



## Profitability, biodiversity and ecosystem services of agroforestry at landscape scale

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Further papers will be uploaded as they are published.



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## 1 Context

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 comprises Deliverable 7.21 in the project and contributes to improving our understanding of the approaches in ecosystem service assessment in European agroforestry. Bio-physical, economic and socio-cultural approaches were applied and combined. In this deliverable we report results from thirteen pilot studies across Europe. They represent well-established agroforestry systems, where ecosystem services (ES) can actually be studied and evaluated.

## 2 Description of research

### 2.1 Titles for seven papers

The deliverable will eventually comprise seven papers. One has been published in a scientific journal, whilst six are manuscripts that have been or will be soon submitted to scientific journals. The papers are:

1. Paper valuing provisioning and regulating ecosystem services and their spatial relationships and similarities among different European agroforestry areas (Annex A):  
Kay S et al. (2017). Spatial similarities between European agroforestry systems and ecosystem services on landscape scale. *Agroforestry Systems* (in press). <https://doi.org/10.1007/s10457-017-0132-3>
2. Paper analysing how society perceives ecosystem services from different European agroforestry landscapes.  
Fagerholm et al. European cross-site comparison of place-based ecosystem services in multifunctional rural landscapes.
3. Paper describing the use of National Forest Inventory Data to assess spatial distribution of Agroforestry Systems dominated by *Castanea sativa* Mill. in north-western Spain (Annex C).  
Roces-Diaz et al. Sweet chestnut agroforestry systems in North-western Spain: classification, spatial distribution and an ecosystem services assessment. Submitted to *Forest Systems*.
4. Paper analysing how different ecosystem services trade-offs, synergies and bundles derived from social and environmental drivers in different landscapes of Europe (Annex D).  
Plieninger et al. Mediation of ecosystem services synergies, trade-offs and bundles by social and environmental drivers in European agricultural landscapes.

5. Paper proposing social-ecological archetypes for understanding current European rangelands and their potential for sustainability (Annex E).  
Hartel T et al. Forum: Social-ecological system archetypes for European rangelands. Submitted to *Rangeland Ecology & Management*.
6. Paper analysing relationships among ecosystem services identified by using bio-physical modelling methods and those perceived by society in different rural landscapes of Europe (Annex F).  
Roces-Diaz JV et al. Exploring the relationships among bio-physical and social-perceived ecosystem services across diverse European rural landscapes. Analysis ongoing.
7. Paper analysing economic profitability of ecosystem services in agroforestry in different European landscapes (Annex G).  
Kay S et al. Economic evaluation of ecosystem services in landscapes with and without agroforestry systems. Analysis ongoing.

## 2.2 The range of study areas and approaches

The studies included in Deliverable 7.21 include a wide variety of study areas and several methodological approaches:

- *Variety of study areas*: the study areas are located in different European landscapes across major biogeographical regions, in order to provide robust estimation of their ecosystem services (ES), independently of local context. Characteristics of study sites, agroforestry systems and related ecosystem services in pilot studies are described in Table 1. For example, Kay et al. (published) compares the spatial patterns of a series of ES across different landscapes, meanwhile Fagerholm et al. (submitted) analyse how these ES are perceived by people from 13 study landscapes across Europe. In a similar way, Plieninger et al. (submitted) explores differences on ES synergies, trade-offs and bundles of socio-cultural perceived ES for these 13 landscapes.
- *Methodological approaches*: studies included in this deliverables use for example robust spatially explicit models of ecosystem services (Kay et al. published) to provide estimations of them for different landscapes. In addition, societal perception of nature benefits were collected by means of interviews (i.e. Fagerholm et al. submitted; Plieninger et al. submitted). This information derives from a Public Participatory Geographic Information Systems (PPGIS) where more than 2,000 people were asked. Rocés-Díaz et al. (analysis ongoing) combine both types of approaches (models and PPGIS data) to study existence of positive and negative relationships among ecosystem services. Lastly Kay et al. (analysis ongoing) analysed relevance of agroforestry systems on these landscapes by including an economical approach to evaluate their profitability.

Table 1. Characteristics of study sites, studied agroforestry systems and related ecosystem services in the seven studies

| <b>Study and short title</b>  | <b>Kay et al. 2017</b><br>Spatial similarities between European agroforestry systems and ecosystem services on landscape scale   | <b>Fagerholm et al.</b><br>European cross-site comparison of place-based ecosystem services in multifunctional rural landscapes   | <b>Roces-Diaz et al.</b><br>Sweet chestnut agroforestry systems in North-western Spain          | <b>Plieninger et al.</b><br>Mediation of ecosystem services synergies, trade-offs and bundles by social and environmental drivers in European agricultural landscapes  |
|---|--|---|---|--|
| <b>Country</b>  | 4 European countries<br>Portugal, Spain, Switzerland, UK   | 10 European countries<br>France, Germany, Greece, Hungary, Portugal, Romania, Spain, Switzerland, Sweden, UK  | Spain   | 10 European countries<br>France, Germany, Greece, Hungary, Portugal, Romania, Spain, Switzerland, Sweden, UK   |
| <b>Agroforestry system</b>  | Montado, Dehesa, Chestnut soutus, Cherry Orchards, Wooded Pastures, Hedgerow landscapes  | Montado, Dehesa, Chestnut soutus, Cherry Orchards, Wooded Pastures (4x), Hedgerow landscapes (2x), Bocage, Olive Groves   | Sweet chestnut soutos   | Montado, Dehesa, Chestnut soutus, Cherry Orchards, Wooded Pastures (4x), Hedgerow landscapes (2x), Bocage, Olive Groves  |
| <b>Study area</b>   | 6 European case study sides: Montaña Oriental Lucense, Spain; The Brecks, England, UK; Franches Montagnes, Switzerland; Schwarzbubenland, Switzerland; Llanos de Trujillo, Spain; Montemor-o-Novo, Portugal. | 13 European case study sides: Montaña Oriental Lucense, Spain; Canton de Loudeac, France; The Brecks, UK; Linköping, Sweden; Franches Montagnes, Switzerland; Schwarzbubenland, Switzerland; Hochkirch-Weißenberg, Germany; Saxon region, Romania; Llanos de Trujillo, Spain; Serena Campiña, Spain; Kassandra, Greece; Montemor-o-Novo, Portugal; Zala, Hungary. | Northern of Iberian Peninsula   | 13 European case study sides: Montaña Oriental Lucense, Spain; Canton de Loudeac, France; The Brecks, England, UK; Linköping, Sweden; Franches Montagnes, Switzerland; Schwarzbubenland, Switzerland; Hochkirch-Weißenberg, Germany; Saxon region, Romania; Llanos de Trujillo, Spain; Serena Campiña, Spain; Kassandra, Greece; Montemor-o-Novo, Portugal; Zala, Hungary. |
| <b>Typical agroforestry-related ecosystem services in study area (mentioned by authors)</b> | Provisioning (food, material and water) and regulating services (nutrient retention, soil preservation, carbon sequestration, pollination and habitat diversity)   | Provisioning (food, material), Regulating (habitat, biodiversity, environmental capacities) and cultural services (outdoor activities; social interaction; aesthetic, existence and inspirational values; culture and heritage)   | Food provision, Material provision, Climate regulation, Erosion control, Traditional knowledge. | Provisioning (food, material), Regulating (habitat and biodiversity, environmental capacities) and cultural services (outdoor activities; social interaction; aesthetic values; culture and heritage; inspirational values; existence values)  |

