mediterranean landscapes, (iv) important meadow plant families, (v) role of grazing in plant diversity of Mediterranean landscapes, (vi) the importance of fungi in ecosystem processes, (vii) the dynamics of fungal communities in Mediterranean wood-pasture landscapes, (viii) the effect of grazing on fungal biodiversity in Mediterranean wood-pastures, (ix) the effect of woodland grazing on ruminants and (x) products and PDO.

3. Mediterranean Ecosystems

3.1. General Characteristics

In five regions of the world and particularly in the Mediterranean basin, California, Chile, South Africa and southwestern and southern Australia, there are areas with a Mediterranean climate, i.e., a climate characterized by dry summers and wet, mild winters [15]. These areas are all grouped between 300 and 400 south or north of the equator [16]. The Mediterranean climate can be defined as a transition system between a temperate and dry tropical climate [15]. The main feature that distinguishes it from other types of climates is the alternation of mild, wet winters with hot, dry summers [17]. Rainfall is the most important qualification in Mediterranean regions, but its quantity and distribution creates very different conditions, particularly in terms of the extent of summer drought [17].

According to Aschmann [18], the Mediterranean climate has rainfall ranging between 275 mm and 900 mm, with at least 65% falling in winter. For most Mediterranean climate regions around the globe, the models consistently project drier futures [19]. According to Vamvaka [20], regardless of the total amount of rainfall, seasonality is the most important parameter for the climate of the Mediterranean basin. Generally, in these areas there are strong seasonal fluctuations in many natural resources, with moisture being the most important of these. Water is abundant during the winter, but during summer is a limiting factor for most organisms. The nutrients are at low levels and their availability varies seasonally [21]. These areas not only have the same climate, but they are also dominated by similar natural vegetation [15]. Mediterranean ecosystems are characterized by evergreen sclerophyllous shrubs or small trees, and even though these areas are geographically distant, the physiognomy of the vegetation is similar [14]. Of the five existing macro-climates in the world, the Mediterranean is the one with the greatest diversity of shrub plants, being considered one of the great biodiversity hotspots worldwide [22].

3.2. Mediterranean Basin

The geographical location of the Mediterranean basin between Europe, Asia and Africa (Figure 2), the complex geological history and climatic conditions created an unusual geological and topographical variety with high mountains, peninsulas and one of the largest archipelagos in the world, which contains several hundred islands and islets [23,24].

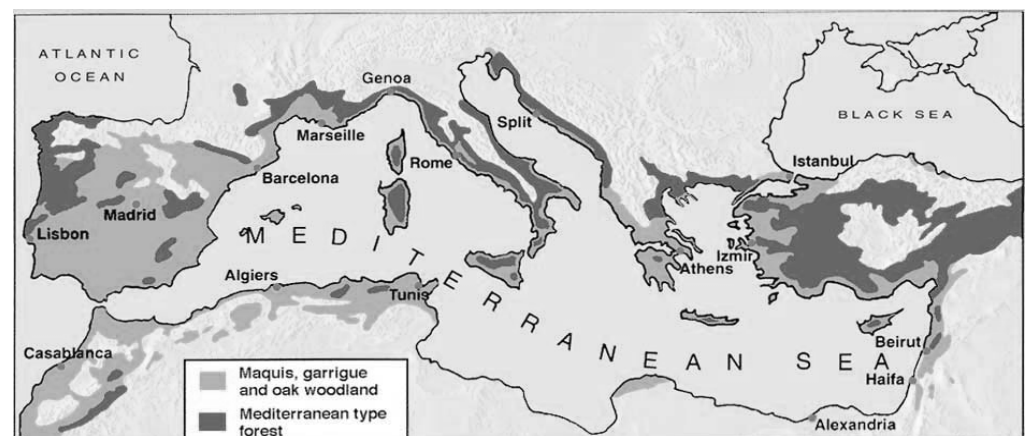


Figure 2. Map of the Mediterranean basin [17].

The geological diversity of the area, combined with the peculiarities of the climate and the special regime nutrients, are the key factors that shaped the landscape around the Mediterranean. It is known that the Mediterranean basin constitutes one of Earth's richest biodiversity hotspots [25]; however, nowadays it is threatened by several human activities [26] including grazing, clearing and fire [27].

3.3. Dynamics of the Communities in the Wood-Pastures of Mediterranean Landscapes

Ecological patterns and ecological functions and processes are strongly linked with each other, and there may be a two-way dynamic interaction between pattern and process [28,29]. Land uses in the past have resulted in a wide range of landscape patterns. The influence of these patterns on ecological processes may persist for long periods [30]. It is known that the growth, mortality and recruitment of individuals are the major factors influencing the dynamics of plant communities [31]. Additionally, different environmental factors affect the distribution and structure of plant populations [32].

