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Multifunctionality and dynamics of silvopastoral systems

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Abstract. Silvopastoral systems (SPs) are present all around Europe, being still important elements of cultural identity of many marginal, stress-prone regions. They are managed mostly as extensive, low-input farming. SPs are used for multiple purposes which generate timber and non-timber forest products, high-quality foods, livestock and game products, recreational and cultural services. SPs have the potential to be an outstanding High Nature Value farming system, however, they are currently facing both environmental and economic threats that might compromise their long-term persistence either by agricultural intensification or by abandonment. In recent decades, needs and challenges emerged in the modern society have led to a new concept of land use. Bioenergy, carbon sequestration, control of nutrient leaching, halting of biodiversity loss and recreational uses could increase economic profitability of SPs. To cope with these new functions, there is a need of innovative techniques and specific policy measures to solve those threats and reinforce their social and ecological roles.

Keywords. Biodiversity – Carbon sequestration – Fire risk control – Soil fertility – Habitat mosaic.

La multifonctionnalité et la dynamique des systèmes sylvo-pastoraux

Résumé. *Les systèmes sylvo-pastoraux (SPs) sont présents partout en Europe. Ce sont des éléments importants de l'identité culturelle de nombreuses régions marginales. Ils sont gérés la plupart du temps extensivement avec de faibles intrants. Les SPs sont utilisés à des fins multiples, pour la production de bois, de fruits, d'aliments de haute qualité, de produits de l'élevage, de gibier, pour les loisirs, et ils fournissent des services culturels. Les SPs ont un fort potentiel pour devenir des systèmes agricoles à haute valeur naturelle, cependant, ils sont actuellement confrontés à des menaces environnementales et économiques qui pourraient compromettre leur persistance à long terme, soit par l'intensification agricole soit par leur abandon. Au cours des dernières décennies, de nouveaux besoins et défis sont apparus dans la société moderne. Bioénergies, séquestration du carbone, contrôle du lessivage des nutriments, arrêt du déclin de la biodiversité et des fonctions de loisirs pourraient augmenter la rentabilité économique des SPs. Pour faire face à ces nouvelles fonctions, il est nécessaire de développer des techniques innovantes et des mesures spécifiques pour résoudre ces menaces et renforcer les rôles sociaux et écologiques des SPs.*

Mots-clés. *Biodiversité – Séquestration du carbone – Contrôle des incendies – Mosaïque de l'habitat.*

I – Introduction

Accordingly to the Bergmeier *et al.* (2010) the silvopastoral systems (SPs) started 7,500 years ago in Southeastern and central Europe. These SPs can be defined as a combination of trees, pastures or crops and/or livestock on the same plot of land (Mosquera-Losada *et al.,* 2012). In more marginal, stress-prone regions and mountains, where agriculture was hardly viable, extensive pastoralism has been the most common and traditional land use. Across Europe, different pastoral landscapes are still dominated by silvopastoral systems that include grazed forests, anthropogenic savannas, wood pastures (trees as fodder), grazed plantations, but also grazed fruit orchards. In

Iberian Peninsula, SPs cover 4.5 million ha, mainly represented by Dehesa and Montados. Similar systems are present in many other Mediterranean regions (Sardinia, Corsica, Crete, Greece, Albania, northern Africa and Western Asia) and in less extension in many other European biogeographic regions (Riguiero-Rodríguez *et al.,* 2009). SPs cover ca. 17 M km^2 in the world (Zomer *et al.,* 2009). Depending on the region, SPs occurs as vanishing relic of historical land-use, or still more or less widespread as multiple-use rangeland (Bergmeier *et al.,* 2010). SPs are frequently diffuse transitions from agriculture to forest lands, and there is still a lack of reliable maps of distribution or any official statistics of their extension (Van Doom and Pinto-Correia, 2007).

SPs have been harvested and/or managed in different ways in the different European socio-economic, political, cultural and environmental scenarios. Somewhere, there has been a deliberate and purposeful integration of woody vegetation (trees or shrubs) with crop and/or animal production systems to benefit from the resulting ecological and economic interactions. However, in many cases woody vegetation has been hardly managed and/or management did not follow underwent ecological and economical changes. Some of them are suffering declining processes as lack of regeneration and exhaustion of resources (Riguiero-Rodríguez *et al.,* 2009). In other cases, especially in mountain areas, abandonment is the harsh reality. Also, the low value of the traditional silvopastoral products in the actual markets is a common concern for all of them.

Despite the well-known socioeconomic and ecological importance of SPs across Europe, only in 2006 this land use system was considered as a specific agroforestry practice in the Common Agricultural Policy (CAP), namely under the Pilar 1 and 2 of the CAP 2007-2013. However, adoption of this financial support schemes has been limited and no relevant impacts on the future sustainability of this land use systems was observed. To achieve this propose many efforts have been conducted in last three years to ensure the full recognition of the silvopastoral systems as an eligible land use for Basic Farm payments in the CAP 2014-2020 period. One of the most interesting windows of opportunity to maintain in a sustainable way the silvopastoral systems across Europe is the new greening architecture of the CAP 2014-2020 diploma. However, some rules concerning the effective application/adoption of this measure will be determined by each member state, representing thus an important moment to highlight the specificities and relevancies of the silvopastoral systems that occurs in each country.