Table 1 (continued). Characteristics of study sites, studied agroforestry systems and related ecosystem services in the seven studies

| <b>Study and short title</b>  | <b>Hartel et al.</b><br>Forum: Social-ecological system archetypes for European rangelands | <b>Roces-Diaz et al.</b><br>Exploring the relationships among bio-physical and social-perceived ecosystem services across diverse European rural landscapes   | <b>Kay et al.</b><br>Environmental economics of twelve European agroforestry systems   |
|---|--|---|--|
| <b>Country</b>  | Europe   | 9 European countries<br>France, Germany, Greece, Portugal, Romania, Spain, Switzerland, Sweden, UK  | 9 European countries<br>France, Germany, Greece, Portugal, Romania, Spain, Switzerland, Sweden, UK   |
| <b>Agroforestry system</b>  | Rangeland  | Montado, Dehesa, Chestnut souts, Cherry Orchards, Wooded Pastures (4x), Hedgerow landscapes (2x), Bocage, Olive Groves  | Montado, Dehesa, Chestnut souts, Cherry Orchards, Wooded Pastures (4x), Hedgerow landscapes (2x), Bocage, Olive Groves   |
| <b>Study area</b>   | Europe   | 12 European study cases:<br>Montaña Oriental Lucense, Spain; Canton de Loudeac, France; The Brecks, England, UK; Linköping, Sweden; Franches Montagnes, Switzerland; Schwarzbubenland, Switzerland; Hochkirch-Weißenberg, Germany; Saxon region, Romania; Llanos de Trujillo, Spain; Serena Campiña, Spain; Cassandra, Greece; Montemor-o-Novo, Portugal. | 12 European study cases<br>Montaña Oriental Lucense, Spain; Canton de Loudeac, France; The Brecks, England, UK; Linköping, Sweden; Franches Montagnes, Switzerland; Schwarzbubenland, Switzerland; Hochkirch-Weißenberg, Germany; Saxon region, Romania; Llanos de Trujillo, Spain; Serena Campiña, Spain; Cassandra, Greece; Montemor-o-Novo, Portugal. |
| <b>Typical agroforestry-related ecosystem services in study area (mentioned by authors)</b> |  | Diverse provisioning, regulating and cultural ecosystem services including modelling and public participatory approaches  | Provisioning (food, material and water) and regulating services (nutrient retention, soil preservation, carbon sequestration, and pollination)   |

Table 2. Approaches: characteristics of ecosystems service (ES) assessment approaches applied in seven studies.

| <b>Study and title</b>                               | <b>Kay et al.</b>  | <b>Fagerholm et al.</b>  | <b>Roces-Diaz et al.</b>  | <b>Plieninger et al.</b>  |
|--|--|--|---|---|
|  | Spatial similarities between European agroforestry systems and ecosystem services on landscape scale | European cross-site comparison of place-based ecosystem services in multifunctional rural landscapes | Sweet chestnut agroforestry systems in North-western Spain: classification, spatial distribution and an ecosystem services assessment   | Mediation of ecosystem services synergies, trade-offs and bundles by social and environmental drivers in European agricultural landscapes   |
| <b>ES approach</b>                                   | Spatially explicit models of ES supply   | Public Participatory GIS of socio-cultural perceived ES  | Identification of Agroforestry Systems and indicators of ES supply  | Public Participatory GIS of socio-cultural perceived ES   |
| <b>Spatial level of analysis</b>                     | Local (Landscape Test Sites)   | Rural landscapes   | Local (Forest plots)  | Rural landscapes  |
| <b>Study area</b>                                    | Six study areas across Europe  | 13 study areas across Europe   | North-western of Iberian Peninsula  | 13 study areas across Europe  |
| <b>Methodological approach and main methods used</b> | Provisioning, regulating and maintenance   | Supporting, provisioning, regulating, cultural   | Identification of field plot where agroforestry systems of <i>Castanea sativa</i> are dominant using forest plot information, discriminant analysis to define classification accuracy. Calculation of ES indicators using descriptive statistics. | Nonparametric correlation analyses to determine bivariate synergies and trade-offs between ES. Cluster analysis performed to identify bundles, and multi-nomial logit models to assess influence of land cover on ES. |

Table 2 (continued). Approaches: characteristics of ecosystems service assessment approaches applied in even studies

| <b>Study and title</b>                               | <b>Hartel et al.</b><br>Forum: Social-ecological system archetypes for European rangelands | <b>Roces-Diaz et al.</b><br>Exploring the relationships among bio-physical and social-perceived ecosystem services across diverse European rural landscapes.   | <b>Kay et al.</b><br>Economic evaluation of ecosystem services in landscapes with and without agroforestry systems |
|--|--|--|--|
| <b>ES approach</b>                                   | Conceptual approach  | Combination of spatially explicit modelling and Public Participatory GIS of socio-cultural perceived ES  | Valuing and monetarise of modelled ES  |
| <b>Spatial level of analysis</b>                     | European level   | Rural landscapes   | Rural landscapes   |
| <b>Study area</b>                                    | Europe   | 13 study areas across Europe   | 12 study areas across Europe   |
| <b>Methodological approach and main methods used</b> | Conceptual approach to classify rangeland archetypes                                       | Combination of both types of data (from ES modelling and PPGIS), analysed using different types of models (e.g. Random Forest or Bayesian) to explore relationships among ES and influence of Agroforestry systems on ES | Analyse economic performance of provisioning and regulating ES   |

Through the use of a range of study areas and approaches, a series of relevant scientific findings about the ecosystem services of agroforestry systems were obtained. For example, differences on spatial distribution of provisioning (materials or food) and regulating (climate regulation, erosion control, etc.) services were found in different landscapes (Kay et al. published). The spatial distribution and current extension of a relevant agroforestry system (*Castanea sativa* soutsos) were assessed in north-western Spain using a forest inventory. These results revealed a clear decline of this type of agroecosystem, and most of the associated ecosystems services. The Spatial patterns of ecosystems services as perceived by society were studied in Fagerholm et al. (submitted), who found large differences in the type of service, but also in relation with the contribution of different types of land uses. Plieninger et al. (submitted) explored relationships among ecosystem services perceived by society and found generally synergistic effects among them showing cohesive role of agroforestry systems on rural landscapes to link human perception and ecological functions. Finally, Kay et al. (analysis ongoing) showed how agroforestry systems can help to increase the social and economic benefits of these rural landscapes.

We conclude that in comprehensive ecosystem service assessment it is advantageous to bring together various approaches and plan an interdisciplinary research bridging natural and social science and economic approaches. Based on the pilot studies presented here, AGFORWARD Deliverable 7.21 performs comparative analyses of the performance of agroforestry systems in terms of ecosystem services across different study sites that represent all major agroforestry systems in Europe.

### **2.3 Description and synthesis of seven papers**

Agroforestry is the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal production systems, in order to benefit from the resulting ecological and economic interactions (Burgess et al. 2015). The diversity of practices encompassed by the term agroforestry is vast and includes land uses such as silvoarable systems, silvoarable systems, hedgerow, shelterbelt and riparian buffer strips, forest farming, and home gardens (Mosquera-Losada et al. 2017, den Herder et al. 2015). These agroforestry systems have played an important role in Europe in the past, and many current traditional land-use systems involve agroforestry. Economic conditions and a drive to produce low cost food decreased the importance of these systems during the twentieth century, but in recent years agroforestry has regained attention in Europe as a means of maintaining food production and profitability whilst enhancing environmental sustainability.

Agroforestry systems provide multiple ecosystem services, ranging from the provision of food, feed and fibre to non-commodity outputs, such as climate, water and soil regulation and recreational, aesthetic and cultural heritage values (e.g. McAdam et al. 2009; Torralba et al. 2016). Assessment of these ecosystem services creates knowledge to understand the supply and demand of ecosystem services, to support awareness raising, and inform the political agenda in the European Union (Cowling et al. 2008; Crossman et al. 2013; Maes et al. 2012). Evaluations of ecosystem functions and their potential provision of ecosystem services to people have been dominated by natural sciences and economics (Seppelt et al. 2011; Fagenholm et al. 2016). The common approaches to assessment have been identified as bio-physical, socio-cultural and economic (Cowling et al. 2008).

This deliverable aims to provide a synthesis of different ecosystem service assessment approaches tested in different agroforestry systems identified for work-package 7. The outputs provide evidence of the opportunities and challenges of each ecosystem service assessment approach and give insight for further synthesizing work in work-package 7. Below, each approach is shortly described and subsequently a synthesis for ecosystem service assessment approaches is presented.

Annex A (Kay et al. 2017) is a study where we compared ecosystem services provision of agroforestry and non-agroforestry landscapes in case study regions from three European biogeographical regions: Mediterranean (montado and dehesa), Continental (orchards and wooded pasture) and Atlantic agroforestry systems (chestnut *soutos* and hedgerows systems). Seven ecosystem service indicators (two provisioning and five regulating services) were mapped, modelled and assessed. Clear variations in amount and provision of ecosystem services were found between different types of agroforestry systems. Overall, our study underlines the positive influence of agroforestry systems on the supply of regulating services and their role to enhance landscape structure.

The article included in Annex B (Fagerholm et al. submitted) presents an assessment of place-based ecosystem services as perceived by residents across 13 rural landscapes in ten countries. The most intensively valued ecosystem service, their spatial patterns, and the respondent and landscape characteristics that determine the perception of the services were shown. The study indicates that mapping multiple ecosystem services, including cultural services, through participatory approaches offers complementary tools to prevailing biophysical and economic valuation approaches.

