Agroforestry of High Nature and Cultural Value: Synthesis of System Descriptions

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1 Context

High nature and cultural value (HNCV) agroforestry includes semi-natural farming systems valuable for biodiversity where primarily grazing but also cultivation is practiced among trees. HNCV agroforestry comprises a range of farming systems and practices that have often co-developed with regional livestock breeds and crops and resulted in distinctive "cultural landscapes" adapted to specific climate and geographic areas. The processes leading from "natural" environments to "cultural landscapes" make a major contribution to the world heritage of biodiversity and are an appropriate focus for scientific research.

Although in the past they formed mosaics of agro-silvo-pastoral systems and landscapes, with different spatial and temporal scales of integration, currently they are managed mostly as extensive silvopastoral systems. They are mostly located in marginal areas of different European regions, where orography, low soil fertility and climate constraints have hampered the development of intensive agriculture. However even so, HNCV areas also provide multiple woody and non-woody plant products, high-quality food, livestock and game products, recreational or cultural services through multiple activities conducted with a comparatively low environmental impact. This includes important regulating services such as carbon sequestration, soil fertilization, microclimate amelioration, and control of atmospheric contamination and soil erosion. The capacity of HNCV agroforestry systems to sustain multiple functions and products has been emphasized as new needs and challenges emerge in modern society.

However, many HNCV agroforestry systems in Europe are facing both environmental and economic threats that might compromise their long-term persistence. Technological and socio-economic change and land use policies are resulting in a loss of traditional empirical knowledge, and a decrease in the profitability and hence the ongoing management of extensive agroforestry systems. Therefore, an important issue in European landscape conservation is the preserve semi-natural traditional HNCV agroforestry systems, preventing both agricultural intensification and land abandonment.

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to the second objective.

2 Agroforestry of high nature and cultural value

Within work-package 2 of the AGFORWARD project, the Participative Research and Development Network (PRDN) focuses on agroforestry of high nature and cultural value. The work-package has five objectives:

i. to identify examples of the best practices, key challenges and innovations to address challenges identified by the stakeholder groups. This was addressed by ten individual stakeholder reports available on the AGFORWARD work-package 2 website (www.agforward.eu)
ii. to describe the key inputs, outputs and ecosystem services flows for selected systems,
iii. to agree within the PRDN, the key innovations or improvements in knowledge needed in order to promote adoption of agroforestry of high nature and cultural value. This was addressed by Moreno et al. (2015a).
iv. to agree and implement within the PRDN an experimental protocol to develop and test proposed innovations at existing experimental plots and through on-farm experiments. This was addressed by Moreno (2015b);
v. to provide and promote guidelines for farmers on how to establish economically viable agroforestry practice in high value tree systems.

The HNCV agroforestry systems studied include those based in Mediterranean, Atlantic, continental, Pannonian and boreal bio-regions (Table 1; Figure 1). This report addresses objective ii by providing a synthesis of ten system description reports completed during 2016 (Table 2).

Table 1. Ten agroforestry systems of high nature and cultural systems studied in AGFORWARD occupy a range of bio-regions

Bio-region	Country	Full name of partner and acronym	Agroforestry system	Report reference
Mediterranean	Spain	Universidad de Extremadura (UEX)	Iberian dehesa	Moreno and Cáceres 2016
	Portugal	Instituto Superior de Agronomia, University of Lisbon (ISA)	Montado: cork oak silvopastoral systems	Paulo et al. 2016
	Italy	Consiglio Nazionale delle Ricerche (CNR)	Grazed oak woodlands in Sardinia	Sanna et al. 2016
	Greece	TEI Stereas Elladas (TEI)	Valonia oak silvopastoral systems	Papadopoulos et al. 2016
Atlantic	France	Institut National de la Recherche Agronomique (INRA)	Bocage agroforestry	Aviron et al. 2016
	UK	Cranfield University (CRAN)	Wood pasture and parkland	Lopez Bernal et al. 2016
Continental	Germany	BTU Cottbus-Senftenberg (BTU)	Agroforestry in the Spreewald floodplain	Tsonkova and Mirck 2016.
	Romania	Babes Bolyai University (UBB)	Wood pasture	Hartel et al. 2016
Pannonian	Hungary	Nyugat-Magyarorszagi Egyetem Kooperacios Kutatasi Kozpont Nonprofit KFT (NYME)	Wood pasture	Vityi and Varga 2016
Boreal	Sweden	European Forest Institute (EFI) and Sveriges Lantbruksuniveritet (SLU)	Reindeer husbandry	Valinger and Lind 2016

Table 2. Ten system reports focused on high nature and cultural value agroforestry provide the basis for this report

Aviron S, Thenail C, Viaud V (2016). System report: Bocage Agroforestry in France. Contribution to Deliverable 2.4, AGFORWARD project, 20 pp. Available online http://www.agforward.eu/index.php/en/bocage-agroforestry-in-brittany-france.html
Hartel T, Răzvan P, Rákosy L (2016). System report: Wood-pasture in Southern Transylvania. Contribution to Deliverable 2.4, AGFORWARD project, 18 pp. Available online http://www.agforward.eu/index.php/en/wood-pastures-in-southern-transylvania-romania.html
Lopez Bernal A, Burgess PJ, Upson M, Garcia de Jalon S (2016). System report: Wood Pasture and Parkland in the UK. Contribution to Deliverable 2.4, AGFORWARD project, 41 pp. Available online http://www.agforward.eu/index.php/en/wood-pasture-and-parkland-in-the-uk.html
Moreno G, Cáceres Y (2016). System report: Iberian dehesa, Spain. Contribution to Deliverable 2.4, AGFORWARD project, 60 pp. Available online http://www.agforward.eu/index.php/en/dehesa-farms-in-spain.html
Papadopoulos A, Pantera A, Mantzanas K, Papanastasis V, Fotiadis G, Papaspyropoulos K (2016). System report: Valonia Oak Silvopastoral Systems in Greece. Contribution to Deliverable 2.4, AGFORWARD project, 19 pp. Available online http://www.agforward.eu/index.php/en/valonia-oak-silvopastoral-systems-in-greece.html
Paulo JA, Crous-Duran J, Firmino PN, Faias SP, Palma JHN (2016). System report: cork oak silvopastoral systems in Portugal. Contribution to Deliverable 2.4, AGFORWARD project, 28 pp. Available online http://www.agforward.eu/index.php/en/montado-in-portugal.html
Sanna F, Re GA, Franca A (2016). System report: Grazed Oak Woodlands in Sardinia, Italy. Contribution to Deliverable 2.4, AGFORWARD project, 21 pp. Available online http://www.agforward.eu/index.php/en/grazed-oak-woodlands-in-sardinia.html
Tsonkova P, Mirck J (2016). System report: Agroforestry in the Spreewald Floodplain, Germany. Contribution to Deliverable 2.4, AGFORWARD project, 20 pp. Available online http://www.agforward.eu/index.php/en/agroforestry-in-the-spreewald-flood-plain-germany.html
Valinger E, Lind T (2016). System report: Reindeer Husbandry in Central Sweden. Contribution to Deliverable 2.4, AGFORWARD project, 9 pp. Available online http://www.agforward.eu/index.php/en/wood-pastures-and-reindeer-in-sweden.html
Vityi A, Varga A (2016). System report: Wood Pasture in Hungary. Contribution to Deliverable 2.4, AGFORWARD project, 13 pp. Available online http://www.agforward.eu/index.php/en/wood-pasture-in-hungary.html

The detailed system description reports (Table 2) include information about i) the extent, distribution and current trends; ii) basic descriptions of the components and structures of the system; iii) main farming management practices; iv) main marketable products; v) measured ecosystems services; vi) assessment of the current economic profitability; and vii) recent initiatives to boost the HNCV agroforestry system/practice. Although system structure, farming activities, and ecological and socio-economic contexts vary among the ten systems, they share some common features and overall all they provide farmers and society with a number of private and public ecosystem services.