Therefore, this paper will review and discuss in detail the concept of multifunctionality of the European silvopastoral systems in order to provide an overview of their socioeconomic, ecologic and cultural relevance. Thus, section 2 and 3 present the goods and services provided by this ecosystem highlighting their importance to achieve a more sustainable agroforestry activity in Europe. Section 4 assesses the current state of the silvopastures dynamics knowledge, in relation to their main patterns and processes over the space and time. Section 5 outlines the importance in reorienting the public perception and management schemes based in a more scientific knowledge and innovative management tools for a more sustainable agroforestry production and ecosystem conservation. Finally, the section 6 provide a global view of what are the main needs and steps to be done to promote the SPs across Europe as an important traditional rural areas to be supported due to their recognized ecological importance but also due to their specific social, economic and cultural requirements.

II – Goods provided by silvopastoral systems

Although SPs are multifunctional systems, and provide a series of products, they are mainly used for animal breeding or tree-derived products. Owners maintain trees either because they barely compete with pasture understory and pasture productivity is not affected by the tree cover, as the case of oaks and many deciduous hardwoods (Fig. 1), or because trees are used as forage supplement. Good examples are oaks in Iberian dehesas that provide leaves and acorns, shrubs in many Mediterranean and mountains pastures, and pollarded trees (Fig. 2). In some cases, trees constitute the main source of fodder as in the Iranian Galazarini (Zabiholahi and Haidari 2013).

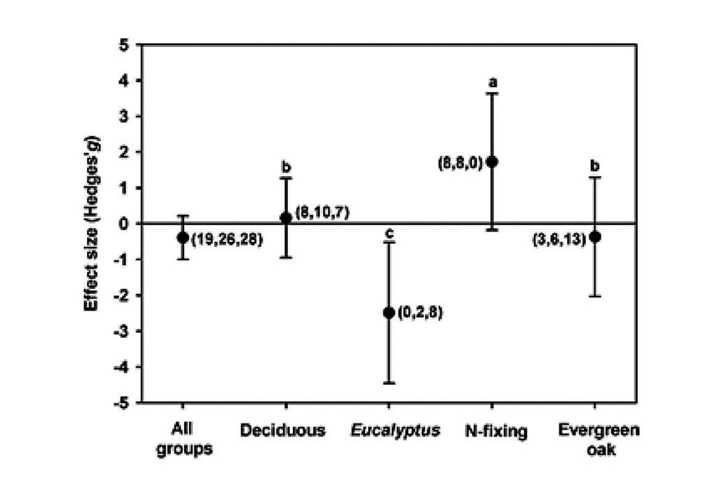

Fig. 1. Mean effect size (Hedges'g) of scattered trees on pasture yield among four functional groups and across all groups (bars = 95% confidence intervals). Adapted from Rivest *et al.,* (2013).

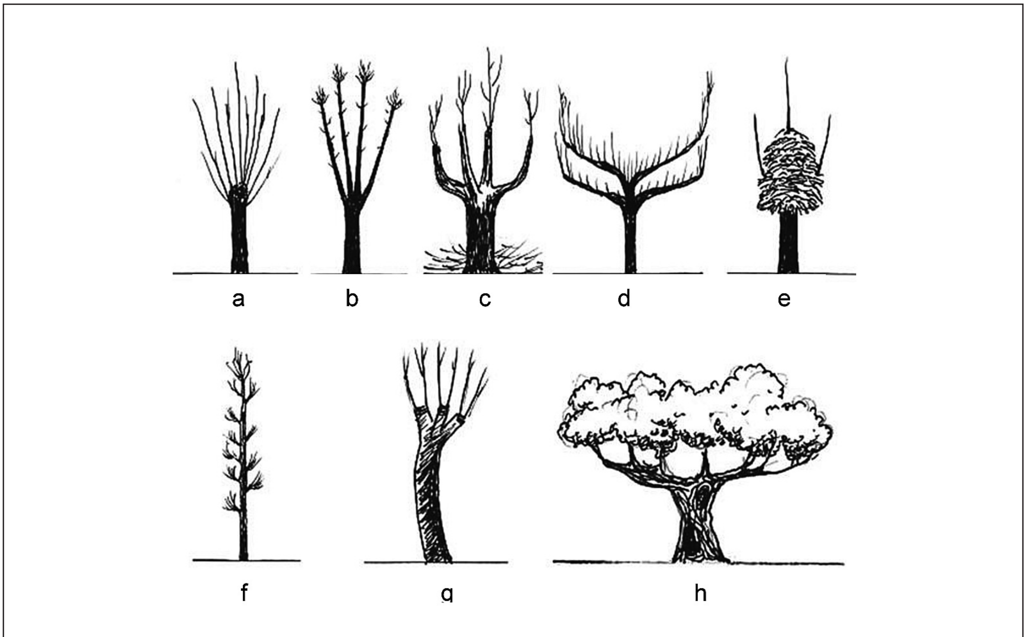

Fig. 2. Traditional management of fodder trees in Greece: (a) pollarded tree of any species, (b, c) pollarded oak trees (d) pollarded mulberry tree, (e) pollarded tree for storage of fodder, (f) shredded oak tree (g) grafted tree for fruit production and (h) lopped olive tree for olives and fodder production (Papanastasis *et al.,* 2009).

