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Traditional agroforestry systems in Europe revisited: a systematic review

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Abstract Traditional agroforestry systems (TAFs) in Europe represent an interface between agriculture and biodiversity conservation, being able to offer sustainable production while supporting diverse ecosystems often with unique species assemblages. This systematic review synthesises research on TAFs conducted between 1992 and 2024 using the PRISMA methodology. We analysed 232 studies to assess TAFs types, their distribution, biodiversity significance, and ecosystem services' contributions across Europe. The findings highlight regional variations, with *dehesa*/*montado* systems dominating Southern Europe and traditional orchards and wood pastures being prevalent in Central and Eastern Europe. Our review gives evidence that TAFs provide multifaceted ecosystem services, such as carbon sequestration, soil fertility enhancement, water regulation, and cultural heritage preservation. Additionally, TAFs harbour a rich biodiversity, particularly among vascular plants, birds, and insects, whose ecological roles are pivotal to the ecological functioning of these systems. Despite their significance, studies indicate that a decline in economic viability and changing land-use patterns have threatened the future of TAFs. This review emphasises the need for innovative management practices that integrate traditional knowledge, alongside political and public support, to ensure the long-term conservation and restoration of TAFs in Europe.

Keywords Agroforestry · Biodiversity · Carbon storage · Ecosystem services · Landscape services

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Introduction

The world is experiencing a series of interlinked environmental crises, including climate change, deforestation, soil erosion, and desertification (Barnosky et al. 2011; IPCC 2021). These crises, driven largely by anthropogenic activity, have led to a rapid decline in ecosystem functions and services, such as water regulation, pollination, and soil fertility, all essential for human needs and well-being (IPBES 2019). The loss of biodiversity is particularly alarming, with a growing body of evidence indicating that human activities are driving an unprecedented decline in species and habitats (IPBES 2019). Despite decades of conservation efforts, biodiversity continues to decline, particularly in agricultural landscapes, where intensified land-use practices, including monoculture farming, deforestation, and overgrazing, contribute significantly to habitat loss and ecosystem degradation (FAO 2007; Torralba et al. 2016; Sattler et al. 2024). Additionally, land abandonment, a significant global phenomenon on all continents (Zerbe 2022) threatens the persistence of TAFs.

In response to these ongoing challenges, there is an urgency for developing innovative strategies that balance agricultural production with biodiversity conservation and the provision of ecosystem services (Berkes 1999; Tsonkova et al. 2012; Fontana et al. 2014; Fagerholm et al. 2016). A proposed approach is the integration of land-sparing and land-sharing strategies within spatially connected mosaic patches in cultural landscapes (Grass et al. 2019). Land-sparing focuses on intensifying production in designated areas to conserve biodiversity in others, whereas land-sharing advocates for agricultural practices that promote biodiversity and ecosystem service conservation on the same land (Grass et al. 2021). These integrated approaches provide a pathway to harmonising agricultural development with ecological sustainability (Plieninger et al. 2015; Torralba et al. 2018) while aligning with the concept of landscape services, which serves as a link between landscape ecology and long-term ecological, social, and economic sustainability (Termorshuizen & Opdam 2009; Zerbe 2022).

A key component of land-sharing strategies is the adoption of low-input agricultural systems, which reduce the reliance on external inputs such as chemical fertilisers and pesticides (FAO 2007). These systems aim to optimise internal production resources, thereby improving sustainability and reducing the environmental footprint of farming (Jose 2009; Fagerholm et al. 2016). Low-input systems have numerous benefits, including reduced production costs, minimised pollution of water and soil, and improved long-term farm profitability (Sarkar et al. 2020). These systems are prevalent in multifunctional traditional cultural landscapes, which have evolved over centuries to strike a balance between human agricultural needs and ecological sustainability (Berkes 1999; Zerbe 2024). The term "traditional" used here refers to land-use practices rooted in long-standing cultural and ecological knowledge, often passed down through generations, and aligned with indigenous and local knowledge systems (Berkes 2000; Viswanath & Lubina 2017; Zerbe 2024). In contrast, the term “sustainable intensification” refers to increasing agricultural productivity through innovation while equally prioritising sustainability to prevent environmental degradation (Petersen & Snapp 2015). Traditional land-use systems, which often rely on extensive, low-input methods, have been shown to support higher levels of biodiversity (Bonari et al. 2017), enable ecosystem functioning, and provide a broader range of ecosystem services such as water regulation, soil fertility, and pollination compared to high-input, intensively managed agricultural systems (Berkes 1999; Duru et al. 2015; Zerbe 2022).

The term traditional agroforestry systems (TAFs) is widely used in the literature to describe multifunctional land-use strategies that encompass long-established, culturally embedded agroforestry practices (e.g., Herzog 1998; Papanastasis et al. 2009; Nerlich et al. 2013; Viswanath & Lubina 2017; Zerbe 2024). In this study, we use “traditional” in a neutral, time-based sense, referring to systems that have been continuously managed for 100 years, which emphasise their long-term ecological adaptation, historical continuity, and socio-cultural integration (Renes 2015; Nair et al. 2017). Agroforestry has been defined by the FAO (2015) as the integration of woody perennials with crops and/or livestock (Fagerholm et al. 2016; Torralba et al. 2018). However, following Sinclair (1999) and Noordwijk et al. (2016), these practices can be understood as components of broader agroforestry systems, which integrate ecological interactions, social-ecological dynamics, policy, and economic contexts. Agroforestry systems are classified into the categories of agrisilvicultural, silvopastoral, and agrosilvopastoral systems, each tailored to specific ecological and cultural contexts in Europe (Herzog 1998). Many TAFs incorporate "trees outside forests" (TOF), such as isolated trees, hedgerows, and scattered trees, which contribute to ecological, productive, and cultural functions across the landscape (Wani et al. 2020). Unlike modern agroforestry, which is often planned to enhance productivity and/or specific ecosystem services through technical interventions (Nerlich et al. 2013; Kay et al. 2019), TAFs have a long history of promoting ecological and socio-cultural benefits, reaching back to the Neolithic when people started to settle and perform agriculture (e.g., forest grazing) (Nerlich et al. 2013). Systems such as the Mediterranean *dehesa/montado* integrate grazing with oak woodlands, while traditional orchards like *Streuobstwiesen* (orchard meadows) in Central Europe reflect multifunctional fruit production practices rooted in local knowledge (Joffre et al. 1988; Plieninger et al. 2015; Hartel & Plieninger 2014).

Beyond their ecological role, TAFs occur within cultural landscapes recognised by international frameworks such as FAO's Globally Important Agriculture Heritage Systems (GIAHS) and UNESCO's Agriculture Heritage Landscapes (Koohafkan & Cruz 2011; Zerbe 2024). Several European TAFs are recognised as GIAHS, for instance, the *dehesa/montado* in Spain and in Portugal, and traditional hay milk farming in the Austrian Alps (FAO 2025). Despite their significance, TAFs are increasingly threatened by land abandonment, agricultural intensification, and socio-economic pressures, leading to a vulnerable state experienced by many traditional systems (Nerlich et al. 2013). However, the role of TAFs in addressing global challenges such as biodiversity loss and climate change is increasingly recognised. By adopting low-input, multifunctional practices, these systems reduce reliance on chemical inputs and optimise internal production resources, leading to lower environmental footprints and improved long-term sustainability (Jose 2009).

While previous studies have examined individual or regional TAFs in terms of their contributions to ecosystem services and biodiversity (Fagerholm et al. 2016; Torralba et al. 2018), a comprehensive and updated overview is still lacking. In particular, there is limited research on the different types of TAFs, their distribution across Europe, and the range of ecosystem services and biodiversity benefits they provide to local and regional communities. While Large Language Models (LLMs) are increasingly used for information retrieval despite their lack of transparency and tendency to generate unverifiable content (Ji et al. 2023), systematic reviews remain essential for transparent and reproducible synthesis (Page et al. 2021). Accordingly, in this paper, we addressed TAFs in Europe through a systematic review which applies the PRISMA framework aims to (1) identify, differentiate, and characterise the multifaceted TAFs in Europe, (2) outline their geographical distribution, and (3) systematically collect the knowledge gained so far on their biodiversity and the ecosystem services they can provide. Based on this, (4) we want to identify key research gaps that can inform sustainable land management practices in the future. In this context, revisiting TAFs means critically re-evaluating their current relevance, contribution, and functionality in light of recent socio-ecological transformations and policy agendas. With this systematic review approach, we would like to make a plea for taking those "old" but not outdated systems stronger into account in rural development and the implementation of the Sustainable Development Goals announced by the UN (2015).

Materials and methods

Study area

The study area covers Europe, which is divided into four regions: Northern, Southern, Eastern, and Western Europe, according to the United Nations Geoscheme for Europe (UNSD 2010). These regions represent a wide range of climatic zones, from the Mediterranean zone in Southern Europe (e.g., Spain, Italy, Greece) to temperate zones in Western and Eastern Europe (e.g., Germany, Austria, Poland, Czechia), and boreal zones in Northern Europe (e.g., Norway, Sweden, Finland). This climatic diversity, combined with Europe's varied geological, geomorphological, vegetation, and cultural landscapes (Bohn et al. 2007), provides an ideal setting for examining TAFs.

Methodology

We followed the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) outlined by Page et al. (2021). This methodology involves the three main steps: identification, screening, and inclusion. These steps are outlined below. The PRISMA flow diagram illustrating the study selection process is presented in Fig. 1.

Identification and literature search

On April 4th 2024, we conducted a literature search using the Web of Science database to identify studies published between 1992 and 2024. The year 1992 was chosen as the starting point due to it coinciding with the Rio Earth Summit, where the Convention on Biological Diversity was adopted, marking a key milestone for biodiversity and sustainable land-use policies relevant to agroforestry systems. The search included studies in the common European languages addressing TAFs. The search strategy employed a combination of terms related to agroforestry systems, ecosystem services, biodiversity, and geographical focus. The term "agroforestry" was first introduced in 1977 (King 1987; Nair 1998). Prior to that, various other names were used to describe similar practices. Therefore, we derived agroforestry-related keywords from official FAO terminology and previous studies on agroforestry systems in Europe (e.g., Smith 2010; Nerlich et al. 2013; Torralba et al. 2016). Ecosystem services and biodiversity terms were aligned with the classification by the Common International Classification of Ecosystem Services (CICES, Haines-Young & Potschin 2018). Although the term "ecosystem services" was introduced by the Millennium Ecosystem Assessment in 2005, many relevant concepts, such as carbon storage, pollination, and cultural values were addressed earlier, therefore, relevant keywords may appear in the literature without explicitly using the term "ecosystem services". Additionally, keywords such as "biodiversity," "cultural landscape," "species

