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Perspective

Wood-pastures of Europe: Geographic coverage, social–ecological values, conservation management, and policy implications

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ABSTRACT

Wood-pastures are archetypes of High Nature Value Farmlands in Europe and hold exceptional ecological, social, and cultural values. Yet, wood-pastures have been through a sharp decline all over Europe, mainly due to processes of agricultural intensification and abandonment. Recently, wood-pastures have found increasing attention from conservation science and policy across Europe. In this paper we (i) perform the first pan-European assessment of wood-pastures, considering individual countries and biogeographic regions, (ii) present the ecological and social–cultural values of a wide diversity of wood-pasture systems in Europe, (iii) outline management challenges around wood-pastures, and (iv) provide insights for the policy agenda targeting wood-pastures in Europe. We estimate that wood-pastures cover an area of approximately 203,000 km^2 in the European Union (EU). They are distributed across all biogeographical regions, but more abundantly in the Mediterranean and Eastern European countries. Substantial ecological values are revealed in terms of landscape level biodiversity, ecosystem dynamics, and genetic resources. Social–cultural values are related to aesthetic values, cultural heritage, and rich traditional ecological knowledge. We discuss the anthropogenic character of wood-pastures, requiring multifunctional land management, which is a major conservation challenge. Despite increasing societal appreciation of wood-pastures, their integration into effective agricultural and conservation policies has proved to be complicated, because institutional structures are traditionally organized within mono-functional sectors. We offer suggestions as to how these shortcomings might be overcome in the Common Agricultural Policy, including Rural Development policy, and the Habitats Directive of the EU. We conclude that research should be guided by a holistic vision of wood-pastures, which integrates information about ecology, societal values, and institutional arrangements.

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1. Introduction

Protected areas may soon cover 17% of the global land surface (Watson et al., 2014), but there is wide recognition that segregated conservation strategies must be complemented by integrative approaches, especially in landscapes shaped by agriculture and forestry (Fischer et al., 2006). Efforts to realign biodiversity conservation with agricultural production have recently gained momentum, as growing competition for land (Smith et al., 2010), urban land expansion (Seto et al., 2011), and land degradation (Plieninger and Gaertner, 2011) make it increasingly difficult to set aside large areas exclusively for biodiversity conservation. One prominent integrative strategy is High Nature Value (HNV) farming, a conservation approach that links ecology, land use, and public policies and expands conservation from traditional site protection to the scale of managed landscapes (Oppermann et al., 2012). The HNV approach was developed in acknowledgement of the crucial importance of low intensity farming for many elements of biodiversity (Halada et al., 2011).

Wood-pastures – landscapes in which livestock grazing co-occurs with scattered trees and shrubs – are archetypes of High Nature Value farmland and excellent model systems to explore how such farmlands could be incorporated into conservation strategies (Bergmeier et al., 2010). They represent an important part of the European cultural and natural heritage, but are also mirrors of dramatic changes in the relationship between people and their natural environment (Rotherham, 2013). Scientific interest in wood-pastures has recently grown across Europe (e.g. Garbarino et al., 2011; Hartel et al., 2013; Horák and Rébl, 2013; Plieninger, 2012; Plieninger et al., 2015; Vojta and Drhovská, 2012). Studies of wood-pastures have been performed at plot or local scales, often generating insight for wood-pasture conservation at large. However, to inform conservation policy, such local research needs to be complemented by studies acting across regions and continents (Schimel, 2011). Therefore, our paper aims to provide the first European synthesis of the available knowledge about wood-pastures. In particular, we (i) evaluate the extent of wood-pastures in Europe by country and biogeographic region, (ii) present the ecological and social–cultural values of the variety of wood-pasture systems in Europe, (iii) outline the management challenges around wood-pastures, and (iv) suggest relevant insights for the policy agenda in Europe.