In addition to the pastoral component of the trees, SPs traditionally provided many other goods, especially timber, firewood and charcoal. Although the use of this energy has almost disappeared, this could have a new chance with the EU target of renewable energy. New opportunities are also open for high quality timber for which new plantations are being managed as silvopastoral systems. Other products have been traditionally produced in SPs, such as fruits in French *pre-vergers*, Dutch *boguards*, Spanish *pomaradas*, Centroeuropean *streuobstwiesen*, cork in Iberian dehesas, honey, mushrooms and medicinal plants. The production of high quality food (meat, milk, cheese) together with the recreational and cultural services could be important drivers of the economic revitalization of SPs. Iberian pig ham is a good example of high quality foods supported by SP practices. Previous research has demonstrated welfare benefits from agroforestry and in some countries producers have capitalized on this in product marketing i.e. the promotion of woodland eggs in the UK, and agroforestry-raised chicken in France and Italy. Good examples of the recreational value of SPs are the parklands in UK (Isted 2005), and Iberian dehesas (Surova and Pinto-Correia 2008; Surova *et al.,* 2013).

III – Ecosystem services

There is a general acknowledgment of the important contribution of agroforestry systems to multiple ecosystem services such as carbon sequestration, water quality, biodiversity conservation, control of desertification, soil preservation (Jose 2009). However, the true potential of silvopastoral systems in particular is not well known yet, and more examples are still needed. Here we demonstrate some examples well documented in the literature, mostly for European cases, and identify some gaps of knowledge.

1. Microclimate amelioration

The positive effect of trees on buffering the daily and seasonal variability of air and soil temperature is widely known (Moreno *et al.,* 2007). Although shade usually has detrimental effects for pasture production in high latitude (Silva-Pando *et al.,* 2002), under dry conditions the reduction of excess of radiation could become an advantage, and pasture production be higher under certain level of shade (ca. 50-75% of full sunlight; Quarro *et al.,* 1995; Kyriazopoulos *et al.,* 2006; Moreno 2008). Indirect effects of mitigated soil temperature variations under tree canopy on soil nutrient dynamic are not well known.

Climate change has been identified as one of the main threat to agriculture across Europe for the future (Brisson *et al.,* 2010). Recent findings indicate that agroforestry systems may be more resilient to climate change, as the tree cover may reduce some concerning events such as early heat and drought stresses on herbaceous understory (Schoeneberger *et al.,* 2012).

Animal welfare is becoming an important issue for the European Union and is included in the strategic guidelines for rural development. The shelter provided by trees in silvopastures is a key element (Rigueiro-Rodriguez *et al.,* 2009). For example, cows kept cool produce more milk under better animal welfare conditions (Oosterbaan and Kuiters 2009).

2. Soil fertilization

The turnover rate of nutrients on the soil surface of SPs is unusually high because the action of herbivores (e.g., litterfall decomposes up to 24 times faster in dehesa than in dense forest; Escudero *et al.,* 1985). Trees also play a prominent role in the process, because roots bring up nutrients from deep in the soil profile that is inaccessible to herbaceous vegetation (Young 1997) and net mineralization is higher beneath than beyond the canopy cover (Gallardo *et al.,* 2000). As result, soils beneath the tree canopy are richer in soil organic matter (SOM) and nutrients than soil beyond the canopy (Moreno *et al.,* 2013).

As a consequence, trees frequently have a positive effect on pasture production (Figure 1), especially in unfertilized oligotrophic soils (Moreno *et al.,* 2007). However, the effect of trees on pasture is a controversial issue. Many authors have reported a positive effect on pasture yield and nutritional quality, length of growing season, and stability against climatic variability, but other studies failed or found the contrary results (see Moreno *et al.,* 2013 for a review). As these authors state, the contradictory results are caused by the complex interactions that occur among trees and pastures, with a dominant role of water competition in dry areas and for light in high latitude regions. However, more studies are still needed to know under what ecological conditions and which species combinations produce the more favorable balance in term of pasture productivity.

3. Carbon sequestration and reduction of greenhouse gases emission

During the past 20 years, there has been an increasing appreciation of the extent of the negative externalities associated with livestock production, either as grazed ruminants or animals such a pigs and poultry (Burgess and Morris 2009). The key negative externalities include methane production by ruminants, ammonia and nitrous oxide production by all forms of livestock production and emissions related to feed production. Recently it was estimated that Europe's meat and dairy consumption was responsible for 14% of the total CO_2 emissions in the EU (Weidema *et al.,* 2008), and livestock production is seen as a key driver of global land use changes, with resulting impacts on climate change and biodiversity.

