

Review

A systematic map of ecosystem services assessments around European agroforestry

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ABSTRACT

Agroforestry offers proven strategies as an environmentally benign and ecologically sustainable land management practice to promote ecosystem services. In this literature review, we systematically consider the agroforestry and ecosystem services literature with the aim to identify and catalogue the knowledge field and provide the first systematic synthesis of ecosystem services research in relation to European agroforestry. We reviewed 71 scientific publications from studies conducted in farmland and forest ecosystems with various types of agroforestry management. Each publication was systematically characterized and classified by agroforestry practice and research approach in order to provide an insight into the current research state in addressing ecosystem services (including methods, indicators, and approaches). Spatial distribution of the case study sites in Europe was also explored. In addition, typical clusters of similar research approaches were identified.

The results show that ecosystem service assessment of European agroforestry is currently focused on the spatially extensive wood pastures in the Mediterranean, Atlantic, and Continental agricultural mosaic landscapes. A specific emphasis has been on regulating, supporting, and provisioning services, such as provision of habitat and biodiversity, food, climate regulation, fibre, and fuel, and the consideration of cultural services has been largely limited to aesthetic value. There is a bias to biophysical and monetary research approaches. The majority of the studies focus on quantitative methods and biophysical field measurements addressing the assessment of only one or two services. Monetary approaches have been applied in less than one fifth of the studies but form a distinctive group.

Our results highlight gaps and biases in the ecosystem service research agenda within agroforestry based on which we conclude that research should aim to diversify from the biophysical and monetary approaches, towards a wider variety of approaches, especially socio-cultural, and a wider coverage of ecosystem services. Stronger consideration of stakeholder participation and introduction of spatially explicit mapping are also important key actions. We make suggestions to advance the promise of ecosystem services provision from European agroforestry in decision making including various actors, stakeholders, and institutions, with strong links to policy processes, such as the EU Biodiversity Strategy and Common Agricultural Policy.

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1. Introduction

The ecosystem services framework has become the most widely adopted integrated framework to study the relations between ecosystems and people. Conceptually it describes how biophysical systems provide a variety of important benefits to human well-being and ultimately it can guide decision-making towards halting or reversing ecosystem degradation (Daily, 1997; Haines-Young and Potschin, 2010; MA, 2005). For this reason the assessment of ecosystem services is important, as it creates the knowledge to understand the supply and demand of ecosystem services, to support awareness raising, and to achieve priority on the political agenda, for example in the European Union (EU) (Cowling et al., 2008; Crossman et al., 2013; Maes et al., 2012).

Assessments of ecosystem functions and their potential provision of services to people have been dominated by natural sciences and economics (Seppelt et al., 2011; Vihervaara et al., 2010). The common approaches to assessment have been identified as biophysical, socio-cultural and monetary (Cowling et al., 2008; de Groot et al., 2010) or alternatively as habitat, system and place-based approaches (Potschin and Haines-Young, 2013). A general tendency in ecosystem service assessments, depicted by the recent literature, is that the measurement of cultural services lags behind the regulating, provisioning, and supporting services categories (Crossman et al., 2013; Martínez-Harms and Balvanera, 2012; Seppelt et al., 2011).

The ecosystem services concept also offers a transformative lens for agroecosystems, the most common anthropogenic ecosystem on the planet (Swinton et al., 2006). While agricultural intensification and expansion are among the most important drivers of ecosystem services degradation (MA, 2005), several multifunctional land-use systems hold the promise to safeguard ecosystem services within commodity production (O'Farrell and Anderson, 2010; Tscharntke et al., 2005). Agroforestry, widely adopted in the world's tropical and subtropical regions, is one of such land-use systems that provide multiple ecosystem services, combining the provision of agricultural and forestry products with non-commodity outputs, such as climate, water and soil regulation, and recreational, aesthetic and cultural heritage values (McAdam et al., 2009). The main trait of agroforestry is the deliberate combination of trees/shrubs with agricultural crops or livestock, with people playing a key management role (Mosquera-Losada et al., 2009). The principal forms of agroforestry in Europe include wood pastures, the use of hedgerows, windbreaks, and riparian buffer strips on farmland, intercropped and grazed orchards, grazed forests, forest farming, and more modern silvoarable and silvopastoral systems. Agroforestry has traditionally formed an important element of European landscapes, but many of these systems have disappeared due to economic and social changes (among others, land abandonment and agricultural intensification),

and the remaining ones are highly vulnerable (Nerlich et al., 2013).

An assessment of the current spatial extent of agroforestry by den Herder et al. (2015) shows that agroforestry is most widely practised in southern Europe, especially in Spain, Portugal, Greece, and Italy. Wood pastures cover an extensive area and are distributed around Europe from the Mediterranean oak tree systems to Boreal wood pastures (Plieninger et al., 2015). Most fruit tree systems are found in central and Mediterranean Europe, with mixed olive cultivation in the Mediterranean being the most area-extensive expression of this agroforestry type. Also the traditional temperate fruit orchards are prominent (Herzog, 1998). Currently, agroforestry in the European Union is practiced at least on an area of 25 million hectares, which is equivalent to about 5.7% of the territorial area and 14.2% of the utilized agricultural area (den Herder et al., 2015).

Agroforestry has the potential to advance sustainable rural development in Europe (Primdahl et al., 2013). A key environmental benefit of agroforestry is the possibility to diversify agricultural landscapes with trees and to increase overall biodiversity (Mosquera-Losada et al., 2009; Nerlich et al., 2013). The key agricultural benefits include the opportunity to significantly increase land resource efficiency and productivity compared to the separation of agricultural and tree systems (Cannell et al., 1996; Graves et al., 2007), and to improve animal welfare. Jose (2009) has raised awareness for the ecosystem services that are mediated by global agroforestry not only to farmers and landowners, but also to society at large. The evidence supporting the promotion of agroforestry specifically in Europe has been reviewed by Smith et al. (2013) with the conclusion that temperate agroforestry balances both productivity and environmental protection through multiple ecosystem services. The challenge, however, lies in mainstreaming this land use practice. A meta-analysis on the role of scattered trees occurring throughout farmland matrix and their role as keystone structures maintaining ecosystem services by Rivest et al. (2013) also concluded that management options exist to conserve and restore trees but farmers need to be supported by relevant policies. In addition, Tsonkova et al. (2012) reviewed the ecosystem services provided by a specific type of temperate agroforestry, named alley cropping systems, and identified benefits in terms of increased carbon sequestration, improved soil fertility, enhanced biodiversity and increased overall productivity on marginal lands. Other reviews regarding European agroforestry practises have been published, for example, by Eichhorn et al. (2006) where the focus was on listing and quantifying the existing systems of silvoarable agroforestry and to document the recent changes and by Nerlich et al. (2013) who characterized traditional agroforestry practices and their disappearance from farmland. These recent reviews do not, however, systematically consider the agroforestry and ecosystem services literature in Europe.

The current review addresses this gap and produces a systematic and comprehensive evaluation of the knowledge field through mapping the conducted studies and applied research approaches for ecosystem services assessment around European agroforestry. The aim of this literature review is to identify and catalogue the knowledge field and provide the first systematic synthesis of ecosystem services research in relation to European agroforestry. The specific questions to address include: (1) What agroforestry systems and ecosystem services have been studied in Europe? (2) What approaches to ecosystem service assessment have been applied in research? (3) How are agroforestry systems, ecosystem services and research approaches interlinked? Based on the findings, the existing research gaps and biases are discussed. We then interpret our results from the perspective of the [Daily et al. \(2009\)](#) framework on “Ecosystem services in decision making” to derive recommendations on how to make research on ecosystem services from European agroforestry more relevant for land use policy and practice.