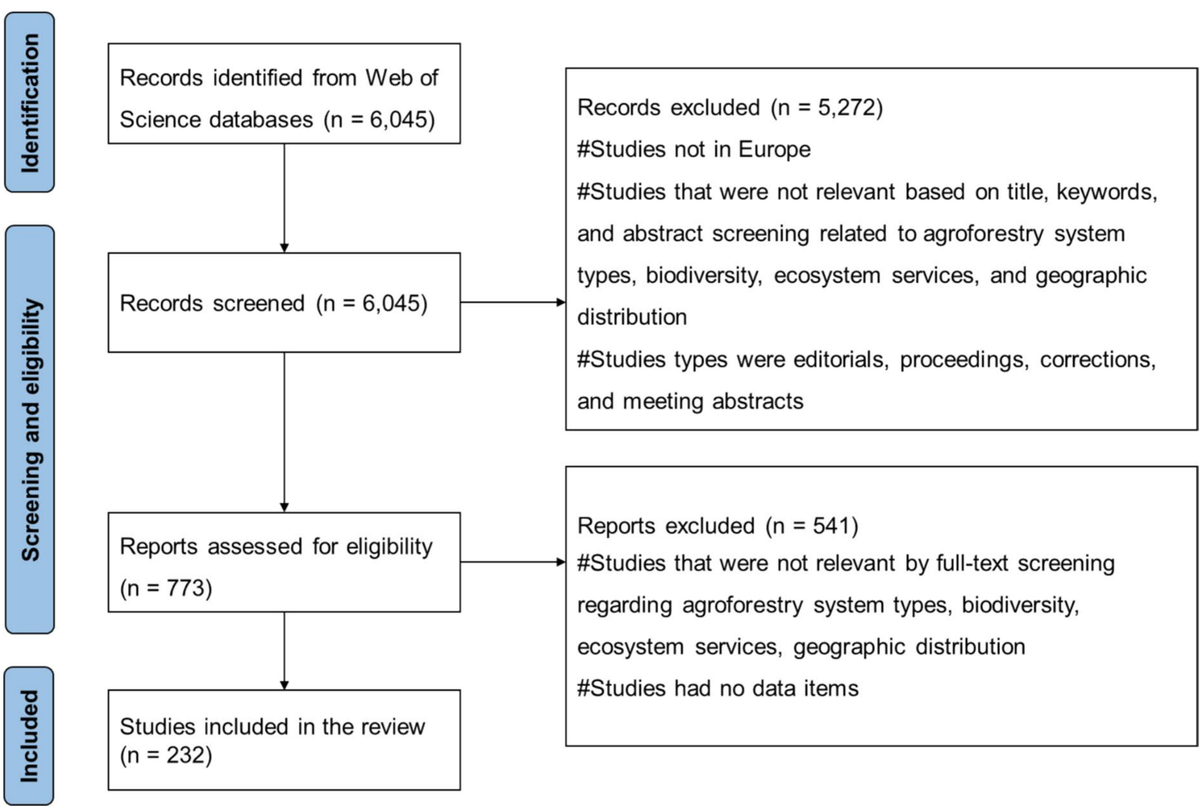

Fig. 1 PRISMA flow diagram for our systematic review on TAFs

diversity", and "species richness" were incorporated to capture the multifaceted nature of TAFs in European landscapes (Jose 2009; Plieninger et al. 2015; Zerbe 2022). The detailed search strings and references are reported in the Supplementary Table S1.

Criteria for the screening

To qualify for inclusion, studies had to be located within Europe and explicitly focus on traditional systems. We defined TAFs as long-established land-use systems that integrate trees or shrubs with agricultural practices and are typically shaped by historical, cultural, and ecological contexts (Zerbe 2024). Papers were included that address primary research questions related to agroforestry systems, focusing on forestry and agricultural components, geographic distribution, ecosystem services, and/or biodiversity. Eligible studies were required to have been published between 1992 and 2024. All review articles, non-research articles, such as editorials, proceedings, corrections, and meeting abstracts, were excluded. Duplicates were removed prior to screening.

Screening and selection

In the initial screening, titles, keywords, and abstracts were reviewed to identify studies meeting the inclusion criteria from 6,045 articles. At this stage, 5,272 articles were excluded due to irrelevant geographic focus, lack of relevance to TAFs, biodiversity, or ecosystem services, or a focus on unrelated disciplines, such as medicine, mathematics, or cell biology. During the subsequent full-text review, the remaining 773 articles were thoroughly evaluated to identify all information relevant to TAFs and to exclude papers that were irrelevant or lacked data. Ultimately, 232 articles met the inclusion criteria and were selected for inclusion in the review. In addition to these, 10 review articles were retained for comparison and discussion purposes; however, they were excluded from the results section to prevent double-counting of data reported in both original studies and review articles.

Inclusion and data compilation

From the 232 studies included in the systematic review, data were extracted according to a predefined framework aligned with the PRISMA methodology to ensure consistency and transparency. Key variables were categorized into several thematic areas with (1) study characteristics, including author(s), title, year of publication, keywords, and DOIs; (2) TAFs type, documenting the specific agroforestry practices described; (3) tree and agricultural components, which detailed tree species, agricultural and/or grazing systems, tree density, and stock density; (4) geographic information, identifying the location of studies; (5) ecosystem services, classified under provisioning, regulating, and cultural services; and (6) biodiversity, with data on species richness, species per area, and conservation status such as red-listed or protected species. The final set of 232 eligible studies was compiled and it is reported in Supplementary Table S2. We summarised the frequencies of the variables and categories involved in the information extraction using descriptive statistics, and visualised the results with the *ggplot2* package in R (R Core Team 2023).

Results

General characteristics of the data

The 232 included studies spanned 21 European countries, with 6.5% (n = 15) covering all of Europe and 7.8% (n = 18) focusing on transnational contexts, particularly in the Mediterranean region (e.g., *dehesa/montado* systems). Spain accounted for the highest number of studies (n = 61; 26.3%), followed by Portugal (n = 34; 14.7%), Romania (n = 20; 8.6%), and Italy (n = 19; 8.2%). In contrast, countries like Albania, Belgium, Estonia, Scotland, and Slovenia contributed only one study each (Fig. 2a). All included papers were published in English, with only 6 papers containing abstracts in German.

Among the various TAFs examined in the literature, the most frequently studied system was the *dehesa/montado* systems, with 85 publications. This was followed by wood pasture systems (n = 45) and both orchard and grazed orchard systems, each represented in 15 studies. Chestnut groves appeared in 12 publications. In contrast, shrubland grazing (n = 3) and alley cropping (n = 4) were the least studied TAFs.

Overall, besides all included papers that focused on describing TAFs, there were 102 articles (44%)

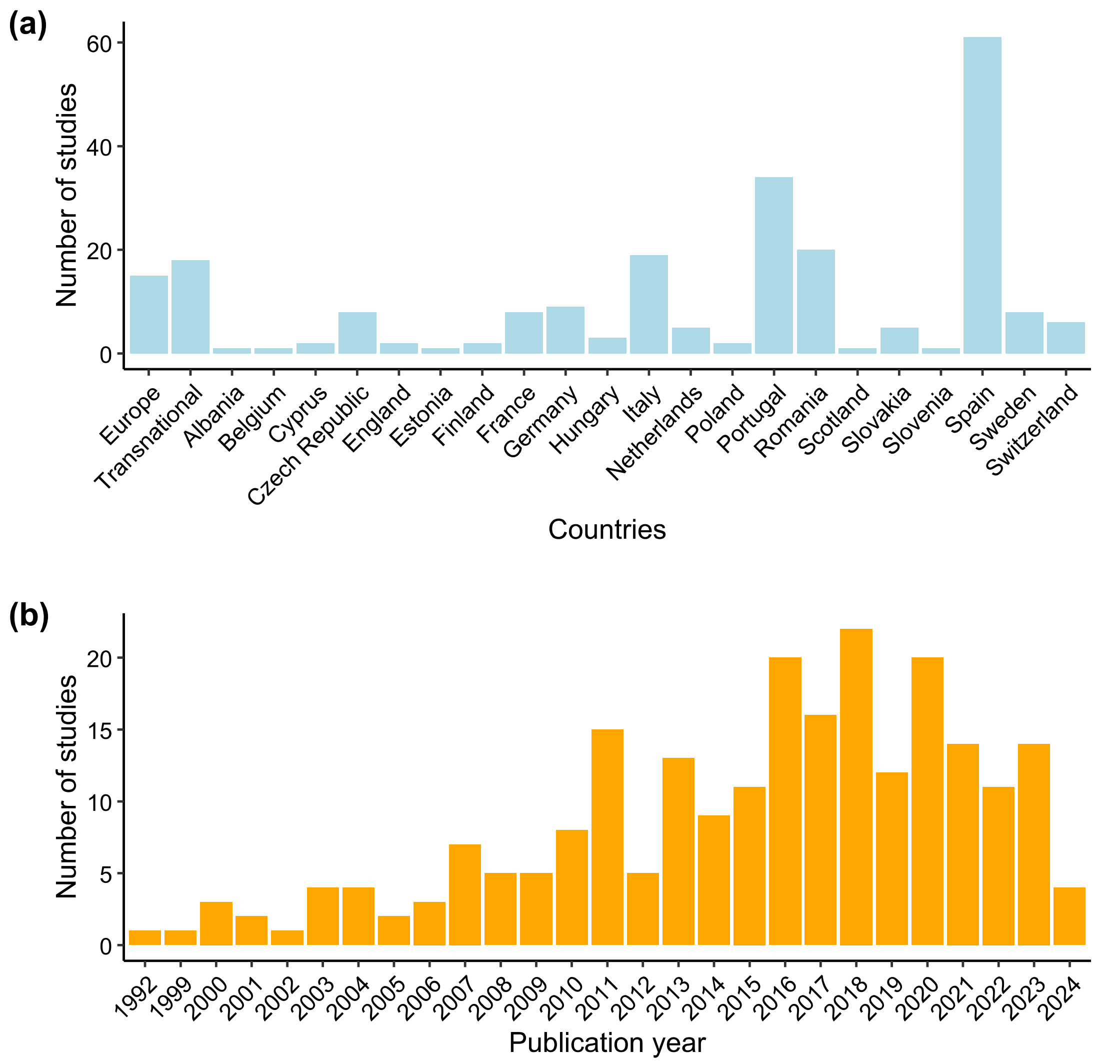

Fig. 2 Number of studies analysed within our review of TAFs (n = 232) per country (a) and by year (b)

focusing on biodiversity, and 72 publications (31%) on ecosystem services. Before the year 2000, publications on traditional agroforestry were relatively scarce. However, the number of relevant articles increased substantially in the following years, peaking in 2018 with 22 studies published (Fig. 2b).

Types of traditional agroforestry systems in Europe

Silvoarable systems, combining agriculture and forestry, include alley cropping, *bocage* in France, fruit orchards throughout Europe, and Mediterranean olive orchards (Table 1). Many of these systems rely on "trees outside forests" (TOF), including isolated trees, hedgerows, and scattered trees, which contribute to ecological, productive, and cultural functions across the landscape (FAO 2025; Wani et al. 2020). Silvopastoral systems, which integrate livestock with trees, are exemplified by wood pastures like the *dehesa* in Spain and *montado* in Portugal. In northern Europe, reindeer husbandry systems in Finland, Norway, and Sweden utilise forest understorey resources. Whereas in Central Europe, well-known agroforestry systems such as Germany's "orchard meadows" (*Streuobstwiesen*) allow livestock and trees to coexist. Lastly, agrosilvopastoral systems, common in the Mediterranean and European Alps, blend cropping, grazing, and forestry.