The integration of trees with livestock is seen as one method to mitigate ammonia emissions, and to store carbon as an offset for methane and nitrous oxide production (Hristov *et al.,* 2013). The contribution of trees to the build-up of the soil carbon pool has been repeatedly reported (Mosquera-Losada *et al.,* 2011) and comparison among pastures and silvopastures show that C pool is significantly higher in the latter ones (Nair 2012). Long-term effects of improved pasture establishment in Portuguese montados caused higher organic-C than those under unmanaged pasture, and the effects were stronger in the presence of oak trees (Gómez-Rey *et al.,* 2012). Howllet *et al.,* (2011a) and Howlett *et al.,* (2011b) reported good examples for Atlantic and Mediterranean oak SPs of Spain. In these studies, soil C was almost doubled beneath tree canopies compared to open pastures. The higher inputs of residues generated by trees in SPs than in tree-less systems may cause high soil C sequestration potential and C could be stored deeper and for longer, what need to be more explored.

4. Water quality

The move from mixed arable-livestock farming towards greater specialization, together with the general intensification of food production has had adverse effects on the environment. Livestock systems have largely become separated into pasture-based (cattle and sheep) and indoor systems (pigs and poultry).The increased losses of nutrients, farm effluents (e.g. livestock wastes), pesticides such as sheep-dipping chemicals, bacterial and protozoan contamination of soil and water are some of the main concerns regarding water quality degradation. There has been a general uncoupling of nutrient cycles, with frequent problems of unacceptable high nutrient deposition or uneven spatial distribution (Hooda *et al.,* 2000).

In this context of the Water Framework Directive, the need for reducing diffuse pollution from agriculture to water bodies imposes important costs to livestock farms (Fezzi *et al.,* 2008). Different studies have showed the capacity of deep rooting trees to capture nutrients from deep layer that are not anymore utilizable by herbaceous plants, and thus reduce nutrient leaching in SPs (e.g., Bambo *et al.,* 2009 and López-Díaz *et al.,* 2011 for N; Nair *et al.,* 2004 and Blazier *et al.,* 2008 for P). Recent research showed integrating pigs in a willow/miscanthus plantation results in a much smaller risk for N leaching than typically seen on grassland with the same stocking rate (Sørensen 2010) and that the pigs only caused limited damage to the trees (Horsted *et al.,* 2012). The optimal tree cover needed for an efficient control of nutrient leaching is however unknown.

5. Biodiversity

Diaz (2008) and Marañon *et al.,* (2009) compiles a huge number of studies that reported a noticeably high diversity of vascular plants, birds, mammals, lizards and butterflies for Iberian dehesas compared to other adjacent land uses. Bermeier *et al.,* (2010) reported similar results for vascular plants, birds, snails and beetles for other European SPs. An increase in invertebrate species and numbers has been reported when moving from open grassland to agroforestry conditions for carbid beetles in Northern Ireland (Cuthbertson and McAdam 1996) and for four arthropod groups in Scotland (Dennis *et al.,* 1996). Burgess (1999) also reports on the benefits of silvoarable systems, relative to traditional agriculture, in terms of the number of birds and mammals. Gillet *et al.,* (1999) determined a plant species richness optimum at 30% of tree cover for SPs of Swiss Jura Mountains.

Trees provide multiple tree-based gradients, in terms of light, soil nutrients and moisture, food availability, refuge, even certain low level of disturbance caused by uneven use of space by livestock (Moreno *et al.,* 2013). This fine-grained mosaic of microhabitats is a key factor for high species diversity of SPs (Bergmeier *et al.,* 2010). Besides, trees are essential sources of food and refuge. Indeed, they have a disproportionate value for different taxa, as reported by Fischer *et al.,* (2010) for birds and bats in an Australian livestock grazing landscape. Compared to treeless sites, bird richness doubled with the presence of the first tree; bat richness tripled with the presence of 3-5 trees (2-ha sites; n = 108 sites of 33 farms); and bat activity increased by a factor of 100 with the presence of 3-5 trees.