2. Material and method

We reviewed scientific publications from studies conducted in farmland or forest ecosystems in Europe with various types of agroforestry management. Our review followed established guidelines for systematic review and systematic mapping ([Bates et al., 2007](#); [Collaboration for Environmental Evidence, 2013](#); [Pullin and Knight, 2009](#); [Pullin and Stewart, 2006](#)) and was oriented along previous review exercises in the field of ecosystem services ([Milcu et al., 2013](#); [Nieto-Romero et al., 2014](#); [Seppelt et al., 2011](#); [Smith et al., 2013](#); [Vihervaara et al., 2010](#)). Evidence-based formalized systematic review frameworks were initially developed in the health sciences and have recently started to raise interest also within conservation and environmental management to guide research and policy-making ([Bilotta et al., 2014](#); [Pullin and Stewart, 2006](#)). The advantages of such a formalized methodology for literature review stems from the rigour and objectivity in the process combined with the underlying philosophy of transparency and independence. The systematic review approach aims to build new knowledge from a rigorous analysis of existing research findings. Systematic mapping, the approach used in this review, has similarities with the systematic review but has a focus on gathering existing literature into a searchable database and provide a transparent evidence base ([Bates et al., 2007](#)).

Electronic academic databases used in the search for relevant items comprised ISI Web of Science, Scopus, CAB Abstracts (Ovid), BIOSIS Citation Index, and Geobase (Ovid). Publication search combined three search strings in English with the following topics: (1) agroforestry and related definitions describing agroforestry systems, structures and practices, (2) ecosystem services and related definitions such as the equivalent of environmental services, and (3) Europe and specific countries. A scoping exercise was performed to pilot search terms and strings to iteratively revise the search terms, presented in detail in [Appendix A](#). We covered a wide variety of terms applied for European agroforestry systems and practices and also aimed to include diverse search terms for ecosystem services. It is nevertheless likely that some relevant publications were not captured in this data search. The use of single ecosystem service types (e.g. nutrient cycling) as search words would have yielded an extensive amount of results but we were interested in those studies that were clearly linked to ecosystem services research. Hence, we covered only studies that defined themselves as ecosystem services research, in line with the literature researches applied by [Martínez-Harms and Balvanera \(2012\)](#), [Nieto-Romero et al. \(2014\)](#) and [Seppelt et al. \(2011\)](#). We did not include grey literature, as we aimed to review internationally published

studies on agroforestry and multiple ecosystem services. Titles and abstracts were stored in an Endnote database and duplicates removed.

The searches were performed in August 2014 and resulted in a total of 286 references including journal articles, reports, books, book chapters, and conference papers. From these we manually selected those studies which: (1) address one or more agroforestry practices within the European biogeographical regions and (2) provide assessment of biodiversity or one or more ecosystem services. Items were selected through a three step filtering process ([Pullin and Stewart, 2006](#)) during which, in the first instance, the inclusion criteria were applied on title. Secondly, items remaining were filtered by abstract (or introduction section or equivalent if an abstract was not available) and, further, by viewing remaining items at full text content. We applied the inclusion criteria conservatively at the different stages of the filtering process, especially title and abstract were in most cases read together, in order not to exclude any relevant publications. If a study and the results were covered in several publications, only one of them was included. To check for data quality and consistency of application of the inclusion criteria, another reviewer went independently through the first filters of title and abstract on a random subsample of 10% of references ([Pullin and Stewart, 2006](#)). A kappa value of 0.729 ($p=0.000$) was calculated, which indicates a substantial level of agreement between reviewers ([Cohen, 1960](#): <0.5). In addition, the review by [Smith et al. \(2013\)](#) was searched for relevant publications. Finally, 71 publications published in English, Spanish, German, and Swedish were considered in the analysis ([Appendix B](#)).

To characterize the context of agroforestry and ecosystem service assessment literature, each publication was classified according to publication characteristics, study location and context, and characteristics of agroforestry practice studied ([Fig. 1](#)). To classify agroforestry practices we developed a typology based on previously suggested categorisations ([Mosquera-Losada et al., 2009](#); [Nerlich et al., 2013](#)) and our interpretation of the agroforestry practices appearing in the data, including wood pastures, woodlots and scattered farm trees, forest grazing, hedgerows, orchards, riparian buffer strips, and modern agroforestry systems (systems often based on traditional practices, modified by research and experience and well adapted to modern farming, e.g. modern tree-pig systems, cf. [Nerlich et al., 2013](#)). A spatial data layer

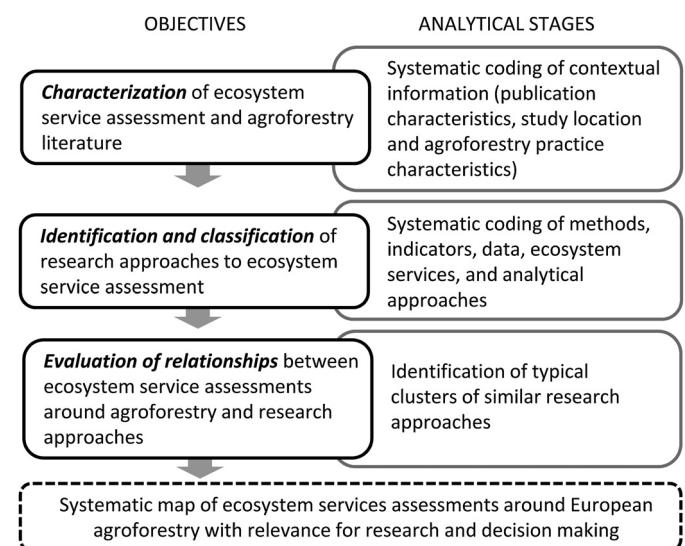


Fig. 1. Objectives of the systematic mapping of ecosystem services assessments around European agroforestry with related analytical stages.

was produced for study site locations. Data on biogeographical region (EEA, 2011) and land system archetype (Levers et al., accepted for publication) were extracted to each site. Subsequently, to identify and classify the research approaches to ecosystem service assessment, each study was coded based on methods, ecosystem services under assessment, data sources, indicators, and analytical approaches. Classification of ecosystem services followed that of the Millennium Ecosystem Assessment (MA, 2005). Data extraction variables are presented in detail in Appendix C. All categories were pretested to guarantee repeatability and consistency.

Characterization of the studied variables was approached through descriptive statistics. Cluster analysis was applied to identify typical clusters of studies approaching ecosystem services and their assessment in similar ways. To reach this goal seven key variables were specified after testing with various amounts of variables (Appendix C). Agglomerative hierarchical clustering with Ward's method and squared Euclidian distance was applied for this purpose in SPSS22 (Everitt et al., 2011; Murtagh and Legendre, 2014; cf. Milcu et al., 2013). Clustering sorts the publications based on the specified key variables starting from n clusters ($n=71$ publications) and continues to sort these into clusters of sameness, following a bottom up logic,

until one cluster remains. Ward's clustering was selected as it is widely understood and readily interpretable. Four clusters were chosen as a meaningful interpretation balancing the inner homogeneity of a cluster and the external heterogeneousness in relation to other clusters. Clusters were examined using descriptive statistics.