Annex C (Roces-Diaz et al. submitted) includes a study case where different types of data – mainly Spanish National Forest Inventory – were used to identify plots with *Castanea sativa* dominated agroforestry systems. We classified these ecosystems and found that the traditional agroforestry systems are of major importance in providing food or cultural services, but showed isolated distribution patterns. Moreover, other types of chestnut-dominated ecosystems, supply important ecosystem services such as biomass provision and climate regulation. The relevance of the ecosystem services of *C. sativa* agroforestry systems is highlighted together with their declining status.

The work included in Annex D (Plieninger et al. to be submitted) is focused on the analysis of the positive and negative associations of multiple ecosystem services within High Nature Value farmland. This study aims to identify ecosystem services synergies, trade-offs, and bundles in agricultural landscapes of high nature value from a socio-cultural perspective. It uses a participatory mapping survey of ten ecosystem services categories among 2,301 rural residents in 13 European sites. It finds two strong and 16 moderate synergies of ecosystem services (out of 46 possible ecosystem services pairs), mainly among different cultural ecosystem services, but it does not reveal moderate or strong trade-offs. This study complements prevailing biophysical and economic analyses of ecosystem services synergies, trade-offs and bundles by a spatially explicit, socio-cultural perspective.

Annex E (Hartel et al submitted) argues that European rangelands can be conceptualized as social-ecological systems, where the human management and the biophysical and functional properties of

the rangelands ecosystems are tightly linked. An outline of four archetypical social-ecological system representations for European rangelands were described based on the landscape physiognomy, capitals involved for co-production of ecosystem services and synergies and trade-offs in ecosystem services resulting from management.

Annex F (Roces-Diaz et al. analysis ongoing) presents work where two different approaches of describing ecosystem services were used: biophysical (derived from ecological models at landscape level) and socio-cultural (derived from public participatory geographic information systems). Data from both approaches were combined and the relationships among them were studied by using different types of models (including Random Forest and Bayesian type). In addition, the influence of the type of agroforestry systems (including arable, high nature value and high tree value) or the influence of the dominant type of land use were included in the analysis.

The work in Annex G (Kay et al. analysis ongoing) compares the economic performance of economic and environmental benefits of agroforestry systems and agricultural practises at the landscape scale. They suggest that agroforestry landscapes showed a slightly reduced output, than non-agroforestry landscapes, when concentrating on provisioning services, especially annual sales revenues for biomass production. However when regulating ecosystem services are included in a valuation of net landscape benefit, agroforestry systems emerged stronger in comparison to landscapes without agroforestry.

### 3 Acknowledgements

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## 5 Annex A: Paper 1: Spatial similarities between European agroforestry systems and ecosystem services at the landscape scale

This is a pre-print version of the following paper:

Kay S, Crous-Duran J, Ferreiro-Domínguez N, García de Jalón S, Graves A, Moreno G, Mosquera-Losada R, Palma J, Rocas-Díaz J, Santiago-Freijanes J, Szerencsits E, Weibel R and Herzog F (2017): Spatial similarities between European agroforestry systems and ecosystem services at the landscape scale. *Agroforestry Systems* doi: 10.1007/s10457-017-0132-3

### Abstract

Agroforestry systems are known to provide ecosystem services which differ in quantity and quality from conventional agricultural practices and could enhance rural landscapes. In this study we compared ecosystem services provision of agroforestry and non-agroforestry landscapes in case study regions from three European biogeographical regions: Mediterranean (montado and dehesa), Continental (orchards and wooded pasture) and Atlantic agroforestry systems (chestnut soutos and hedgerows systems). Seven ecosystem service indicators (two provisioning and five regulating services) were mapped, modelled and assessed.

Clear variations in amount and provision of ecosystem services were found between different types of agroforestry systems. Nonetheless regulating ecosystems services were improved in all agroforestry landscapes, with reduced nitrate losses, higher carbon sequestration, reduced soil losses, higher functional biodiversity focussed on pollination and greater habitat diversity reflected in a high proportion of semi-natural habitats. The results for provisioning services were inconsistent. While the annual biomass yield and the groundwater recharge rate tended to be higher in agricultural landscapes without agroforestry systems, the total biomass stock was reduced. These broad relationships were observed within and across the case study regions regardless of the agroforestry type or biogeographical region. Overall our study underlines the positive influence of agroforestry systems on the supply of regulating services and their role to enhance landscape structure.

### Keywords

Biodiversity, biomass production, carbon sequestration, erosion, groundwater recharge, nitrate leaching, pollination,

### 5.1 Introduction

Around forty percent of the European land area is used for agriculture (Eurostat 2013). Farmers cultivate the land to ensure food, fodder, energy and material supply, and by doing so, they shape the rural landscape (van der Zanden et al. 2016). Structural changes in agriculture, due to mechanisation and intensification of production, are thus reflected as visible changes in the landscape. Larger fields and farms as well as the removal of landscape elements such as trees, hedgerows, or wet areas have been some of the consequences (Biasi et al. 2016), resulting in the loss of the associated functions and environmental problems such as water pollution, erosion, and biodiversity loss (Tilman 1999). Thus, the performance of agricultural land should not only be

evaluated in relation to its production function but also in terms of demands for environmental, regulating, and aesthetic benefits from landscapes (Dale and Polasky 2007).

The Millennium Ecosystem Services Assessment outlined the value of ecosystems and their ecosystem services (ES) into provisioning, regulating and cultural services (MEA 2003; Haines-Young & Potschin 2013) and showed how these were degrading on a global scale. Subsequently this has triggered increased efforts in measuring, quantifying and mapping ES (e.g. Maes et al. 2012a) along with assessments of synergies and trade-offs in ES (e.g. Turner et al. 2014; Mouchet et al. 2017) in order to maintain the functionality of ecosystems and their benefits to society.

Agroforestry which deliberately integrates woody elements like trees or shrubs with agricultural crops and/or livestock has been proposed as an alternative land use approach that could potentially enhance ES provision (Pimentel et al. 1992; Jose 2009). Agroforestry systems (AF) have been identified for their high nature value and biodiversity (McNeely and Schroth 2006; Oppermann et al. 2012) and are listed for this in the EU Habitats Directive, receiving protection under the NATURA 2000 network (European Commission 1992). Their positive impact on all three ES pillars (provisioning, regulating and cultural, e.g. Torralba et al. 2016) and biodiversity are well studied at a local scale in wooded pastures (Moreno et al. 2016) and fruit orchards (e.g. Bailey et al. 2010), but little research exists on the benefits of agroforestry systems at the pan-European scale.

This paper therefore explores the potential of traditional temperate agroforestry systems to provide provisioning and regulating ES and investigates their spatial impact at the landscape scale. The cultural ES provision is presented by Fagerholm et al. (2016). We conducted case studies in three European biogeographical regions (Mediterranean, Continental and Atlantic). The study aimed to answer two specific research questions: (1) Do agroforestry practices enhance landscape in comparison to agricultural land by providing additional regulating ES? (2) Are these effects similar in different regions even though the specific types of agroforestry are different? In order to answer these two questions, we identified a set of case study areas in our selected biogeographical regions, modelled the provision of ES for each agroforestry system in those areas, and then aggregated the findings to make our assessment across all the case studies.

## **5.2 Data and Methods**

Six traditional European agroforestry landscapes (extent > 50 km<sup>2</sup>) in Mediterranean, Continental, and Atlantic regions were selected. In each region, four to seven adjacent municipalities were chosen and land use was broadly classified into agriculture (non-agroforestry) and agroforestry based on regional land use classification. In each of these two categories, four landscape test sites (LTS) of 1 km x 1 km each were selected randomly. A field protocol was used to map the habitats and the AF trees or AF hedgerows via a combination of aerial photograph interpretation and fieldwork in all LTS in a uniform manner. Field data were digitised and intersected with AF elements to generate habitat maps that allowed to undertake spatial ES assessment.

### *Case study regions*

The selected case study regions with typical agroforestry systems were: (1) montado in Portugal, (2) dehesa in Spain, (3) cherry orchards and (4) wooded pastures in Switzerland, (5) chestnut soutos in Spain and (6) hedgerow agroforestry landscapes in the United Kingdom. The systems differ in

character, management and objectives. Figure 1 shows the location of the regions, the composition and pictures of the LTS.