Table 1 Types of traditional agroforestry systems in Europe, their categories differentiated according to FAO (2015), their main agricultural and tree components, geographic occurrence reflected by the studies, and selected references (for references, see Supplementary Table S2)

Type acc. to FAO	Traditional agroforestry system	Other names	Agriculture components	Tree components	Main geographic occurrence	References
Silvoarable	Alley cropping	Alley coppice, tree inside the field, tree on the edge of the field, boundary planting, pollarding	Maize (*Zea mays*), potatoes (*Solanum tuberosum*), winter barley (*Hordeum vulgare*), winter wheat (*Triticum aestivum*)	Walnut (*Juglans regia*), poplar (*Populus* spp.), checker tree (*Sorbus torminalis*), wild cherry (*Prunus avium*)	Several countries in Western and Southern Europe	149, 176, 225, 230
	Hedgerow	*Bocage*, contour hedging, shelterbelt, tree-line hedgerow	Barley (*Hordeum vulgare*), beetroot (*Beta vulgaris*), cereal, chickpea (*Cicer arietinum*), field bean (*Vicia faba*), garlic (*Allium sativum*), maize (*Zea mays*), potato (*Solanum tuberosum*), rapeseed (*Brassica napus*), sunflower (*Helianthus annuus*), vetch-pea (*Vicia sativa*), wheat (*Triticum aestivum*)	Apple (*Malus domestica*), chestnut (*Castanea sativa*), cherry (*Prunus avium*), hazel (*Corylus avellana*), hawthorn (*Crataegus monogyna*), oak (*Quercus* spp.), pine (*Pinus* spp.), poplar (*Populus* spp.), walnut (*Juglans regia*), willow (*Salix* spp.)	Traditionally widespread in France, Germany, Greece, Italy, Portugal, Spain, Netherlands, UK	12, 15, 31, 52, 144, 145, 146, 232, 236
	Orchard	Apple orchard, fruit orchard, home garden, olive orchard, *pré-verger*, *Streuobstacker*, vineyard orchard	Asparagus (*Asparagus officinalis*)	Apple (*Malus domestica*), cherry (*Prunus avium*), citrus (*Citrus* spp.), olive (*Olea europaea*), palm (*Arecaceae* spp.), pear (*Pyrus communis*), plum (*Prunus domestica*), vine (*Vitis vinifera*), walnut (*Juglans regia*)	Cyprus, Czechia, Germany, Italy, Poland, Spain	34,42, 68, 83, 86, 88, 92, 121, 129, 159, 167, 178, 187, 215, 240
Silvopastoral	Chestnut groves	Sweet chestnut groves	Grazing cattle, sheep	Mainly chestnut (*Castanea sativa*), occasionally accompanied by beech (*Fagus sylvatica*), fir (*Abies* spp.), oak (*Quercus* spp.), and vine (*Vitis vinifera*)	Albania, France, Italy, Spain, Switzerland	13, 22, 72, 73, 76, 93, 124, 134, 150, 157, 158, 182

Table 1 (continued)

Type acc. to FAO	Traditional agroforestry system	Other names	Agriculture components	Tree components	Main geographic occurrence	References
	Grazed orchard	Cherry orchard, fruit orchard, orchard grassland, orchard meadow, olive orchard	Cereal, haymaking, grazing cattle, goats, horses, sheep	Almond (*Prunus dulcis*), apricots (*Prunus armeniaca*), apple (*Malus domestica*), beech (*Fagus sylvatica*), chestnut (*Castanea sativa*), cherry (*Prunus avium*), citrus crops (*Citrus* spp.), walnut (*Juglans regia*), pear (*Pyrus communis*), peaches (*Prunus persica*), pine (*Pinus* spp.), plum (*Prunus domestica*), oak (*Quercus* spp.), hornbeam (*Carpinus* spp.)	Temperate (e.g., Germany, Poland, Romania, Slovakia, Slovenia, Czechia) and Mediterranean Europe (e.g., Italy, Spain)	6, 23, 84, 95, 112, 131, 143, 159, 191, 215, 220, 227, 240, 241, 242
	Forest pasture	Forest grazing, larch meadow, larch pasture, larch wood pasture, *Lärchenwiesen/-weiden, Hutewald*	Grazing cattle, goats, horses	Larch (*Larix decidua*), pine (*Pinus sylvestris*), spruce (*Picea abies*)	Widespread in Europe	17, 57, 62, 85, 200, 239
	Grazed olive	Olive grazing, olive grove	Grazing donkeys, sheep	Olive (*Olea europaea*), occasionally accompanied by cherry (*Prunus avium*) and oak (*Quercus* spp.)	France, Hungary, Italy, Romania, Slovakia, Spain	11, 20, 41, 130, 160, 180, 214, 231
	Grazed vineyard	Vineyard grazing, vineyard in wood pasture	Grazing donkeys, sheep	Vine (*Vitis vinifera*), occasionally accompanied by cherry (*Prunus avium*) and oak (*Quercus* spp.)	Austria, Germany, France, Italy, Hungary, Portugal, Romania, Slovakia, Switzerland	5, 41, 55, 115, 133, 195, 201, 214, 223, 231, 233

Table 1 (continued)

Type acc. to FAO	Traditional agroforestry system	Other names	Agriculture components	Tree components	Main geographic occurrence	References
	Grazed woodland	Ancient woodland, *Baumwiesen*, grazed grassland, *pannage*, pasture woodland, woodland pasture, wooded grassland	Grazing cattle, horses, moose, roe deer, sheep, goats	Ash (*Fraxinus excelsior*), beech (*Fagus sylvatica*), birch (*Betula pendula*), chestnut (*Castanea sativa*), hazel (*Corylus avellana*), hornbeam (*Carpinus betulus*), Larch (*Larix decidua*), maple (*Acer* spp.), oak (*Quercus* spp.), olive (*Olea europaea*), pine (*Pinus* spp.), spruce (*Picea abies*)	Albania, Czechia, Europe, Italy, Netherlands, Portugal, Scotland, Sweden, UK	17, 21, 45, 93, 94, 101, 151, 193, 194, 202, 209, 210, 211
	Shrubland grazing	*Garrigue*, heathland, *herriza*-heathland, *krattskogar*, parkland system, shrubland, *Wacholderheide*	Grazing cattle, ponies, sheep, goats	Trees (Phanerophytes): birch (*Betula pendula*), carob (*Ceratonia siliqua*), juniper (*Juniperus phoenicea*), olive (*Olea europaea*), pine (*Pinus* spp.); Shrubs (Nano-phanerophytes & Chamaephytes): broom (*Genista sphacelata*), cretan yarrow (*Achillea cretica*), Erica heath (*Erica australis*), heather (*Calluna vulgaris*), Italian valerian (*Valeriana italica*), lentisk (*Pistacia lentiscus*), rockrose (*Cistus* spp.), thyme (*Thymus capitatus*), thorny burnet (*Sarcopoterium spinosum*)	Atlantic Europe	16, 66, 141

Table 1 (continued)

Type acc. to FAO	Traditional agroforestry system	Other names	Agriculture components	Tree components	Main geographic occurrence	References
	Wood-pasture	Silvopastoral system, *sugherete*, *taungya*, *Weidfeld*	Grazing cattle, goats, horses, pigs, sheep, buffalo	Beech (*Fagus sylvatica*), birch (*Betula pendula*), hornbeam (*Carpinus betulus*), oak (*Quercus* spp.), pine (*Pinus* spp.), spruce (*Picea abies*)	All over Europe	3, 10, 19, 43, 50, 58, 60, 64, 77, 78, 79, 80, 81, 87, 91, 102, 105, 106, 114, 122, 123, 132, 135, 136, 138, 139, 140, 147, 165, 184, 186, 192, 196, 199, 207, 218, 221, 222, 224, 226, 228, 229, 234, 238, 239
	Dehesa/ *montado*	Portuguese wood-pasture, Spanish wood-pasture	Grazing cattle, cows, goats, pigs, sheep (e.g., Black Merino)	Oaks (*Quercus* spp.), olive (*Olea europaea*), vine (*Vitis vinifera*)	Portugal, Spain	1, 2, 4, 7, 8, 9, 24, 25, 26, 27, 28, 29, 32, 33, 36, 37, 38, 39, 40, 46, 48, 53, 56, 59, 61, 63,65, 67, 69, 70, 71, 74, 75, 82, 89, 98, 100, 103, 104, 107, 108, 109, 110, 111, 113, 116, 118, 119, 120, 126, 127, 137, 142, 153, 154, 155, 156, 161, 162, 163, 168, 169, 170, 171, 172, 173, 175, 179, 181, 183, 185, 189, 190, 203, 204, 205, 206, 208, 212, 213, 216, 217, 235
Agrosilvopastoral	Agrosilvopastoral	Multiple integrated TAFs	Barley (*Hordeum vulgare*), cattle grazing, oilseed (*Brassica napus*), sugar beet (*Beta vulgaris*), wheat (*Triticum aestivum*), pig grazing	Apple (*Malus domestica*), cherry (*Prunus avium*), vine (*Vitis vinifera*), oak (*Quercus rotundifolia*), olive (*Olea europaea*), peach (*Prunus persica*), poplar (*Populus* spp.), walnut (*Juglans regia*), orange (*Citrus sinensis*)	Throughout Europe	18, 30, 44, 47, 49, 51, 96, 97, 125, 128, 148, 174, 188, 197, 198, 219, 237

Besides single TAFS, 11 articles (4.7%) investigated multiple TAFs.

The *dehesa*/*montado* systems, studied in 36.6% (n = 85) of included articles, are TAFs with animal grazing under various oak species (e.g., *Quercus ilex*, *Q. suber*), range from 20 to 400 trees per hectare and support traditional livestock breeds like, for example, Black Merino sheep and Iberian pigs (Acha & Newing 2015).

Shrubland grazing, forest pasture, and grazed woodland accounted for 1.3% (n = 3), 2.6% (n = 6), and 5.6% (n = 13) respectively. Wood pasture systems, still largely present in Romania, account for 19.4% (n = 45) of the studies. These systems, some of the oldest in Europe dating back to the Neolithic period, emerged in southeastern and Central Europe, were adapted approximately 6,000 years ago in Britain, northwestern Germany, and Denmark, and about 4,000 years ago in the Baltic and Scandinavian areas (Rackham 2008; Bergmeier et al. 2010; Mosquera-Losada et al. 2012). They integrate livestock grazing with wooded or partially open areas, featuring tree densities of 10 to 50 trees per hectare and stocking rates of 0.7—2.2 sheep, and 0.4—0.8 cattle per hectare (Fig. 3c). Livestock in traditional systems include mainly sheep, cattle, and goats, which graze from late April to mid-October.

Orchard systems, including both orchards with crops and grazed orchards (13%, n = 30) in Central Europe (e.g., Germany, Czechia), combine fruit trees like apple (*Malus domestica*) and pear (*Pyrus communis*), as well as nut trees like walnut (*Juglans regia*), with livestock grazing and crop cultivation (Fig. 3d). In France (*pré-verger*) and Germany, tree densities range from 20 to 100 trees per hectare.

Silvoarable systems such as alley cropping and hedgerows (5.6%; n = 13) integrate crops like wheat, maize, and barley with trees such as walnut (*Juglans regia*), poplar (*Populus* spp.), and wild cherry (*Prunus avium*). Found in Belgium, Germany, and Italy, these systems use alley cropping to optimise land use, maintain soil fertility, and provide crop shelter. In Atlantic and Central Europe, hedgerows serve as living barriers, preventing wind erosion and providing firewood and timber.

Vineyard systems (4.7%; n = 11), common in the Mediterranean region and those regions with a mild temperate climate in Central Europe, combine vineyard with grazing by sheep or donkeys, occasionally interspersed with olive and oak trees (Fig. 3e). Around 2,500 to 3,000 years ago, viticulture spread across Europe from Italy after the ancient Greeks introduced vineyard cultivation (Griffith 2004). Chestnut groves (5.2%; n = 12) in Italy, France, and Spain integrate grazing with tree farming. These systems involve periodic pruning and harvesting of timber and nuts, while grazing practices help control undergrowth and maintain open soil conditions, thereby facilitating the establishment of new chestnut saplings. Chestnut cultivation has spread across Europe, mainly for its fruits, which were used to produce flour, rather than for timber or poles as chestnut coppice, which is a traditional forest system (Mattioli et al. 2015).

Ecosystem services of TAFs

According to the reviewed studies on TAFs, a broad range of ecosystem services is provided (Table 2). From the 72 included publications, we found 16 studies (22.2%) simultaneously addressed provisioning, regulating, and cultural services, whereas the remainder focused on one or two service categories only. Among all articles, regulating services were by far the most frequently examined feature in 77.8% (n = 56) of the papers, followed by provisioning services at 37.5% (n = 27). Cultural services appeared in 20.8% (n = 15) of the studies, with a strong emphasis on cultural landscapes and recreation (Fig. 4). For example, Plieninger et al. (2015) showed how wood-pasture systems in Spain preserve traditional farming and support local farmers. Garrido et al. (2017) emphasised that traditional knowledge, cultural landscapes, and heritage values, which are rarely considered in ecosystem service assessments, were among the most frequently acknowledged ecosystem services in the *dehesa* system. Rolo et al. (2021) discussed how Mediterranean agroforestry systems enhance the cultural identity of rural communities and social cohesion.