2. Extent of wood-pastures in Europe

For the quantification of wood-pastures, we used information from the LUCAS project of the EU, a geo-referenced database of 270,277 points that provides harmonized and comparable statistics on land use and land cover across the whole of the EU's territory in 2012 (EUROSTAT, 2015). The database covers 27 European countries (EU-27 hereafter), and consists of a systematic sample with points spaced 2 km apart (around 1,100,000 points). Each point of the first phase sample was photo-interpreted and assigned to one of the following seven pre-defined land cover strata: arable land, permanent crops, grassland, wooded areas and shrubland, bareland, artificial land, and water. In a second stage, a quarter of the points were visited and interpreted at ground level in 2012. This second stratified sample (with >270,000 points; located every 4 km × 4 km, on average) was selected according to the proportion of each of the seven main land uses in every European region (NUTS2 level). A scheme maximizing the distance of the points, both in the same and in different strata (region × land use), was designed as a sample selection method, producing a quasi-regular grid of points (Martino et al., 2009). Nevertheless, for logistic limitations, points above 1500 metres of altitude and those far from the road network were considered inaccessible and excluded (Eurostat, 2015). The presence of trees in the observational point was assessed considering a 20 m radius. On the basis of the LUCAS data, we defined wood-pastures as those sampled points that show a combination of a tree cover (density of tree-crown >5%) with a pasture cover (grassland communities with clear evidences of grazing, coded as land use U111 in the LUCAS database). We mapped three categories of wood-pastures: (1) pastures in open woodlands, including those points with woodland (density of tree-crown >10%) as the primary land cover (coded as C10 to C33), and with grassland as the secondary land cover (coded as E10 and E30); (2) pastures with sparse trees (density of tree-crown between 5% and 10%), directly defined in the LUCAS database as a specific land cover class (coded as E10); and (3) pastures with cultivated trees (coded as B71 to B81) with recorded grazing land use, i.e. excluding points that are ungrazed permanent croplands rather than fully-fledged wood-pastures (see Fig. 1 for examples). As a result, we found that the LUCAS database contains 12,772 points that we considered wood-pastures. Given the comprehensive sampling grid that was included in LUCAS, the set of points can be viewed as representative of the land cover at EU but for the larger countries also at national scales (Table 1). Hence, in order to estimate the extent of wood-pastures, we multiplied the proportion of points defined as wood-pasture in each country by the surface of the country divided by the overall number of LUCAS points in this country. As sample density varied between 3 and 12 points per 100 km^2, an alternative approach based on Thiessen proximal polygons was generated for every sample point (i.e. the lower the sample density is, the bigger are

Fig. 1. Examples (from top to bottom) of (a) pastures in open woodlands (Dehesa with *Quercus ilex* in Torrecillas de la Tiesa, Spain), (b) pastures with sparse trees (pasture with scattered *Fagus sylvatica* trees in Eastern Transylvania, Romania), and (c) pastures with cultivated trees (orchard meadow in Lenningen, Germany).

the polygons), which produced very similar results (data not shown).

We estimate that wood-pastures cover a total of approximately 203,000 km^2 in the EU27 (4.7%, Fig. 2), with roughly 109,000 km^2 being pastures with sparse trees, 85,000 km^2 pastures in open woodlands, and 9000 km^2 pastures with cultivated trees (mainly grazed olive groves and fruit trees). Out of 1,053,000 km^2 of grasslands in the EU, 19.3% are represented by wood-pastures. The largest extent of wood-pastures is found in Spain, France, and Romania (Table 1). Pastures with sparse trees have their largest surface in the Mediterranean (Spain, France, Italy) and Eastern European countries (Romania, Bulgaria). Pastures in open woodlands are particularly concentrated in Spain and Portugal, where they occur mainly as holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) wood-pastures (called *dehesas* and *montados*). Grazed pastures with cultivated trees are found across the Mediterranean countries, with the highest extent being found in Spain, Greece, Portugal, and Italy. Wood-pastures cover 10.8% of the Mediterranean biogeographical region, 5.6% of the Black Sea region, and 4.7% of the Alpine region as defined by the European Environment Agency. Wood-pastures cover less than 4.0% in the Continental, Boreal, Atlantic, Pannonian and Steppic regions. Since we did not include shrublands (even if grazed and with presence of sparse trees) and grazed forests without pasture understory in our definition of wood-pastures, the numbers of the extent of wood-pastures in the EU-27 are conservative estimates. The figures should also be treated with caution as there are many interpretation issues and other variables at play. For example, mountainous and other remote areas may be underrepresented in the LUCAS survey, and information concerning management and tenure of wood pastures is very poor (e.g. simultaneous presence of tree and grass cover may be integrated in the same parcel or management unit or in adjacent ones).

Table 1
Extent of three categories of wood-pastures in the 27 EU member states derived from the LUCAS database. See text for further details.

Country	Pastures in open woodlands (km^2)	Pastures with sparse trees (km^2)	Pastures with cultivated trees (km^2)	Wood-pasture total (km^2)	Proportion of territory covered by wood-pasture (%)
Austria	364	766	221	1350	1.6
Belgium	150	501	25	676	2.2
Bulgaria	969	10,278	201	11,448	10.3
Cyprus	16	47	35	99	1.7
Czech Rep.	314	457	86	857	1.1
Denmark	524	112	0	636	1.5
Estonia	21	960	0	981	2.1
Finland	274	598	0	872	0.3
France	6644	13,861	544	21,049	3.7
Germany	2494	2752	344	5591	1.6
Greece	4200	8007	1246	13,454	10.1
Hungary	180	1985	0	2166	2.3
Ireland	1540	1981	0	3521	5.1
Italy	3610	10,477	1059	15,145	5.3
Latvia	102	848	0	950	1.5
Lithuania	84	2124	67	2275	3.5
Luxemburg	24	60	24	108	4.2
Malta	0	0	0	0	0.0
Netherlands	128	112	32	271	0.8
Poland	1058	3573	114	4746	1.5
Portugal	10,724	2693	1135	14,553	16.4
Romania	981	15,278	731	16,990	7.2
Slovakia	140	718	0	857	1.8
Slovenia	139	919	38	1095	5.4
Spain	36,771	19,407	1917	58,096	11.7
Sweden	2150	3086	20	5256	1.2
UK	3448	4410	140	7998	3.3
EU-27	**85,219**	**109,247**	**8901**	**203,367**	**4.7**

3. Ecological values of European wood-pastures

The exceptional ecological values of wood-pastures are a result of their contribution to landscape level biodiversity, their dynamic character, and their role as a repository of genetic resources.