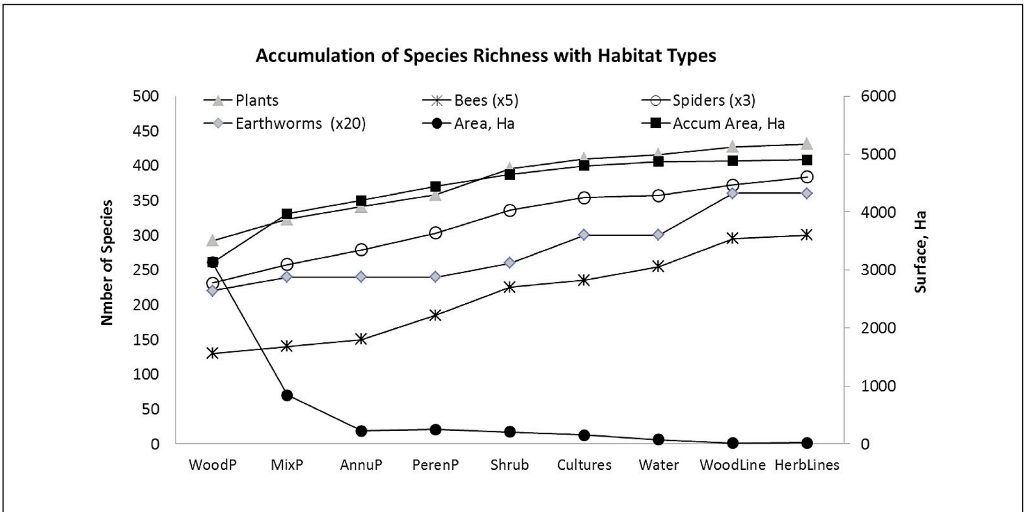

Fig. 3. Curves of accumulation of species with different habitats types of Iberian dehesas compared with the accumulation of surface occupied by those habitats. WoodP, MixP, AnnuP and PerenP refer to wood pastures, mix, annual and perennial pastures (Moreno *et al.,* 2014). Note that main fields (pastures that all together cover > 90% of farm surface) harbors only ca. 70% of species, and that marginal habitats contributed significantly to species richness of the dehesa farms.

In a recent study conducted in Iberian dehesas, Moreno *et al.,* (2014) reported higher species richness for vascular plants (primary producers), bees (pollinators), spiders (depredators) and earthworms (decomposers) in wood pastures than in adjacent monopastures. Moreover, there was very high β diversity (spatial heterogeneity) among different types of pasture within farms. While monopasture plots shared a high number of species among them, plots with wood pastures exhibited very different species assemblages. Finally, although wood pastures and monopastures displayed high number of species (alpha diversity), the fine mosaic of habitats within farms, including some marginal habitats and linear features (common in many silvopastures) played a very significant role in terms of species richness at farm-level and landscape-level (γ diversity; Fig. 3). Indeed, habitat heterogeneity at multiple spatial scales has been revealed as key for biodiversity conservation (Benton *et al.,* 2003; Concepción *et al.,* 2012).

6. Reduction of fire risk

Within Europe, Mediterranean rangelands and forests are prone to wild fire. Although less important, some continental and atlantic mountainous regions also suffer periodical wildfires. Important projects of silvopastoral management of fire-prone rangelands have been successfully implemented in Southern France (Etienne *et al.,* 1996), Italy (Pardini 2002; Franca *et al.,* 2012) and Spain (Rigueiro-Rodríguez *et al.,* 1999; Ruiz-Mirazo *et al.,* 2011; Casals *et al.,* 2009). Livestock feces, trampling and browsing can kill shrubs at a medium term, although anti-nutritional components of woody vegetation hinder the efficiency of livestock as fireguard (Rigueiro-Rodríguez *et al.,* 2009). Pasadolos-Tato *et al.,* (2009) evaluated the economics of silvopastoral systems established in Northern Spain on abandoned croplands afforested with *Pinus radiata* D. SPs were always more profitable than single timber production systems when fire risk was included in the analyses. Casals *et al.,* (2009) found that forest grazing is seen as the best cost-effective treatment (6-30 € ha^{-1} per year depending on animal type and management system adopted), in spite of the fact that it requires certain investments (water supplies, fences…) and must be combined with complementary shrub control. Using combination of manual and mechanical treatments alone costs 200-300 € ha^{-1} per year, with a return interval of 3-to-5 years. Fuel reduction by prescribed fires costs 600-1,000 € ha^{-1} and cannot be used repeatedly without jeopardizing the nitrogen fertility of the ecosystem (Casals *et al.,* 2004).

IV – Silvopastures dynamic: patterns and processes

Extensive SPs result from a simplification, in structure and species richness, of native forests, and are attained by tree clearance, eliminating of shrubs, and favoring grasses by means of grazing and occasionally forage sown. The landscape formed is maintained by a balance between divergent ecological processes such as grazing pressure and tree regeneration (Battler *et al.,* 2009). The coexistence of patches of pastures, woodlands and/or isolated trees is therefore a result of an unstable equilibrium, which can lead either to closed forests or to open pastures. Adequate grazing pressure for the maintenance of sufficient but not excessive tree/shrub regeneration is crucial for the persistence of SPs.

Low profitability is becoming a common characteristic of most of European SPs and owners are pushed either to the intensification of the farms (e.g., increasing stocking rate) or to their abandonment (Campos *et al.,* 2009; Pinto-Correia *et al.,* 2011). Intensification produces a loss of habitat and biological diversity. In Europe, many traditional SPs, especially those associated to fruit orchards or dense networks of hedgerows, were lost along the XXth century by farm consolidation programs (Eichhorn *et al.,* 2006). When intensification is made through the increment of stocking rate, leads to progressive soil degradation, lack of tree regeneration, overage of tree population, and thus to a gradual deforestation (Smit *et al.,* 2005; McEvoy *et al.,* 2006; Mayer 2009; Moreno and Pulido 2009; Plienninger *et al.,* 2010).