As reflected in Table 1, agrosilvopastoral systems provide diverse products, such as food (meat, milk, cereals, fruits, nuts), raw materials (timber, firewood, cork), and other categories like herbs. Silvoarable systems, such as those with edible plants like asparagus (*Asparagus officinalis*) and fennel (*Foeniculum vulgare*), contribute to local food production. Silvopastoral systems, including chestnut and olive orchards,

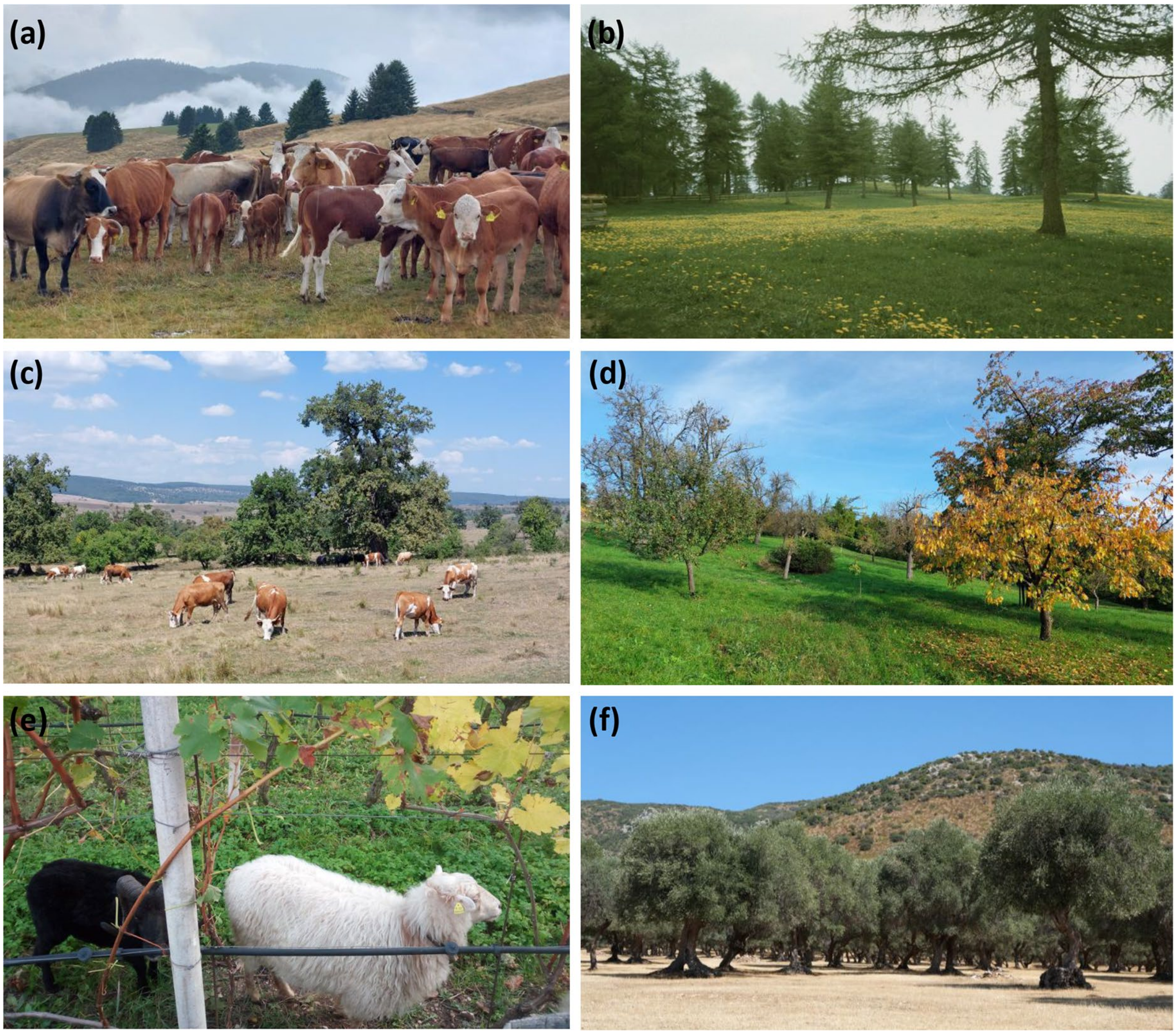

Fig. 3 Traditional agroforestry systems; *Allmendweiden* (communal pastures) in Southern Black Forest, Germany (a), Larch meadow in South Tyrol, Italy (b), Wood pasture in Transylvania, Romania (c), S*treuobstwiesen* (apple orchard) in Hessen, Germany (d), Vineyard grazed with sheep in South Tyrol, Italy (e), Olive grove in Maremma Regional Park, Italy (f). Photo credits: G. Bonari (f), T. Plieninger (a,c,d), S. Zerbe (b,e)

supply food (e.g., honey, chestnuts) and materials (e.g., timber, firewood). Wood pastures provide livestock, wild food, timber, and multiple crops.

TAFs contribute to crucial regulating services, such as carbon storage and sequestration, water purification, pest control, microclimate stabilisation, the enhancement of soil quality, and erosion control. Hereby, silvoarable and silvopastoral systems might differ in the main services they provide. Particularly, carbon storage and sequestration were addressed in the reviewed studies. The storage and sequestration capacity strongly depends on the type of TAFs (e.g., woodland pasture, orchard), tree density, and land management (e.g., pasture, meadow). Aboveground carbon storage, for example, ranged from 5 Mg C ha^{-1} in UK's grazed woodlands (Smith 2014) to 2,160 Mg C ha^{-1} in French hedgerow systems (Viaud & Kunnemann 2021). Belowground carbon storage, for instance, ranged from 265 Mg C ha^{-1} in Italian's larch pastures (Nagler et al. 2015) to 610 Mg C ha^{-1} in French's hedgerows systems (Viaud & Kunnemann 2021).

Table 2 Specific ecosystem services (categories according to CICES, Haines-Young & Potschin 2018) of TAFs in Europe (for types, see Table 1) addressed in the reviewed literature, with a selection of references, see Supplementary Table S2

TAFs categorised by FAO	CICES Section	Division	Group	Class and service description	References
Agrisilvicultural systems (including silvoarable, alley cropping, and orchards)	Provisioning	Biomass	Cultivated crops	Food from cultivated plants: vegetable (incl. asparagus), thyme, fennel, Mediterranean strawflower, elm-leaved blackberry, fiddle dock, Spanish oyster thistle, cereals	2, 11, 13, 20, 30, 149, 182
	Provisioning	Biomass	Cultivated/wild crops	Plant-based food and beverage: chestnuts, fruits (incl. berries), nuts, herbs	
	Provisioning	Biomass	Animal-based food	Food from domesticated animals: milk, cheese, meat, eggs, honey	
	Provisioning	Biomass	Animal-based resources	Livestock feed: fodder (e.g., grass, silage, acorns)	
	Provisioning	Biomass	Materials	Wood, fibre, energy materials: timber, firewood, bark (e.g., cork), charcoal	
	Regulating	Regulation	Biotic environment	Support for regulating species: pest control, pollination	
	Regulating	Regulation	Soil and atmospheric processes	Soil stabilisation, carbon storage: carbon sequestration, soil erosion regulation	
	Regulating	Mediation of waste flows	Hydrological processes	Water purification and retention: water filtration, detoxification	
	Cultural	Indirect interaction	Spiritual, symbolic, and heritage	Sense of place, cultural heritage	
	Cultural	Direct interaction	Physical and experiential use	Learning, tourism, visual appreciation: education (e.g., learning from nature), festival, recreation and aesthetics	
Silvopastoral systems (including forest pasture, grazed woodland, and wood pasture)	Provisioning	Biomass	Animal-based resources	Livestock feed: fodder (e.g., grass, silage, acorns)	12, 24, 27, 48, 53, 64, 65, 80, 89, 95, 111, 142, 144, 145, 165, 173, 203, 205, 210, 216, 224, 232, 235
	Provisioning	Biomass	Animal-based food	Reared animal products: meat, milk, wool, honey	

Table 2 (continued)

TAFs categorised by FAO	CICES Section	Division	Group	Class and service description	References
	Provisioning	Biomass	Wild plants	Edible wild plants, aromatic plants and fungi	
	Provisioning	Biomass	Materials	Wood, fibre, energy materials: timber, firewood, bark (e.g., cork), charcoal	
	Regulating	Regulation	Atmospheric processes	Climate regulation, local cooling and shading, climate regulation, air quality regulation, carbon storage and carbon sequestration	
	Regulating	Regulation	Soil processes	Soil and sediment processes: soil stability and filtration	
	Regulating	Regulation	Biotic environment	Habitat provision, seed dispersal, pollination, disease and pest regulation	
	Cultural	Indirect interaction	Spiritual and symbolic	Sense of place, aesthetic and historic identity	
	Cultural	Direct interaction	Physical and experiential use	Leisure, tourism, exploration, symbolic meanings, hunting, employment opportunity, inspiration, and education	
Agrosilvopastoral systems (including chestnut groves with grazing and crop, wood pasture integrated systems)	Provisioning	Biomass	Cultivated/wild crops	Plant-based food and beverage: chestnuts, olive, fruits (incl. berries), nuts, herbs and fungi	11, 13, 18, 20, 44, 96, 125, 148, 182, 197, 198
	Provisioning	Biomass	Animal-based resources	Livestock feed: fodder (e.g., grass, silage, acorns)	
	Provisioning	Biomass	Animal-based food	Food from domesticated animals: milk, cheese, meat, eggs, honey	
	Provisioning	Biomass	Materials	Wood, fibre, energy materials: timber, firewood, bark (e.g., cork), charcoal	
	Provisioning	Regulation	Biotic environment	Habitat provision, seed dispersal, and biodiversity genetic pool protection	

Table 2 (continued)

TAFs categorised by FAO	CICES Section	Division	Group	Class and service description	References
	Regulating	Regulation	Atmospheric processes	Climate regulation, local cooling and shading, carbon storage, carbon sequestration	
	Regulating	Regulation	Soil processes	Soil and sediment processes: soil stability and filtration	
	Regulating	Mediation of waste flows	Hydrological processes	Water flow stability and purification	
	Cultural	Indirect interaction	Spiritual and symbolic	Cultural identity, spiritual meaning, traditional festival and cultural symbols	
	Cultural	Direct interaction	Physical and experiential use	Education, tourism, employment opportunity, inspiration, social relations, aesthetics, and outdoor enjoyment	

Biodiversity of TAFs

Biodiversity in TAFs has been studied in 102 studies, including studies which cover multiple taxonomic groups and encompass various systems. The most studied organisms were plants, accounting for about 49% of the reviewed research (n = 50) (Fig. 5). Studies on animal diversity accounted for 38.2% (n = 39), and 13 studies (12.8%) investigated both animals and plants, where we also included lichens and fungi. Vascular plants were mostly studied (39.2%; n = 40), followed by birds with 22 studies (21.6%). A smaller part of the reviewed studies addressed tree and shrub species, bryophytes, lichens, and fungi among the plants and beetles (Coleoptera), butterflies (Lepidoptera), spiders (Arachnida), earthworms (Lumbricina), bats (Chiroptera), reptiles (Squamata), and mammals (Mammalia).

Regarding biodiversity of TAFs, the number of species was recorded and certain species of nature conservation concern were highlighted. The highest vascular plant species richness was recorded for the *dehesa*/*montado* systems in Spain and Portugal, ranging from 225 up to 431 species in each system in an area of 150 hectares (Pereira & Da Fonseca 2003; Moreno et al. 2016). Also, wood pasture systems and grazed shrubland showed a high plant diversity, particularly woody species diversity. Bokdam & Gleichmann (2000) recorded 88 woody species in a shrubland grazing system with a 5-hectare area extension. Swedish wood-pasture systems provided habitat for up to 65 lichen species on an area of 6 hectares, including the rare and nationwide near-threatened species *Cliostomum corrugatum*, *Buellia violaceofusca*, and *Ramalina baltica* (Paltto et al. 2011).