The composition of the native vegetation of an area undergoes constant change from season to season, from year to year, and during long periods. By the term "composition", we mean the percentage of soil cover of the different species of native vegetation of an area. So, we can draw conclusions from the changes in the composition of native vegetation,

which pose great importance for the factors that depend on them. Some changes in the composition of vegetation have a permanent character, while others are simply temporary. Still, other changes are entirely caused by natural causes such as variations in climatic conditions, grazing animals, fires and other disturbances [22]. It is a fact that severe landscape changes can be found in the Mediterranean basin because of its extensive land use [33]. Mediterranean landscapes are the outcome of the combined action of climate, types of substrates, topographical forms, vegetation and historical human activity going back thousands of years. In the Mediterranean basin, people of Paleolithic times used fire to hunt and gather food [34–37], and afterwards, millennia of severe pressure that provoked burning, cutting and grazing non-arable lands, clearing, terracing, and cultivating arable areas, brought about a large number of strongly human-modified landscapes [38]. As the decades pass, it is observed that in the northern rim of the Mediterranean, the combination of industrialization and abandonment of the countryside led to many abandoned fields, increasing the cover of early-succession species (many of which are very flammable) and changing the landscape pattern [39,40].

A wood-pasture can consist of rich or poor flora. The plants that make up the flora of the wood-pastures are distinguished by the herbs that make up the herbaceous vegetation and by the shrubs and trees, which are the woody vegetation. The physicochemical properties of the soil, the climatic conditions of each region, the relief of the soil, the altitude and the anthropogenic effects contribute to the formation of the vegetation of a region [41,42].

Climatic conditions prevailing in Mediterranean environments, especially during the long, hot and dry summer induce specific phenological, morphological, physiological and ecological strategies in plants that live in these environments [4]. High temperatures that prevail in the summer in combination with a simultaneous lack of water drain herbaceous vegetation in the understory of clusters as well as portions of the standing woody biomass. This material and the dry herbaceous phytomass form a highly combustible litter [43]. Several Mediterranean plant species produce combustible substances, such as essential oils and resins. Together with climatic conditions, these plants can “support” the start and spread of fires. The Mediterranean ecosystems have evolved under the periodic action of fire, producing long-lasting landscape patterns [44]. Furthermore, it may sweep away [45] or contribute to the invasion [46,47] of different species and thus trigger changes in landscape and ecosystem processes. Post-fire succession in the Mediterranean plant communities is a way of autosuccession [43,48–55] in which the burned community maintains the floristic identity with time, as observed previously by Hanes [56]. Different studies concluded that plants have the ability to dominate these fire-prone ecosystems by evolving numerous adaptation mechanisms, particularly concerning post-fire regeneration [33,36,57].

3.4. Important Plant Families in Meadows

The most abundant and economically important families are the grasses (Poaceae) and legumes (Fabaceae), as they are grown to meet basic dietary needs [41]. These plant families are highly adaptable and can withstand the adverse conditions of grazing and cutting, and are cultivated for grazing, hay, silage and for fruit harvesting. They also provide satisfactory germination, protection from soil erosion and contribute to its nutritional value. The high percentage of grasses gives a good composition for grazing, while the high percentage of legumes in wood-pasture ecosystems contributes to a good conservation of soil fertility, as well as its progressive improvement [41,58]. Trees can also affect the seasonal distribution of pasture growth and nutritional quality, and this also affects the quantity of pasture consumed by the livestock [1,59].

Other significant botanical families are present in wood-pastures (e.g., families of Asteraceae, Brassicaceae, Geraniaceae, Rosaceae, Lamiaceae) with their ecological value being indisputable, both in terms of the biodiversity and productivity of grassland ecosystems [41,42,58]. Furthermore, the role of trees and shrubs in forest ecosystems is very important and multifarious. The most important benefits that they provide are the follow-

ing: (a) the production of wood for commercial and other purposes, (b) the production of fruits and resins, (c) the satisfaction of recreational needs (e.g., prey, landscape improvement, etc.), (d) soil stability, (e) the regulation of the hydrological function of catchment areas, (f) maintenance of the biodiversity and (g) contribution to the balance of forest ecosystems [41,42,58].

4. Grazing Management in Mediterranean Wood-Pastures

4.1. Role of Grazing in Plant Diversity of Mediterranean Landscapes

The rangelands of the Mediterranean region play an important role both for the forage material production and the conservation of biodiversity in plant communities at the landscape level. These two management purposes are not conflicting but complementary when the management is based upon the knowledge of the effect of grazing on the ecology of these ecosystems [60]. Thirdwood [61] suggested that grazing by domestic animals is among the major causes of forest degradation, with goats being singled out for their predilection of woody forage. Tsoumis [62] also shared such ideas: “pastoral economy had a much greater influence on deforestation of the Mediterranean region than agricultural clearances.” Moreover, overgrazing with or without wildfires has been reported as the most important agent of desertification in many parts of Greece [63–65].