3.1. Contribution to landscape level biodiversity

Spatial heterogeneity in wood-pastures operates at multiple scales. Canopy-caused resource gradients (e.g. light conditions, wind, temperature, soil fertility) determine a ubiquitous fine-scale heterogeneity at the plot scale. Wood-pastures are often more heterogeneous environments than other managed ecosystems in the same biogeographical region such as closed forests or open, treeless farmlands. This is caused by the wide cover of native vegetation in wood-pastures, their structures and succession stages as well as the density and age structure of the tree communities. Structural heterogeneity creates ecological niches for a wide

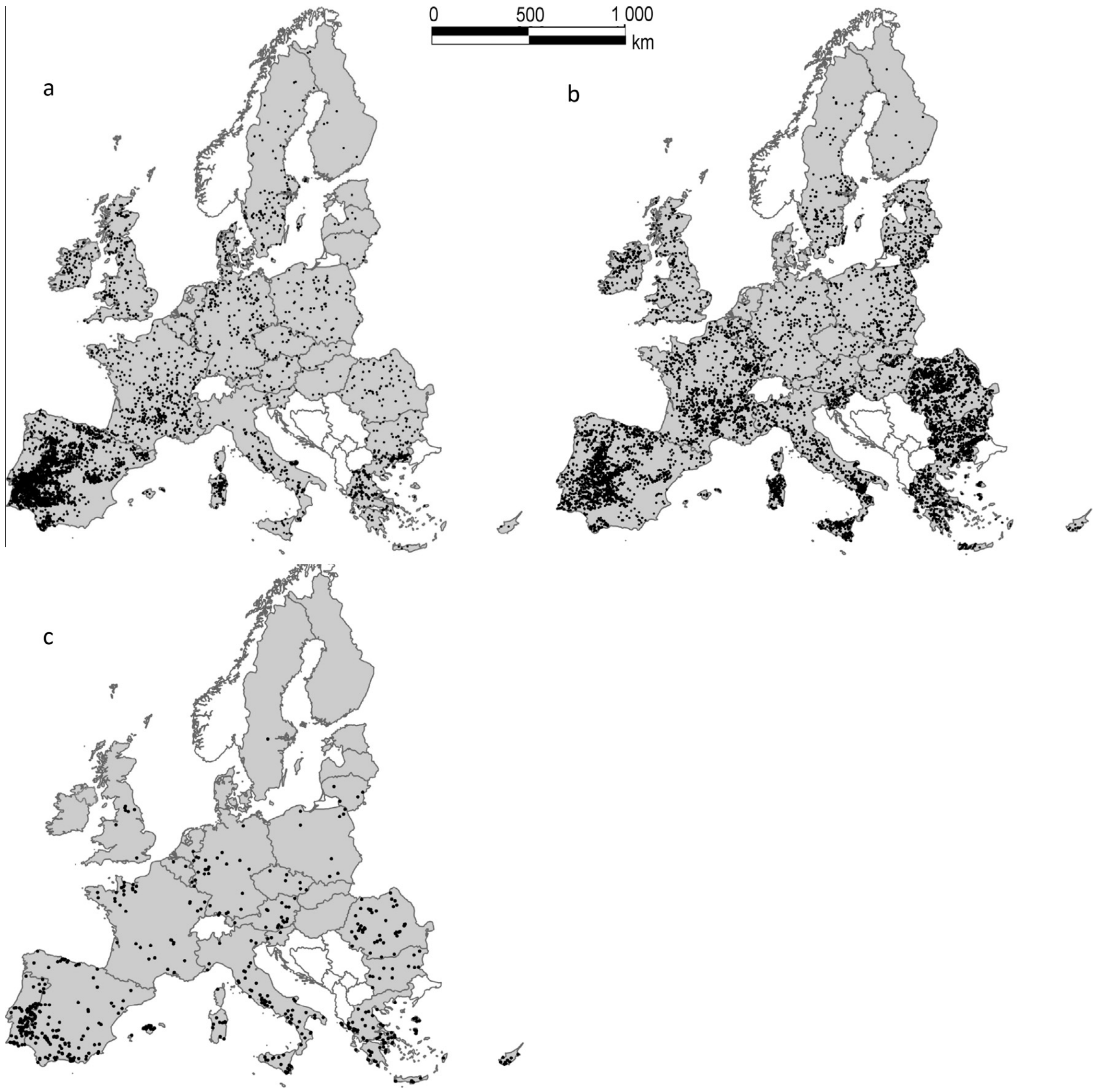

Fig. 2. Distribution of wood-pastures in Europe ((a) pastures in open woodland, (b) pastures with sparse trees, and (c) pastures with cultivated trees). Grey background indicates the surveyed area, while areas in white remained unconsidered. Note that points represent the location but not the extent of wood-pastures as they are not at scale.