Agrosilvopastoral systems in Southern Europe provide habitat for a large number of bird species. Domokos & Domokos (2016) recorded 65 bird species on about 3 hectares. The high bird species richness was also reported from Polish apple orchards (Kajtoch 2017) and German traditional vineyards (Rösch et al. 2019). Bat species have been reported from Swedish wood-pastures, amounting to 12 bat species listed in the IUCN Red List species (e.g., *Myotis dasycneme, M. nattereri*, and *Eptesicus serotinus*) (Wood et al. 2017). *Dehesa* supported 60 bee species on an area of 150 hectares (Moreno et al. 2016), while Czech orchards harboured up to more than 400 beetle species on 25 hectares, including

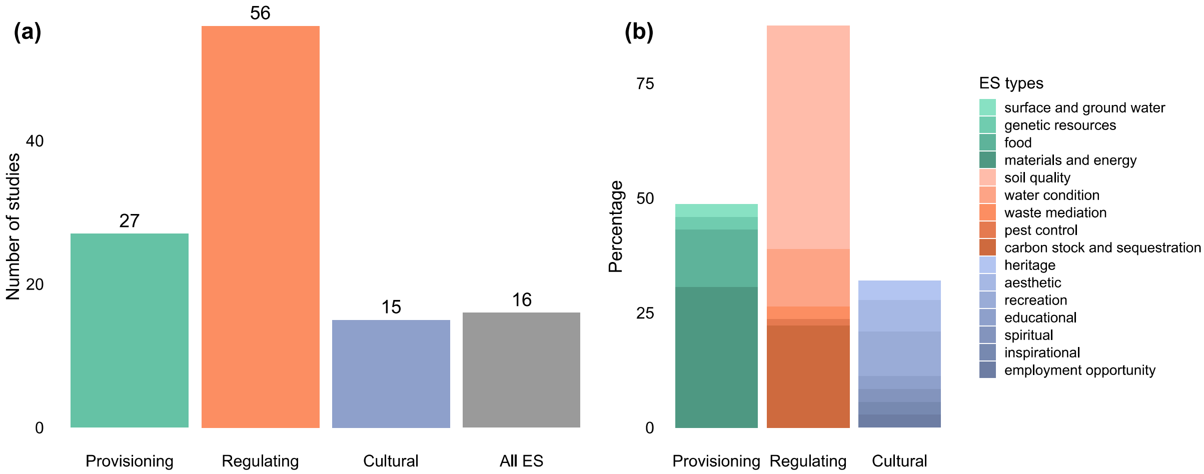

Fig. 4 Number of studies focusing on the provisioning, regulating, and cultural ecosystem services (ES) (a), and the proportion of studies dedicated to each type (according to CICES, Haines-Young & Potschin 2018) of ecosystem services (b), acknowledging that a single study may address multiple ecosystem services

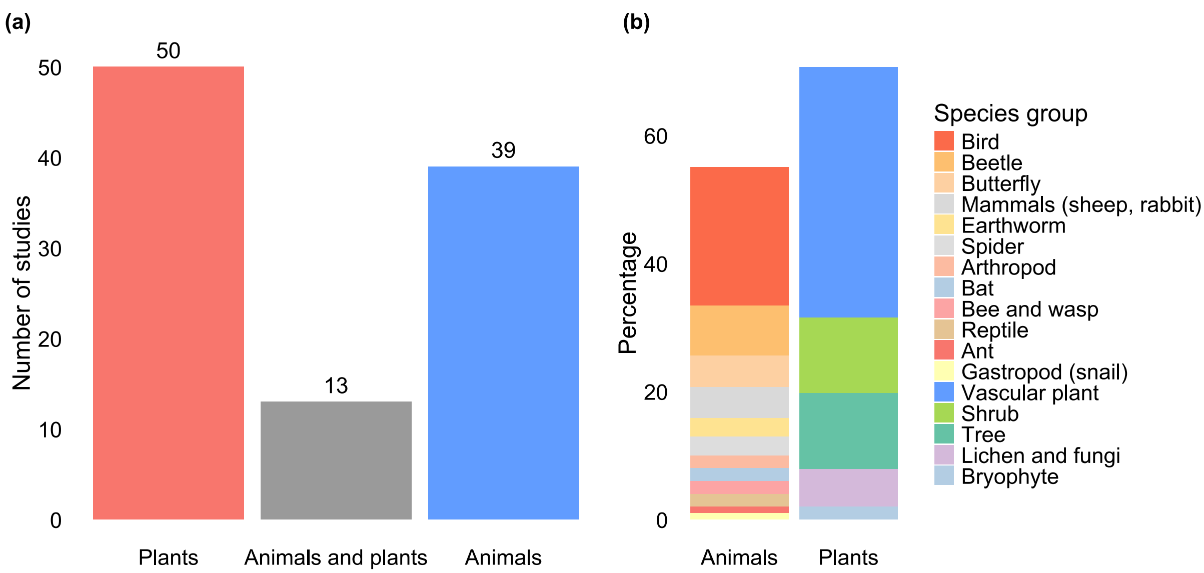

Fig. 5 Number of reviewed studies which address plant or animal diversity or both (a), specified with regard to the taxonomic groups (b). For visualisation and analysis, we included lichens and fungi with plants

17 red-listed species (Horak 2014). Spider diversity was investigated on Romanian wood-pastures with a record of 140 species in 21 spider families on an area of 250 hectares, also including Red List species on the national level; even two spider species were new for Romanian fauna, namely *Synageles subcingulatus* and *Talavera parvistyla* (Gallé et al. 2017).

Besides the high species numbers of TAFs, considerable numbers of species of conservation concern have been recorded, including some endemic species. In *dehesa* system characterised by cork oak (*Quercus suber*) and holm oak (*Q. ilex*), rare and threatened species have been found, such as the eagle species *Aquila adalberti,* the latter included in the IUCN Red List (González et al. 2008). Portuguese *montado*, hosted vulnerable plant species at the national level, like *Helictochloa lusitanica* (Díaz et al. 1997; Valente et al. 2010). In Romania, Transylvanian wood pastures harbour rare vascular plants such as *Salvia transsylvanica* and near-threatened bird species like the European pied flycatcher (*Ficedula hypoleuca*) (IUCN 2021; Cremene et al. 2005; Dorresteijn et al. 2013). In these systems, the endemic species *Aconitum peterfii* has been recorded (Cremene et al. 2005). Also, in Spanish grazed shrublands endemic woody species at the national level have been found, such as *Genista tridens* (Gil-López et al. 2018).

Detailed species information, including conservation status across TAFs, is available in Supplementary Table S3.

Discussion

Our review on TAFs in Europe reveals their multifaceted types, which have served or are still serving manifold purposes for local communities and rural economies. The tree components part of the land-use systems encompasses a high number of tree and shrub species across Europe, with a considerable number of indigenous broad-leaved and coniferous tree species used for timber, fruit (including oil production in the case of olives) or nut production and as fodder for animals (e.g., leaves or young branches). Under the trees, which also provide regulating services (e.g., on the micro-climate of the land-use system or erosion protection on slopes), the various species and breeds of grazing animals produce meat, fur, and dairy products. In silvopastoral systems, trees additionally provide shade that reduces heat stress and supports higher productivity and welfare in grazing livestock (Goncherenko et al. 2024; Ripamonti et al. 2025). In other systems, biomass of herbs and grasses is produced for feeding animals in stalls or cereals and vegetables serve for self-sufficiency as well as for local and regional markets. TAFs all over Europe have been developed during the past centuries related to geology and soil, geomorphology, local species pools (e.g., including local breeds), traditional knowledge on land management practices, and the specific needs of local communities and the demands of local rural markets.

Regarding the production of diverse timber and non-timber products and manifold cultural ecosystem services, particularly the large number of studies on the Mediterranean *dehesa/montado* systems (e.g., Cardinael et al. 2017; Plieninger et al. 2021) documented their high importance for the multifunctionality of cultural landscapes and sustainable landscape development in the past (Zerbe 2022). However, recent analyses indicate that large areas of *dehesa* are misclassified as forest in remote-sensing datasets, which underscores the persistent underrepresentation of multifunctional agroforestry systems in land-use evaluation (Lawson et al. 2024). Comparable multifunctional roles are also evident in chestnut (*Castanea sativa*) groves with main occurrences in Italy and France, which combine nut production with grazing (Pantera et al. 2018; Rolo et al. 2021). In former times, being an additional agricultural production option in cultural landscapes with limited provision of natural resources, Sweet chestnut today has advanced to a niche product of high importance for rural economies, for example, in the Southern Alps (Bender 2010; Conedera et al. 2004). Thereby, Sweet chestnut is the raw material for multiple products such as bread, cake, and beer (Seliger et al. 2024).

An increasing number of studies investigate TAFs with regard to their potential to adapt to and mitigate climate change (Fagerholm et al. 2016). For Mediterranean wood pastures, for instance, the considerable potential of carbon storage has been revealed (Cardinael et al. 2017; Kay et al. 2018; Leal et al. 2019; Pecchioni et al. 2020; Ivezić et al. 2021). Traditional low-input and extensively managed agroforestry systems promote stable below-ground carbon storage by maintaining soil structure (Faivre et al. 2017) and above-ground carbon storage related to tree density and age and land management (Nagler et al. 2015). The wide range of carbon storage amounts and sequestration rates revealed up to now, however, calls for more systematic approaches to enhance comparability of data and traditional land-use systems across Europe.

Cultural ecosystem services of TAFs, such as recreation, aesthetics, symbolic and identity values, and natural and cultural heritage preservation are more difficult to assess and quantify compared to provisioning and regulating services due to their intangible nature (Rolo et al. 2021). These services, however, gain increasing importance e.g., for sustainable tourism approaches and concepts such as eco or green tourism and agritourism (Acha & Newing 2015; Roblek et al. 2021; Joshi et al. 2025) since TAFs can bridge traditional practices with modern societal needs, although this aspect is underrepresented in policy discussions up to now (Helming et al. 2013; Plieninger & Huntsinger 2018; Sørensen et al. 2021).

There is a growing number of studies which reveal that traditional land-use types are more diverse in terms of species and habitats compared to intensive systems (Zerbe 2022). Particularly, European TAFs have been investigated in this regard, focusing on diverse taxonomic groups, rare and Red List species of national and global concern, and endemics. The diverse horizontal and vertical structures of TAFs promote ecological niches for many plant and animal species, also encompassing fungi, lichens, and microorganisms. It has been documented that rare and highly threatened plant and animal species can have a habitat in TAFs while large parts around them are intensively managed and species-poor. Outstanding examples are the Iberian lynx (*Lynx pardinus*) and European turtle dove (*Streptopelia turtur*) in Mediterranean wood-pastures and Central European orchards (Plieninger & Wilbrand 2001; Rösch et al. 2019). Pollinators, crucial for many agricultural production systems and globally in steep decline due to land-use change and pesticide application in intensive agriculture (Dicks et al. 2021) can be most abundant in TAFs (Rundlöf et al. 2008; Udawatta et al. 2021; Basu et al. 2024). In conclusion, TAFs not only contribute to biodiversity but also to agrobiodiversity (Clara Manasa et al. 2024) and, due to their manifold land-use practices also to agrodiversity (Mariel et al. 2021; Zerbe 2022).