3. Results

3.1. Characteristics of agroforestry and ecosystem service assessment literature

The 71 reviewed publications are peer-reviewed journal articles (83%) and book sections (17%) published between 1993 and 2014 (Fig. 2B). More than 80% of the publications have appeared since 2007 (Fig. 2B). The publications cover 151 study sites in a total of 12 European countries (Fig. 2A and C). Most of the study sites are located in Spain (45%), the UK (15%), and France (14%) and mainly in the Mediterranean (44%), Atlantic (36%), and Continental (17%) biogeographical regions, the majority of them being patch (38%) and local (37%) scale studies rather than regional or national scale (25%) (Fig. 2A and D). Two studies are performed at European scale (Reisner et al., 2007; Schulp et al., 2014) and two address modelled

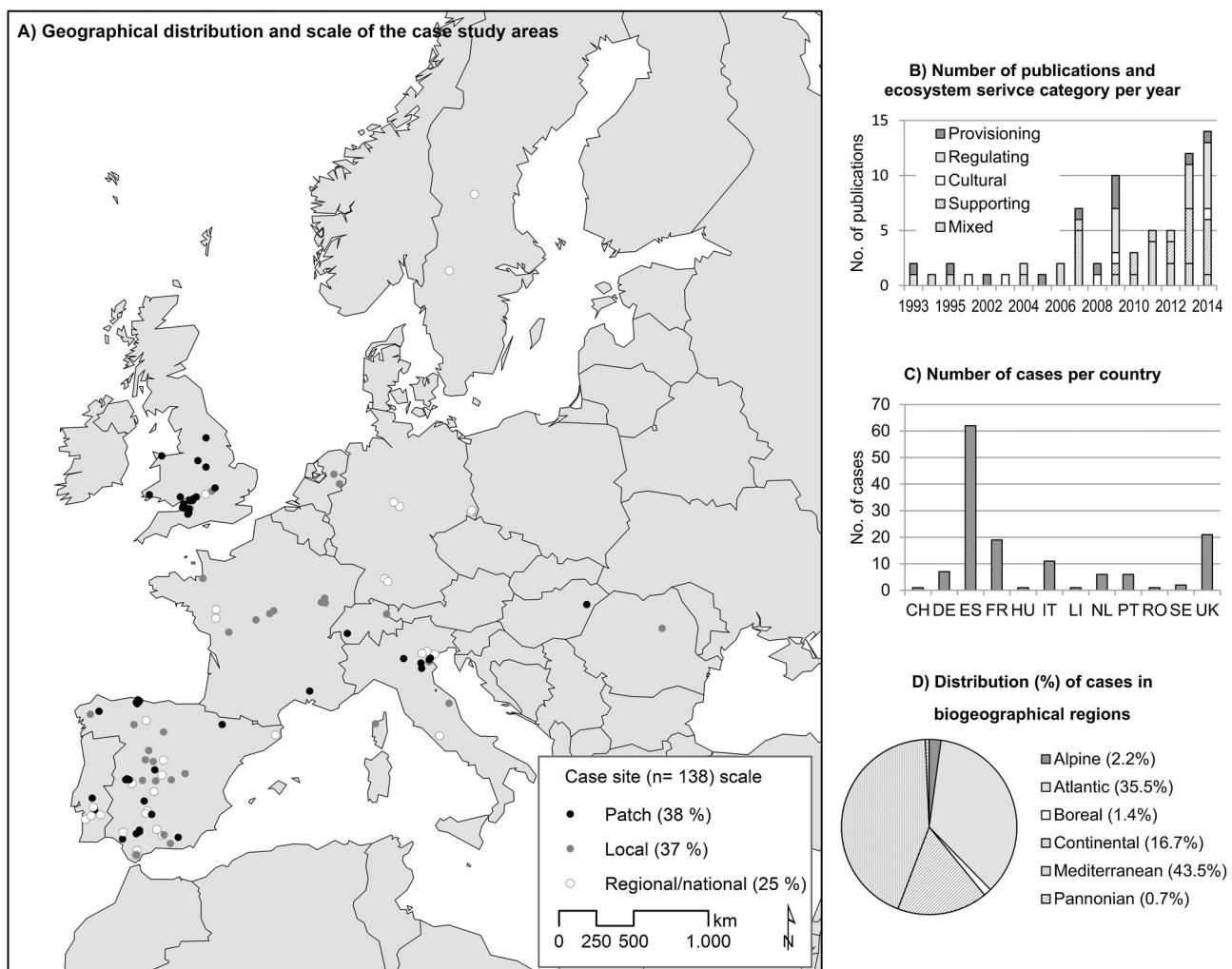


Fig. 2. Geographical distribution and the scale of the case study sites ($n=138$, 13 sites missing due to lack of data) addressed in the 71 publications: (A) geographical distribution and scale of study areas, (B) number of publications and ecosystem service category per year, (C) number of case study sites per country, and (D) distribution of case in the European biogeographical regions.

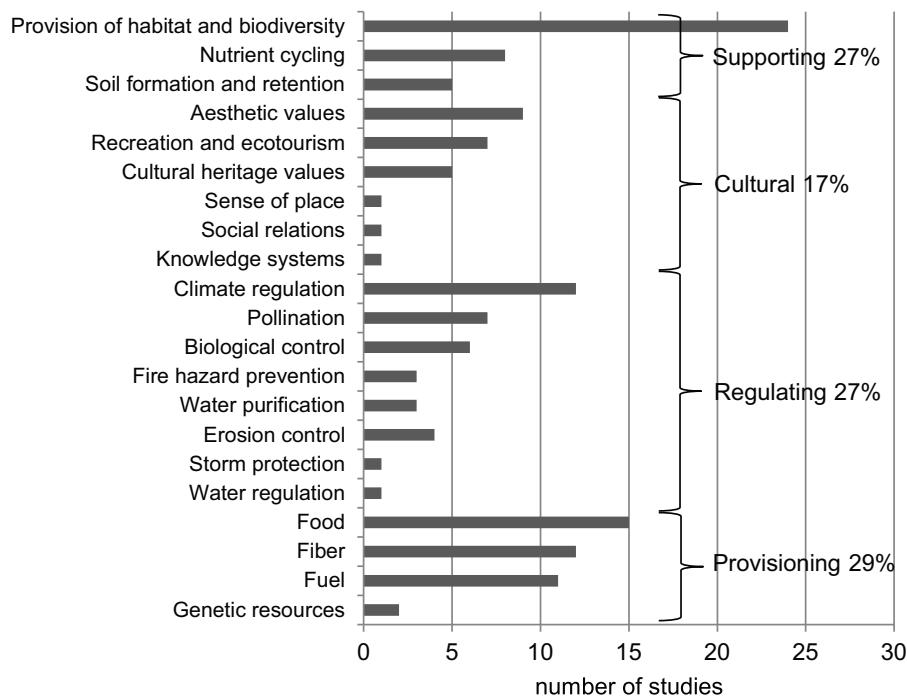


Fig. 3. Frequency of the different ecosystem services appearing in the 71 publications and their share (%) in ecosystem service categories.

landscapes (Brownlow et al., 2005; Kaeser et al., 2011). The number of study sites per publication varies between 1 and 20 (mean 2.7, SD 4.1), with most studies (79%) focusing on 1–2 sites.