Livestock grazing has extensively altered the composition and structure of grasslands throughout the world. Relatively predictable patterns of compositional and structural change with regard to long-term grazing have been substantiated in numerous perennial grasslands. Compositional changes most frequently involve the substitution of late-seral dominants by early or mid-seral species, while structural changes often involve the replacement of tallgrasses by mid- or shortgrasses [66]. Caldwell and others [67] mentioned that “less severely grazed species gain a competitive advantage by preempting resources previously used by the dominant species in the absence of grazing”. Long-term selective grazing can differentially affect population persistence among various species and thereby modify community composition and structure. Grazing can change the structure of plant communities by reducing biomass, damaging sensitive species and promoting the development and establishment of resistant species [68,69]. The characteristics of the location are the most significant factors affecting the composition of species in the understory. Understory vegetation is key to the ecological changes that occur for several or dozens of years and the vegetation structure can show differences in disturbances that occur in the region [70,71]. It is widely known that natural disturbances affect the abundance, the process of succession and biodiversity in many plant communities [72–74]. Thus, the species composition and diversity can be used as indicators of the disorder in a region [75–78], such as for different light availability conditions, structures of vegetation [79,80] and different moisture and soil fertility levels [81–84].

In Mediterranean ecosystems and particularly in Mediterranean shrublands, herbivores in vegetation mosaics vary in space and time. The leaves of different species vary in their physical and chemical characteristics, and therefore, in their attractiveness as food. Young leaves tend to be more tender and nutritious than more hard and dry mature leaves, which places restrictions on the food preferences of herbivores. Herbaceous plants begin their growth in early spring and age/die much earlier in the summer than bushy plants. Semi-deciduous shrubs lose some of their leaves during the summer period, while those of these shrubs that are dimorphic, have summer leaves with different morphology and chemical composition in the winter. Finally, evergreen shrubs and trees show significant differences in several characteristics of the leaf. The nutritional value of plant tissue for the herbivore or otherwise the “food quality” is regarded as a very decisive factor on the pressure of grazing, and therefore the damage that plants receive. The nutritional value consists of a number of parameters, such as the amount of nitrogen and the water contained in the plant tissue, the species, the molarity of defensive and tissue hardness [85,86].

It is important to mention the contradictory position: that limited grazing seems to lead to the extinction of grazing-prone species or to flammable biomass piling up [87]. Nowa-

days, because of the drastic reduction in human activities in the region, including grazing due to urban sprawl, extensive wildfires occur, especially in southern European countries.

4.2. *The importance of Fungi in Ecosystem Processes*

Fungi are widely distributed and comprise a heterogeneous group (taxonomically and phylogenically) which are found in both terrestrial and aquatic ecosystems and under different—sometimes even extreme—environments [88]. Fungi coexist along with other organisms in an ecosystem; the actual number and the ecological role of fungal species existing in the different ecosystems is extremely difficult to assess [89–91]. Fungi develop dynamic interactions with a wide range of other organisms (plants/trees, animals, other microorganisms) and with the environment (abiotic factors), regulating vital ecosystem processes, among those being nutrient availability and decomposition [90]. According to Dighton [90], fungi are intimately involved in major ecosystem services and functions which relate to: (i) primary production by making nutrients available for plant growth and/or enhancing nutrient uptake in the rhizosphere; (ii) secondary production by providing food for both vertebrate and invertebrate animals and through other fungal/faunal interactions; (iii) pathogenic effects (parasites) on plant/tree and animal populations and communities; and (iv) interactions with human activities (pollution, built environment).

Despite the fact that fungi act as ecosystem engineers in many habitats, they only started to receive attention as essential components of natural ecosystems during the last few decades [86]. Only recently, ecologists realized the highly important influence of the interactions occurring among plants/trees (at both root and aerial level), animals and fungi in ecosystem functioning and biodiversity maintenance [88,91,92]. Moreover, some fungal species can develop mutualistic associations with other organisms (e.g., mycorrhizal relationships with trees in forest ecosystems) or they may act as natural enemies (biocontrol agents) and prevent attacks from pathogens and herbivores [91]. Fungi also provide services for other organisms (including mammals, plants, insects and other microorganisms), operating as direct or indirect food resources for many of them [91]; additionally, they are often critically involved in microhabitat formation (e.g., tree cavities), which is a prerequisite for the maintenance of several birds, mammals, arthropods and epiphytes [91,92].