Overgrazing is one of the causes argued by many authors for the progressive loss of young trees in scattered-trees systems (Fisher *et al.,* 2009; Pinto-Correia and Godinho 2013; Fig. 4). Gibbons *et al.,* (2008) developed a simulation model to predict the rates at which these trees are declining in several landscapes, including some SPs. They predicted that mature trees would be lost from these landscapes in 90-180 years if current trends persist. The loss of scattered mature trees was most sensitive to tree mortality, stand age, number of recruits, and frequency of recruitment. Management need therefore be adapted to ensure the long persistence of extensive SPs that depends on soil fertility conservation and the natural regeneration of trees. A more rational grazing scheme, including periodical grazing exclusion, has been proposed for Iberian dehesas (Pulido *et al.,* 2010), what still deserves more research.

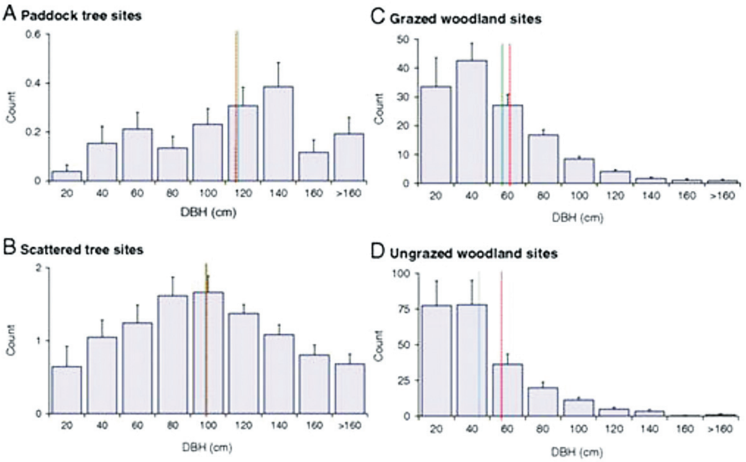

Fig. 4. Mean count of trees (and standard error) in different diameter classes across four agrarian systems that follow a decreasing gradient of grazing pressure: paddock (*A*), scattered (*B*), grazed (*C*), and ungrazed (*D*). Mean diameter is indicated by a dotted red line and median diameter is indicated by a solid green line (Fisher *et al.,* 2009).

Undergrazing results in the loss of the characteristic open two-layer structure of SPs to become dense forests or scrublands. Papanastasis *et al.,* (2009) described the rapid loss of SPs due to the progressive cessation of pastoral activities in Greek mountains, where the rural population exodus deprived these areas of the necessary labor to maintain SPs activities. Buttler *et al.,* (2009) reported a good example of patterns and processes occurring in mountain SPs based on experimental and observational studies carried out at various spatial scales across Swiss Jura Mountains. They revealed a high heterogeneity of large herbivore activities at both fine and large scales, with strong influence on the dynamics of plant species in the herb layer. Natural tree regeneration was closely affected by both herbivores activity and heterogeneous environment (e.g., presence of nurse plants). They also found out that with low grazing pressure a rich spatial mosaic is maintained, and it lost when grazing pressure is increased. Through a spatially explicit mosaic compartment model, Gillet (2008) modeled the dynamics of these silvopastoral ecosystems showing that the patterns of vegetation and cattle habitat use evolved very slowly toward a permanent state dominated by wood-pastures, strongly dependent on the spatial configuration of the environment. However, taking into account the effect of climate change, closed forests and densely wooded pastures tended to dominate and vegetation diversity to decrease (Fig. 5).