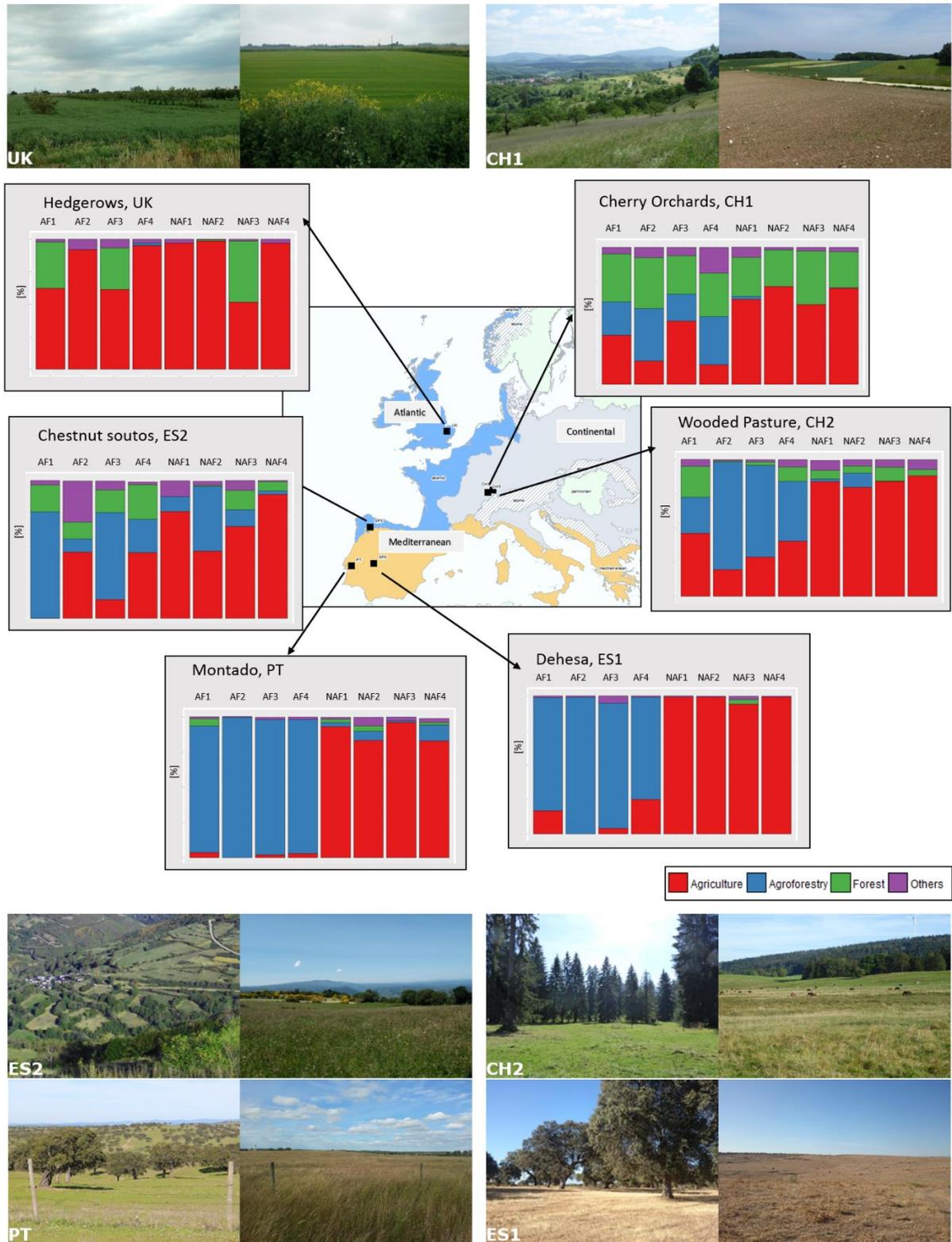


Figure 1. Location of the case study region, habitat composition and pictures of agroforestry (AF, left) and non-agroforestry (NAF, right) landscape test sites (LTS).

- (1) Montados occupy an area of 736,775 hectares in Portugal (AFN 2010) and are characterized by low density trees (25-50 trees ha<sup>-1</sup>) combined with agriculture or pastoral activities (Pereira and Tomé 2004). The main tree species are cork oak (*Quercus suber* L.) and/or holm oak (*Quercus rotundifolia* Lam.). Depending on the main tree species present, two different types of “montados” exist: 1) Cork oak montado where cork extraction is dominant, and 2) Holm oak montado where livestock (mainly cattle or sheep) are grazed during spring and Iberian pigs feed on acorns in autumn (Gaspar et al. 2007). The habitat mapping was done in Montemor-o-Novo, located in Central Portugal.
- (2) Dehesas are very similar to holm oak montados, with *Quercus ilex* L. In Spain dehesas occupy around 3.5 million hectares of land (Plieninger et al. 2015) and has a random pattern of around 25 trees ha<sup>-1</sup> where permanent grassland provides fodder in the form of acorns and grass for animal production. In addition to this, the timber and many other non-timber products are used (Fagerholm et al. 2016). The LTS selected for the ES assessment were located in Trujillo, in the southern Spanish region of Extremadura.
- (3) The cherry (*Prunus avium* L.) orchards are located in the north-western part of Switzerland. Traditional fruit orchards are widespread in central Europe (approximately 1 million hectares, (Herzog 1998a)) and were mainly established for subsistence and commercial fruit production. The cherry orchards in the Cantons of Solothurn and Basel-Landschaft usually consist in 50 – 80 trees ha<sup>-1</sup> of mixed age on permanent grassland that is grazed with cattle and occasionally mown.
- (4) The spruce (*Picea abies* L.) dominated wooded pastures, are located in the Jura mountains in western Switzerland, covering about 50,000 hectares (Herzog 1998b). Wood pastures are common in mountain areas and typically consist of dense and sparse woodland in a mosaic pattern (Buttler et al. 2009). The trees produce timber and fodder, typically for free ranging cattle and horses. The case study site was located around Saignelégier in the Canton Jura.
- (5) Chestnut (*Castanea sativa* Miller) soutos are a traditional land use system in north-western Iberia (Nati et al. 2016). They consist of ancient valuable trees (400 years old), are protected by the NATURA 2000 habitat network and occupy more than 350,000 hectares of land in Galicia and about 40,000 ha in Portugal. The system produces chestnut, fruit, and timber. In addition, it is known for mushroom production and in some areas grazed with pigs (Rigueiro-Rodríguez et al. 2014). The case study site was located in the western mountains of Lugo province in Galicia (Spain).
- (6) The hedgerows landscape in eastern England covers around 551,000 hectares of land and is widely spread in the UK (den Herder et al. 2017). The case study region near Thetford, in the Breckland district of Norfolk, consists of cereal crops surrounded by hedgerows. These contain several species of broadleaf trees and shrubs that were traditionally used for firewood. In addition to their use for marking field boundaries (living fence), they are used as a wind-break to reduce soil erosion by wind.

#### *Indicator assessment*

For each LTS we evaluated seven ES indicators; namely biomass yield and groundwater recharge rate as provisioning ES and the regulating services nitrate leaching, carbon sequestration, soil erosion, and biodiversity divided into pollination and habitat richness. The selection follows the Common International Classification of Ecosystem Services (CICES) classification (Haines-Young and Potschin

2013) with focus on relevant indicators in agriculture and agroforestry systems. The indicators, methods and data sources are summarised in Table 1.

Table 1. Ecosystem services indicators, methods and references.

| <b>CICES Section - Division</b>   |                      | <b>ES indicator</b>       | <b>Model</b>           | <b>Unit</b>   | <b>References</b>                                 |
|-----------------------------------|----------------------|---------------------------|------------------------|---|---|
| <b>Provisioning</b>               | Material             | Biomass yield             | EcoYield-SAFE          | t dry matter ha <sup>-1</sup> yr <sup>-1</sup><br>t dry matter ha <sup>-1</sup> | Palma et al, submitted.; van der Werf et al. 2007 |
|                                   | Water                | Groundwater recharge rate | Water balance          | mm  | Allen et al. 1998; Hürdler et al. 2015            |
| <b>Regulating and maintenance</b> | Nutrient retention   | Nitrate leaching          | MODIFFUS 3.0           | kg N ha <sup>-1</sup> yr <sup>-1</sup>  | Hürdler et al. 2015                               |
|                                   | Soil preservation    | Erosion                   | RUSLE                  | t soil ha <sup>-1</sup> yr <sup>-1</sup>  | Renard et al. 1997; Panagos et al. 2015           |
|                                   | Climate regulation   | Carbon sequestration      | EcoYield-SAFE, Yasso07 | t C ha <sup>-1</sup> yr <sup>-1</sup><br>t C ha <sup>-1</sup>                   | Liski et al. 2005; Palma et al. submitted         |
|                                   | Pollination          | Pollination               | Lonsdorf               | %   | Lonsdorf et al. 2009                              |
|                                   | Gene pool protection | Habitat richness          | SIDI, SoSNH, HD        | Unitless  | Bailey et al. 2007; Billeter et al. 2008          |

Indicators were calculated using spatial ES assessment models based on the habitat maps in combination with climate (online climate tool CliPick, (Palma 2017), soil (European Soil Database (ESDB)) and topographical information (International Centre for Tropical Agriculture (CIAT), digital elevation model (DEM) by Reuter et al. (2007) and Jarvis et al. (2008)) for each case study region.