However, degradation, climate change, the loss and fragmentation of natural habitats and the deposition of nitrogen and other pollutants comprise threats for fungal biodiversity [91,93]. The state of fungal biodiversity, like that of plants, animals and birds, should be recorded in order to design and prioritize management and/or conservation measures based on fungal population status in specific habitats. Threatened fungal species can only be identified if their ecology and distribution are well understood [94]. This information is not available for mycobiota of the Mediterranean area [94]; instead, in many central and northern European countries (UK, Sweden, Finland, Norway) fungal red lists are already widely used and action plans have been launched in order to protect specific fungal habitats and species [91].

During the last few decades, many countries have developed conservation programs with direct measures on habitat level and they are not so much focused on specific species [91]. However, many unspotted or unknown organisms (especially microorganisms) are often ignored in those conservation programs, whilst the organisms involved in a particular habitat should be considered together in order to identify their interactions and prioritize action measures at the species level. In terms of fungal conservation, it is very important to provide more insight into the ecology of fungal species in their preferential environments (substrate, climatic range, altitude, etc.), assess indicator species, population dynamics and their periodicity and identify their role in the ecological processes of their habitat.

4.2.1. The Dynamics of Fungal Communities in Mediterranean Wood-Pasture Landscapes

Wood-pastures comprise ancient places of natural and historical heritages for many Mediterranean countries. The management of wood-pastures is critical for biodiversity maintenance. However, as mentioned in previous sections, during the last few decades, considerable decline has been observed in many of those biotopes; this decline is causing a threat to many species inhabiting wood-pastures, including fungi. Often, fungi comprise very good indicators of traditional rural biotopes [95]; however, the available data and information of the occurrence, distribution, ecology and conservation biology of fungal species, the interactions with their habitat and environmental factors in wood-pastures in the Mediterranean region, are scarce and segmented [96].

The factors regulating fungal diversity are relatively poorly understood [97,98]. Ecosystems with a Mediterranean climate are considered to exhibit a relatively higher fungal biodiversity [98,99] with plant/tree host diversity, density, host demography, community composition of a particular habitat (flora, fauna, microorganisms), local effects (e.g., natural canopy gaps, microclimate development), soil composition, texture, altitude, and human interventions (e.g., type of applied management) being some of the most important factors affecting fungal diversity in a particular habitat [100].

Some studies focused on macrofungi (fungi with visible fruit bodies) in forest ecosystems, but only few of those were carried out in Mediterranean environments, specifically in France, Italy and Spain [98,101,102]. Richard et al. [100] studied the diversity and the fruiting patterns of ectomycorrhizal and saprobic fungi in *Quercus ilex* dominating in Mediterranean forest. Few surveys have been carried out in Italian woodlands of *Q. ilex*, *Q. pubescens*, *Q. cerris* and recorded macrofungal species in detailed lists [103–110]. Meanwhile, in Andalusia, communities of macrofungi were studied in *Q. suber* and *Q. ilex* forests [111]. A more integrated study was carried in Liguria stands of *Q. rotundifolia* (formely known as *Q. ilex*) in order to identify fungal species, evaluate fungal communities and determine the principal environmental gradients which shape the fungal communities in the sampled areas [98].

The above-mentioned studies provided some basic but important insights on the distribution, ecology and phenology of fruiting in many fungal species; however, some species are extremely rare, they do not produce visible fruit structures or they fruit only at certain time points and under very specific conditions; therefore, the detection and monitoring of such species is not an easy task [112]. In many cases, human activities impact fungal diversity and communities over various scales in relation to vegetation [98]. The topic of studying fungal biodiversity and conservation biology in relation to influences by human activities (including invasions by alien fungal species), land-use change and climate change is becoming increasingly important and has not been addressed yet in Mediterranean wood-pasture ecosystems. Wood-pastures comprise a typical example of an ecosystem where tight interactions among human activities and various other organisms are observed. The accurate recording of fungal species distribution in time and space and their population dynamics under the various environmental conditions is extremely important and absolutely necessary in order to decode the keystone role of certain species in certain ecological processes, prioritize management measures and improve the sustainability of their habitats. In the case of wood-pastures, studies on the effects of grazing on plants and fungal communities would aid the development of national recording schemes (for vegetation and fungi) for Mediterranean countries. Additionally, this would allow us to identify sites with critical biodiversity stages due to overgrazing or changes in land use (e.g., abandonment), to specify the criteria for sites of major conservation importance, to design appropriate action plans for priority sites and to monitor the applied management practices in order to enhance the sustainability of those areas. On the other hand, the quality of animal products is highly affected by the type of vegetation grazed. Therefore, this type of study can have a binary role if correlated with the nutritional effects of the grazed vegetation on the quality of the animal products; grazing practices can then be

introduced so as to improve the quality of the produced animal products and increase the added value of those products.