In total, 21 different ecosystem services including biodiversity have been studied. The most common services assessed in the sample are provision of habitat and biodiversity, food, fibre, climate regulation, and fuel (Fig. 3). In general, provisioning, regulating, and supporting services are equally addressed (with 29%, 27%, and 27% share of all studied services respectively), with 17% share

including an assessment of cultural services. Addressing more than one ecosystem service category in a study has become more prominent after the mid-2000s (Fig. 2B, category mixed).

3.2. Characteristics of agroforestry practices

The studied agroforestry practices are dominated by wood pastures (44%) including Spanish *dehesa* and Portuguese *montado* landscapes and other grazed woodlands (Fig. 4). Silvoarable

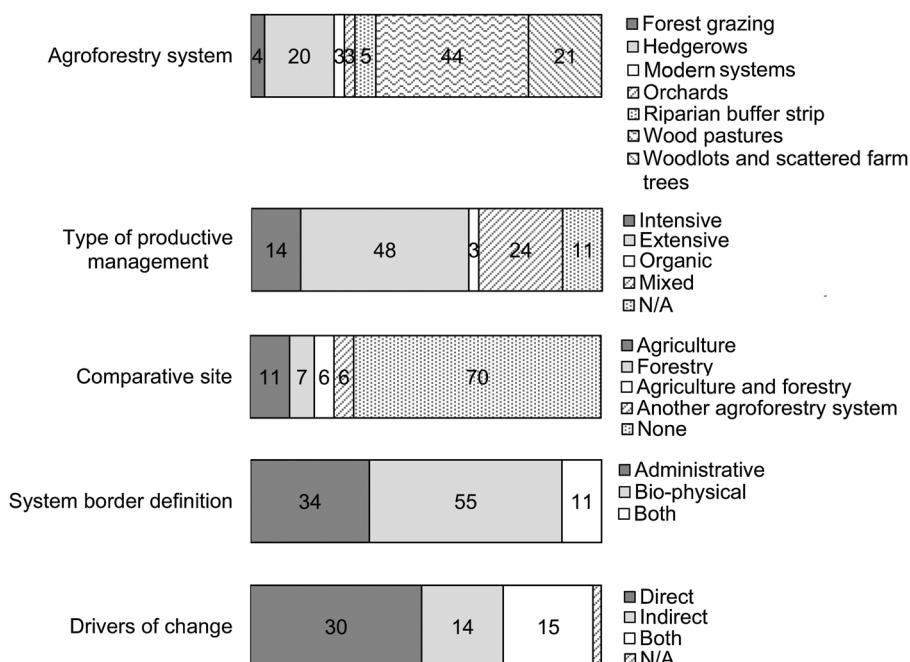


Fig. 4. Variables characterizing agroforestry systems with relative proportions (%) of studies (category labels with value less than 3% are not shown in the figure).

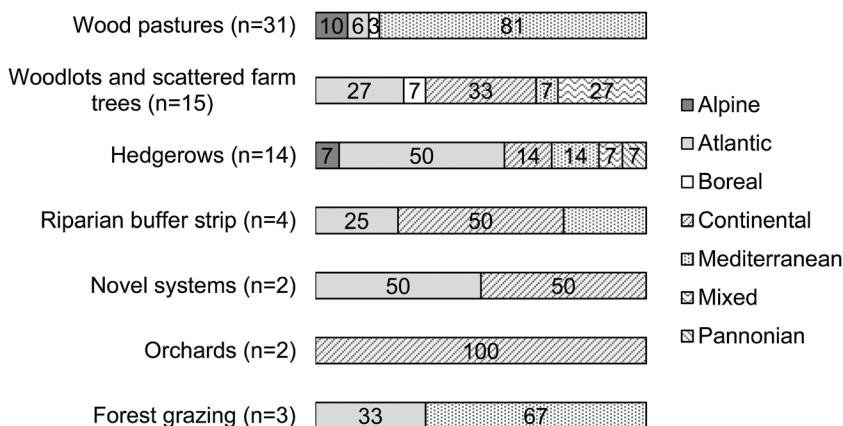


Fig. 5. Distribution of agroforestry systems addressed in the studies ($n = 71$) within the European biogeographical regions (in %).

systems are also prominent, most often characterized by agricultural mosaic landscapes with woodlots and scattered farm trees (21%), hedgerow systems (20%), and riparian buffer strips (6%). Forest grazing, orchards, and modern agroforestry systems have gained less attention in the reviewed literature (4%, 3% and 3% of studies respectively). Wood pastures are mainly addressed in the Mediterranean biogeographical region (81%) and silvoarable systems mostly in the Atlantic and Continental regions (Fig. 5). Hedgerow systems are the most heterogeneous type in terms of biogeographical regions, whereas orchards have been studied only in the Continental region.

Approximately half (48%) of the studies are based on extensive management, with only 14% categorized as intensively managed. Mixed productive management (e.g. both organic and intensively managed conventional farms) and organic management comprise 24% and 3% respectively (Fig. 4). In terms of land system archetypes, a significant share of the patch and local scale study sites are located on arable cropland (classes 3, 4, and 5: 41.3%) or on grassland (classes 7, 8, and 9: 25.7%, Table 1). Both of these land systems are represented 15% more compared to their spatial extent in Europe. Then again, studies located in areas defined as forest systems are less present compared to their spatial extent (classes 11 and 12:

Table 1
Relative proportion of land system archetypes (LSA, [Levers et al., accepted for publication](#)) characterizing patch and local scale study sites and their distribution in the European Union.

Class	Land system archetype ^b	Study areas (%) (n=97) ^a	Areal coverage (%) in European Union
1	High-intensity cropland (high arable cropland cover and yields, accompanied by very high permanent cropland yields)	1.0	1.3
2	Large-scale permanent cropland (high permanent cropland cover and above average permanent crop yields)	6.2	3.8
3	High-intensity arable cropland (high fertilizer input, high arable cropland cover, and high arable yields)	13.4	7.5
4	Medium-intensity arable cropland (medium fertilizer input, high arable cropland cover, and somewhat above average arable yields)	17.6	11.9
5	Low-intensity arable cropland (low fertilizer input and high arable cropland cover with average arable yields)	10.3	6.2
6	Fallow farmland (high fallow farmland and low values for other indicators of agricultural intensity)	1.0	3.9
7	High-intensity livestock farming (high livestock density, very high grassland cover, and very high grassland yields)	8.2	0.9
8	Medium-intensity livestock farming (medium livestock density, very high grassland cover, and high grassland yields)	8.2	4.0
9	Low-intensity livestock farming (low livestock density, high grassland cover, and somewhat above average grassland yields)	9.3	5.9
10	Low-intensity grassland area (very high grassland cover (often used for grazing) and low values for all other indicators)	11.3	9.2
11	High-intensity forest (high forest cover and high forest harvesting)	1.0	8.3
12	Low-intensity forest (high forest cover and low values for all other indicators)	2.1	19.3
13	High-intensity agricultural mosaic (high cropland and grassland yields, high fertiliser input, and high livestock density with moderately high agricultural coverage and low forest cover)	5.2	4.5
14	Low-intensity mosaic (no marked differences from indicator mean values. Cropland and grassland cover as well as fertilizer and livestock density are slightly below average, while forest cover and arable yields are slightly above average)	5.2	11.5
15	Urban built up (high urban built up cover and low values for all other indicators)	0.0	1.8

^a Regional/national scale studies ($n = 34$) were excluded from analysis to appreciate the spatial resolution (3 km × 3 km cell size) of the land system archetype data. Also, case study sites not spatially covering the LSA data ($n = 7$, e.g. studies located in Switzerland) were excluded.