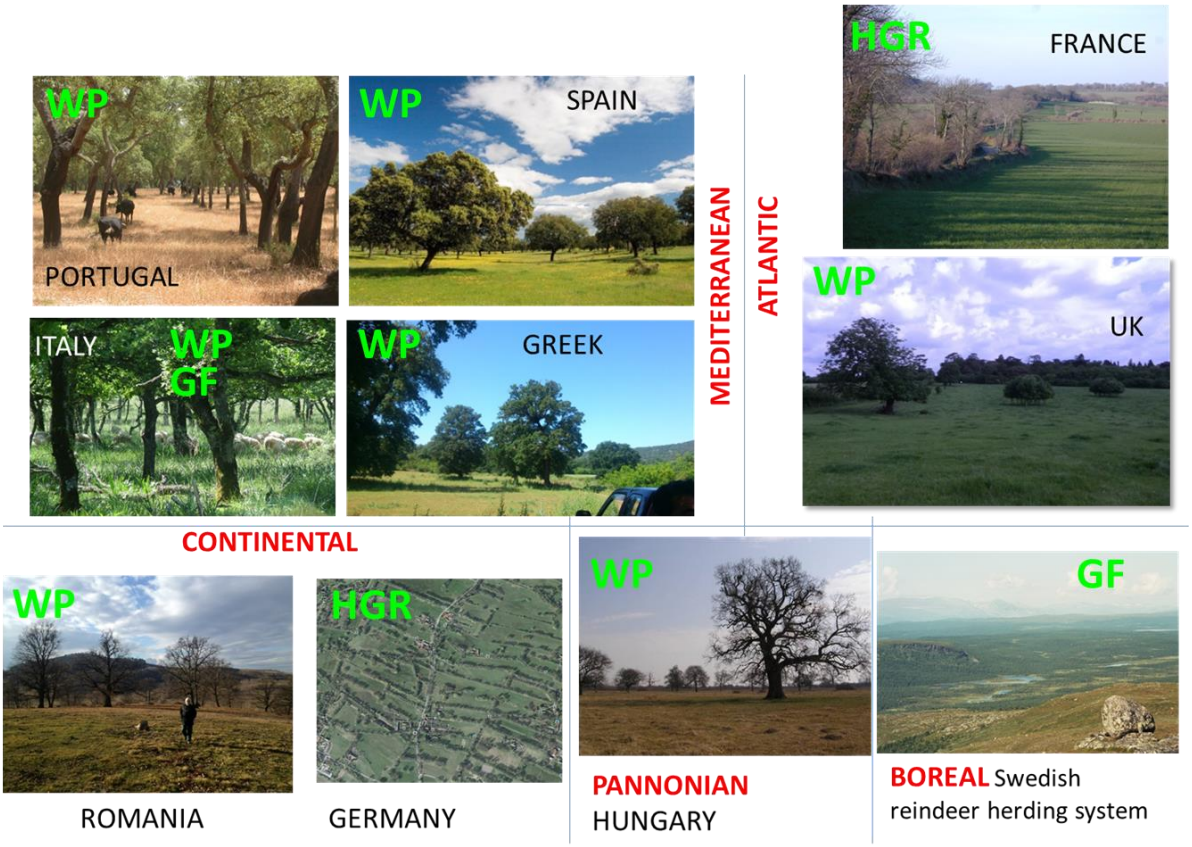

Figure 1. Images of the ten agroforestry systems of high nature and cultural value selected by AGFORWARD project as representative of the different European biogeographical regions. Most are wood pastures (WP), but there are also grazed forests (GF) and hedgerows typical of livestock or mixed-farming areas (HGR).

High Nature Value (HNV) farms have been defined in relation to three criteria: i) high biodiversity i) low-inputs; and ii) presence of semi-natural vegetation and features. These criteria are typically met, at a farm level in Europe, by extensive pasturelands. Indeed, the more recent European map of HNV farming (Parachinni et al. 2008) aims to represent semi-natural vegetation associated with low intensity livestock production. In a recent revision coordinated by the Institute of Agroecology and Biodiversity (IFAB) and the European Forum on Nature Conservation and Pastoralism (EFNCP), these farms are included in the Type 1 HNV farmland category, and two additional categories are defined (Oppermann et al. 2012). Type 2 HNV farmlands are mosaics of low intensity agriculture and natural and structural elements. This category includes species-rich arable lands, permanent crops (mostly fruit orchards and olive groves, and to a less extent, carob woodlands) and mosaic of low-intensity farmland and landscape features. Type 3 HNV farmlands support rare species or a high proportion of European or world populations of species of conservation interest.

HNV farmland of Type 1 includes certain types of forest habitats that are partially used for agriculture. They include a range of silvopastoral systems associated with low-intensity livestock rearing such as grazed woodlands, pollarded woodlands, wooded pastures, meadows with pollarded trees, and semi-open pastures. They consist of grassland, scrub or woodland or a combination of different types,

although patches of intensive forage production can be also essential part of an HNV farming systems (Oppermann et al. 2012).

In these systems, trees are deliberately maintained and managed although establishment depends more on natural regeneration than tree planting. The vegetation, which is often "semi-natural", has been historically influenced by grazing, browsing and pannaging by domestic livestock, and the trees have often been managed by pruning or pollarding for biomass and fodder. The vegetation has often developed in conjunction with the evolution and use of regional livestock breeds and crops resulting in the development of distinctive "cultural landscapes" adapted to specific climate and geographic areas. We refer to these systems as agroforestry systems of High Nature and Cultural Value (HNCV).

In a lesser extent, grazed (and rarely intercropped) olive groves and fruit orchards are also agroforestry systems of HNCV. In the AGFORWARD project they are reported in another work-package focused on agroforestry with high value trees (Pantera et al. 2016). Certain areas of arable and permanent crops that form mosaics with different kind of ecological features (such as hedges, tree lines, and small woods) function also as agroforestry landscapes of HNCV, but rarely include farms where trees are deliberately managed as part of the farming activity. These HNCV agroforestry systems are studied in AGFORWARD project but are not included in this report (see Moreno 2015).

Within the AGFORWARD project, high nature and cultural value (HNCV) agroforestry includes semi-natural farming systems valuable for biodiversity where cultivation and/or grazing is practiced among trees. HNCV agroforestry comprises a range of farming systems and practices that have often co-developed with regional livestock breeds and crops and resulted in distinctive "cultural landscapes" adapted to specific climate and geographic areas. The processes leading from "natural" environments to "cultural landscapes" make a major contribution to the world heritage of biodiversity and are an appropriate focus for scientific research.