4.2.2. The Effect of Grazing on Fungal Biodiversity in Mediterranean Wood-Pastures

Grazing is considered a management strategy which can be used as a useful conservation tool with the concurrent improvement of rural sustainability [113]. Grazing pressure in habitat can influence both animal performance (productive responses, economic output) and the biodiversity of flora and fauna (including microorganisms) [113]; on the other hand, the types of grazing animals (species, breed, age, physiological status), stocking rate and available vegetation in terms of quantity and quality determine the grazing pressure in a particular habitat [113]. Consequently, grazing effects depend on many factors and the development of an appropriate or optimal grazing system should be based on specific management objectives for each habitat or landscape [113]. It is assumed that a mosaic of vegetation is created through grazing, which in turn favors the creation of habitat patches for species living in these biotopes [114]. Moreover, mixed grazing is stated to generate greater habitat heterogeneity compared to monospecific grazing; this leads to the formation of a wider range of available niches (for a diversity of organisms) and microclimatic conditions [113]. The successional dynamics of vegetation is therefore linked with animal grazing and considerably affects habitat biodiversity [112]. One of the major impacts of grazing to the habitat is that the amount of nutrients and litter in the soil is decreased [115,116]; this greatly benefits the growth of many fungal species [117]. Other impacts which favor growth conditions for fungi are related to the changes in the amount of light at ground level (solar radiation), soil temperature, moisture and pH [116–118].

Despite the major importance of fungi in the biodiversity of Mediterranean wood-pasture biotopes, the effects of the grazing pressure on the fungal diversity have been neglected so far. To the best of our knowledge, there are no concrete data on the interaction between livestock grazing and fungal diversity in Mediterranean wood-pastures. Most of the research work has focused on the effects of grazing to plant diversity so far. Some general and scarce information on the effects of grazing on fungal diversity were mainly based on the previous knowledge regarding grazing–plant interaction [119–122]. Many studies have pointed out that there is a congruence between plant and fungal communities [123–126]. The diversity of tree species is often linked with higher macrofungi diversity, mainly because of the development of diverse available substrates which are created for macrofungi growth [127]. According to Arnolds [128], reduced litter in the soil benefits the development of most mycorrhizal fungal species. However, according to Zervakis and Venturella [96], mycorrhizal fungi were variably affected by grazing; the effects were mainly correlated to the degree of grazing and the yearly variability in precipitation. A strong but localized effect was highlighted between canopy gaps and the fruiting of saprobic and ectomycorrhizal (symbiotic) fungi in old-growth *Q. ilex* Mediterranean forest [97–100]; canopy gaps allow direct light to reach the forest floor, which in turn stimulates changes in soil abiotic conditions (temperature, soil nutrients, moisture) and drive physiological and metabolic activities of the fungal symbionts and other organisms [90,93]. A significant relationship between macrofungi species diversity and plants was recorded in areas which are not affected by intense glaciation [129].

In order to assess the diversity of fungi in Mediterranean wood-pastures, we need to design and develop appropriate management practices for their conservation, which are necessary to investigate topics such as: (i) the differences in the species richness and their population dynamics between grazed and ungrazed wood-pastures; (ii) the effect of grazing pressure (intensive, intermediate, ungrazed) in relation to the fungal community composition; (iii) the interrelationships between the different trophic levels (plant/trees–animals–fungi); if the different fungal functional (trophic) groups are equally represented in grazed and ungrazed wood-pastures; (iv) the indirect effects of grazing on fungal growth (soil, temperature, light, pH, etc.). Such studies are labor intensive and time consuming (involving years of seasonal observations) and require specialist knowledge.