The estimations of AF trees biomass production, crop yields and carbon sequestered (divided into annual use e.g. cereals, fruits, prunings, timber and total stock) by the systems' above and below ground biomass were provided using the EcoYield-SAFE model, a process-based agroforestry growth model that was calibrated for the assessed systems (Palma et al., submitted). In the hedgerow agroforestry landscape in the UK, observed data from farms were utilised. The average yield for cropland production came from FAO (2017).

The groundwater recharge rate was assessed using the water balance equation, which links precipitation (P), evapotranspiration (E), surface runoff (R) and the belowground water exchange ( $\Delta S$ ). The latter is the sum of storage change in the soil ( $\Delta S_{\text{Soil}}$ ) and the ground water recharge ( $\Delta S_{\text{Groundwater recharge}}$ ) (Equations 1, 2).

$$P = E + R + \Delta S \quad \text{with} \quad \Delta S = (\Delta S_{\text{Soil}} + \Delta S_{\text{Groundwater recharge}}) \quad (\text{Equations 1, 2})$$

Precipitation was based on climate data for each case study region from the online climate tool CliPick (Palma 2017). Evapotranspiration was calculated by the FAO Penman-Monteith equation (Allen et al. 1998) and the MODIFFUS 3.0 methodology (Hürdler et al. 2015) was applied to assess

the surface runoff. The groundwater recharge rate (GWRR) involves the amount of rainfall that percolates into the groundwater (Equation 3).

$$GWRR = \frac{\Delta S_{\text{Groundwater recharge}}}{P} * 100 \quad (\text{Equation 3})$$

In particular, DEM and soil information obtained from Panagos et al. (2012); Hiederer (2013); Ballabio et al. (2016); Makó et al. (2017) were used.

The assessment of nitrate leaching was based on the water cycle modelling and by deploying the MODIFFUS 3.0 method (Hürdler et al. 2015), an empirical model for nitrate and phosphorus losses. Herein leaching values for each land cover class weighted by factors for soil characteristics, fertilizer application, and drainage were set.

The RUSLE equation (Renard et al. 1997) was applied to assess soil loss by water. Herein the rainfall-runoff erosivity factor (R) is multiplied by the soil erodibility factor (K), the slope length factor (L), the slope steepness factor (S), the cover management factor (C) and the support practice factor (P). These results in the average soil loss (A) (Equation 4).

$$A = R * K * L * S * C * P \quad (\text{Equation 4})$$

The spatial data were provided from the European Soil Database (ESDB) (in particular Panagos et al., 2014, Panagos et al., 2015, Panagos et al., 2016).

Carbon sequestration was estimated as the sum of above and below ground crop and tree biomass, based on EcoYield-SAFE and in addition the soil organic carbon (SOC), modelled in YASSO0.7 (Liski et al. 2005). The YASSO model was primarily developed for forest stands, focusing on the decomposition of biomass fractions and their effects on soil carbon. The carbon assessment was divided into annual sequestration rate and total carbon stock.

The biodiversity assessment was divided into functions and capacities of nature represented by pollination and habitat richness and diversity. Lonsdorf et al. (2009) equations were spatially applied for evaluating the pollination potential for cavity and ground nesting species for 100 and 350 m flight and foraging distances. As a pre-requisite, flowering and nesting facilities for wild pollinators were recorded during the habitat mapping (except for the UK case study region). Landscape metrics, computed from the habitat maps of the LTS, were used as proxies for habitat richness (Billeter et al. 2008), particularly the Simpson diversity index (SIDI), the share of semi-natural habitat (SoSNH) and the number of semi-natural habitat types (HD).

The analysis of ES was conducted on two spatial levels. Firstly, the analysis was done at regional level comparing agroforestry and non-agroforestry LTS of each case study region separately. Secondly the results were aggregated at a landscape level including all LTS. All results were statically tested using t-tests and linear regressions in R (R Development Core Team 2013). The spatial analysis was performed in ArcGIS10.4 (ESRI 2016) and SAGA GIS (Conrad et al. 2015). The methods were described in detail by Kay et al. (submitted).

### 5.3 Results

Examples of the LTS habitat maps are shown in Figure 2. The range of results, separately per ES indicator, obtained from the model are summarised in Figure 3. Herein the spatially explicit results are aggregated to case study level, divided into agroforestry (AF) and non-agroforestry (NAF) LTS and arranged into Mediterranean, Continental and Atlantic regions. The analysis was done (i) for each case study and (ii) aggregated across all case study regions.

#### 5.3.1 Biomass

The annual use of biomass, mainly the crop yield plus tree prunings, ranged from 1.7 up to 14.5 t ha<sup>-1</sup> yr<sup>-1</sup> with an average of 4.3 t ha<sup>-1</sup> yr<sup>-1</sup>. In most regions, agricultural NAF LTS showed higher annual yields than AF landscapes. Exceptions were the Mediterranean systems, where the agroforestry LTS produced higher yields. Statistically validated differences between NAF and AF plots were found for montado, cherry orchards and spruce pasture (Table 2 and Figure 3). Over all regions, the variation between AF and NAF LTS was not statistically significant.

For the total stock value at any one time (t DM ha<sup>-1</sup>), which represents mainly the total volume of timber, the trends were reversed. With 25 t ha<sup>-1</sup>, AF landscapes had higher average biomass stocks than NAF (15.6 t ha<sup>-1</sup>). The outcomes varied between 0.1 t ha<sup>-1</sup> to 72 t ha<sup>-1</sup>. The overall comparison showed no significant difference between AF and NAF, while in montado, dehesa and spruce pasture significant variations were found.

#### 5.3.2 Groundwater recharge

The groundwater recharge rate varied between 18 and 54 % of the annual precipitation. The lowest values were obtained in agroforestry landscapes in the United Kingdom, while the highest values were in non-agroforestry LTS in Galicia and Portugal. The evapotranspiration was always higher in agroforestry areas. The recharge rate in AF LTS ranged between 28.7 % and 46.4 % with an average of 36.9 %. In NAF LTS the range was higher: between 35.3 % to 54.9 %, with an average of 43.6 %. These differences were statistically significant across all regions ( $p < 0.01$ ).

#### 5.3.3 Nitrate leaching

Values for nitrate leaching were very low, especially in southern Europe. They ranged between nearly 0 up to 37 kg N ha<sup>-1</sup> yr<sup>-1</sup>. AF LTS tended to leach less nitrate than NAF LTS; in average 5.2 kg N ha<sup>-1</sup> yr<sup>-1</sup> in AF as compared to 9.9 kg N ha<sup>-1</sup> yr<sup>-1</sup> in NAF. These overall differences between land cover classes were significant ( $p < 0.05$ ). Within the regions, cherry orchards and spruce pasture in Switzerland, dehesa and montado showed statistically verifiable variations between agroforestry and non-agroforestry test sites (Table 2).