3 Components and vegetation structure

HNCV agroforestry systems vary in structure, components, farming activities and management practices (Table 3). The most frequent structure is a two-layered wood pasture devoted to livestock production. They typically combine scattered large trees with an understory of native grasses and livestock. The wood pastures are often extensive grazing systems (e.g. Iberian dehesas), but they can also occur within agrosilvopastoral mosaics that also include arable land, open pastures, sparse ancient trees, and forests. Crop production may be integrated either at plot level (e.g. periodical intercropping in dehesa wood pasture plots in Spain and Portugal) or at farm level (e.g. intermixed arable lands in agrosilvopastoral farms in Italy and Greece). Other agroforestry systems such as grazed forests and hedges surrounding fields are also important for biodiversity conservation on European farmlands, and they can be included as HNCV agroforestry systems.

Table 3. The structure, components, farming activities, management practices, and main marketable products associated with ten types of high nature and cultural agroforestry system across Europe

System	Structure and components	farming activities and management practices	Main marketable products
Montado, Portugal Dehesa, Spain	Oak (mainly cork oak in montado and holm oak in dehesas) at < 80 trees ha^{-1} + grass understory + livestock (0.2–0.5 LU ha^{-1})	Planting trees and/or natural regeneration, shrub control, periodical cropping and regular grazing. Debarking of cork oaks. Transhumance	Meat, cheese cork firewood, charcoal hunting, fishing
Agrosilvopastoral mosaics, Sardinia, Italy	*Quercus* spp. (7-250 trees ha^{-1}) + grass understory + occasional cereal crops + shrub understory + dairy sheep in more open stands and cattle in more dense stands (0.2-.5 LU ha^{-1})	Forest policy in Sardinia restricts and seasonally limits grazing in the woods. Vertical short-distance transhumance	Dairy sheep, cattle, pig and goat meat
Valonian oak silvopasture, Greece	*Q. ithaburensis* and other *Quercus* (40-50% tree cover) + grasses and bushes understory + sheep, goats, pigs, cows (< 1 LU ha^{-1})	Grass can be grazed directly by livestock or cut in more productive areas to provide animal feed (silage or hay)	Meat and dairy products (sheep, goats, pigs, cows) Acorns, acorn cups, fuelwood, artefact, Tourism, and herbs
Bocage, Bretagne, France	Lines of high- and medium-stem trees (multispecific; hardwoods) surrounding fields. Hedgerow density varies between 16 and 94 m ha^{-1}	Planting hedges, with or without bank, pruning, thinning and harvesting. Cultivation of maize, winter cereals and temporary or permanent grass	Milk, beef, pork, eggs Crops (cereal and silage maize) Timber, firewood, mulch, biomass
Wood pastures and parklands, UK	Traditional land use in the UK comprising open-grown trees	Trees (often pollarded), grazing livestock, and an understorey of grassland or heathland	Meat and fuelwood Ad-hoc harvesting of blackberries and mushrooms
Spreewald Biosphere Reserve: Hedgerows contouring meadows, Germany	Trees (including *Alnus glutinosa*) and shrubs hedgerows surrounding meadows and field crops. Inter-row spacing ~50 m. Deadwood up to 50% of stand trees.	Cattle grazing (3 per ha from May to October) and mowing of grass. Traditional harvest of hedgerow biomass every 5-15 years now needing special permission and most are almost abandoned.	Meat Milk Biomass for heating and cooling
Transylvanian wood pastures, Romania	*Quercus robur*, *Q. petraea*, *Pyrus communis, P. pyraster* + natural grass + cattle + sheep ~ 0.3 LU ha^{-1}	Grazing	Lamb and sheep (meat and milk)
Wood pastures, Hungary	Mosaic of open grassland, wood pastures with ancient trees and forest. Sheep, cattle, buffalo, goat. Mostly traditional breeds for the Carpathian-basin.	Grazing is officially prohibited in forests, but livestock use woody species as fodder.	Meat, cheese Fuelwood and wild fruits, Edible plants and mushrooms
Forests devoted to reindeer husbandry, Sweden	Conifers + birch forest: 1500-2000 trees/ha. Understory rich in herbs, berries and terrestrial and arboreal lichens. Grazed by migrating reindeer herds. Stocking rate < 0.01 ha^{-1}	Soil scarification, planting/ seeding, and natural regeneration , with further cleaning, thinning and clear-cut (cycles of 100-130 years)	Wood Meat Milk

In wood pastures, trees are usually at a low density (e.g. 10-60 trees ha^{-1} in Iberian dehesas), but there are also open wood pastures (e.g. 4-7 old trees ha^{-1} in Romania) and dense forests managed as silvopastoral systems (e.g. up to 1500-2000 trees ha^{-1} in boreal forest grazed by reindeers). For hedgerow systems, inter-row spacing varies from about 50 m (Spreewald flood plain) to several 100 m (French bocage). In the French bocage, hedgerow density ranges from 16 to 94 m ha^{-1}. Large old trees are frequent in these systems. For instance, Moga et al. (2016) showed that in Transylvania that the largest old trees are concentrated in wood-pasture systems and not in high forests. The density of large, old oaks in 25 wood-pastures of Romania ranged between 0.0085 – 1.25 trees ha^{-1}.

In Mediterranean countries, landscapes are frequently dominated by oak-based wood pastures comprising a low number of oak species, such as the evergreen *Quercus ilex* and *Q. suber* in Iberian dehesas and montados, and the deciduous *Q. ithaburensis* in Greece. Mixtures of oak species are also frequent, as the case of Sardinian agrosilvopastoral farms (*Q. ilex, Q. suber and Q. pubescens*). In general, wood pastures based on evergreen oaks are more open than those based on deciduous oaks (*Q. pubescens, Q. pyrenaica*), which form dense grazed forests.

Pendunculate oak (*Q. robur*) is common in Continental and Atlantic systems but it is usually mixed with many other hardwood species such as *Quercus petraea*, *Q. cerris*, *Pyrus communis*, *P. pyraster*, *Fagus sylvatica, Carpinus betulus, Fraxinus angustifolia, Acer campestre, Tilia sp.* and *Sorbus torminalis.* The following three species: *Salix sp, Populus sp, Alnus glutinosa*, are probably more likely to be found in hedges than as scattered trees in wood pastures. Boreal silvopastures are dominated by conifer species and birch (*Betula spp.*).

The understory is typically dominated by multiple assemblages of native pastures species that vary from below-tree canopy areas to more open areas. In dry Mediterranean regions, the pasture community is dominated by self-seeding annual species, being soil covered by green herbaceous plants only from mid-October to mid-June. In more humid sites, pasture understories can be dominated by perennial species such as sedge (*Carex* spp), meadow soft grass (*Holcus lanatus*), creeping buttercup (*Ranunculus repens*), rabbitfoot clover (*Trifolium arvense*), bitter dog *(Rumex obtusifolius*) and reed sweet-grass (*Glyceria maxima*).