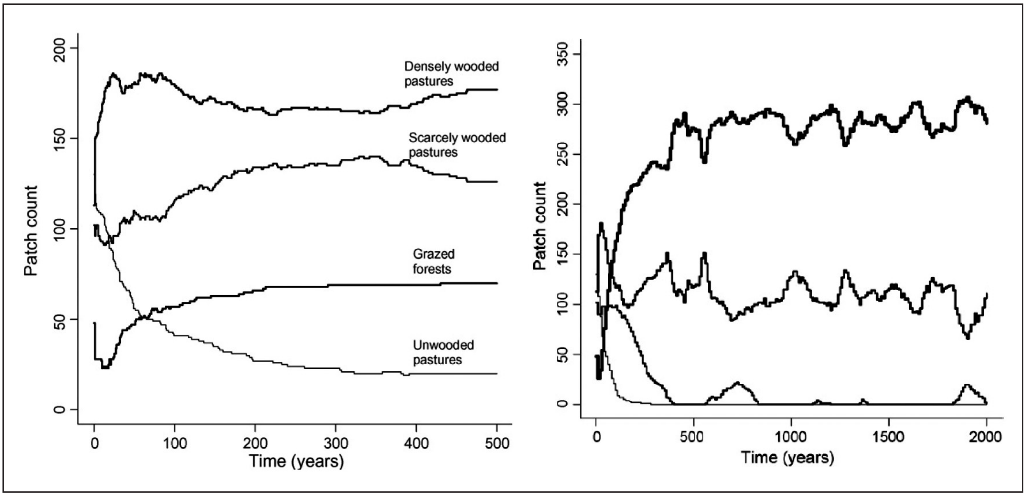

Fig. 5. Simulation of the dynamics of the landscape mosaic in a pasture-woodland in Swiss Jura mountains with environmental and management conditions fixed to their initial values (left) or including a linear temperature increase of 1.2 ºC per century (right). (Adapted from Gillet 2008).

V – Challenges and new opportunities

SPs, mostly based on traditional empirical knowledge, are increasingly threatened due to over-simplification of management techniques and rural depopulation. Currently they constitute only a minor part of the total livestock production. In these circumstances, and in order to be able to compete with conventional products, both the public perception and the management schemes must urgently be reoriented. For this reason, there is a strong demand for scientific knowledge and innovative management tools that may constitute an integrated system of support for decision making. Here we discuss some open fields of innovations.

1. Tree regeneration and nursery plants

One of the most determinant issue in the ecological sustainability of the system is strongly related with tree regeneration. The age structure of many systems is unbalanced (e.g. the Dehesa system in Spain and the parkland system in the UK). Methods to increase the cover of young trees include tree planting with protective fencing, but this can be very expensive. In recent years, important effort are being initiated to find out new management practices that reconcile land use (grazing) with tree regeneration, and promising results indicate the important role that nursery shrubs and periodical grazing exclusion could play (Gómez-Aparicio, 2009; Pulido *et al.,* 2010). Further analyses are needed to disentangle the effect of the different factors and nurse species involved in the regeneration process of trees (Rolo *et al.,* 2012).

2. Ecological intensification

Livestock breeders are interested in increasing the quality of the feed as well as to diversify forage offer (mitigating seasonal shortages). Some recent experiences in Portuguese *montado*, with the sowing of biodiverse permanent mixtures rich in legumes (Aguiar *et al.,* 2011) and in Sardinian oak woodlands, with the sowing of mixtures of autochthonous pasture grasses and legumes (Franca *et al.*, pers. comm.) evidence the need of a specific selection of seed mixtures suitable for silvopastoral purposes, where herbaceous plants have to cope with shade and competition imposed by trees. Intercrops with leguminous *shrubs forage* (*Medicago arborea*, *Atriplex* sp., *Acacia sp.*), but also with mulberry (*Morus* spp) and carob (Ceratonia siliquoa) is a promising way to overcome seasonal shortages of forage. Some studies have been conducted to identify shrubs species of nutritional value as part of the summer or winter diet of livestock (Robles and Passera 1995). Under current trend to aridification of Mediterranean region, shrubs species with high water-use efficient need to be explored as fodder source.

The genetic base of currently sown pastures is very narrow: more than three-quarters of the grass cultivars registered in the European Union are of just six species, and *Lolium perenne* and L. *multiflorum* account for more than 80 percent of the forage grass seed sold in the EU (Batello *et al.,* 2008). All them were selected under full sunlight conditions. Moreover, the availability in the seed market of pasture species suitable for dry environments (e.g. semiarid Mediterranean areas) is still scarce (Porqueddu and Gonzalez, 2006). There is need of widening the choice of available high-value grass and legume cultivars by exploring, evaluating and selecting from a wide range of species of several genera. More specifically there is still a need to improve our understanding of the positive (facilitative) and negative (competitive) effects of trees on different pasture species (or genotypes) to be used to improve pasture quality and productivity in SPs (Fig. 6).

3. High Nature Value farming

Agricultural intensification has led to a widespread decline in farmland biodiversity across many different taxa (Benton *et al.,* 2003), but farmland also hosts many species that depend on appropriate agricultural management (Kleijn *et al.,* 2003). One current proposal is that at least 7% of the utilized agricultural area of each farm should be allocated to ecological focus areas, which could include landscape features, buffer strips or afforested areas. It has been proposed that conserving what is left is more effective than getting back to what was lost, and consequently biodiversity conservation is more likely to be effective on farmlands that are already managed at low intensity and that retain a certain amount of seminatural vegetation (Kleijn *et al.,* 2011). At farm level, these criteria are mostly accomplished by extensive pasturelands that consist of grassland, scrub or woodland or a combination of different types, used for raising livestock (Parachinni *et al.,* 2008). Indeed, extensive pasturelands are dominant in the last European map of High Nature Value farming (Oppermann *et al.,* 2012).