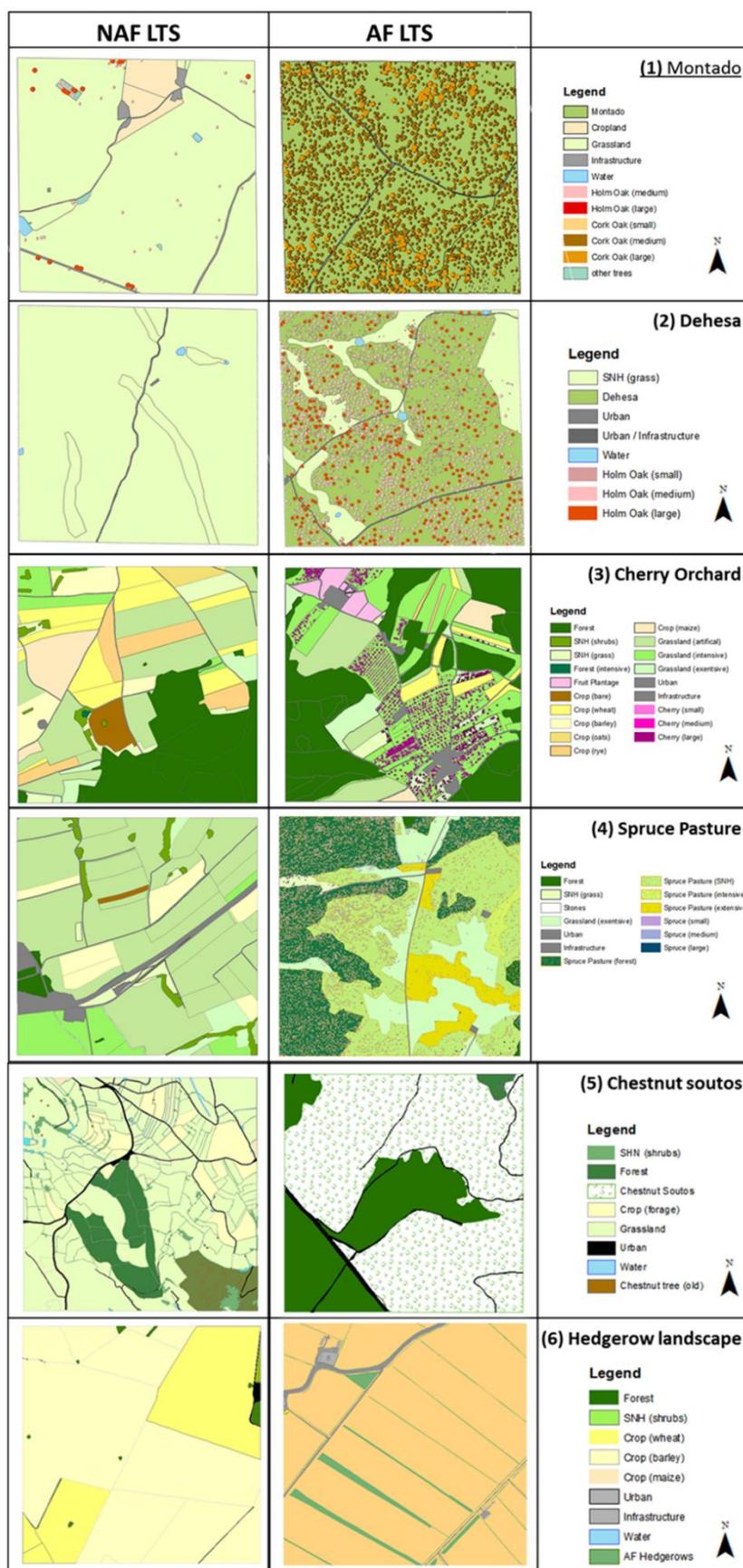
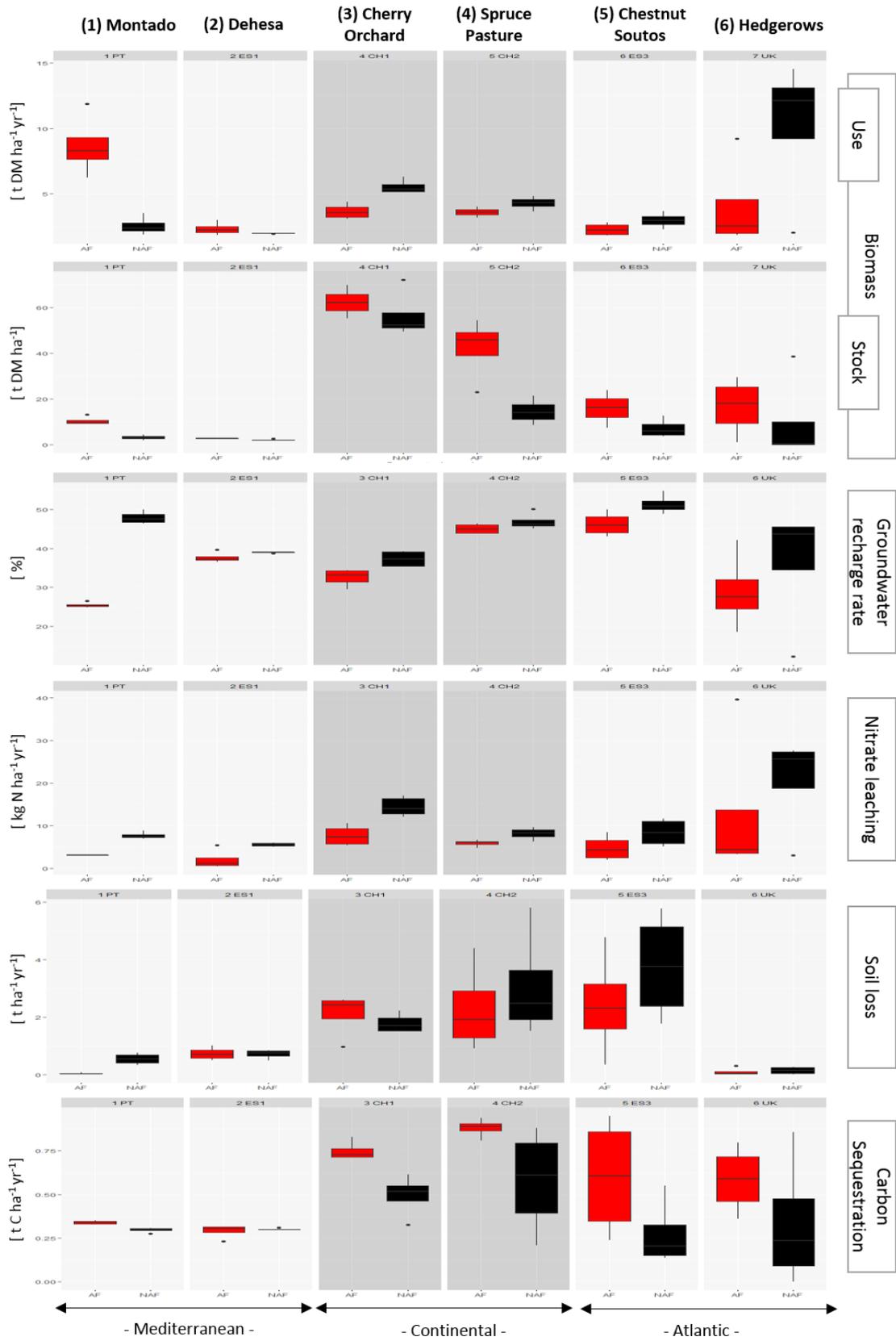


Figure 2. Examples of habitat maps of an agroforestry (AF) and a non-agroforestry (NAF) landscape test site (LTS) for each case study region.