Three major global landscape development trends increasingly threaten TAFs on a global scale, namely urbanisation, land-use intensification, and land abandonment (Zerbe 2022). Many studies have linked the decline of biodiversity and ecosystem services with the change of traditional, low-input land-use practices to intensive, high-input practices. This has been shown, for example, for carbon storage and sequestration (Lal et al. 2015; Pecchioni et al. 2020). Increased mechanised interventions and high fertilisation rates in intensive systems can accelerate soil organic carbon turnover, potentially reducing net sequestration benefits over time (Lal et al. 2015). Land abandonment and rewilding of ecosystems and landscapes might create some benefits for nature conservation (Quintas-Soriano et al. 2022), but, in general, pose a threat to cultural values (Rey Benayas et al. 2007). This holds particularly true for TAFs with their often-high biodiversity and manifold ecosystem services. In Eastern Europe, the decline of traditional agroforestry systems is further intensified by two concurrent processes: land abandonment and the expansion of industrialised agricultural practices (Bergmeier et al. 2010; Hartel et al. 2013; Hartel & Plieninger 2014). In Romania, where traditional and diverse wood pastures remain abundant, agro-industrial expansion is transforming cultural landscapes into monocultures (Stoicea et al. 2023). While modern agroforestry is increasingly promoted for climate-smart agriculture and innovation, a critical evaluation of these systems, however, reveals that although they might be more productive, they often fail to address the needs of environmentally friendly production and socio-economic sustainability compared to traditional practices (Harvey & González 2007). Moreover, the shift from traditional to modern systems can have a negative impact on cultural ecosystem services, particularly the sense of place and cultural heritage, while reducing attractiveness of rural landscapes for tourism (Plieninger et al. 2015; Torralba et al. 2018).

A future outlook

Today, agroforestry is considered to have the potential to address key global and regional policy challenges related to climate change, biodiversity conservation, and sustainable land management (Manning et al. 2006; Helming et al. 2013; Soulard et al. 2018). International initiatives like the FAO's Sustainable Agricultural and Rural Development program and the EU's Common Agricultural Policy (CAP) offer frameworks for integrating agroforestry into broader environmental strategies (Helming et al. 2013; Soulard et al. 2018). The integration of agroforestry as an Ecological Focus Area (EFA) under the CAP allows farmers to receive payments for implementing these practices (EU Regulation 1307/2013) (Santiago-Freijanes et al. 2021). Similarly, the EU Green Deal, Farm to Fork Strategy, and Biodiversity Strategy for 2030 highlight agroforestry as a nature-based solution that enhances carbon sequestration, soil health, and ecological connectivity (European Commission 2020a, 2020b). Policies such as the European Climate Change Programme and the Global Alliance for Climate-Smart Agriculture recognise agroforestry as a key tool for climate change adaptation and mitigation (Santiago-Freijanes et al. 2021). The

2023 revision of the CAP further includes financial support through Eco-Schemes, Agro-Environmental and Climate Measures (AECMs), and Rural Development programs, yet adoption remains limited due to administrative barriers, fragmented funding, and lack of awareness among farmers (Den Herder et al. 2017; EU Regulation 2021/2115). The presence of TAFs within heritage landscapes (e.g., FAO-GIAHS, UNESCO Agricultural Heritage) underscores their multifunctional contributions, such as maintaining long-term ecological functions, enhancing biodiversity, and preserving cultural knowledge. This highlights the importance of landscape-scale management approaches that simultaneously support conservation, cultural heritage, and rural livelihoods (Plieninger et al. 2021; Zerbe 2022; FAO 2025). As governments continue to develop climate-smart agriculture strategies, agroforestry should be fully integrated into policies that support sustainable food production (Dupraz 2005; Jose 2009; Garrido et al. 2017). To overcome current challenges, enhancing financial support, simplifying regulations, and improving advisory services are considered crucial (Burgess & Rosati 2018). Policymakers should also expand financial incentives, develop integrated agroforestry action plans, and strengthen knowledge-sharing platforms to maximise benefits for biodiversity, climate resilience, and sustainable agriculture (García de Jalón et al. 2018; Mosquera-Losada et al. 2018). Although increasingly acknowledged in policy frameworks, agroforestry systems are rarely classified as distinct land-use types in EU national inventories. Instead, they are classified under agriculture or forest categories, limiting accurate assessment of their extent (Den Herder et al. 2017; Lawson et al. 2024).

Limitations and research gaps

This systematic review identifies several critical research gaps in TAFs, which play a key role in mitigating biodiversity loss and addressing climate change. While agroforestry systems such as *dehesa/montado* in the Mediterranean region have been well-documented (Hidalgo-Galvez et al. 2023), there has been less focus on systems in Northern and Eastern Europe, including wood-pastures in Scandinavia and traditional grazing systems in the Balkans (Torralba et al. 2018). Historical practices such as swidden-fallow, or slash-and-burn cultivation, also illustrate how farming and forestry have long been interconnected in Europe, for example, the *Svedjebruk* system in Sweden (Dove 2015). Such practices highlight the deep-rooted connections between farming and forestry which are closely related to TAFs.

The number of articles included in the review does not accurately represent the comprehensive coverage of TAFs in Europe, as grey literature was excluded from the analysis. Additionally, research published in non-English languages, particularly Russian, remains underexplored, limiting the breadth of knowledge on TAFs in these regions. This gap restricts our understanding of the potential and challenges of these systems across diverse environmental and socio-cultural contexts within Europe (Plieninger et al. 2021). Furthermore, much of the existing research on TAFs tends to focus on short-term outcomes, often neglecting the long-term trade-offs in ecosystem services and sustainability (Jose 2009).

Conclusions

The preservation and revitalisation of TAFs, in combination with sustainable modern land-use practices, offer promising options to contribute to the UN Sustainable Development Goals (UN 2015) directly (e.g., Goals 12 and 15) or indirectly (e.g., Goals 3 and 8), particularly in rural environments. These systems enhance food security and contribute to the economic resilience of rural communities. Key policy frameworks, including the EU Green Deal, Common Agricultural Policy (CAP), and Climate Adaptation Strategy offer essential support through financial incentives, expanded research funding, and better incorporation of agroforestry into national land-use policies. To safeguard the future of these systems, policymakers should prioritise evidence-driven strategies, long-term ecological and economic assessments, and innovative land management practices that integrate traditional and modern knowledge. Strengthening institutional collaboration, fostering interdisciplinary partnerships, and enhancing knowledge exchange among farmers and researchers will be vital in mainstreaming agroforestry as a scalable, climate-resilient land-use model. Given the accelerating threats of biodiversity loss and climate change, immediate action is essential to preserve these multifunctional land-use systems and ensure their role in sustainable agricultural and environmental policies.

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Author contribution SZ conceived the research idea; THL wrote the paper with contributions of SZ; THL with contributions from GB and TP performed statistical analyses and prepared the figures; SZ and MS acquired funding. All authors discussed the results and commented on the manuscript.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Conflict of Interests The authors declare no competing interests.

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References

Acha A, Newing HS (2015) Cork oak landscapes, promised or compromised lands? A case study of a traditional cultural landscape in Southern Spain. Hum Ecol 43:601–611. https://doi.org/10.1007/s10745-015-9768-7

Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, Quental TB, Davis AJ (2011) Has the Earth's sixth mass extinction already arrived? Nat 471(7336):51–57. https://doi.org/10.1038/nature09678

Basu P, Ngo HT, Aizen MA, Garibaldi LA, Gemmill-Herren B, Imperatriz-Fonseca V, Vanbergen AJ (2024) Pesticide impacts on insect pollinators: current knowledge and future research challenges. Sci Total Environ 954:176656. https://doi.org/10.1016/j.scitotenv.2024.176656

Bender O (2010) Sweet chestnut cultures in the Southern Alps–conservation and regional development. J Prot Mt Areas Res Manag 2:5–14. https://doi.org/10.1553/eco.mont-2-1s5

Bergmeier E, Petermann J, Schröder E (2010) Geobotanical survey of wood-pasture habitats in Europe: diversity, threats and conservation. Biodivers Conserv 19:2995–3014. https://doi.org/10.1007/s10531-010-9872-3

Berkes F (1999) Sacred ecology: traditional ecological knowledge and resource management. Taylor & Francis, London, pp 198–203

Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl 10(5):1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Bohn U, Zazanashvili N, Nakhutsrishvili G, Ketskhoveli, N (2007) The map of the natural vegetation of Europe and its application in the Caucasus Ecoregion. Bull. Georg. Natl. Acad. Sci. 175(1):112–121.

Bokdam J, Gleichman JM (2000) Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. J Appl Ecol 37(3):415–431. https://doi.org/10.1046/j.1365-2664.2000.00507.x

Bonari G, Fajmon K, Malenovský I, Zelený D, Holuša J, Jongepierová I, Kočárek P, Konvička O, Uřičář J, Chytrý M (2017) Management of semi-natural grasslands benefiting both plant and insect diversity: the importance of heterogeneity and tradition. Agric Ecosyst Environ 246:243–252. https://doi.org/10.1016/j.agee.2017.06.010

Burgess PJ, Rosati A (2018) Advances in European agroforestry: results from the AGFORWARD project. Agroforest Syst 92:801–810. https://doi.org/10.1007/s10457-018-0261-3

Cardinael R, Chevallier T, Cambou A, Béral C, Barthès BG, Dupraz C, Chenu C (2017) Increased soil organic carbon stocks under agroforestry: a survey of six different sites in France. Agric Ecosyst Environ 236:243–255. https://doi.org/10.1016/j.agee.2016.12.011

Clara Manasa PA, Salimath S. K, Hegde R, Maheswarappa V, Gooli M (2024) Agrobiodiversity vis-à-vis agroforestry: Cultivating a sustainable future. Int. J. Res. Agron. 7(3):176–186. https://doi.org/10.33545/2618060X.2024.v7.i3Sc.428

European Commission (2020a) The European Green Deal. European Commission Communication. https://knowledge4policy.ec.europa.eu/publication/communication-com2019640-european-green-deal_en. Accessed on 24 Feb 2025

European Commission (2020b). The EU Biodiversity Strategy for 2030. European Commission Communication. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en. Accessed on 24 Feb 2025

Conedera M, Krebs P, Tinner W, Pradella M, Torriani D (2004) The cultivation of *Castanea sativa* (Mill.) in Europe, from its origin to its diffusion on a continental scale. Veg Hist Archaeobot 13:161–179. https://doi.org/10.1007/s00334-004-0038-7

Cremene C, Groza G, Rakosy L, Schileyko AA, Baur A, Erhardt A, Baur B (2005) Alterations of steppe-like grasslands in Eastern Europe: a threat to regional biodiversity hotspots. Conserv Biol 19(5):1606–1618. https://doi.org/10.1111/j.1523-1739.2005.00084.x

Den Herder M, Moreno G, Mosquera-Losada RM, Palma JH, Sidiropoulou A, Freijanes JJS, Burgess PJ (2017) Current extent and stratification of agroforestry in the European Union. Agric Ecosyst Environ 241:121–132. https://doi.org/10.1016/j.agee.2017.03.005

Díaz S, Cabido M (1997) Plant functional types and ecosystem function in relation to global change. J Veg Sci 8(4):463–474. https://doi.org/10.2307/3237198

Dicks LV, Breeze TD, Ngo HT, Senapathi D, An J, Aizen MA, Potts SG (2021) A global-scale expert assessment of drivers and risks associated with pollinator decline. Nat Ecol Evol 5(10):1453–1461. https://doi.org/10.1038/s41559-021-01534-9

Domokos E, Domokos J (2016) Bird communities of different woody vegetation types from the Niraj Valley. Romania Turk J Zool 40(5):734–742. https://doi.org/10.3906/zoo-1510-64

Dorresteijn I, Hartel T, Hanspach J, von Wehrden H, Fischer J (2013) The conservation value of traditional rural landscapes: the case of woodpeckers in Transylvania, Romania. PLoS ONE 8(6):e65236. https://doi.org/10.1371/journal.pone.0065236

Dove MR (2015) Linnaeus' study of Swedish swidden cultivation: Pioneering ethnographic work on the 'economy of nature.' Ambio 44(3):239–248. https://doi.org/10.1007/s13280-014-0543-6

Dupraz C (2005) From silvopastoral to silvoarable systems in Europe: sharing concepts, unifying policies. In: Silvopastoralism and sustainable land management. Wallingford UK: CABI Publishing, 376–379. https://doi.org/10.1079/9781845930011.0376.