^b The archetype mapping relied on twelve indicators representing (a) the spatial extent of broad land use classes (and changes therein), pertaining to both agriculture and forestry in Europe and (b) the management intensity within these broad classes (and changes therein). This analysis was supplemented by a set of 14 indicators determining the spatial patterns of location factors and drivers of land change across Europe.

3.1% vs. 27.6%). Of the publications 30% consider an assessment of ecosystem services in agroforestry as compared to pure forms of agriculture or forestry or to another agroforestry system. However, in the majority of the studies this is not done (Fig. 4). Most studied agroforestry sites are delineated by biophysical (55%) borders such as watersheds, valleys, and forest areas. Furthermore, drivers of ecosystem change, as stated by the authors, are prevalent, with direct drivers threatening 30% of the study areas, indirect 14%, and both direct and indirect drivers noted for 15% of these study areas (Fig. 4). Among the direct drivers land abandonment in silvopastoral systems, agricultural intensification or conversion to agricultural land are frequently mentioned. Commonly cited indirect drivers are EU and national policies that incentivise afforestation and intensification of European agriculture.

3.3. Research approaches to ecosystem service assessment around European agroforestry

In the reviewed literature, the most common approach applied to ecosystem service assessment within European agroforestry is biophysical assessment (79% of all studies), followed by monetary (13%), socio-cultural (6%), and mixed approaches (3%) (Fig. 6). Mixed approaches appearing in our sample combine the biophysical with socio-cultural or monetary approaches (Baumgärtner and Bieri, 2006; Borin et al., 2010). Following these figures, the clear majority (93%) of the studies is based on quantitative methods for ecosystem service elicitation and to lesser extent on qualitative (4%) or mixed (3%) methods. In the majority of studies, the assessment focuses on only one ecosystem service (58%) or two to five services

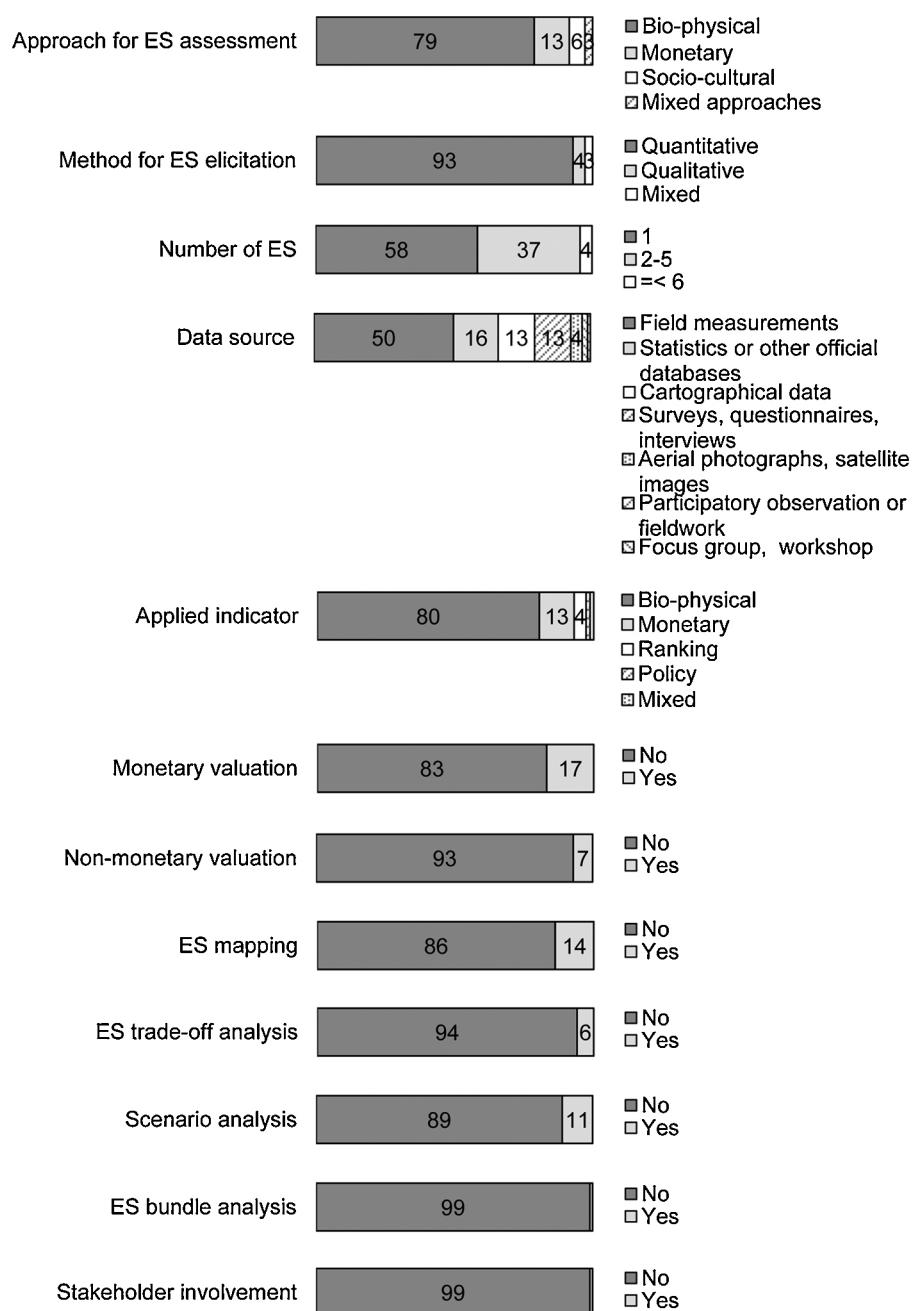


Fig. 6. Variables characterizing research approaches to ecosystem service assessment with relative proportions of studies (category labels with value less than 3% are not shown in the figure).

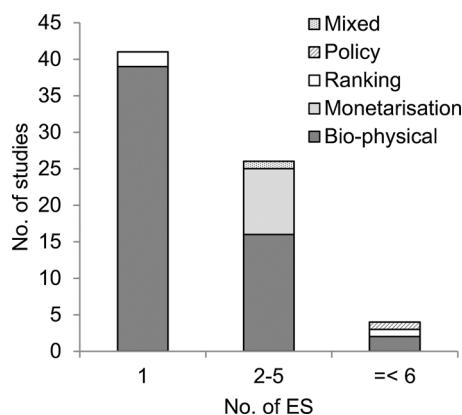


Fig. 7. Number of studies according to the number of ecosystem services assessed with the applied indicators for ecosystem service assessment.

(37%) (mean 2.3, SD 3.4). More than six services are assessed only in a few studies (3 studies, 4%) with the highest number amounting to 27 services (Plieninger et al., 2013).