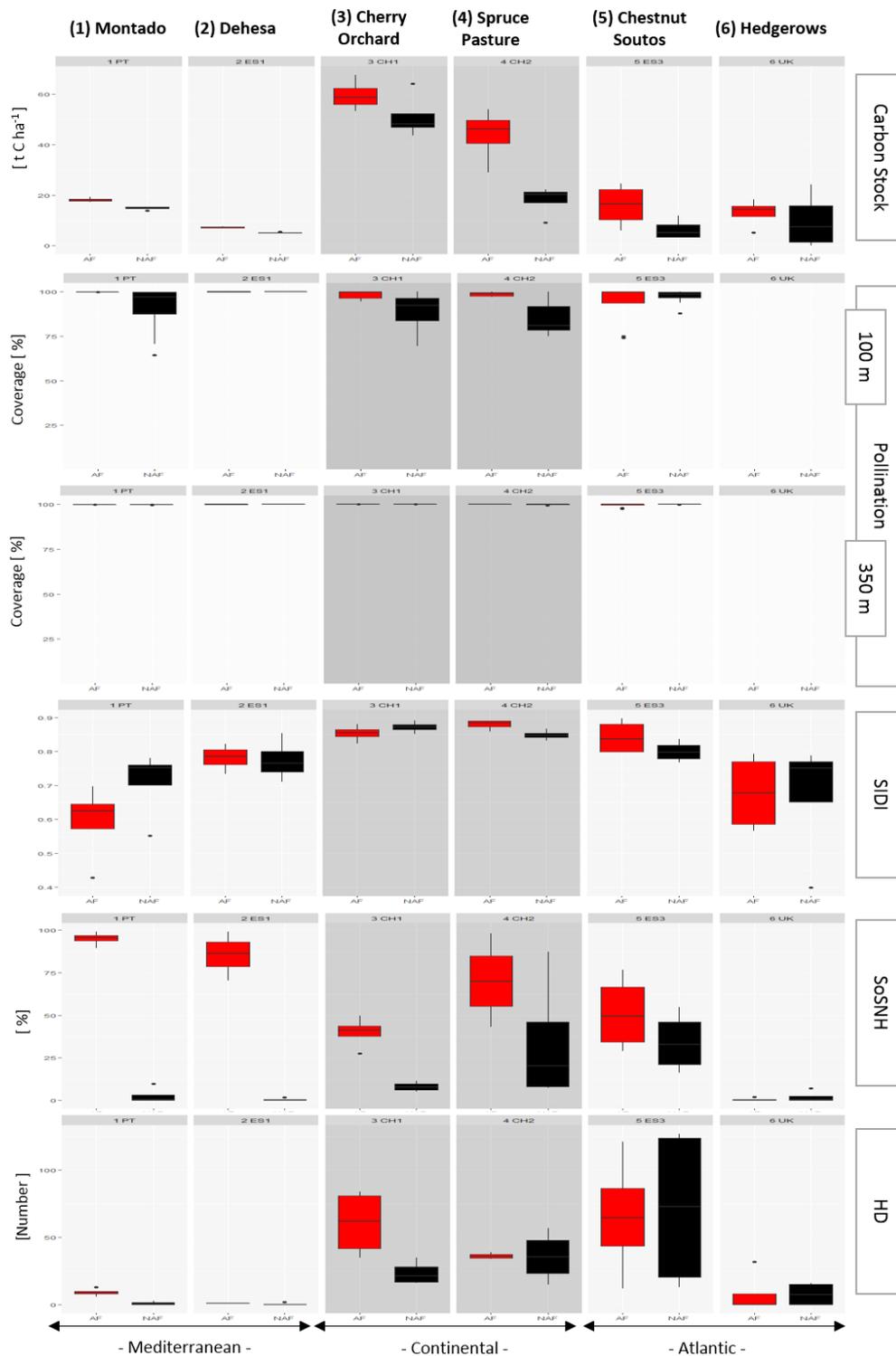


Figure 3. Summary of ES assessment grouped into agroforestry (AF - red) and non-agroforestry (NAF - black) landscape test sites for each case study region clustered into Mediterranean, Continental and Atlantic regions. Pollination services could not be evaluated for the UK. The bar graphs indicate mean values (horizontal line), standard deviation (upper and lower limits of boxes), range of values (lines) and outliers (points) [SIDI: Simpson's diversity index, SoSNH: share of semi-natural habitat, HD: Habitat Diversity]

### 5.3.4 Soil loss

The indicator of soil loss showed strong variations within and across regions. The average loss was  $1.39 \text{ t ha}^{-1} \text{ yr}^{-1}$  in AF, covering a range of  $0.01$  to  $4.7 \text{ t ha}^{-1} \text{ yr}^{-1}$ , and  $1.59 \text{ t ha}^{-1} \text{ yr}^{-1}$  in NAF ( $0.04$  -  $5.80 \text{ t ha}^{-1} \text{ yr}^{-1}$ ). No significant differences were found among AF and NAF LTS across all regions and within case study regions. Because soil loss and topography are closely interlinked, we tested soil loss against slope. Standard multiple linear regression models were used to relate AF and NAF LTS (Figure 4), p-values for slope were statistically significant ( $p < 0.01$ ) and showed a reducing effect of AF on soil loss.

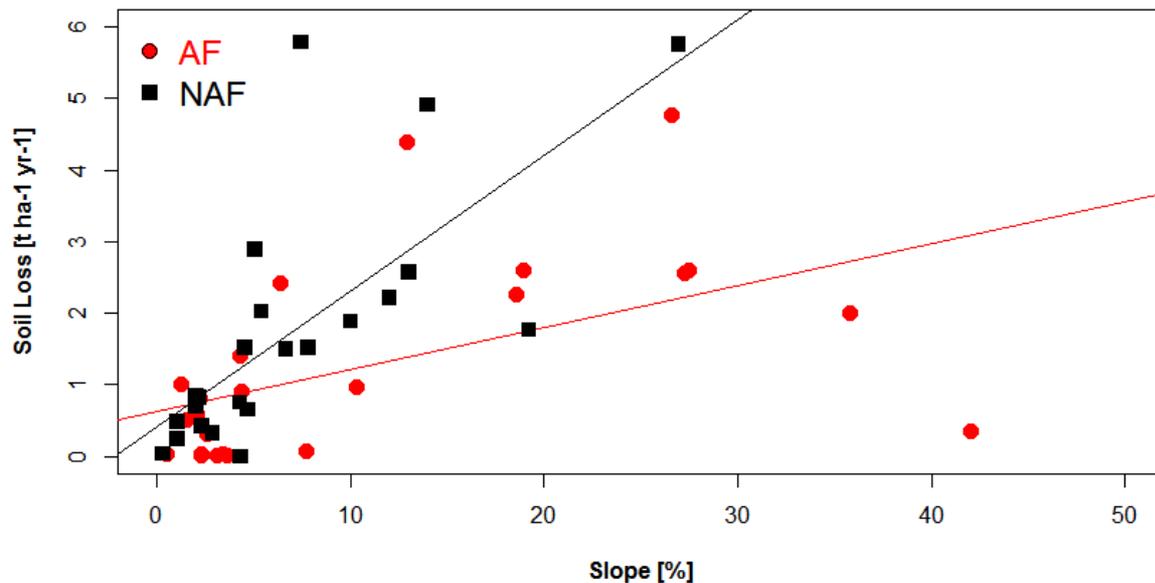


Figure 4. Erosion assessment grouped into agroforestry (AF, red) and non-agroforestry (NAF, black) landscape test sites as a function of the slope. [p-value:  $1.395 \times 10^{-5}$ , Adjusted R2: 0.394]

### 5.3.5 Carbon sequestration

The carbon assessment was divided into an annual carbon sequestration rate and the total carbon stock. The model results varied strongly within and across case study regions. In the overall trend agroforestry landscapes sequestered on average  $0.57 \text{ t C ha}^{-1} \text{ yr}^{-1}$ , while in NAF the value was around  $0.37 \text{ t C ha}^{-1} \text{ yr}^{-1}$  ( $p < 0.01$ ). The lowest average C sequestration rate was in cropland dominated landscapes in the UK and the highest in an agroforestry LTS in Switzerland. Results showing significant differences were found in the montado and the cherry orchards.

The model outcomes for carbon stock were similar to the carbon sequestration rate: in all case study regions, the agroforestry landscapes had a higher average amount of carbon stock compared to NAF LTS ( $26.2$  versus  $17.1 \text{ t C ha}^{-1}$ ). However, there was no overall significant difference between agroforestry and non-agroforestry areas. Significant variation was found in montado, dehesas and spruce pasture.

### 5.3.6 Pollination

The model demonstrated that pollinators and their services could potentially cover the whole area of most LTS within a distance of 350 m around the nesting facilities. The only exceptions were two NAF LTS in UK, where no flowering and nesting facilities for pollinators were mapped. Significant differences were found between all AF and NAF LTS for 100 m foraging distances. For the case study

regions, significant effects were found for 100 m foraging radius in montado, cherry orchards, spruce pasture and hedgerow landscapes.

### 5.3.7 Habitat Richness

The Simpson's diversity index assessment ranged between 0.3 and 0.89. The highest levels of diversity were recorded in the Swiss case study regions, while the lowest values were observed in a non-agroforestry LTS in the UK. None of the differences were statistically significant, though.

The variability of SoSNH was huge, with an overall trend towards a higher share of semi-natural habitats in agroforestry landscapes ( $p < 0.001$ ). In particular, this difference was statistically significant in the montado, dehesa and cherry orchard case study regions.

The indicator Total HD was also derived from mapping and showed wide-ranging values between 10 to more than 100 semi-natural habitat types per LTS. Although no correlation could be found across all case study regions, significant differences between the categories AF and NAF were revealed in the montado and the cherry orchard landscapes.