range of organisms. In particular, large, old trees are more common in wood-pastures than in other managed ecosystems, including forests (Hartel et al., 2013). These trees are known to act as ecological keystone structures (Manning et al., 2006). Wood-pastures in Romania have distinctive passerine bird communities, with more functional groups and higher absolute species richness than closed forests and treeless pastures (Hartel et al., 2014b). Similarly, oak wood-pastures in Spain have carabid assemblages that are distinct from those of closed forests (Taboada et al., 2011), and plant, bee, spider, and earthworm assemblages distinct to adjacent open pastures (Moreno et al., personal communication), thus contributing to landscape scale biodiversity. Richer saproxylic beetle communities were reported with increasing openness around old, hollowing trees from the Czech republic (Horák and Rébl, 2013 for click beetles) and Sweden (Koch Widerberg et al., 2012 for other beetle species), suggesting that there are significant differences in the species communities of these organisms between wood-pasture and closed forests. Ancient trees in wood-pastures also contain significantly more lichen species than those being surrounded by secondary woodland as a result of grazing abandonment (Paltto et al., 2011). There is a considerable number of saprotrophic fungi and mycorrhizal fungi which are more common in wood-pasture type of landscapes (Diamandis and Perlerou, 2008; Reyna-Domenech and García-Barreda, 2009).

Management practices contribute to the biodiversity value of the wood-pastures. For example, extensive grazing with buffalo and cattle contributes to the maintenance of ponds, which are of crucial importance for the protected yellow bellied toad (*Bombina variegata*) (Hartel and von Wehrden, 2013), while pollarding can promote hollowing in certain tree species, making the trees attractive for saproxylic biodiversity (Sebek et al., 2013). Multifunctionality and multiple management practices have been identified as main drivers of high biodiversity of Iberian dehesas (Díaz et al., 2013). Some species may be regionally restricted to wood-pasture landscapes, for example shade-tolerant unpalatable geophytes such as peonies (*Paeonia* spp.) and hellebores (*Helleborus* spp.) in southern Europe (Chaideftou et al., 2009). Wood-pastures often cover large contiguous areas, providing part of the home ranges of some large carnivores, such as the brown bear (*Ursus arctos*), or threatened species, such as Iberian lynx (*Lynx pardinus*) or Spanish imperial eagle (*Aquila adalberti*), which find important food resources in wood-pastures

(Bergmeier et al., 2010; Roellig et al., 2014). Thus, wood-pastures can be considered umbrella ecosystems providing habitats for many species of conservation interest (Bergmeier et al., 2010).

3.2. Dynamic character

Current ancient wood-pasture systems may be the closest analogues to the pre-human, semi-open, and dynamic landscapes of parts of lowland Europe (Pokorný et al., 2015; Sandom et al., 2014). The temporal variation of natural forces such as mega-herbivores, climatic events, pests, and predators could have resulted in a fluid and dynamic landscape (sensu Manning et al., 2009) where pulses of tree and shrub regeneration were followed by opening of the woodlands. Dynamic human land-use through shifting rotation management systems, extensive livestock grazing, shrub clearing, or hay making, together with the high regenerative potential of the trees and shrubs creates a constantly changing landscape mosaic (Chételat et al., 2013). For example, the regeneration of trees in a Spanish wood-pasture is higher in areas with transhumant grazing (which represented a seasonal impact of livestock on the vegetation) than in areas with permanent grazing (Carmona et al., 2013). Thus, multifunctional management of wood-pastures may resemble or mimic the natural drivers of pre-human ecosystems, which are thought to function as dynamic mosaics. These are driven by an alternation of plant facilitation and competition, phases of grazing and regeneration. Spatial asynchronization of this cyclic mechanism causes shifting mosaics with patches of all structural vegetation types involved (Olff et al., 1999). This intrinsic dynamic mechanism is nowadays widely talked about – and sometime applied – in conservation management in Western Europe, aiming to restore wood-pasture landscapes.

3.3. Genetic resources

Trees in wood-pastures have often been planted or selected by humans over centuries. Wood-pastures therefore harbour a large part of the European trees species, and potentially high genetic diversity (Bergmeier et al., 2010). Oaks, beech, and other tree species from the Fagaceae family were maintained for their mast, which was an important food for pigs and sheep for centuries. Wild fruit trees such as pears, cherries, plums, and apples (*Pyrus* spp., *Prunus* spp., *Malus* spp.) were also spared from cutting and wood clearing because of their fruits. Though not abundant these trees are much more frequent in wood-pastures than in closed (semi-natural and natural) forests. Among the rare, locally distributed or threatened tree species occurring in wood-pastures and their margins are for example *Malus sylvestris* (Central and South Europe), *Malus dasyphylla* (Southeast Central Europe, Balkans), *Mespilus germanica* (Southeast Balkans and Southwest Asia, naturalized in parts of Central and South Europe), *Prunus cocomilia* (East Mediterranean), *Pyrus pyraster* (Central, East and South Europe), and *Sorbus domestica* (South and Central Europe) (Garbarino and Bergmeier, 2014). Many of these, particularly in wood-pastures of South-East Europe, represent wild fruit tree relatives. For example, wild species of *Pyrus* and *Prunus* have been used for grafting domestic pears, plums, cherries, and almonds. As a consequence of century-long breeding in other populations, many wood-pastures and semi-wild orchards have become important reservoirs of old landraces and cultivars (Paprštein et al., 2015).