These conventional methods for surveying fungi richness and abundance are limited by taxonomic identification, may cause the disturbance or destruction of habitats, and may rely on methods in which it is difficult to detect small or elusive species, thus making estimates for entire communities impossible [130]. However, more recently, advances in environmental DNA (eDNA) metabarcoding have enabled the broad application of this method in multi-kingdom biodiversity monitoring; for reviews, see, e.g., [130,131]. eDNA can complement traditional methods by targeting different species, sampling greater diversity, and increasing taxonomic resolution [132]. Additionally, it has useful applications in detecting the first occurrences of invasive species, the continued presence of native species thought to be extinct or otherwise threatened, and other elusive species occurring in low densities that would be difficult to detect by traditional means. Nevertheless, before being applied to fungal communities in Mediterranean areas, it is important to take into consideration the necessity of selecting different appropriate substrates to broadly capture all biota present in the ecosystem [133]. Therefore, preliminary studies are needed to optimize this tool for Mediterranean terrestrial ecosystems. The use of the eDNA tool for the detection and monitoring of a specific species or group of organisms can be incorporated alongside traditional monitoring and can unravel different aspects of management in Mediterranean wood-pastures. For instance, nematode communities are among the most valuable communities in soil in regard to understanding nutrient dynamics. It is well known that nematodes play an important role in determining soil functioning [134], since a significant part of nutrient interchange in soils takes place because of the activity of microbial-feeding nematodes [135]. Free-living nematodes can serve as soil indicators because of their high species richness and abundance. Nematodes are very adaptable and common in almost any soil type [136] and they conform to the general characteristics required of a bio-indicator [137]. Soil nematode communities have the potential to provide insights into many ecological studies such as the effects of grazing activity. In grazing systems, grazing intensity and timing should be planned well in order to adopt sustainable grazing management and increase soil organic matter and encourage soil structure [138]. It is well known that grazing results in a more structured nematode community [139]. Unfortunately, there is a limited number of studies that evaluate these effects on free-living nematodes. Li et al. [140] showed that heavy grazing resulted in reduced organic matter and that the grazing intensity influenced the number of nematodes overall [141]. In addition, the Maturity Index of nematodes (MI) was found to be significantly influenced by the grazing strategy. A considerable number of studies have shown that there is a significantly positive effect of grazing on nematode communities in different types of grasslands [141,142]. On the other hand, the abundance of total nematode community was found to be significantly lower on seriously disturbed sites [142]. However, in 1988, it was shown that the exclusion of grazing in areas with a long history of grazing can be considered as a disturbance, meaning a more diverse community of nematodes can be maintained under continuous moderate grazing [143]. Enhancing research on nematode communities and links with the grazing system is an important step towards understanding soil ecosystems under different grazing management strategies. To this end, studies are needed to further evaluate the use of nematode communities under different grazing strategies.

4.3. Effect of Wood Land Grazing on Ruminants

In the past, woody species were considered poor feed for animals and efforts were made to control or eradicate them from grasslands. Over the last 25–30 years, this attitude has changed, and substantial research has been performed to show that woody species are important forage resources in the Mediterranean areas of Europe. Animal production in this part of Europe is constrained by the rugged and highly fragmented landscape, the rich but variable vegetation and complex land-use systems [144]. The most important factor that affects herbage production and animal performance is the Mediterranean climate [145,146]. Woody species are both spontaneous and cultivated in the Mediterranean areas of Europe and constitute indispensable feed resources for livestock during the whole

year, but especially during the long and dry summer period. Woody plant communities, such as shrublands and woodlands, are much more widespread in the Mediterranean areas of Europe than grasslands. Different livestock species have been used as a control tool for the Mediterranean understory, with goats being the most widely used animal for this purpose, due to their more selective nature and their ability to tolerate many secondary compounds [147]. Natural woody communities can be grazed directly by livestock, with shrublands being the most appropriate feed resources for goats [147]. Goats are most appropriate to utilize the high fiber, low N forage produced on shrublands and woodlands [148,149]. In the extensive livestock production systems of Mediterranean goat and sheep husbandry, both depend on browse and herbage produced by wooded rangelands during certain times of the year to satisfy their needs for nutrients [149–158].

Browse plants (leaves and twigs) (e.g., *Quercus coccifera*, *Cistus incanus*, *Rubus* sp.) and herbaceous plants (e.g., *Festuca* sp., *Dactylis glomerata*, *Trifolium* sp., *Medicago* sp. and *Vicia* sp.) are important forage sources for goats throughout the year and for sheep during the dry periods when herbage is limited [156]. The herbaceous component contributes more than 50% of the goat's diets during spring when herbs are green. During the rest of the year, goats select huge amounts of browse (>60%). Leaves of all forage species contribute more than 70% during all periods, while twigs of shrubs and stems from herbaceous species are low but constant throughout the year [159]. Studies by Dini [160], Platis and Papanastasis [161], Papachristou and Papanastasis [162], Papachristou [154] and Ainalis et al. [163] suggested that during summer, when herbaceous plants are dormant and herbage is of low quality and availability, forage of woody vegetation has to meet nutritional requirements for the grazing animals [163–165]. Deciduous woody fodder species are an effective supplement to low-quality forage and significantly increase crude protein intake. Therefore, browse-based protein supplementation seems to be a practical means of maintaining the body weight of goats grazing on low-quality forage (e.g., Mediterranean kermes oak shrublands) during the summer period [155]. Moreover, the heterogeneous forage environment of wooded rangelands offers conditions that may favor a very fast intake for small ruminants that discriminate between forage materials, while at the same time maintaining an intake rate higher than that observed during their meal [166,167].