Bushes may also be present depending of the grazing intensity. For instance, shrub understories in wood pasture can be associated with low grazing pressure or abandonment (as occurs in some ancient UK wood pastures). In fact partial shrub encroachment can be beneficial for tree regeneration (Rolo et al. 2013) and livestock feeding (López-Díaz et al. 2015) in Mediterranean wood pastures. Berries and terrestrial and arboreal lichens are common and can be important to livestock in boreal regions. In the bocage agroforestry system, a mix of woody species (high- and medium-stem trees and bush species) can form multilayer hedges of different height and width. For instance in Spreewald hedge trees are combined with glossy buckthorn (*Frangula alnus* Mill.), common buckthorn (*Rhamnus cathartica* L), buckthorn (*Rhamnus alaternus* L.), wild rose (*Rosa canina* L.), blackberry (*Rubus sectio rubus*), European cranberrybush (*Viburnum opulus* L) and hops (*Humulus lupulus*). At Spreewald, deadwood formed up to 50% of standing tree biomass.

Cattle and sheep are present in most of the systems, but some Mediterranean systems include goats, and there are pigs in some Iberian cases and buffalo in some Eastern European systems. HNCV wood

pastures support many traditional breeds. The stocking rates are typically low e.g. about 0.3 livestock units (LU) ha^{-1} in Portuguese montados and Transylvanian wood pastures, 0.2–0.5 LU ha^{-1} in Iberian dehesas, and < 1 LU ha^{-1} in Valonian Greek silvopastures. Boreal forests are grazed by migrating reindeer herds at a stocking rate of less than 0.01 LU per hectare.

4 Farm management practices

HNCV agroforestry systems are mostly devoted to livestock production. The pasture understory layer is generally grazed by livestock, but mowing to store supplementary feed (silage or hay) is common in more productive areas/years. Periodical crops, in many cases fodder crops, are also common, especially in Mediterranean countries such as Spain, Portugal and Italy (Eichhorn et al. 2006). Livestock also browse woody species as fodder, either palatable shrubs and/or pruned trees. In oak-based wood pastures, pannaging is a traditional practice, and this practice is still quite important for fattening Iberian pigs in Spanish dehesas and Portuguese montados.

Most of the systems were created by gradual opening of native forests, removing the shrub layer and part of the tree cover. More useful tree species were conserved in preference to others. For instance, in Iberian dehesas *Quercus ilex* that produces more and less bitter acorns were preferred. Continuous grazing, browsing and trampling hamper tree and bush species regeneration, favouring the development of an open forest structure and a pasture layer of high fodder quality. Periodical cultivation (e.g. about every 10 years) is practised in some cases to control shrub encroachment.

In more fertile soils, cultivation is practiced more often (e.g. about every four years) to produce marketable crops and supplementary fodder that can be used in winter in wet regions, and in summer in Mediterranean countries. In the past transhumance was commonly practiced to overcome the natural limitation of wood pastures to produce enough forage resources throughout the year. Nowadays, transhumance is only practiced by reindeer herds and more marginally by herds in Sardinia (vertical short-distance transhumance) and Spain (short and long distance transhumance).

After the initial thinning and pruning to shape the tree stem and canopy, trees were periodically pruned to i) feed livestock, ii) provide firewood and charcoal, iii) favour fruit production e.g. holm oak trees in Iberian dehesas, and iv) increase light transmittance for intercrops. Although tree management practices are currently often abandoned, new markets for biomass product such as mulch and bioenergy could bring a new opportunity for these practices. Indeed, biomass harvesting is being studied in relation to hedgerow management. An exceptional case is the periodical debarking of cork oaks (every 9-10 years) in Iberian dehesas and montados but also in wood pastures of Italy and Southern France.

Many HNCV agroforestry systems involve interactions between forest and farmland and rules that restrict grazing and tree management are common in many countries. For instance, forest grazing is forbidden in Hungary and Romania (but in fact livestock use woody species as fodder), woodland grazing is periodically limited in Sardinia woodlands, and woody biomass harvests need special permission in the Spreewald floodplain. An absence of grazing could favour the reforestation of old wood pastures, but grazing can also compromise the long-term persistence of trees. Although tree planting may have been practised in the past, it is becoming a more common practice in many cases.

For instance, planting hedges is becoming again common in the French bocage, and increased tree cover in Iberian dehesas is funded by an agroforestry measure in the Common Agricultural Policy.

5 Ecosystem services

Agroforestry provides a range of ecosystem services including provisioning, regulating, habitat, and cultural services. These are each covered in turn.

5.1 Provisioning services

Farming has been an important driver of reduced tree cover on agricultural land in Europe. However, farmers have promoted or deliberately maintained trees in HNCV agroforestry systems because trees provided a range of products. These include high quality foods (such as honey, mushrooms, fruits and nut), energy (such as firewood and charcoal), materials (e.g. cork and timber), fodder (e.g. browse, acorns, and chestnut) and game (e.g. pigeons and wild boar).

Livestock production is the key commercial aim of most HNCV agroforestry systems. Unfortunately we still do not know under which conditions the net effect of trees on pasture shift from negative to positive (Rivest et al. 2013; Torralba et al. 2016). For instance negative, positive and neutral effects of the trees on pasture yield in Iberian dehesas have been reported. Also extensions of the growing period of pasture understories (Figure 2) can also be more important than the net effect on yield. Moreover, López-Díaz et al. (2015) have shown that even though trees can reduce the pasture biomass production, the total metabolic energy produced in the Iberian dehesas (pasture understory + acorn + tree leaf browse) increase with tree cover up to roughly 60-70% cover. There is a need for more in-depth studies that compare the forage value of wood pastures against open pastures under different edapho-climatic conditions and vegetation structures.

Figure 2. Trees in Iberian dehesas affect the phenology of the pasture understory. In winter pasture growth is greater beneath the tree canopy in the winter (left) and in the summer (right).

Farmers and other stakeholders identified protection for livestock (shelter) as an important ecosystem service of HNCV agroforestry. We also think that there is a need for more studies on the quantification of the metabolic energy saved by livestock due to the sheltering effect of the trees, as this is an additional economic advantage of wood pastures.

There is a long list of marketed goods produced in the European HNCV agroforestry systems. While high quality livestock-based foods (meat, cheese, milk, eggs) are common to most of the systems

studied, some goods are regionally specific. For instance, cork is the main marketable products of Portuguese montado (also important in Spanish dehesas and Sardinian silvopastures), and Valonian acorn cups is used for tanning in Greece. In some cases, specific labels are identified for the products of the HNCV agroforestry systems (e.g. Iberian jam, Sardinian cheeses: cheeses such as Pecorino Romano PDO, Pecorino Sardo PDO and Fiore Sardo PDOI).

Although some of the traditionally important provisioning services (e.g. tree hay, fruits) are now largely abandoned, other goods are still traded. They include timber, firewood, charcoal, mulch, wild fruits (e.g. syrup and jam from rosehips and mulberry), honey, mushrooms, wild edible, medicinal and aromatic plants. Recreational activities such as hunting and fishing, education and leisure activities can also provide an income. In Spain, hunting is frequently more profitable than livestock breeding for some dehesa farms (hilly areas), and birdwatching is an important commercial activity in the dehesa territory (Table 2). In Germany the high aesthetic and cultural value of the Spreewald floodplain is important for tourism. It is estimated that 2 to 2.2 million people visit the area between May and September each year.

5.2 Regulating services

HNCV agroforestry systems provide a range of regulating ecosystem services including accumulating carbon as biomass. For instance, in the Spreewald hedgerows the average growth increment for the period 2000 to 2010 was 6.3 and 6.7 m^3 ha^{-1} yr^{-1} for the regions of Oberspreewald and Unterspreewald, respectively. Compared with the average timber use of 2.9 and 3.3 m^3 ha^{-1} yr^{-1} in these regions, the trees are storing a significant amount of carbon in their biomass (MLUL 2012).