4. Social–cultural values of European wood-pastures

While social–cultural values are much less researched than ecological values, some studies are available on the aesthetic and cultural heritage values, and on the traditional practices able to maintain them. Some of these social–cultural values of wood-pastures are related to the gathering of wild products, for example mushrooms and asparagus, and hunting practices (Oteros-Rozas et al., 2014).

4.1. Aesthetic and recreational values

Humans have been fascinated by the beauty of wood-pastures for a long time (Woodcock, 1984). Moreover, recreation and nature tourism activities often depend on the aesthetic value attached to them. The mosaic land cover, the presence of livestock, or the presence of scattered, old trees all contribute to their aesthetic values (López-Santiago et al., 2014). A particularly high aesthetic value was attributed to the extensive oak wood-pastures of Spain (*dehesas*) (García-Llorente et al., 2012) and Portugal (*montados*) (Barroso et al., 2012). Different stakeholders may put different weight on the aesthetic value of wood-pastures, based also on other values and benefits. For example, farmers tend to value open wood-pastures managed for livestock highly, while nature tourists and hunters prefer wood-pastures with higher density of shrubs and environmental managers those with higher density of trees (Barroso et al., 2012; Pinto-Correia et al., 2011). These differences are driven by diverse motivations behind landscape preferences (Barroso et al., 2012) which embrace aspects of tradition, knowledge types, cultural identity, or associated recreational activities (Hartel et al., 2014a; García-Llorente et al., 2012). In spite of such differences regarding the structural details, all stakeholder groups preferred landscape configurations which are similar to wood-pastures (Surová et al., 2014).

4.2. Cultural heritage

Many wood-pastures have had continuity since pre-modern times (AD 500-1700) and are therefore important from a cultural and historical point of view (Jørgensen and Quelch, 2014), though their cultural heritage values have been rarely investigated. Many wood-pastures bear legacies from historical land uses. For example, Mediterranean wood-pastures host terraces, stone walls, threshing floors, and other infrastructural elements that give evidence of past land-use practices (Plieninger et al., 2011). Further, coppicing and pollarding have been ancient practices across European wood-pastures that nowadays represent cultural legacies from the past (Jørgensen and Quelch, 2014; Kirby et al., 1995). The ancient borders between wood-pastures and forests also bear a rich cultural heritage (Szabó, 2010). The combination of soil productivity, economic demands, land ownership, and other factors often led to locally specific land management practices, which created today's cultural heritage values (Szabó and Hédl, 2013). Many of these practices, for example those related to seasonal livestock movements (transhumance) (Oteros-Rozas et al., 2014), can be considered cultural heritage values by themselves.

4.3. Traditional knowledge

The strong reliance of local communities on the provisioning services of wood-pastures resulted in the development of profound ecological knowledge, for example, about the location and the spatial and temporal availability of natural resources (e.g. water availability, primary productivity, medicinal plants), about the effects of livestock on trees and shrubs, and about responses to disturbances such as diseases (Oteros-Rozas et al., 2013). Therefore, traditional and local ecological knowledge is considered a valuable complement to scientific studies for improving understanding and stewardship of wood-pastures (Bürgi et al., 2013; Varga and Molnár, 2014). The acknowledgement of traditional knowledge around wood-pastures is also essential to ensure the provision of multiple ecosystem services, including food, genetic resources, soil fertility, habitat for species, nature tourism and cultural identity (Calvet-Mir et al., 2012; Lamarque et al., 2011). Recognition of wood-pasture related traditional knowledge can be used, together with the wood-pasture itself, as a contribution towards rural development because it promotes environmental awareness, eco-tourism and recreation, the creation of localized food brands, income generation outside agricultural production, social support for traditional management practices, and the transmission of this knowledge to new generations (Bieling and Konold, 2014).

5. Management challenges

A major challenge for the conservation of current wood-pastures is their anthropogenic origin and thus the need of constant and specific management. Livestock grazing is the most influential and dominant management intervention which drives the structure and dynamics of wood-pastures. Grazing is complemented by forestry practices (such as logging, coppicing, or pollarding), shrub clearing, mowing tall herb vegetation, or using controlled fire (Van Uytvanck, 2009). Multiple management practices are, therefore, indispensable for the long-term preservation of wood-pastures in Europe.