In the wet months, goats consume the largely defenseless undergrowth of herbaceous species, whereas in the dry months when herbs are dry or no longer available, they are left with only the kermes oak with its physical and chemical defenses [156]. The fact that plant defenses are so widespread and often herbivores have no choice but to consume plants with defenses suggests that they are well aware of the consequences of eating most plant species [168]. This latter point gives reasons to think that sheep and goats have significant knowledge of the plant species and their defenses in their home rangeland. In relation to plant defenses, animals avoid defenses where possible, and if not possible, select the plant with the least effective defense. This may be simple and indeed obvious, but it enables animals to react quickly to changes in habitat composition across seasons.

Overall, the positive outcome from grazing in silvopastoral systems is arriving from increased production and animal welfare [169]. In order to further increase the beneficial role of grazing in animal nutrition, the development of more adaptive conservation and land management systems is required. Therefore, the traditional knowledge and local familiarity of herders is essential [170,171].

Products and PDO

Over the years, the impact of the environment and human intervention gave rise to various characteristics of animal products unique for each region. An important part of the specificity of the products owes its existence to the utilization of mountain pastures. The special geomorphological characteristics and the biodiversity that characterizes these specific areas, as well as the number of agricultural improvements (fertilization, grazing management) directly affect the characteristics of the various dairy products, but also those of meat [172].

The specialized metabolites of the dicots that originate in mountainous grazing areas, such as terpenoids or phenolic compounds, have the ability to indirectly affect the fatty acid profile of animal products through the animal's digestive system and metabolic process. The variability of breeds and needs of the animals raised in these areas, as well as the management system of the mountain pastures, also influence the choice of grazing and the phenology of the grazed pastures. It is essential in order for the animal products to reflect the uniqueness and diversity of the area where they originate to consider the above factors when corrective measures are intended [172].

In Europe, many agricultural (14%) and livestock (18%) enterprises are located in mountainous areas and host 20.4% of sheep and 46.8% of goat EU population. Those animals provide 32.0% of the total goat and ewe milk and 23.4% of the sheep meat [173]. These data highlight the quantifiable importance of mountain productivities for the ruminant livestock sector that is also involved in preserving the landscape and the rural social network.

Traditionally, sheep grazed local grassland regarded as less-favored pastures. In order for producers to overcome the constraints of distant areas, they had to promote milk production and thus increase the feed purchases and inputs in farms. Until the 2000s, the intensification of forage harvesting was used as an efficient alternative to grazing. Since 2000, the PDO specifications included new requirements that forced farmers to utilize forages. As an example, grazing ewes should be fed with forage coming for 75% from the PDO area and ewes should graze two or three months during the grazing period [174].

To produce a traditional food product, the suckling lambs are fed exclusively on maternal milk from birth to slaughter (average age of 40 days and body weight of 10–12 kg). However, grazing pasture is an interesting alternative [175] because ewes and lambs have good performance and the use of natural resources is increased.

- Meat

Ruminants grazing on mesophilic grasslands (MGs) can utilize forage of higher palatability, nutritive value and concentration of originators (e.g., C18:3 n3) for the synthesis of beneficial fatty acids (FAs) (e.g., ruminic acid and omega-3 FA) in dairy and meat products. In order to obtain animal products richer in nutraceutical compounds, agropastoral practices that promote MG formation, such as intensive management and soils with higher moisture content, are essential [176]. Research demonstrates that the present practice for changing intensive to free grazing systems affects meat characteristics. One of the most pretentious characteristics is the color, the most important attribute taken into account by end users in their purchase choice [174]. The subcutaneous fat of lambs from pastures had higher yellowness (b^*), connected with the existence of carotenoids, flavonoids and α -tocopherol in their food intake [177], than those from concentrate-based diets. Likewise, fat from suckling lambs whose mothers grazed had greater yellowness and redness than that from lambs whose mothers were fed hay [178]. This probably resulted from the low grass consumption by the lamb [179] in addition to the intake of milk carotenoids [180]. Grass-fed lambs may provide meat with a low degree of fat and red meat color [181]. The meat quality of lamb raised exclusively on maternal milk can be improved with the addition of grass to the diet [182], due to the high quality of milk from grazing sheep [183]. The amount of linolenic acid in the intramuscular fat of lambs fed with milk from grass-fed ewes was higher. The feeding scheme related to birth and lactation affects the milk FA profile [178]. The fatty acids that are mainly affected by grazing are CLA, C18:1t11 and PUFA, n-6/n-3 ratio, with a positive effect on human health. Grazing during the animal's dry period, regardless of post-partum feeding, can change the FA composition, increasing the CLA content in meat. The degree of the increase in CLA, C18:1t11 and PUFA n-3 of grass-based diets in comparison to concentrated diets depends on the maturity, diversity and conservation of the forage [184].