Table 2: Summary of statistically significant differences (p-values as a result of independent 2-group t-test) between agroforestry (AF) and non-agroforestry (NAF) landscape test sites (LTS) for all Ecosystem Service indicators in each case study and across all case study sites [PT: Montado Portugal, ES1: Dehesa Spain, CH1: Cherry Orchards Switzerland, CH2: Spruce pasture Switzerland, ES2: Chestnut soutsos, Spain, UK: Hedgerow agroforestry United Kingdom; \*:  $p < 0.05$ , \*\*:  $p < 0.01$ , \*\*\*:  $p < 0.001$ , NA: Pollination services could not be evaluated for the UK; (AF): AF LTS values higher, (NAF): NAF LTS values higher ]

| Ecosystem Service Indicators          |               | Case study regions |          |          |         |         |    | All case study regions |
|---------------------------------------|---------------|--------------------|----------|----------|---------|---------|----|------------------------|
|                                       |               | PT                 | ES1      | CH1      | CH2     | ES2     | UK |                        |
| Biomass                               | Use           | ** (AF)            |          | ** (NAF) |         |         |    |                        |
|                                       | Stock         | ** (AF)            | * (AF)   |          | * (AF)  |         |    |                        |
| Water                                 | Recharge Rate | *** (NAF)          |          | * (NAF)  |         | * (NAF) |    | ** (NAF)               |
| Nutrient retention                    |               | ** (NAF)           |          | ** (NAF) | * (NAF) |         |    | * (NAF)                |
| Soil conservation                     |               | * (NAF)            |          |          |         |         |    |                        |
| Carbon                                | Sequestration | ** (AF)            |          | * (AF)   |         |         |    | ** (AF)                |
|                                       | Stock         | ** (AF)            | *** (AF) |          | ** (AF) |         |    |                        |
| Pollination                           | 100m cavity   |                    |          |          | * (AF)  |         | NA |                        |
|                                       | 100m ground   |                    |          |          |         |         | NA |                        |
|                                       | 350m cavity   |                    |          |          |         |         | NA |                        |
|                                       | 350m ground   |                    |          |          |         |         | NA |                        |
| Simpson's diversity index (SIDI)      |               |                    |          |          | * (AF)  |         |    |                        |
| Share of semi-natural habitat (SoSNH) |               | *** (AF)           | *** (AF) | ** (AF)  |         |         |    | *** (AF)               |
| Habitat Diversity (HD)                |               | ** (AF)            |          |          |         |         |    |                        |

## 5.4 Discussion

The results demonstrate a positive impact of agroforestry practices and systems on the supply of regulating ES at the landscape scale for all compared agroforestry systems regardless of type, region or composition. This is all the more remarkable as the agroforestry area is between 5 % in the hedgerow landscapes in the UK, where only the hedgerows are qualified as AF and around 95 % in dehesas, Spain (Figure 1). Also, most LTS included all habitat types present in the respective region, i.e. also NAF landscapes contained some agroforestry plots – although at a much lower percentage than the AF LTS. Thus, differences between ES indicator values at LTS scale are less striking than they would have been at plot scale. However, plot scale comparisons are misleading for ES that involve processes that interact spatially (e.g. erosion, pollination). Nonetheless the positive effect on regulating ES provision is directly interlinked with the amount of agroforestry in the LTS.

Nitrogen leaching mainly occurs during autumn and winter season, when the nutrient uptake of plants is limited, but also during spring caused by intensive rainfall. Approaches for reducing these effects like using crops with higher water requirements, optimized fertilization and a permanent, year-round land cover optimally with trees were positively examined by for example Joffre et al. (1999), Herzog et al. (2008) and López-Díaz et al. (2011). In line with those observations, considering the tree as a permanent crop, nitrate leaching in the AF LTS was systematically lower than in the NAF LTS.

García-Ruiz et al. (2015) compared erosion rates in a meta-analysis. Slope and precipitation had the highest effect on soil loss, immediately followed by land use. Our AF LTS tended to have overall higher slope percentages. As a result, there was no significant difference between AF and NAF LTS, except for the orchards, where soil loss was actually higher in the agroforestry landscapes because orchards were systematically present on steeper slopes than the non-agroforestry land uses. Only in the montado LTS, erosion was significantly reduced on AF LTS.

Due to high biomass stock and lower decomposability of tree leaves and roots (Cornwell et al. 2008), AF LTS showed higher carbon sequestration rates and higher landscape carbon stock compared to agricultural LTS. The overall high carbon storage is particularly high in the Swiss case study regions. This is mainly due to the heterogeneous landscape structure and the amount of productive forest areas in the LTS. Yet, a recent investigation in an apple intercropping system showed increased carbon soil contents already seven years after tree planting (Seitz et al. 2017). The carbon sequestration rate in spruce wooded pasture is remarkably high, following the high productivity of coniferous tree species (Bebi et al. 2013). Chestnut sotos in Atlantic climates showed slightly lower values, hence the variance was higher within the region. Interestingly, small variations were found in dehesa in comparison to montado. This may be a result of the lower tree density in dehesa and edaphoclimatic conditions, changing storage in trees that can have wide difference in carbon storage (Palma et al. 2014). Howlett et al. (2011) measured an additional soil carbon storage in oak dominated agroforestry systems of around 4 % in comparison to pasture without trees.

Zulian et al. (2013) examined pollination services at European scale. In natural reserves and areas with semi-natural habitats, the full service was determined. Agroforestry systems were qualified as semi-natural habitats and provide a high level of pollination services. Only little differences were found between AF and NAF LTS within the case study regions, mainly due to geographical proximity

between the LTS and the overall complexity of the examined landscapes. Agri-environmental schemes have in general a positive impact on pollinator species richness and abundance, hence, these effects are even more strongly related to the structure and complexity of the broader landscape context (Scheper et al. 2013) .

Biodiversity needs to be evaluated at the landscape rather than at the plot scale, due to the importance of spatial interactions between habitats and species (e.g. Tscharntke et al. 2005). For the biodiversity metrics use here, differences were larger between case study regions than between AF and NAF LTS. This indicates the influence and relevance of broad landscapes contexts ( $> 1 \text{ km}^2$ ) in biodiversity assessments. In several case study regions, habitat diversity (SIDI) was lower in AF LTS than in NAF LTS. This is due to, for example, the lower diversity of crops in the cherry orchard landscapes and uniformly mapped AF in montados. The share of semi-natural habitats (SoSNH), on the other hand, was consistently higher in AF LTS than in NAF LTS because agroforestry systems were classified as semi-natural, in line with the European Habitats Directive (European Commission 1992) and the European High-Nature Value categories (Oppermann et al. 2012). In the UK hedgerow landscape, however, only the area of the hedgerows were classified as SNH, which leads in total to a low SNH coverage. Comparatively fewer habitats types (HD) in montado and dehesa are again a result of their large and homogenous spatial extent (Gaspar et al. 2007) and therefore uniform mapping of these systems. Nevertheless, marginal-unmanaged habitats, even if they only occur occasionally, are crucial for biodiversity in Iberian dehesas (Moreno et al. 2016).

Regarding provisioning ES, the results were more heterogeneous. The annual biomass use tended to be higher in NAF than in AF LTS except for montado. In this case the comparable agricultural practice was permanent grassland and in the Mediterranean climate, the presence of woody vegetation actually increases the forage availability by reducing wind speed and the water deficit in some periods of the year (Moreno and Cubera 2008; Pardini 2009), in addition to the acorns that also provide forage. Yield differences between the montado and dehesa case study regions could be explained by different agro-climatic conditions and tree density in the case studies (montado 50 vs. dehesa 20 trees  $\text{ha}^{-1}$ ). In contrast, the biomass stock tended to be higher in AF LTS as compared to NAF LTS. This is due to the long-term biomass stored in trees. The high values in the Swiss case study regions are related to the biomass rich forest, which are part of the LTS. Variable climate conditions account for differences between the NAF landscapes in the two Swiss case study regions. While in the orchard region the focus is on cereal production, the mountain area produces mainly grass and fodder for animals. For groundwater recharge – the other provisioning ES that was evaluated, the findings were again consistent across case study regions and agroforestry systems. Vegetation cover strongly affects groundwater recharge (Campos et al. 2013) and evapotranspiration is usually higher when trees are present, due to the higher biomass stock and the increased interception of rainfall (e.g. Bellot et al. 1999; Grubinger 2015). Consequently, groundwater recharge tended to be lower in the agroforestry landscapes across all LTS. The highest values occurred in regions with high precipitation rates, like in the chestnut sotos or the spruce pasture.

## 5.5 Conclusion

The spatially-explicit link between ecosystem service provision and landscape structure enables a general assessment of the contribution of agroforestry to landscape enhancement. The multifunctionality of agroforestry systems in comparison to agricultural landscapes was reflected by

reduced nitrate losses, higher carbon sequestration, reduced soil loss, higher pollination services and higher proportions of semi-natural habitats. Higher annual yields and higher groundwater recharge rates were linked to NAF areas. Whilst in traditional agroforestry landscapes the provisioning ecosystem services were lower and less biomass was leaving the system per hectare and year (with exception of Mediterranean agroforestry systems), regulating ES tended to perform better in AF landscapes.

Overall our study underlines that traditional agroforestry systems regardless of type, region and composition have a beneficial impact on the provision of regulating ecosystem services at the landscape scale. These general findings encourage to expect comparable results also for innovative agroforestry systems such as alley cropping or intercropping and grazed orchards. Against this background agroforestry systems can make a significant contribution to foster European environment policy and promote sustainable agriculture.

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