The higher capacity of HNCV agroforestry systems to store carbon compared to treeless systems has been highlighted for different Mediterranean wood pastures (e.g. Howlett et al. 2011; Seddaiu et al. 2013; Francaviglia et al. 2014). Although over short time periods trees on grazing land may reduce carbon in the first 0-10 cm of soil (Upson et al. 2016), soil organic carbon contents measured in topsoil under old hedgerows can be up to 2.5 times higher than those in the adjacent crop field (Walter et al. 2003). The importance of hedgerow systems to store carbon has been also noted for the Spreewald floodplain. Together with soil carbon accumulation, soil fertility increases with the presence of the trees, increasing the availability of most of the nutrients studied (Moreno et al. 2007).

The capacity to improve water infiltration and prevent soil erosion is mentioned for Iberian dehesas (Table 3), but also for the Continental Spreewald floodplain and the Atlantic bocage. Several studies demonstrate erosion-control by hedgerows, with high spatial variability at the landscape scale (Lacoste et al. 2015). The regulation of the nitrate and phosphorus pollution is emphasised in Britany where hedgerows are designed to improve the groundwater quality. At a watershed scale, the nitrate flux brought by water surface decreased when the hedge tree density increased (Benhamou et al. 2013). The average reduction for extensively managed grassland in Germany is between 0 and 20 kg N ha^{-1} when compared to intensively managed grassland and between 30 and 70 kg N ha^{-1} when compared to agricultural land (Osterburg et al. 2007). The average costs of preventing N leaching for the former were estimated at 100€ ha^{-1} and for the latter at 400€ ha^{-1} (Matzdorf et al. 2010). The importance of grazing wood pastures to control wildfires is highlighted by Mediterranean cases (Franca et al. 2012).

Table 4. Effect of trees on wood pastures on the control of soil erosion in Iberian dehesas. Data compiled in Moreno and Pulido (2009)

Parameters	Tree cover			
	Wood pastures (High tree density)	Wood pastures (Medium tree density)	Treeless pastures	Beneath canopy
Soil cover (%)	85	55	35	80
Runoff (% of rainfall)	12	30.5	36.3	11.1
Soil erosion rate (g m^{-2} y^{-1})	3.1	5.2	5.8	0.9

5.3 Habitat services and biodiversity

By definition agroforestry systems of HNCV are biodiverse. The ancient trees of British, Hungarian and Romanian wood pastures are especially rich in fungi, epiphytes, macroinvertebrates, bats and birds. In an ancient oak wood-pasture of Romania, with 133 hectares, there were 476 species of vascular plants, 121 species of macromycetes, 281 species of Lepidoptera, 40 species of xylophagous beetles, 27 species of nesting birds and 38 species of mammals (Hartel et al. 2013). Wood-pastures contain more bird species and functional groups than high forests and open pastures (Hartel et al. 2014). More recent surveys carried out by these authors in a moderately intensively grazed wood-pasture (with 1.1 LU/hectare) revealed an exceptional diversity of spider communities in such systems, with 140 species and four new species of spiders for Romania.

In Portugal, a comprehensive biodiversity survey on a 220 ha montado farm has identified 264 fungi, 75 bryophytes, 304 vascular plants and 121 vertebrate species were recorded (Santos-Reis and Correia 1999). In Spain, 135 species in 0.1 ha in holm oak dehesas and 60–100 species per 0.1 ha in cork oak stands have been described (Marañon 1986). The diversity of butterflies in bocage was found to be higher in hedgerow banks than other herbaceous habitats, in relationships with a high diversity of plant species (Ouin and Burel 2002). Le Feon (2010) found that the diversity of pollinators such as solitary bees increased with hedgerow density in farming landscapes, due to the high quality of nectar and nesting resources in these elements. Regarding the communities of natural enemies of crop pests, the diversity of predatory carabid beetles, ladybugs and aphid parasitoids in cereals fields was found to be positively related to the density of hedgerows and/or their proximity to crops in the surrounding landscape (Puech et al. 2015). Studied agroforestry systems are also important for the conservation of Red List Species, such as Iberian Lynx, Iberian Imperial Eagle, Black Vulture and Black Stork in dehesas and montados, but also stag beetle (*Lucanus cervus*) in UK wood pastures, and *Caltha palustris*, *Ranunculus auricomus* agg., *Stellaria palustris*, *Carex vesicaria*, *Lychnis flos-cuculi* in Spreewald floodplain (LUGV 2011).

Trees in agroforestry systems provide additional resources for many species, but also a refuge for nesting and they introduce spatial heterogeneity on the distribution of resources (tree-based gradients *sensu* Moreno et al. 2013). Although high biodiversity values found in Iberian dehesas can be partly explained by the scattered trees in pastures, the intimate mix of tree and treeless pastures and marginal habitats has also a significant role (Moreno et al. 2016).

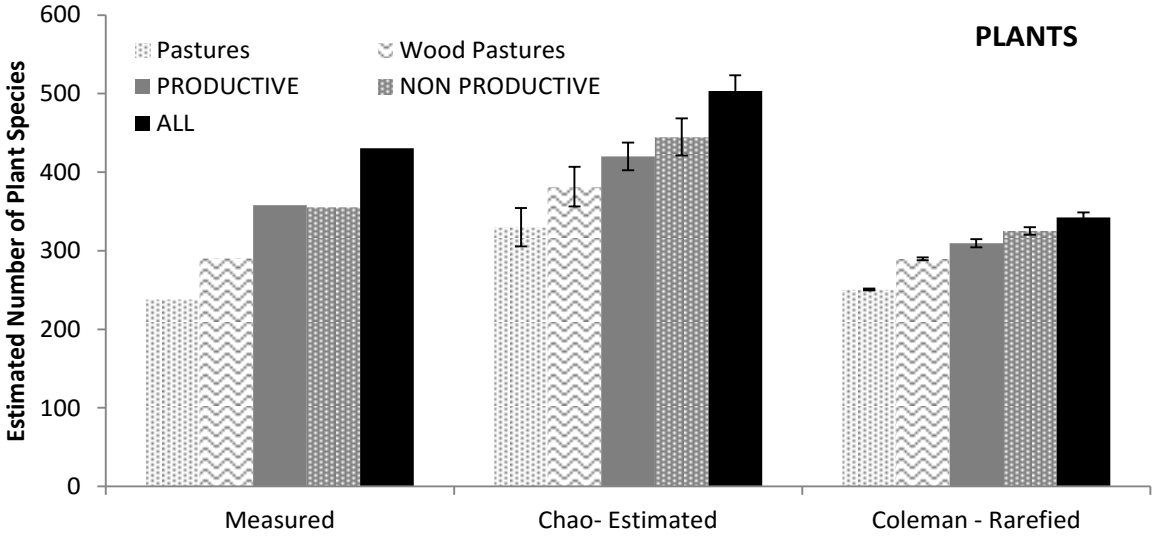

Figure 3**.** Comparison of plant species richness at different habitats of ten Iberian dehesas. Note that species richness is higher in wood pastures than in open pastures, but both together (Productive habitats) harbour more species than any of them taken separately. Also the presence of other, non-productive habitats add new species demonstrating the importance of habitat diversity of HNCV agroforestry systems (Moreno et al. 2016)

The grazing scheme also affects biodiversity. In Sardinia the Shannon biodiversity index for flora was 2.5-4.8 in grazed areas and 1.3-3.8 in ungrazed areas (Re et al. 2014). Research conducted in Romania showed that wood-pastures grazed with buffalo and cattle contain significantly more small wetlands than those grazed by sheep. The reason of this is that the buffalo and cattle disturb the native vegetation which allows the maintenance of small wetlands. By contrast, sheep avoid wet areas resulting in vegetation enrichment in the wet areas. The yellow-bellied toad is highly abundant in buffalo grazed wood-pastures while less abundant in sheep grazed systems (Hartel and von Wehrden 2013).