5.1. Important components of wood-pasture management: Livestock grazing

Among the components of wood-pasture management, limiting the grazing pressure, choosing the grazing regime, and allowing for time and space gaps between grazing activities are relevant practices for ensuring tree regeneration while halting the encroachment of dense shrub cover. A grazing pressure threshold is usually expressed as the number of grazing animals per hectare per year (animal units, AU $ha^{-1}\,y^{-1}$). Thresholds that prevent or enable woody species regeneration differ depending on tree species, livestock, regions, wood-pasture types, and management phases. For the main regeneration phases in the New Forest (UK), maximum grazing pressure thresholds amount to 0.3 AU $ha^{-1}\,y^{-1}$ for cattle, 0.15 AU $ha^{-1}\,y^{-1}$ for ponies, and 0.45 AU $ha^{-1}\,y^{-1}$ for deer (Mountford and Peterken, 2003). Former pastures and arable fields in Belgium have similar thresholds of 0.35 and 0.50 AU $ha^{-1}\,y^{-1}$ that allow tree regeneration in the developing mosaic vegetation during the first 5–10 years after the cessation of agricultural use (Van Uytvanck, 2009). One rarely explored advantage of wood-pastures is the reduction of fodder needs of livestock thanks to tree shelter under unfavourable climatic conditions (Higgins and Dodd, 1989). Concerning the grazing regime, in some locations studies have found that a year round 'natural grazing' by mixed, free-ranging feral herbivores, with populations limited by late winter conditions is preferable from a conservation point of view to seasonal grazing limited by summer fodder (Mountford and Peterken, 2003). In practice, it is desirable that managers have knowledge about the grazing capacity of a site in wintertime, allowing them to choose an appropriate grazing density, prevent mortality, and meet EU legislation that obliges the removal of livestock carcases. The former requires lower stocking rates, supports greater habitat diversity, and allows trees to regenerate in open areas (Helmer, 2002). Browsing intensity on saplings is much greater in spring and summer, when saplings have nutritious buds and green leaves, than in spring or winter (Van Uytvanck, 2009). Therefore, woodland regeneration is not prevented by winter-grazing or year-round grazing by domestic herbivores (e.g. cattle, sheep). However, there are differences in browsing response according to tree or shrub species, plant size at the moment of browsing, local site conditions, frequency of browsing, amount and type of tissue eaten, and competition with ground vegetation (Hester et al., 2006). For a large variety of trees, short time gaps in grazing (2–3 years) facilitate regeneration in grassland vegetation and, equally important, allow growth beyond the browseline of large herbivores. Longer grazing exclusion is particularly needed for Mediterranean wood-pastures (Smit et al., 2008). Thus, appropriate variation of time gaps in space and time allows regeneration of woody species and conservation of grassland values at the same time (Uytvanck et al., 2008).

5.2. Important components of wood-pasture management: Forestry practices

To maintain wood-pastures and their values, particular forest management practices are needed as well, often to be considered on a tree-by-tree basis (Fay, 2004). The standard forestry practices aim to enhance growth of the main tree stems as these are the valued end-product. In wood-pastures the objectives of forestry practices are different, aiming to produce branches for fodder, firewood, and poles that are cut on relatively short cycles (Read, 2006). Trees valued for their shade or for their fruit, including acorns for pannage (Jørgensen, 2013), might be left with well-developed crowns. Particular management efforts are needed to maintain the old trees for as long as possible to allow for any species living in or on them to transfer to the new generation when it becomes suitable. This may involve reducing ground compaction around roots and impeding bark damage by livestock, as well as removing the branches that have become too large, endangering tree stability (Lonsdale, 2013). Restoration of pollarding, where this was once carried out, has been tried successfully in some sites on old trees even after several decades without cutting, but is likely to be less successful the longer the period since the trees were last cut (Read et al., 2010). Where encroachment of young saplings around veteran trees has occurred, an additional management priority is to reduce tree competition by removing young trees surrounding veteran ones – a practice known as 'haloing' (Alexander et al., 2010). More general thinning out of the young growth may be required to create gaps to improve herbage production, leaving a low density of stems that can develop large crowns under free growth conditions or might be turned into new pollards. The net effects of trees on pasture production are strongly context-dependent, but they are overall neutral to positive for deciduous tree species, and neutral to negative for evergreen ones, as revealed by a recent meta-analysis (Rivest et al., 2013) and several empirical studies (e.g. Gea-Izquierdo et al., 2009; Rozados-Lorenzo et al., 2007; Sigurdsson et al., 2005; Teklehaimanot et al., 2002). Positive effects are mainly due to shelter and improved soil fertility, negative impacts due to competition for light, water and nutrients (Moreno et al., 2013). Further studies are needed to understand under which ecological conditions and plants traits the tree effects change from net competitive to net facilitative (Blaser et al., 2013). The number of young trees to be encouraged in open ground or left after thinning in-filled wood-pasture must allow for mortality (Lonsdale, 2013): not all the young trees will survive more than the approximately 150 years needed before they start to develop hollows and other veteran tree characteristics. However the more that are left the greater the overall canopy cover will be, leading to increased competition for the existing veteran trees and greater reduction of herbage production because of shading. The density and number of veteran trees needed to support key invertebrate species (Bergman et al., 2012) must also influence the replacement rate. How the young trees are then managed depends on local circumstances and objectives. Some may be pollarded to maintain the traditional practice and products from the wood-pasture and to speed-up the creation of hollows and other features associated with high value for saproxylic invertebrate and bats (Sebek et al., 2013).