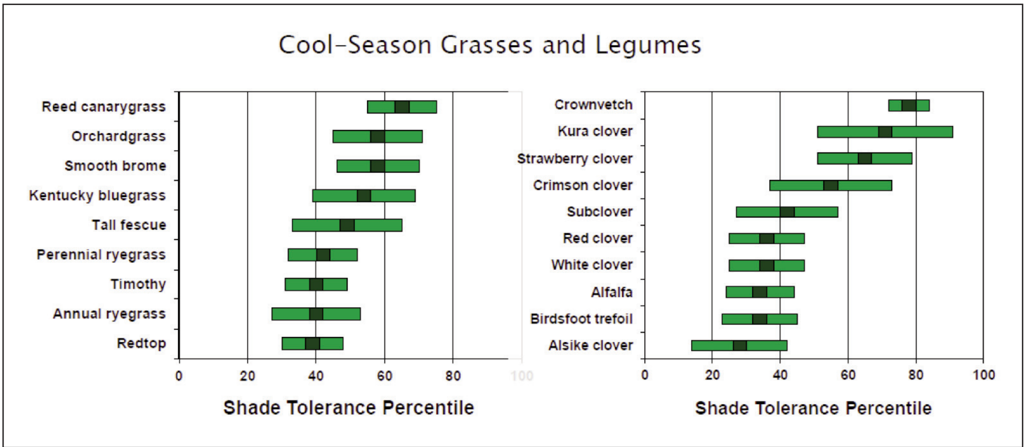

Fig. 6. Results of ten years of screening forage species for shade tolerance that clearly demonstrate that many cool-season forages benefit from 40% to 60% shade when grown in Missouri. Grazing trials have proven to be successful at least in the short-term (Adapted from Garret *et al.,* 2004).

4. Carbon sequestration and Life Cycle Assessments

The increasing intensification of many SPs, especially those in Mediterranean regions, has produced a worrying loss of soil quality (Coelho *et al.,* 2004), and new management practices that favor the increment of soil organic matter are now needed. Two kinds of materials could be useful for this purpose: ramial wood (Dodelin *et al.,* 2007) and biomass charcoal (Kimetu *et al.,* 2008). Both imply a "source" ecosystem (they can be produced in SPs) and a "sink" ecosystem (can be used to improve soil conditions and at the same time to store C for long time). In Europe there is an increased demand of biomass crops dedicated to bioenergy (Burgess *et al.,* 2012). The opportunity to produce (or use the excess of) wood biomass in SPs as local or in-farm source of energy has gained a recent interest. Incorporating life cycle assessments (LCA) that compute C cycle and overall C sequestration/emission for agrarian systems and products is also needed, and presumably would give a new momentum to SPs (Upson and Burgess 2012).

5. Branding high quality products of SPs

Advances in reliable assessments of the LCA, together with the identification (and quantification) of multiple ecosystems services provided by SPs should be associated with controlled certification processes. This would enable consumers to buy products with high environmental added-value. There is a focus on producing and marketing high value products from SPs. One of the most prominent examples is pig meat production in the Iberian dehesas with local Iberian pig. In other systems (e.g. Parkland systems in the UK), the systems are of particularly high cultural value. New needs for natural and high quality products derived from extensive SPs need also to be explored, as acorn-derived products (tannins for tan leather and for antioxidant uses, gluten-free flours, unsaturated fat …). However, the pace at which new market demands and environmental changes arise exceeds the capacity of individual managers to react accordingly. There is a need for decision-making support tools and more, for joint participatory actions supporting decision, which should be implemented (Pinto-Correia and Godinho 2013).

VI – Research agenda

There is an urgent need of promotion of SP practices across European pastoral areas that will advance sustainable rural development, i.e. innovative practices to assure the ecological persistence of SPs, improved competitiveness, and social and environmental enhancement.

To achieve this, we propose:

1. The elaboration of a comprehensive and categorized map, and the associated database of pastoral systems and grazing strategies within forest and woodland;
2. Selection and multiplication of species suitable for different silvopastoral conditions, with focus on site-specific mixtures, identified on the basis of pedo-climatic conditions and grazing characteristics;
3. Studies focusing on the conditions under which net balance of trees is positive (facilitation) or negative (competition) for pasture understory, what surprisingly is still lacking;
4. Improved knowledge on how silviculture and management practices can make forest more productive and better adapted to climate change adapted (e.g., determine the optimum tree density);
5. The analysis of consequences and opportunities of woody encroachment of extensive pastoral systems (as fodder and nursery plants) should also deserve more attention;

6. The scientific evaluation of environmental services, as reducing forest fires, C storage reinforcements, control of water loss and quality, and biodiversity preservation, under different environmental and management context;
7. Improved understanding of the trade-offs among those services;
8. Diversification and increment of forage offer (mitigating seasonal shortages) and other marketable products of SPs;
9. Economical evaluation of SPs including environmental goods and services (green accounting);
10. Finally, the popularization of the link among silvopastoral practices with the production of high-quality products and the provision of public environmental services.
11. And finally, there is a need for an increased understanding on landholders decision making process, and the drivers that mostly affect their choices, so that better targeted public interventions can be developed.

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