As consequence of these natural values, many of the agroforestry systems of HNCV here described are listed in the EU Habitats Directive[1]. Some examples are the i) Galicio-Portuguese oak woods with *Quercus robur* and *Quercus pyrenaica* (Code 9230) in Mediterranean and Atlantic region; ii) Dehesas with evergreen *Quercus* sp. (Code 6310) in South-Western Mediterranean region; iii) Valonia oak grazed forests (Code 9350) in Southern and Eastern Greece; iv) Pannonian wooded pastures and meadows included several of habitats of the list (91EO priority, 91FO, 91GO priority, 91HO priority, 91MO, 91NO priority); vi) Fennoscandian wooded pastures (Code 9070; priority) in boreal regions and vii) Fennoscandian wooded meadows (Code 6530) in boreal and continental regions. Wood pastures have been identified as a priority habitat in the UK. In Spain nearby 50% of the dehesas are protected by Natura 2000. The German Spreewald floodplain is protected by Natura 2000, all of the reserve is considered a Special Protected Area, and 27% is considered an important flora-fauna-habitat.

[1] Annex I under the categories of natural and semi-natural grasslands formations and forests

5.4 Cultural services

The primary objective for the management of some systems is the maintenance of a cultural landscape of high aesthetic value and the associated traditional knowledge and potential for tourism. Indeed, for the Iberian dehesas, environmentally-related income streams are more important than income from agricultural products which sometimes do not coves labour costs (Campos et al. 2013). In Germany the willingness to pay to preserve biodiversity of HNCV grasslands in Germany amounted to approximately 10€ per month (Matzdorf et al. 2010).

Romanian wood-pastures, when were communally managed, had the following important cultural services:

- Bringing together the local community each year e.g. for pasture clearance and maintenance activities. Every member of the community had an obligation to take part in these activities depending on the number and types of livestock. These activities are still remembered by old people in the community. These activities could serve as good community organization model around pasture management.
- Sets of rules existed regarding the use of the collapsed/fallen large old trees in the wood-pastures. These trees were used strictly on the community benefits e.g. by local carpenters.
- Ancient wood-pastures were arenas for cultural gatherings (e.g. Sighisoara, Medias, Rupea and Sibiu towns). Most of these gatherings were cancelled in the communist regime and now new initiatives are reviving these gatherings (e.g. the 'Breite days'; Sighisoara, Mihai Eminescu Trust).

Several acknowledgments of the cultural value of wood pastures are reported across Europe. The history of the tree is related with Greek history and mythology as it is one of the most frequently mentioned species in classical and contemporary literature is the Valonian oak (Pantera et al. 2009). In Italy grazing in public oak woodland gives social and environmental benefits such as wildfire protection, wildlife habitat, and areas of high cultural value for tourism. In Britany, hedges were essential for field delimitation in the bocage landscape and to provide multiple tree products, and now bocage is viewed as the traditional agricultural landscape in Brittany. In Hungary, wood pastures are viewed an employment opportunity for traditional herders. Also ancient, old trees are viewed as a focus for tourism and recreation and a focus for the transmission to children the traditional knowledge about livestock keeping, nature conservation and traditional crafts.

6 Area and current trends

HNCV agroforestry systems, such as wood pastures and other livestock-based agroforestry systems, are still common in certain Mediterranean and Eastern Europe regions (Plieninger et al. 2015; den Herder et al. 2016), especially where soil fertility and density of population are low. In the Iberian Peninsula, dehesas and montados cover up to 5 million ha (Figure 4). Italy and Greek also have large wood pasture areas, although the dividing line between forests and wood pastures is unclear and estimations of the wood pasture area are still imprecise. Wood pastures and grazed forest are also common in boreal regions. For instance, around 24 million ha of forests are still devoted to reindeer husbandry in Scandinavian countries, although only 450,000 ha has be defined as wood pasture (Figure 4).