5.3. Facing land-use changes: Abandonment vs intensification

Wood-pastures are nowadays facing the effect of two contrasting land-use changes, namely abandonment and intensification, together with conversion into other landcover types (Bugalho et al., 2011; Plieninger, 2012). A frequent driver of the abandonment of wood-pastures has been rural marginalization and decline of livestock farming (Plieninger and Bieling, 2013) and the introduction of organized forestry in areas previously managed as pastoral systems. Reduction or exclusion of livestock grazing in wooded pastures favours the encroachment of trees and shrubs. This in turn leads to a decline of landscape heterogeneity, with a subsequent erosion of the ecological and social–cultural values of wood-pastures. In contrast, overgrazing and wood overexploitation are probably the most important drivers of wood-pasture loss in the southernmost parts of Europe. A decline in palatable perennial herbaceous species and lacking tree regeneration is sometimes followed by a complete disappearance of vegetation and subsequent soil erosion (Chaideftou et al., 2011; Moreno and Pulido, 2009). In many oak dominated wood-pastures, increased grazing pressure is often associated with a reduction in old-growth tree density, regeneration failure, and tree ageing (Bergmeier et al., 2010).

6. Policy implications: Beyond conservation legislation

Integrating wood-pastures into new agricultural and conservation policies has proved to be complicated, as institutional structures are traditionally organized within mono-functional sectors, with different bodies at different administrative levels often dealing with agriculture, forestry, environment etc. These challenges and possible ways to overcome them are exemplified in the way wood-pastures are treated in the Common Agricultural Policy, including Rural Development policy, and the Habitats Directive of the EU.

6.1. Common Agricultural Policy

The Common Agricultural Policy (CAP) provides essential economic support to farmers managing wood-pastures in the form of direct payments that are intended for all active farmers in the EU. These payments are especially needed by low-intensity livestock farmers, as their income from sales is often insufficient to cover costs, and they are particularly justified because the market generally does not reward the great variety of ecosystem services they provide (Plieninger and Bieling, 2013).

The CAP applies rules that determine whether land (arable, permanent crops, permanent grasslands) is eligible for direct payments, which has important implications for wood-pasture conservation. Permanent grasslands are described as land used to grow grasses or other herbaceous forage. In the 2013 CAP reform, it has been added that permanent grasslands "may include other species such as shrubs and/or trees which can be grazed provided that the grasses and other herbaceous forage remain predominant as well as, where Member States so decide, land which can be grazed and which forms part of established local practices where grasses and other herbaceous forage are traditionally not predominant in grazing areas" (European Union, 2013b: 619). Under this rule, Member States are given the option of applying a maximum allowable tree density on pastures (increased from 50 trees ha^{-1} under the old CAP to 100 trees from 2014), or a system of pro-rata reductions in eligibility, in proportion to the coverage of trees or other landscape elements seen as not productive. In principle, there is no limit to the number or coverage of trees that are used for grazing, but these must be distinguished from trees that are not grazed (European Commission, 2014). The result of the reformed CAP is a system of rules and exceptions that potentially allows Member States to implement a well-adapted approach to pastures with trees and landscape features if they choose to and if they make extra administrative efforts. However after the heavy fines imposed by the European Commission on Member States for being too lax, authorities may prefer the simpler option of excluding any land that could raise the suspicions of EU auditors, while farmers may find it easier to remove trees and other features to avoid losing payments (Beaufoy, 2014).

Policy options for a clearer recognition of wood-pastures through the direct payment system of the CAP have been suggested (Beaufoy, 2014). Rather than defining the maximum number of trees or percentage of crown cover permitted on pastures, EU rules could allow for trees as long as they are part of a functioning pastoral system, as defined in terms of livestock density or grazing days. Additional eligibility criteria could be designed at national or regional levels. Also, the term 'wood-pasture' could be introduced as an explicit category of 'pasture' in the policies supporting farming. In this way, specific rules could be applied allowing for a proportion of the wood-pasture area to be eligible for payment as regeneration areas without the clearance and grazing activities that characterize actively used non-wooded pastures.

6.2. EU Rural Development Policy

Through its Rural Development Policy, the EU provides schemes to support specific rural development activities (inside and beyond the farming sector) (European Union, 2013a). Among these, agri-environment schemes are potentially very useful for wood-pastures, as, for example, they can help to encourage appropriate grazing patterns and to manage tree regeneration. They are intended to provide payments for farmers who take on environmental commitments above and beyond those established under the rules on Good Agricultural and Environmental Condition (GAEC) of the CAP. According to the current regulation Member States are meant to "make [agri-environment] support available throughout their territories, in accordance with their national, regional or local specific needs and priorities" and "the additional needs of farming systems that are of high nature value should be given specific attention" (European Union, 2013a: 491). However, only a very small minority of wood-pastures in the EU has been engaged in such schemes so far (though precise data are lacking).