Of the data used in the studies, 70% were derived from primary data sources, mainly from field measurements (50% of all data sources) and surveys, questionnaires, and interviews (13%) (Fig. 6). Aerial photographs and satellite imagery (4%), participatory observation or ethnographic participatory fieldwork (2%), and focus groups or workshops (1%) were not widely applied. The remaining 30% consisting of secondary data sources include statistics and other official databases (16%) and cartographical data (13%).

The applied indicators for ecosystem service assessment are dominated by biophysical indicators (80%), followed by monetary (13%), ranking (4%), and policy (1%) indicators or the combination of the previous (1%) (Fig. 6). The only study applying mixed indicators combines biophysical, monetary, and ranking (Borin et al., 2010) and the only one applying policy indicators uses official databases to find indicators on supranational policies and regional institutional structures (Thiel et al., 2012). Biophysical indicators are especially related to studies measuring one indicator, and monetary or mixed indicators applied in the studies including two to five indicators (Fig. 7). Studies that adopt six or more indicators apply biophysical, ranking, or policy indicators. Subsequently, around one fifth (17%) of the studies apply monetary valuation, mainly market price and cost approaches (90% of studies applying monetary valuation) or contingent valuation (27%) (Fig. 6). Choice experiments (Hasund et al., 2011) and deliberative valuation (Johansson, 1995) are both applied in one study. Additionally, some studies (7%) undertake non-monetary valuation, which can include ranking of importance of ecosystem services and sceneries in landscape photographs.

Mapping of ecosystem services is rarely adopted and only used in 14% of studies. Also, ecosystem service trade-off analysis is applied only in a few studies (6% of studies) and analysis of service bundles is even less common (1%, Palma et al., 2007) (Fig. 6). Scenario analysis is performed in 11% of studies with the main approaches of behavioural scenarios applied in seven studies and scenarios addressing behavioural changes and climate change in one study. Active involvement of stakeholders in the design, implementation or analysis of the scientific research regarding ecosystem services is rare (1%). It is applied in one study, where the local level landscape users (farmers, shepherds, entrepreneurs, hobby gardeners, local policy makers) assessed the possible future drivers of cultural landscape changes and their likely impacts on ecosystem services provision through stakeholder-based scenarios (Plieninger et al., 2013).

3.4. Relationships between ecosystem service assessments and research approaches around European agroforestry

In the cluster analysis we identified four groups of publications. The largest cluster A ($n=25$) has the majority of publications with the principal focus being Mediterranean wood pastures and woodlots and scattered farm tree systems in Continental and other biogeographical regions (e.g. Boreal and Alpine) (Fig. 8). Quantitative methodologies and biophysical approaches based on field measurements for the assessment of mostly a combination of different ecosystem services or only regulating and supporting services, including provision of habitat and biodiversity, nutrient cycling, soil formation and retention, climate regulation, food, and fibre, are dominant (e.g. Corral-Fernandez et al., 2013; Garcia-Tejero et al., 2013; Hussain et al., 2009; Lozano-Garcia and Parras-Alcantara, 2013; Moreno Marcos et al., 2007). In addition, monetary approaches and especially use of mixed data sources, such as surveys, questionnaires, interviews, and statistics, are found in group A. These are applied in the assessment of multiple especially provisioning and cultural ecosystem services including food, fuel, fibre, and recreation and ecotourism (Campos and Caparros, 2006; Campos et al., 2007, 2008; Fernandez-Nunez et al., 2007; Hasund et al., 2011; Johansson, 1995).

In the second largest group B ($n=21$) the majority of publications have a dominance of quantitative methodologies and biophysical approaches based on field measurements to study mainly wood pastures in the Mediterranean and Continental regions (Foldesi and Kovacs-Hostyanszki, 2014; Graves et al., 2007; Guerra et al., 2014; Joffre and Rambal, 1993; Parras-Alcantara et al., 2014). Group B also includes publications addressing the assessment of cultural services, such as aesthetic values, recreation, cultural heritage values and knowledge systems, approached through surveys, questionnaires, interviews, participatory observation and ethnographic participatory fieldwork by applying ranking and monetary indicators (Babai and Molnar, 2014; Campos et al., 2009; Franco et al., 2003; Gomez-Limon and Lucio Fernandez, 1999).

Group C ($n=15$) comprises exclusively Atlantic agricultural mosaic landscapes with mainly hedgerow, woodlot, and scattered farm tree systems. These are approached through field measurements of biophysical indicators to assess regulating, supporting and provisioning ecosystem services, such as provisioning of habitat and biodiversity and pollination (e.g. Gelling et al., 2007; Macfadyen et al., 2011; Minarro and Prida, 2013; Rollin et al., 2013).

Group D ($n=10$) addresses Continental and Mediterranean silvoarable and silvopastoral systems, including riparian buffer strips, orchards, forest grazing, hedgerows, and modern agroforestry systems. Ecosystem service assessment of these systems is characterized by field measurements of biophysical indicators for regulating or supporting services, e.g. for the provision of habitat and biodiversity, fire hazard prevention, and soil formation (Alessandro and Marta, 2012; Cardinali et al., 2014; Robles et al., 2009). However, focus groups and official databases have also been used to measure a diversity of ecosystem services through policy and ranking indicators (Plieninger et al., 2013; Thiel et al., 2012).

4. Discussion

This review has been motivated by calls for multifunctional landscapes and land-use systems (O'Farrell and Anderson, 2010; Wu, 2013) in which agroforestry plays a major role. We revealed a substantial and rapidly growing number of studies on agroforestry