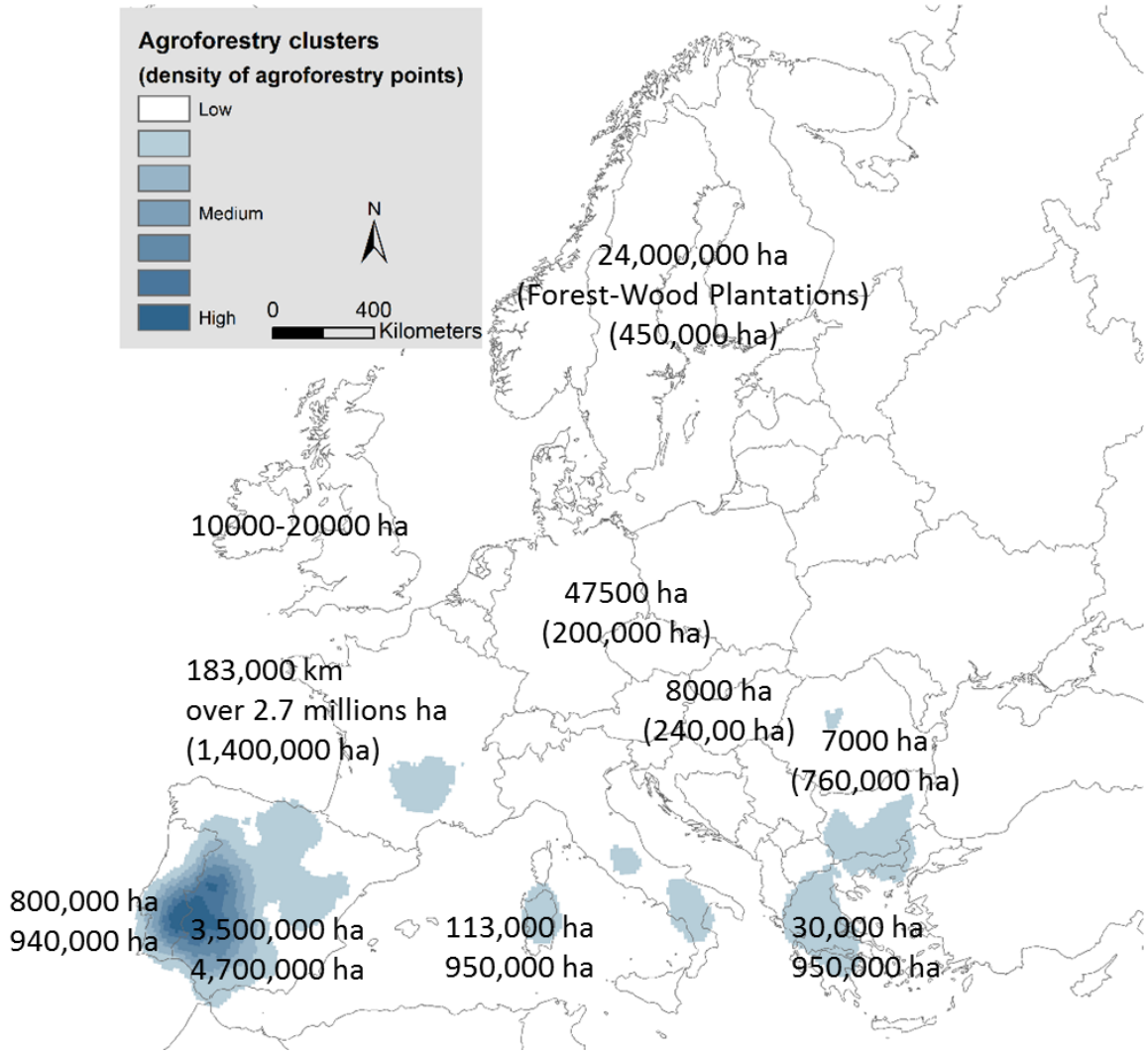

Figure 4**.** Map of the regions that harbour most of the European extensive agroforestry systems that generally can be viewed as high nature and cultural value farms (adopted from den Herder et al. 2016). Numbers represent the estimated area for each study system, based either on the literature compilation recorded in the ten case study reports (see Table 2 for references) and on our own estimations using LUCAS database (den Herder et al. 2016) (data in brackets).

In the lowlands of central and northern parts of Europe, wood pastures are generally found on a small scale, often confined to designated conservation areas, and managed according to targeted management plans. Some examples are in Germany on the Swabian Jura, in Slovenia alongside the river Save, the New Forest in southern England, Turopolje pig grazing freely in Croatia, cattle grazing in trans-Danubian wooded meadows, lowland County Leitrim in Ireland, small woodland and woodland patches in central and northern Italy, and wooded banks in the Netherlands.

Although the area of HNCV agroforestry systems cannot be delimited with current maps, databases and statistics, den Herder et al. (2016) estimated that agroforestry systems covered around 15.5 million hectares in Europe (EU-27), and that most of this surface could be defined as agroforestry systems of HNCV (Figure 4). It is also difficult to quantify the current trend in terms of cover of these systems.

Most HNCV agroforestry systems in the 10 case study reports (Table 2) are declining in area or quality, with the exception of Iberian dehesas and montados and the Sardinian agrosilvopastoral landscapes. However the old age of the tree populations in Iberian dehesas and the lack of tree regeneration remain main concerns for stakeholders (Moreno et al. 2015c; Figure 5). Likewise in Valonian oak wood pastures, the average tree age exceeds 200 years (Papadopoulos and Pantera 2013).

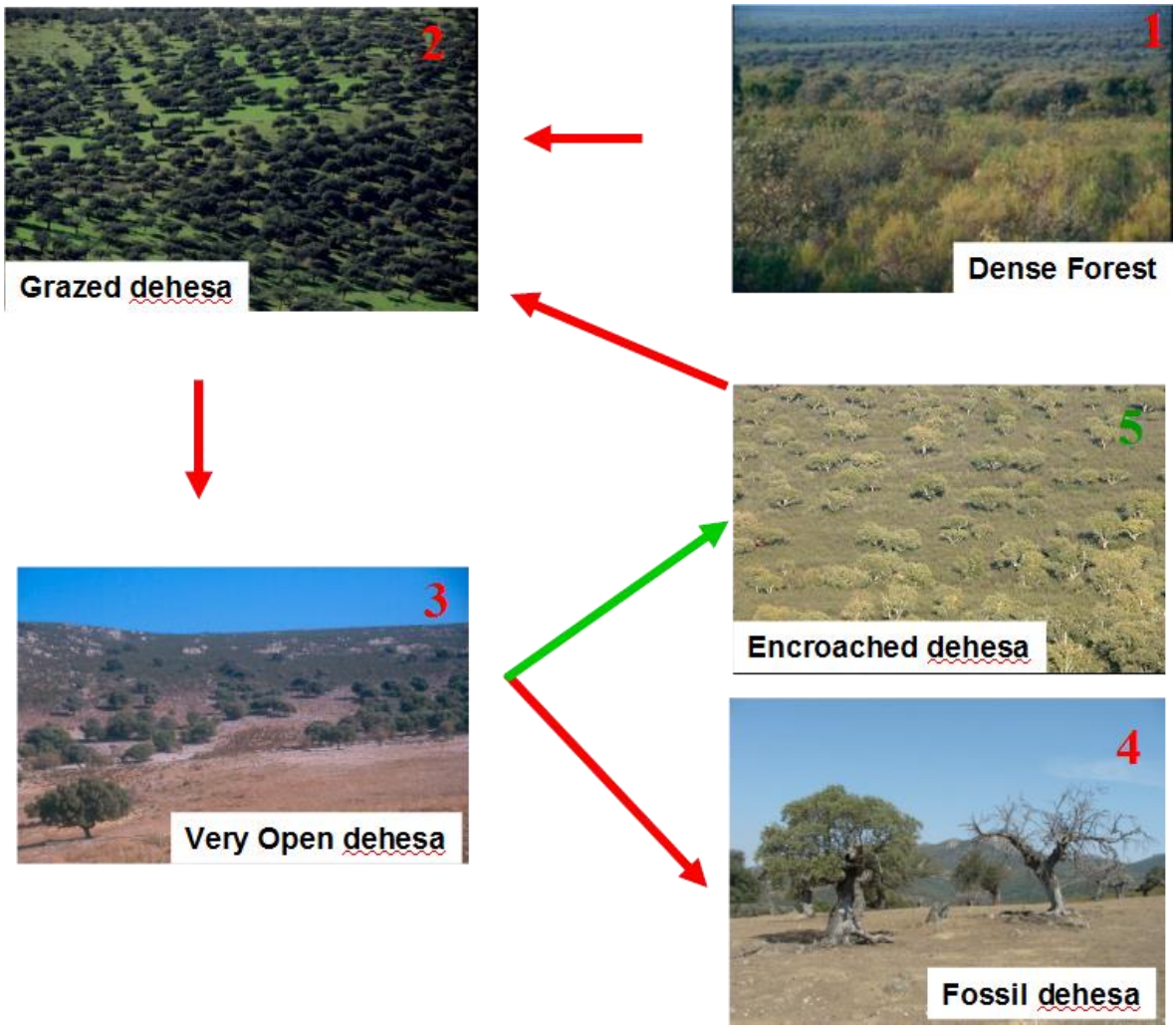

Figure 5. The pessimistic (end in 4) and optimistic (from 5 follow to 2) cycle of the Iberian dehesa. After thinning the original dense forest, continuous grazing (and/or cropping) produces a progressive loss of tree cover ending in treeless pastures (pessimistic cyle) unless active measures for regeneration of woodland are taken, such as planting trees or temporary cessation of grazing (optimistic cycle).

Wood pastures still cover millions or at least hundreds of thousands ha in Mediterranean countries. By contrast in Romania, there is estimated to be only about 7000 ha of actively-farmed wood pastures. In UK wood pastures and parklands, the grazing and pollarding of wood pastures declined from the 19th century, but there are about 10,000-20,000 ha where there are conservation programmes that aim to preserve natural, cultural and aesthetic values.