Duru M, Therond O, Martin G, Martin-Clouaire R, Magne MA, Justes E, Sarthou JP (2015) How to implement biodiversity-based agriculture to enhance ecosystem services: a review. Agron Sustain Dev 35:1259–1281. https://doi.org/10.1007/s13593-015-0306-1

Fagerholm N, Torralba M, Burgess PJ, Plieninger T (2016) A systematic map of ecosystem services assessments around European agroforestry. Ecol Indic 62:47–65. https://doi.org/10.1016/j.ecolind.2015.11.016

Faivre N, Fritz M, Freitas T, De Boissezon B, Vandewoestijne S (2017) Nature-based solutions in the EU: innovating with nature to address social, economic and environmental challenges. Environ Res 159:509–518. https://doi.org/10.1016/j.envres.2017.08.032

FAO (2007) Low-input agriculture and sustainable development. https://www.fao.org/family-farming/detail/en/c/1115210/. Accessed on 24 Feb 2025

FAO (2015) Agroforestry systems and practices: An overview. Food and Agriculture Organization of the United Nations. https://www.fao.org/agroforestry/en/.. Accessed on 24 Feb 2025

FAO (2025) Food and Agriculture Organization of the United Nations. *Europe and Central Asia, Globally Important Agricultural Heritage Systems*. https://www.fao.org/giahs/regions/europe-and-central-asia/en/. Accessed on 21 Aug 2025

Fontana V, Radtke A, Walde J, Tasser E, Wilhalm T, Zerbe S, Tappeiner U (2014) What plant traits tell us: Consequences of land-use change of a traditional agro-forest system on biodiversity and ecosystem service provision. Agric Ecosyst Environ 186:44–53. https://doi.org/10.1016/j.agee.2014.01.006

Gallé R, Urák I, Nikolett GS, Hartel T (2017) Sparse trees and shrubs confer high biodiversity to pastures: case study on spiders from Transylvania. PLoS ONE 12(9):e0183465. https://doi.org/10.1371/journal.pone.0183465

García de Jalón S, Burgess PJ, Graves A, Moreno G, McAdam J, Pottier E, Vityi A (2018) How is agroforestry perceived in Europe? An assessment of positive and negative aspects by stakeholders. Agroforest Syst 92:829–848. https://doi.org/10.1007/s10457-017-0116-3

Garrido P, Elbakidze M, Angelstam P, Plieninger T, Pulido F, Moreno G (2017) Stakeholder perspectives of wood-pasture ecosystem services: a case study from Iberian dehesas. Land Use Policy 60:324–333. https://doi.org/10.1016/j.landusepol.2016.10.022

Gil-López MJ, Segarra-Moragues JG, Ojeda F (2018) Floristic distinctiveness and endemic richness of woody plants highlight the biodiversity value of the *herriza* among all Mediterranean heathlands. Plant Ecol Divers 11(1):111–119. https://doi.org/10.1080/17550874.2018.1443351

Goncherenko GA, Báez F, Fedrigo JK, Santa Cruz R, Claramunt M, Mercadante VR, Viñoles C (2024) Silvopastoral systems as a strategy to attenuate the negative effects of heat stress on productivity of beef cows grazing natural grassland. Agroforest Syst 98:1995–2011. https://doi.org/10.1007/s10457-024-01081-9

González LM, Oria J, Sánchez R, Margalida A, Aranda A, Prada L, Molina JI (2008) Status and habitat changes in the endangered Spanish imperial eagle *Aquila adalberti* population during 1974–2004: implications for its recovery. Bird Conserv Int 18(3):242–259. https://doi.org/10.1017/S0959270908000245

Grass I, Loos J, Baensch S, Batáry P, Librán-Embid F, Ficiciyan A, Tscharntke T (2019) Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. People Nat 1(2):262–272. https://doi.org/10.1002/pan3.21

Grass R, Hötzel MJ, Koch A (2021) Land-sharing vs. land-sparing approaches in European agroforestry: A review of ecological, economic, and social outcomes. Environ Sci Policy 122:60–72. https://doi.org/10.1016/bs.aecr.2020.09.002

Griffith MP (2004) Ancient wine: the search for the origins of viniculture. Econ Bot 58(3):488–488. https://doi.org/10.1663/00130001(2004)058[0488:DFABRE]2.0.CO;2

Haines-Young R, Potschin M (2018) CICES V5.1: a common international classification of ecosystem services for the European Union. J Environ Manage 228:174–182.

Hartel T, Plieninger T (2014) European wood-pastures in transition: a social-ecological approach. Routledge, London. https://doi.org/10.4324/9780203797082

Hartel T, Dorresteijn I, Klein C, Máthé O, Moga CI, Öllerer K, Fischer J (2013) Wood-pastures in a traditional rural region of Eastern Europe: characteristics, management and status. Biol Conserv 166:267–275. https://doi.org/10.1016/j.biocon.2013.06.020

Harvey CA, González Villalobos JA (2007) Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. Biodivers Conserv 16:2257–2292. https://doi.org/10.1007/s10531-007-9194-2

Helming K, Diehl K, Geneletti D, Wiggering H (2013) Mainstreaming ecosystem services in European policy impact assessment. Environ Impact Assess Rev 40:82–87. https://doi.org/10.1016/j.eiar.2013.01.004

Herzog F (1998) Streuobst: A traditional agroforestry system as a model for agroforestry development in temperate Europe. Agroforest Syst 42:61–80. https://doi.org/10.1023/A:1006152127824

Hidalgo-Galvez MD, Matías L, Cambrollé J, Gutiérrez E, Pérez-Ramos IM (2023) Impact of climate change on pasture quality in Mediterranean dehesas subjected to different grazing histories. Plant Soil 488(1):465–483. https://doi.org/10.1007/s11104-023-05986-9

Horak J (2014) Fragmented habitats of traditional fruit orchards are important for dead wood-dependent beetles associated with open canopy deciduous woodlands. Naturwissenschaften 101(6):499–504. https://doi.org/10.1007/s00114-014-1179-x

IPBES W (2019) Intergovernmental science-policy platform on biodiversity and ecosystem services. Summary for policy makers of the global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services. IPBES Secretariat, Bonn, Germany. https://www.de-ipbes.de/. Accessed on 24 Feb 2025

IPCC (2021) Sixth assessment report: Climate change 2021: The physical science basis. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/. Accessed on 24 Feb 2025

IUCN (2021) The IUCN Red List of Threatened Species. International Union for Conservation of Nature. https://www.iucnredlist.org/. Accessed on 24 Feb 2025

Ivezić V, Yu Y, Werf WV (2021) Crop yields in European agroforestry systems: a meta-analysis. Front Sustain Food Syst 5:606631. https://doi.org/10.3389/fsufs.2021.606631

Ji Z, Lee N, Frieske R, Yu T, Su D, Xu Y, Fung P (2023) Survey of hallucination in natural language generation. ACM Comput Surv 55(12):1–38. https://doi.org/10.1145/3571730

Joffre R, Vacher J, de los Llanos C, Long G (1988) The dehesa: an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain. Agroforest Syst 6(1):71–96. https://doi.org/10.1007/BF02344747

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agroforest Syst 76(1):1–10. https://doi.org/10.1007/s10457-009-9229-7

Joshi S, Panzer-Krause S, Bucur A, Atomulese A, Zerbe S, Sauerwein M (2025) Exploring ecotourism in rural Romania: visitor perceptions in a traditional multifunctional cultural landscape. Environ Syst Decis 45(2):1–11. https://doi.org/10.1007/s10669-025-10007-4

Kajtoch Ł (2017) The importance of traditional orchards for breeding birds: the preliminary study on Central European example. Acta Oecol 78:53–60. https://doi.org/10.1016/j.actao.2016.12.010

Kay S, Crous-Duran J, Ferreiro-Domínguez N, García de Jalón S, Graves A, Moreno G, Herzog F (2018) Spatial similarities between European agroforestry systems and ecosystem services at the landscape scale. Agroforest Syst 92:1075–1089. https://doi.org/10.1007/s10457-017-0132-3

Kay S, Graves A, Palma JH, Moreno G, Roces-Díaz JV, Aviron S, Herzog F (2019) Agroforestry is paying off–economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. Ecosyst Serv 36:100896. https://doi.org/10.1016/j.ecoser.2019.100896

King KFS (1987) The history of agroforestry. Agroforestry: A decade of development, ICRAF, 1–11.

Koohafkan P, Cruz MJD (2011) Conservation and Adaptive Management of Globally Important Agricultural Heritage Systems (GIAHS). J Resour Ecol 2(1):22–28. https://doi.org/10.3969/j.issn.1674-764x.2011.01.004

Lal R, Negassa W, Lorenz K (2015) Carbon sequestration in soil. Curr Opin Environ Sustain 15:79–86. https://doi.org/10.1016/j.cosust.2015.09.002

Lawson G, Muraru C, Bertomeu M, Corbacho J (2024) Defining forests and agroforests in the EU (EURAF Policy Brief No. 15, v5, 13 November 2024). European Agroforestry Federation. https://doi.org/10.5281/zenodo.7936686

Leal AI, Correia RA, Palmeirim JM, Bugalho MN (2019) Is research supporting sustainable management in a changing world? Insights from a Mediterranean silvopastoral system. Agroforest Syst 93(1):355–368. https://doi.org/10.1007/s10457-018-0231-9

Manning AD, Fischer J, Lindenmayer DB (2006) Scattered trees are keystone structures–implications for conservation. Biol Conserv 132(3):311–321. https://doi.org/10.1016/j.biocon.2006.04.023

Mariel J, Carrière SM, Penot E, Danthu P, Rafidison V, Labeyrie V (2021) Exploring farmers' agrobiodiversity management practices and knowledge in clove agroforests of Madagascar. People Nat 3(4):914–928. https://doi.org/10.1002/pan3.10238

Mattioli W, Mancini LD, Portoghesi L, Corona P (2015) Biodiversity conservation and forest management: the case of the sweet chestnut coppice stands in Central Italy. Plant Biosyst 150(3):592–600. https://doi.org/10.1080/11263504.2015.1054448

Millennium Ecosystem Assessment (2005) *Ecosystems and human well-being: Synthesis*. Island Press, Washington,