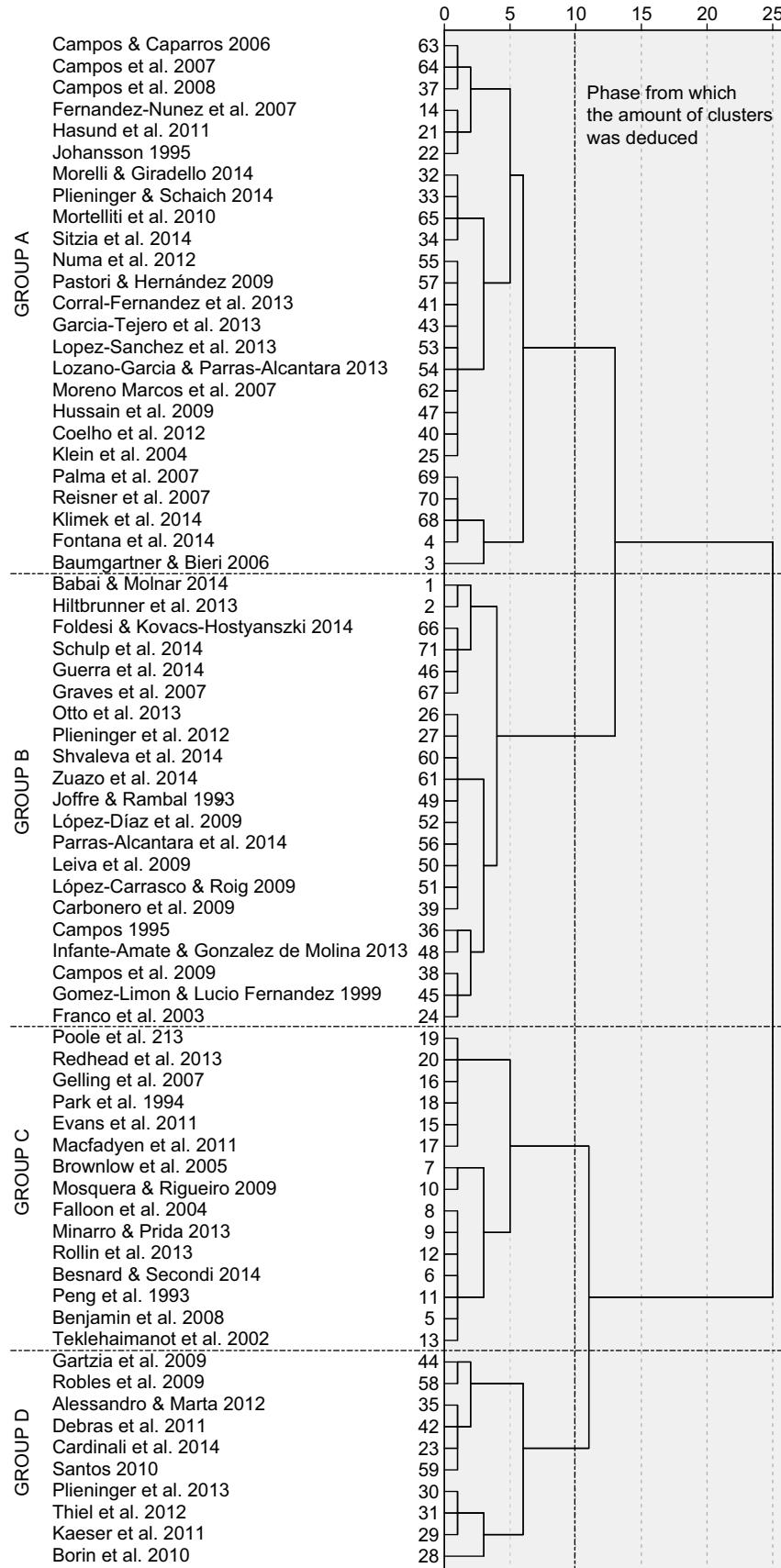


Fig. 8. Dendrogram showing the four groups of publications deduced from the cluster analysis.

and ecosystem services in Europe. However, this body of literature is small when compared to the vast extent of agroforestry lands in Europe. Hotspots of research were Mediterranean Europe, the UK, and France (Fig. 2), whereas agroforestry systems in the Nordic Countries and Eastern Europe (e.g. the diverse wood pasture systems described by Bergmeier et al., 2010) received little attention. A broad range of agroforestry systems was considered, both silvopastoral and silvoarable systems and intensively and extensively managed systems (Fig. 4). While grassland, livestock, and arable cropland systems were well-covered, the role of agroforestry in forest lands and land mosaics of different intensities were clearly understudied (Table 1).

To incorporate ecosystem services into decision making around land use is a commonly identified challenge (Maes et al., 2012; Nieto-Romero et al., 2014; Robertson and Swinton, 2005). At the same time, public policies (for example, the Common Agricultural Policy (CAP) and in particular the rural development programmes of the EU) offer options to enhance rural development through the establishment of agroforestry. The conceptual framework by Daily et al. (2009) specifies leverage points for mainstreaming ecosystem services into decision making along five key nodes, comprising of *Decisions*, *Ecosystems*, *Services*, *Values*, and *Institutions*. Three key actions have been defined for each link between the nodes (Daily et al., 2009). In the following, we use this framework to identify the key limitations of current agroforestry research on ecosystem services (as revealed by our systematic review) and to reflect on how agroforestry research can contribute more comprehensively to decision making on ecosystem services.

4.1. Decisions → ecosystems: actions and scenarios

The first action in the Daily et al. (2009) framework stresses that to inform decisions that affect ecosystems, (1) collaboration with stakeholders that define important scenarios of alternative future uses of land, water, and other natural resources is needed. Also, there is a need for (2) improved methods for assessing the current condition, and predicting the future condition, of ecosystems and (3) state-of-the-art programs for long-term monitoring of biodiversity and other ecosystem attributes.

The agroforestry research covered in our review frequently identified direct and indirect drivers of ecosystem change (Fig. 4), but both long-term monitoring and forward-looking scenario development was rare (Fig. 6) and the number of ecosystem services addressed was small (Fig. 7). Future research could provide the needed information by putting stronger focus on ecosystem services provision under alternative future policy and/or behavioural scenarios in collaboration with stakeholders, following established standards (Oteros-Rozas et al., in press).

This requires, firstly, a proper inclusion of agroforestry into existing European monitoring systems such as LUCAS (Land Use and Land Cover Aerial Frame Survey) and CORINE (Coordination of Information on the Environment) land cover data (den Herder et al., 2015). Formal designations of land use and cover in the EU are typically separated into land which falls within the remit of the CAP, and areas such as woodland and forests which do not. This artificial separation has limitations as the integration of trees with agriculture frequently provides landscape-level benefits such as enhanced biodiversity, runoff control, and soil conservation (Jakobsson and Lindborg, 2015; King, 2010; Plieninger et al., 2015). A better way would be to monitor agroforestry practices within a continuum of agriculture and forestry systems.

Secondly, agroforestry assessments need to include a broader set of ecosystem services. Agroforestry studies frequently measure the efficiency of agroforestry through “land equivalent ratios” (Graves et al., 2010), which are based on only two or three

provisioning services. More comprehensive metrics that also account for cultural, regulating, and supporting services are needed and stakeholder involvement to define future scenarios for these. The approach by Agbenyega et al. (2009) which (focusing on community woodlands) also included ecosystem dis-services could be applied more generally to agroforestry as well. For regions rich in agroforestry (such as Mediterranean Europe) such assessments of biodiversity and ecosystem services may be advanced towards long-term monitoring programs that would allow longitudinal studies. Also, better use should be made of data repositories of completed agroforestry studies to share information (cf. Crossman et al., 2013).

4.2. Ecosystems → services: biophysical models

According to the Daily et al. (2009) framework, translation of ecosystem condition and function into ecosystem services (1) requires collaboration with stakeholders to define services that people care about. It also builds on (2) development of transparent, flexible models of ecological production functions at scales relevant to decision making and testing, and (3) refining of these models in different social and agro-ecological zones.

Stakeholder involvement was very low in the agroforestry studies we reviewed (Fig. 6). Also studies were mostly performed at plot to local scales, and typically in one study site only. Compared to broader ecosystem service assessments (Seppelt et al., 2011), mapping approaches received minimal attention in agroforestry research. As ecosystem services are per definition the benefits provided by ecosystems to society (MA, 2005), future agroforestry research has to build more strongly on the participation of farmers, landowners, residents, and other relevant actors (cf. Díaz et al., 2015; Scholte et al., 2015; Seppelt et al., 2011). Such collaboration is promoted, for example, through landscape-level stakeholder workshops (such as those established in EU FP7 project AGFORWARD, <http://www.agforward.eu/index.php/en/>). More citizen science approaches that appreciate the capabilities of various actors to collect valuable data as citizen sensors or share their local knowledge (including traditional ecological knowledge, land management practices and experiential knowledge dealing with landscape values) related to ecosystem services would be helpful as well.