The situation of HNCV hedgerows is similar as illustrated by the two AGFOWARD cases studies (Aviron et al. 2016; Tsonkova and Mirck 2016). The bocage in France covers about 2.7 million ha with 183,000

km of hedgerows in Bretagne. However farm intensification has tended to reduce the length and quality of hedgerows and hedge planting schemes during the 1990s have not compensated for the loss of hedgerows over the same period (Le Dû et al. 2008; Thenail et al. 2014). The hedgerows in the German Spreewald Biosphere Reserve are almost abandoned and rejuvenation is hindered by trampling and grazing by cattle, and tree diseases (*Phytophthora alni* for black alder and *Hymenoscyphus fraxineus* for ash). Currently deadwood forms up to 50% of stand biomass of the trees In the Spreewald Reserve.

7 Profitability

Unfortunately, there is no systematic evaluation of the farm profitability for European agroforestry systems of HNCV, with the exception of the Iberian dehesas, which is here used as a reference system.

Iberian dehesa is an extensive but labour-intensive land-use system. Hence increased labour costs in Europe have threatened the profitability and sustainability of the dehesa since mid-20th century (Gómez-Gutiérrez 1992). Commercial profitability of direct dehesa products is usually low even negative, with a range of −14.7 to 9.7% for the net value added (Escribano and Pulido 1998). According to Gaspar et al. (2009), mixed systems (beef cattle–sheep–Iberian pigs) are the closest to the traditional systems with a highly diverse production, an optimal use of the system's resources, and little dependence on external subsidies, but such systems are not necessarily the most profitable. Dehesas with cork oaks and low livestock grazing and red-deer hunting (Campos et al. 2001), and dehesas with a high stocking rate and a high level of Iberian pig production (Gaspar et al. 2009) are commercial profitable.

Campos and Ovando (2015) reported the results of a comprehensive study based on the interviews with 843 forest owners and in-depth analysis of 58 forest farms (including dehesas). The study i) integrated commercial and non-commercial products in a consistent manner, ii) integrated a production account with a capital account, iii) distinguished between intermediate output and final output, allowing for the estimation of activity-level values and iv) provided spatially explicit results at micro-scales. They summarized the total income generated in 2010 by the different activities, separating labour, manufactured income and environmental income. The results indicated that most of the societal benefits came from environmental incomes while the income from production hardly covered labour costs. Unfortunately, disaggregated results for other HNCV agroforestry systems are not available yet, but results of the stakeholders meeting held for the ten cases studies show clearly that the low profitability of these agroforestry systems could compromise seriously their future persistence (Moreno et al. 2015a).

Although systematic assessment of the profitability for other systems are not available, current trends of abandonment or more rarely of intensification (losing gradually the tree layer) indicate that HNCV agroforestry struggle in the current global market. Surprisingly, few products are currently marketed as products of HNCV agroforestry despite the high quality of the goods produced and a willingness of consumers to pay for high quality products with low ecological footprints. Indeed, better branding for these products was stressed as one the more important innovation to increase the resilience of these systems. Given the low productivity of these marginal farming systems, it seems essential to derive economic advantages from the high nature and cultural value of these systems. This may be through

the products from the system, but society could also support the sustainability of HNCV agroforestry by placing a monetary value for public cultural benefits.

8 Recent initiatives to boost the HNCV agroforestry

Given the worrying situation of HNCV agroforestry systems in Europe, with low profitability leading to the slow abandonment of many traditional practices, some initiatives are emerging across Europe to invigorate these systems and to enhance or conserve their natural and cultural value. Some examples identified in the ten study cases are provided below.

In Portugal and certain Spanish regions the installation of new HNCV areas and the maintenance, improvement of productive capacity and increase resilience of existing HNCV are supported through rural development programme (2014-2020) measures.

Private initiatives to increase economic resilience are also common. In Hungary formerly abandoned areas are being farmed again as wood pastures to supply the demand the organic and high quality foods. In Sweden forest plans of intensive timber plantations are being adapted to support reindeer husbandry. A plan for the rejuvenation of the abandoned hedgerows in the German Spreewald floodplain has also been initiated. The program, called "Spreewald Grassland Shares", aims to stimulate public involvement in maintaining the traditional landscape of Spreewald. Buying a share for the amount of 50€ guaranties the maintenance of 0.1 ha of grassland for one year. New hedge planting schemes have been implemented since the 1990s to re-establish the French bocage in France. The objectives in hedgerow planting include the maintenance of the cultural landscape and the regulation of nitrate and phosphorus pollution. In the two latter cases, the use of tree biomass is viewed as a new opportunity for farmers. Indeed an increasing value placed on biomass is allowing the re-opening of excessively thickened wood pastures.

In UK, pollarding and grazing activities in old abandoned wood pastures is re-introduced to maintain the cultural landscape in areas of public recreation. In Romania, several measures have been initiated to promote the social-ecological values of the wood-pastures from Southern Transylvania. These include i) the preservation and valuing of the ancient trees and wood-pastures (oak reservation at Breite, Sighisoara); ii) highlighting 85,000 ha of wood pastures as valuable landscapes needing protection in the management plan of a local Natura 2000 site; iii) the building of milk collecting centres in villages to promote markets for traditional products and motivating farmers to use their wood pastures; iv) involving local communities in the conservation of the wood-pasture habitats (Saxon villages of Southern Transylvania); v) using education and awareness rising projects (‘The Remarkable Trees of Romania’, ‘Find the oldest tree’ and ‘One oak for every pupil’), and vi) initiation of the ‘Old Trees’ artistic event in three major Romanian cities to popularize ancient trees.

In southern Spain (Andalucía region), the RAPCA program (Network of Firebreak Areas Managed with Grazing) works with 222 shepherds who manage 6690 ha of wood pastures with 78,000 sheep, 17,000 goats and 1,200 cattle to reduce wildfire risk in the Andalusian forests. Shepherd benefit by about 43 € ha^{-1}, which is 3-4 times less than the cost of mechanical cleaning of firebreaks. This program is recovering thousands has of old wood pastures in Andalucía region and will soon be adopted by other Spanish regions (Figure 6).

Figure 6**.** Newly created wood pastures, that are grazed, are used as a firebreak in the Andalucian forests in Southern Spain.

9 Conclusions

Many traditional HNCV agroforestry systems and associated agro-silvo-pastoral practices have become less profitable during the 20th century and the systems have either evolved in dense forests and shrublands or been deforested by the gradual loss of trees. However recently, HNCV agroforestry systems have acquired interest again for their ecological, cultural and recreational value, through the support of agri-environment programmes, and the rising demand for high quality food. The high aesthetic value of these cultural landscapes also offers potential for tourism.

Currently the management of many wood pasture systems prioritizes the productivity of the herbaceous layer and tree management is in decline. However there are numerous new projects to rejuvenate or restore ancient trees, hedgerows, or tree cover, and support practices such as forest grazing, pollarding or the use of pannage. However there remain uncertainties on how to restore and maintain these systems in an environmentally and economically sustainable way when the income from the products is similar to the labour costs. Research on the best agroforestry management practices to deliver the most valuable products and public services are still needed.

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