DC. https://www.millenniumassessment.org/documents/document.356.aspx.pdf
Moreno G, Gonzalez-Bornay G, Pulido F, Lopez-Diaz ML, Bertomeu M, Juárez E, Diaz M (2016) Exploring the causes of high biodiversity of Iberian dehesas: the importance of wood pastures and marginal habitats. Agroforest Syst 90:87–105. https://doi.org/10.1007/s10457-015-9817-7
Mosquera-Losada MR, Santiago-Freijanes JJ, Rois-Díaz M, Moreno G, den Herder M, Aldrey-Vázquez JA, Rigueiro-Rodríguez A (2018) Agroforestry in Europe: a land management policy tool to combat climate change. Land Use Policy 78:603–613. https://doi.org/10.1016/j.landusepol.2018.06.052
Mosquera-Losada MR, Moreno G, Pardini A, McAdam J.H, Papanastasis V, Burgess PJ, Lamersdorf N, Castro M, Liagre F, Rigueiro-Rodríguez A (2012) Past, present and future of agroforestry systems in Europe. In: Nair P, Garrity D. (eds) Agroforestry - The Future of Global Land Use. Advances in Agroforestry, Springer, Dordrecht, 9:285–312. https://doi.org/10.1007/978-94-007-4676-3_16
Nagler M, Fontana V, Lair GJ, Radtke A, Tasser E, Zerbe S, Tappeiner U (2015) Different management of larch grasslands in the European Alps shows low impact on above- and belowground carbon stocks. Agric Ecosyst Environ 213:186–193. https://doi.org/10.1016/j.agee.2015.08.005
Nair PKR, Viswanath S, Lubina PA (2017) Cinderella agroforestry systems. Agroforest Syst 91(5):901–917. https://doi.org/10.1007/s10457-016-9966-3
Nair PKR (1998) Directions in tropical agroforestry research: past, present, and future. In: Nair PKR., LattCR. (eds) Directions in Tropical Agroforestry Research. Forestry Sciences, Springer, Dordrecht, 53:223–245. https://doi.org/10.1007/978-94-015-9008-2_10
Nerlich K, Graeff-Hönninger S, Claupein W (2013) Agroforestry in Europe: a review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. Agroforest Syst 87:475–492. https://doi.org/10.1007/s10457-012-9560-2
Noordwijk MV, Coe R, Sinclair F (2016) Central hypotheses for the third agroforestry paradigm within a common definition. ICRAF Working Paper, 233. Nairobi: World Agroforestry Centre. https://doi.org/10.5716/WP16079.PDF
Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372. https://doi.org/10.1136/bmj.n71
Paltto H, Nordberg A, Nordén B, Snäll T (2011) Development of secondary woodland in oak wood pastures reduces the richness of rare epiphytic lichens. PLoS ONE. https://doi.org/10.1371/journal.pone.0024675
Pantera A, Burgess PJ, Mosquera Losada R, Moreno G, López-Díaz ML, Corroyer N, McAdam J, Rosati A, Papadopoulos AM, Graves A, Rigueiro Rodríguez A (2018) Agroforestry for high value tree systems in Europe. Agroforest Syst 92:945–959. https://doi.org/10.1007/s10457-017-0181-7
Papanastasis VP, Mantzanas K, Dini-Papanastasi O, Ispikoudis I (2009) Traditional agroforestry systems and their evolution in Greece. In: Rigueiro-Rodróguez, A., McAdam, J., Mosquera-Losada, M.R. (eds) Agroforestry in Europe. Advances in Agroforestry, 6. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-8272-6_5
Pecchioni G, Bosco S, Volpi I, Mantino A, Dragoni F, Giannini V, Tozzini C, Mele M, Ragaglini G (2020) Carbon budget of an agroforestry system after being converted from a poplar short rotation coppice. Agron 10(9):1251. https://doi.org/10.3390/agronomy10091251
Pereira PM, Da Fonseca MP (2003) Nature vs. nurture: the making of the montado ecosystem. Conserv. Ecol. 7(3). https://www.jstor.org/stable/26271966
Petersen B, Snapp S (2015) What is sustainable intensification? Views from experts. Land Use Policy 46:1–10. https://doi.org/10.1016/j.landusepol.2015.02.002
Plieninger T, Huntsinger L (2018) Complex rangeland systems: integrated social-ecological approaches to silvopastoralism. Rangel Ecol Manag 71(5):519–525. https://doi.org/10.1016/j.rama.2018.05.002
Plieninger T, Wilbrand C (2001) Land use, biodiversity conservation, and rural development in the dehesas of Cuatro Lugares, Spain. Agroforest Syst 51:23–34. https://doi.org/10.1023/A:1006462104555
Plieninger T, Hartel T, Martín-López B, Beaufoy G, Bergmeier E, Kirby K, Van Uytvanck J (2015) Wood-pastures of Europe: Geographic coverage, social - ecological values, conservation management, and policy implications. Biol Conserv 190:70–79. https://doi.org/10.1016/j.biocon.2015.05.014
Plieninger T, Flinzberger L, Hetman M, Horstmannshoff I, Reinhard-Kolempas M, Topp E, Moreno G, Huntsinger L (2021) Dehesas as high nature value farming systems: a social-ecological synthesis of drivers, pressures, state, impacts, and responses. Ecol Soc 26(3):23. https://doi.org/10.5751/ES-12647-260323
PRISMA (2009) Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). https://www.prisma-statement.org/. Accessed on 4 Apr 2024
Quintas-Soriano C, Buerkert A, Plieninger T (2022) Effects of land abandonment on nature contributions to people and good quality of life components in the Mediterranean region: a review. Land Use Policy 116:106053. https://doi.org/10.1016/j.landusepol.2022.106053
R Core Team (2023) R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Austria. http://www.R-project.org
Rackham O (2008) Ancient woodlands: modern threats. New Phytol 180(3):571–586.
EU Regulation 1307/2013 (2013) Council Regulation (EC) 637/2008 and Council Regulation (EC)73/2009. https://op.europa.eu/en/publication-detail/-/publication/67f7db2a-9d73-11ed-b508-01aa75ed71a1. Accessed on 24 Feb 2025
EU Regulation 2021/2115 (2021) Regulation (EU) 2021/2115 of the European Parliament and of the Council. https://environment.ec.europa.eu/publications/regulation-eu-20212115_en. Accessed on 24 Feb 2025

Renes H (2015) Historic landscapes without history? A reconsideration of the concept of traditional landscapes. Rural Landsc 2(1):2–16. https://doi.org/10.16993/rl.ae
Rey Benayas JM, Martins A, Nicolau JM, Schulz, JJ (2007) Abandonment of agricultural land: an overview of drivers and consequences. CABI Reviews, pp.14. https://doi.org/10.1079/PAVSNNR20072057
Ripamonti A, Finocchi M, Pulina A, Franca A, Seddaiu G, Turini L, Mele M, Mantino A (2025) Effects of tree presence on forage yield and nutritive value in agroforestry livestock systems: a global systematic review. Agroforest Syst 99:110. https://doi.org/10.1007/s10457-025-01214-8
Roblek V, Drpić D, Meško M, Milojica V (2021) Evolution of sustainable tourism concepts. Sustainability 13(22):12829. https://doi.org/10.3390/su132212829
Rolo V, Roces-Diaz JV, Torralba M, Kay S, Fagerholm N, Aviron S, Moreno G (2021) Mixtures of forest and agroforestry alleviate trade-offs between ecosystem services in European rural landscapes. Ecosyst Serv 50:101318. https://doi.org/10.1016/j.ecoser.2021.101318
Rösch V, Hoffmann M, Diehl U, Entling MH (2019) The value of newly created wood pastures for bird and grasshopper conservation. Biol Conserv 237:493–503. https://doi.org/10.1016/j.biocon.2019.07.036
Rundlöf M, Bengtsson J, Smith HG (2008) Local and landscape effects of organic farming on butterfly species richness and abundance. J Appl Ecol 45(3):813–820. https://doi.org/10.1111/j.1365-2664.2007.01448.x
Santiago-Freijanes JJ, Mosquera-Losada MR, Rois-Díaz M, Ferreiro-Domínguez N, Pantera A, Aldrey JA, Rigueiro-Rodríguez A (2021) Global and European policies to foster agricultural sustainability: agroforestry. Agroforest Syst 95(5):775–790. https://doi.org/10.1007/s10457-018-0215-9
Sarkar D, Kar SK, Chattopadhyay A, Rakshit A, Tripathi VK, Dubey PK, Abhilash PC (2020) Low input sustainable agriculture: a viable climate-smart option for boosting food production in a warming world. Ecol Indic 115:106412. https://doi.org/10.1016/j.ecolind.2020.106412
Sattler C, Schrader J, Hüttner ML, Henle K (2024) Effects of management, habitat and landscape characteristics on biodiversity of orchard meadows in central Europe: a brief review. Nat Conserv 55:103–134. https://doi.org/10.3897/natureconservation.55.108688
Seliger A, Ammer C, Seidel D, Zerbe S (2024) Drivers of tree regeneration in coniferous monocultures during conversion to mixed forests in Central Europe-implications for forest restoration management. Forest Ecosystems. https://doi.org/10.1016/j.fecs.2024.100244
Sinclair FL (1999) A general classification of agroforestry practice. Agroforest Syst 46(2):161–180. https://doi.org/10.1023/A:1006278928088
Smith P (2014) Do grasslands act as a perpetual sink for carbon? Glob Change Biol 20(9):2708–2711. https://doi.org/10.1111/gcb.12561
Smith J (2010) The history of temperate agroforestry. Progressive Farming Trust Limited, Cirencester.
Sørensen IH, Torralba M, Quintas-Soriano C, Muñoz-Rojas J, Plieninger T (2021) Linking cork to cork oak landscapes: mapping the value chain of cork production in Portugal. Front Sustain Food Syst 5:787045. https://doi.org/10.3389/fsufs.2021.787045
Soulard CT, Valette E, Perrin C, Abrantes PC, Anthopoulou T, Benjaballah O, Paoli JC (2018) Peri-urban agro-ecosystems in the Mediterranean: diversity, dynamics, and drivers. Reg Environ Change 18:651–662. https://doi.org/10.1007/s10113-017-1102-z
Stoicea P, Toma E, David L, Constanti A. R, Budileanu A (2023) Performance of large agricultural companies in Romanian agriculture. Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural Dev. 23(1). https://managementjournal.usamv.ro/pdf/vol.23_1/volume_23_1_2023.pdf
Termorshuizen JW, Opdam P (2009) Landscape services as a bridge between landscape ecology and sustainable development. Landsc Ecol 24:1037–1052. https://doi.org/10.1007/s10980-008-9314-8
Torralba M, Fagerholm N, Burgess PJ, Moreno G, Plieninger T (2016) Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agric Ecosyst Environ 230:150–161. https://doi.org/10.1016/j.agee.2016.06.002
Torralba M, Fagerholm N, Burgess PJ, Moreno G, Plieninger T (2018) A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures. Sci. Adv. 4(5):eaar2176. https://doi.org/10.1126/sciadv.aar2176
Tsonkova P, Böhm C, Quinkenstein A, Freese D (2012) Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: a review. Agroforest Syst 85:133–152. https://doi.org/10.1007/s10457-012-9494-8
Udawatta RP, Rankoth LM, Jose S (2021) Agroforestry for biodiversity conservation. Agroforest Ecosyst. Serv. 245–274. https://doi.org/10.1007/978-3-030-80060-4_10
United Nations (2015) Transforming our world: The 2030 agenda for sustainable development. United Nations. https://sdgs.un.org/2030agenda
UNSD (2010) UN Geoscheme- Standard M49. https://unstats.un.org/unsd/methodology/m49/. Accessed on 24 Feb 2025
Valente LM, Savolainen V, Vargas P (2010) Unparalleled rates of species diversification in Europe. Proc R Soc Lond B Biol Sci 277(1687):1489–1496. https://doi.org/10.1098/rspb.2009.2163
Viaud V, Kunnemann T (2021) Additional soil organic carbon stocks in hedgerows in crop-livestock areas of western France. Agric Ecosyst Environ 305:107174. https://doi.org/10.1016/j.agee.2020.107174
Viswanath S, Lubina PA (2017) Traditional Agroforestry Systems. In: DagarJ, Tewari V (eds) Agroforestry. Springer, Singapore. https://doi.org/10.1007/978-981-10-7650-3_3
Wani AA, Mehraj B, Masoodi TH, Gatoo AA, Mugloo JA (2020) Assessment of Trees Outside Forests (TOF) with Emphasis on Agroforestry Systems. In: Dagar JC, Gupta SR, Teketay D. (eds) Agroforestry for Degraded Landscapes. Springer, Singapore. https://doi.org/10.1007/978-981-15-6807-7_4
Wood H, Lindborg R, Jakobsson S (2017) European Union tree density limits do not reflect bat diversity in

wood-pastures. Biol Conserv 210:60–71. https://doi.org/10.1016/j.biocon.2017.04.001

Zerbe S (2022) Restoration of multifunctional cultural landscapes: merging tradition and innovation for a sustainable future, 30. Springer Nature, Cham. https://doi.org/10.1007/978-3-030-95572-4

Zerbe S (2024) Traditional cultural landscapes revisited: Classification, diversity, services, and their restoration. DIE ERDE 155(2):67–86. https://doi.org/10.12854/erde-2024-669

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