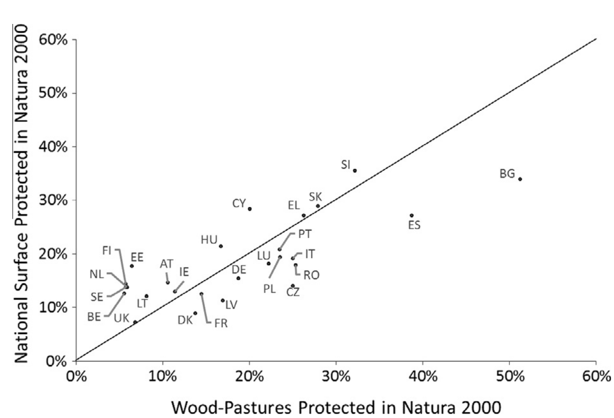

Fig. 3. Proportion of wood-pastures protected by the Natura 2000 network in 27 European countries, compared to the proportion of the countries' territory that is covered by the network (source: European Environment Agency).

There is also a specific scheme in the Rural Development regulation for the establishment of agro-forestry systems on agricultural land, but this intended for tree copping as an adjunct to arable systems as much as for establishing silvo-pastoral systems until now.

Available policy options to support active farming and positive management of wood-pastures could be harnessed much more intensively by national and regional authorities, using the various measures available under the Rural Development Policy. Agri-environment is the most important of these, but there are other complementary measures such as aid for investments and for management plans.

6.3. EU Habitats Directive

The Habitats Directive is the major EU legislative instrument for wildlife and nature conservation. Adopted in 1992, the aims of the Directive are to maintain and restore favourable conservation status of natural habitats and of wild fauna and flora of Community interest (European Union, 1992). Natura 2000, a pan-European network of protected areas, is at the core of the Directive.

Among the 233 European natural habitat types listed in Annex I of the Directive (European Union, 1992), 65 are to some extent related to wood-pasture (European Commission, 2013). However, only four habitat types are explicitly recognized as grazed woody formations (i.e. *Juniperus communis* formations on heaths or calcareous grasslands, Arborescent matorral with juniper, Dehesas with evergreen oaks, and Fennoscandian wooded pastures). Our analysis of LUCAS data reveals that 27.6% of the wood-pastures in the EU-27 are included in the Natura 2000 network (17.7%, 31.2%, and 25.6% of wood-pastures with cultivated trees, in open woodlands and with sparse trees, respectively). Although 27.6% is above of the proportion of the area covered by Natura 2000 in the EU-27 territory (17.5%), wood-pastures are still underrepresented in many countries (Fig. 3).

Many Annex I habitat types related to wood-pasture refer actually to forest habitats but managing these as, or restoring them towards, forests as demanded by the definition given in the Interpretation Manual, would endanger many of the specified ecological and social–cultural values of wood-pastures. If criteria and definitions of forest habitats were strictly applied (which they are frequently not), wood-pastures would have to be assessed as in unfavourable conservation status (Bergmeier et al., 2010). Adequate forest management, as defined in the management plans of many Natura 2000 sites, focusses on natural processes and aims to maintain or restore ungrazed, dense, and tall forest. In this way, restoration would lead to natural old-growth forest rather than safeguarding open wood-pasture. In current practice, however, sustainable livestock grazing in forests of Natura 2000 sites is frequently tolerated, at least in South and Southeast Europe and UK.

The resulting uncertainty in Natura 2000 sites of what should be managed as forest, pasture, or wood-pasture calls for clarification. Some wood-pastures are seen as forest while others are recognized as pastures, neither providing optimal management prescriptions for wood-pastures (Bergmeier, 2008). Conservation of many outstanding wood-pastures that are not included under the Natura 2000 network due to their – presumably – poor conservation status (judged from the perspective of natural forest) could be fostered through introducing a new habitat group into the Habitats Directive – wood-pasture – that would acknowledge the particular conservation values of wood-pastures.

7. Conclusion

Given that the High Nature Value of wood-pastures is the result of a long-lasting and complex interaction between humans and nature, a narrow disciplinary research agenda has limited capacity to provide solutions for the sustainable conservation of wood-pastures. Therefore, research should ideally be guided by a holistic vision which integrates information about ecology, societal values, and governance. Ecological research would provide information on biodiversity, patterns in species distribution and abundance, and the ecological processes underlying these patterns, the keystone structures for biodiversity, and the status of and main threats to wood-pastures. In many European countries there is little large-scale spatial and process-based monitoring of wood-pastures. Data are lacking on surface area, species composition, animal density and herding seasonality, tree age structure and rejuvenation, tenure, and current and past land use. This is the evidence needed to develop policies to protect and maintain wood-pastures. A second research dimension would identify the societal value of the wood-pastures, including their ecological and social–cultural values. The knowledge generated by ecosystem service research can be a powerful tool in developing contextual policies for wood-pastures, because it gives insights into the societal relevance of these landscapes under various bioclimatic, social–cultural and economic settings. A third research dimension would address the institutional arrangements which govern wood-pastures. Wood-pastures by definition are heterogeneous landscapes with elements of woody vegetation and open areas, and a varied institutional framework to match. The future of wood-pastures depends on the ability of these various institutional arrangements to form a common vision and to show the flexibility to implement such a vision. Research could support such visioning by facilitating an understanding of the nature of these potential institutional barriers and of the kinds of innovative changes that could be adopted in order to maintain the ecological and social–cultural values of wood-pastures.

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