- Cheese

With regard to dairy products and especially cheese, their characteristics are the result of the interaction of livestock with the environment. As a fermentation product, the rumen microflora is the one that initially transforms the organoleptic characteristics of the product produced. This microbial community is directly affected by the mobility of the animals and the complexity of the vegetation used as fodder [172].

Practical knowledge gained by farmhouse cheesemakers is associated with the influence of specific vegetal communities found in mountain grasslands on cheese organoleptic properties. Those distinctive characteristics are gained in mountain conditions where vegetation gradients and complementary plant mosaics are met even within similar grassland according to variable micro-climates, soil and agricultural practices [172].

Pastures are poor in terpenoids, while plant compounds are rich and extensively variable in forbes [185]. These compounds are responsible for the differentiation of the scents and aromas in cheese and vary according to the forages fed to the livestock [186,187]. Several studies concluded that terpenoids can easily move from herbage to milk [188], while others highlighted differences in milk terpenoids composition according to the botanical composition of grass or hay [189,190].

During the sensory analysis of milk, the concentration of essential oils rich in terpenoids should be ten times higher than those in milk derived from grazing animals, even on extremely bio-differentiated pastures, in order to reach the threshold for sensory perception reported by Tornambe et al. [191]. Additional milk elements, such as polyphenols, are other vegetable metabolites that can be shifted to milk [192]. The fatty acid profile in milk can also affect cheese sensory characteristics [193]. A greater concentration of PUFA in milk can lead to a poorer fat melting point, with a subsequently less firm, softer and melting texture of cheese [194]. When a considerable amount of PUFA is oxidized, large amounts of odor active compounds during ripening can also generated. This procedure can have an important effect on cheese scent and aromas [195]. Cheese appearance does not remain unaffected from the composition of the fatty acids in milk [196], probably because during pressing, the PUFA-rich fat creates oil and therefore contributes to the growth of molds and yeasts.

- Success stories of mountain ruminant farming

The long-term feasibility and attractiveness of mountain livestock farming mostly relies on higher farm gate prices for productions. Although the differences in the milk and meat sector between mountain and intensive farming are still in favor of the first, many different patterns can still be found in different sectors or regions. Successful stories of certain mountain areas depend on the enthusiasm and commitment of local stakeholders that inspire and introduce a variety of differentiated food products [193] that contribute to an added-value food chain. Elements such as tradition and local know-how of agricultural practices can be proven as valuable opportunities. The value of the interactions between livestock products and local history, culture, tourism, handcraft and gastronomy can initiate the creation of a unique product, also known as a “basket of goods” [197]. This practice can develop an extensive added-value output utilized from certain geographically limited regions. There are unique success stories that rely on the differentiation of a terroir product correctly identified and protected by a Geographical Indication. The popular models of Beaufort, Comte and Laguiole are related to the respective mountain areas in France or the Aosta Valley in Italy. These examples appear to be replicable in similar mountain areas where farm density remains vital [198].

5. Conclusions

The lack of prior research on the interactions among different trophic levels (plants/trees, animals, microorganisms) and environmental factors in Mediterranean wood-pastures highlights an important opportunity for future study of the biodiversity of those ecosystems and the exploitation of opportunities for the rural development of those ecosystems.

In order to set up the basis for appropriate management practices in Mediterranean wood-pastures, it is absolutely necessary to conduct future studies on this topic; the studies should be thoroughly focused on the interactions among the different trophic levels (plant/trees, animals, microorganisms) and on the recording of critical species which relate either to important ecosystem processes or are important for rural development (economically important plant, fungal, animal species) or both. In this way, it will be possible to enhance sustainability in those biotopes, value plant and fungal bioindicators, assess the effects of grazing on animal welfare and/or increase the quality of the animal products produced and therefore increase marketable (added) value. Integrated studies which combine multi-level ecological research are essential in order to identify regional and/or national needs in terms of biodiversity, genetic resources, sustainable rural development and conservation policies. eDNA is a promising tool which can supplement traditional monitoring and contribute to assessing multi-level trophic interactions, increasing detailed knowledge on biodiversity and the species-specific occurrence and abundance of Mediterranean wood-pastures. The opportunities to harness higher-level interdependencies and interactions between the biodiversity of soil, plants, above and below-ground animals, and the environment are immense, and offer great potential if they can be understood, directed and actively managed.

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