Currently, it is not clear which agroforestry practices contribute which kinds of ecosystem services and at what levels of provision, with some agroforestry systems being more multifunctional than others. Production models of agroforestry (such as Farm-SAFE and Yield-SAFE, cf. Graves et al., 2007) do exist, but they need to be advanced towards the inclusion of a broad and relevant set of ecosystem services at multiple spatial scales. To match the scales of decision making, upscaling of insights to national and EU levels is particularly required. Stronger development of mapping approaches is another desideratum to help creating spatially explicit models of service supply and demand across spatial and temporal scales (Crossman et al., 2013; Martínez-Harms and Balvanera, 2012; Willemen et al., 2015).

In addition, it would be beneficial to establish Pan-European networks of study sites that include land management practices of different types and intensities within varying biogeographical settings to refine existing models and to obtain generalized insight into ecosystem services provision from agroforestry.

4.3. Services → values: economic and cultural values

In order to make the societal value of an ecosystem explicit, according to the Daily et al. (2009) framework (1) direct biophysical measurements need to be complemented with monetary and socio-cultural valuation at the spatial and temporal

scales that are relevant for decision-making. Also, (2) developing non-monetary methods for valuing human health and security, and cultural services, and incorporating these in easy-to-use, easy-to-understand, but rigorous tools for valuing ecosystem services is required. Another need is (3) the development of methods for identifying who benefits from ecosystem services, and where and when those who benefit live relative to the lands and waters in question.

Our review confirms that agroforestry followed the larger trend of ecosystem services research (as observed by Vihervaara et al., 2010) of generally focusing on regulating, supporting, and provisioning services, while paying less attention to cultural services, which are mainly limited to assessments of aesthetic values (Fig. 3). Also, there was a strong dominance of biophysical assessment approaches and indicators, and a low representation of monetary and socio-cultural approaches and indicators (Fig. 6). Trade-offs and bundles among ecosystem services were rarely analyzed (Fig. 3). For more comprehensive understanding of the importance of ecosystem services, empirical research should be directed to a wider variety of research approaches and to a wider coverage of ecosystem services (Martín-López et al., 2014). There is a clear need for more studies of cultural ecosystem services and also for the direct contributions of agroforestry to human well-being (e.g. in terms of public health benefits), with inspiration derived from the various methods and indicators developed (cf. Hernández-Morcillo et al., 2013; Milcu et al., 2013). Identifying service trade-offs between land management practices, assessing ecosystem services for particular actor groups, and analyzing bundles of ecosystem services may be one important way towards understanding how different stakeholders have access to and benefit from ecosystem services (Felipe-Lucia et al., 2015). Studies considering trade-offs and bundles allow better understanding of the complex dynamics, interactions, resilience, and adaption of landscape structure into functions and finally to valued benefits (Setten et al., 2012; Termorshuizen and Opdam, 2009). They are also a prerequisite for expanding current production models towards social-ecological production functions that take into account the social factors underpinning ecosystem services (Reyers et al., 2013).

4.4. Values → institutions: information

To embed the values of ecosystems in institutions, the Daily et al. (2009) framework calls for (1) piloting initiatives that include incentives for the protection of ecosystem services and fostering recognition of the value of these services. It also demands (2) determining the merits and limitations of various policy and finance mechanisms and (3) developing institutions to achieve representation and participation by stakeholders.

The body of literature that we reviewed generally did not elaborate such initiatives. This topic is nevertheless relevant for agroforestry, as institutional changes towards agroforestry often do not generate direct benefits for land users and landowners, which typically depend on marketed provisioning services. To foster change towards agroforestry, markets need to be developed for the specific ecosystem services provided by agroforestry as identified in this review. This comprises existing products (e.g. jamón ibérico from Spanish wood pastures or apple juice from orchard meadows), brands, development of labels (e.g. organic agriculture, Forest Stewardship Council, protected geographic origin), and a general move towards “landscape labelling” (Ghazoul et al., 2009). There are also excellent examples of upscaling of existing pilot initiatives (e.g. by integrating forest certification, high conservation value, and payment ecosystem

services conservation tools in Mediterranean cork oak savannas, Bugalho et al., 2011; Bugalho and Silva, 2014; Dias et al., 2015).

Various policy and finance mechanisms can also be capitalized on. For example, the capacity of agroforestry practices to enhance ecosystem service provision can be encouraged through public policies such as the EU Biodiversity Strategy to 2020 (the major strategy of the EU to protect biodiversity and ecosystem services). The second target of the strategy, out of six, is to ‘maintain and restore ecosystems and their services (incorporation of green infrastructure in spatial planning)’, and the third target is to ‘increase the contribution of agriculture and forestry to biodiversity’ (EU, 2011). Also, agricultural support schemes, such as the CAP, can promote practices such as agroforestry towards co-delivery of ecosystem services and multifunctional land use (e.g. Plieninger et al., 2012). The legal and administrative separation between agriculture and forestry in current EU thinking (and in current monitoring systems, as described above) is a limitation to such efforts. A particularly important barrier of a policy mechanisms for agroforestry is the limited eligibility of wood-pastures for receiving CAP (Plieninger et al., 2015). Here, not only the EU, but also member states should use more flexibility to create a supportive framework for agroforestry.

4.5. Institutions → decisions: incentives

To understand the incentives by institutions that promote decision making incorporating the role of ecosystem services, Daily et al. (2009) suggest (1) broad discussion and inquiry into what motivates people and how social norms evolve, especially in the context of nature is required. Also, (2) incorporating traditional knowledge and practices into modern conservation approaches and (3) developing a broader vision for conservation are proposed.

Though these guidelines are much broader in scope than our systematic review, we suggest that more research on the connections between values and land management actions is needed for an improved uptake of agroforestry practices by farmers, focusing on collaboration, capacity-building and learning. Financial flows and tangible incentives motivating behaviour towards fostering ecosystem services and conservation may be especially important for business-minded land managers and farmers (Raymond et al., 2015). Also, as mentioned above, practical/local/traditional/non-scientific knowledge in agroforestry and ecosystem service assessments could be acknowledged more widely (Hernández-Morcillo et al., 2014; Turnhout et al., 2012). This calls for participation of various stakeholders, including different age groups, ethnicities, and power asymmetries.

5. Conclusions

Agroforestry has been recognized as a sustainable land management practice that realigns commodity production with safeguarding ecosystem services (Jose, 2009), but research on the linkages between agroforestry and ecosystem services has not been fully explored. Reviewing published literature from Europe, we provide a systematic insight into this research field. Agroforestry and ecosystem services are mission-oriented research fields. For being uptake by land use policy and practice, the insights from this research need to meet the requirements of individuals, communities, corporation, and governments making decisions. Advancing the directions by Daily et al. (2009) (and specifying these directions for European agroforestry), we propose that the following key actions can contribute to

making future agroforestry research more relevant for decision making:

- Stronger consideration of stakeholder participation to define, map, value, and foster ecosystem services;
- Introduction of spatially explicit mapping into agroforestry research, building on existing platforms such as InVEST (www.naturalcapitalproject.org);
- Adoption of multiscale and upscaling approaches in ecosystem service assessment that are better able to inform both the scales of national and EU policy;
- Diversification of assessment approaches and methods that go beyond biophysical assessment and monetary valuation;
- Coverage of a broader suite of ecosystem services, in particular integration of cultural ecosystem services and aspects of human well-being as well as consideration of trade-offs, synergies, bundles, beneficiaries, and power relations around ecosystem services.

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Appendix A. Search terms applied in the review.

Publication search for the review consisting of three search strings with the following search terms applied to title, abstract and keywords in the specified databases:

- (1) Agroforestry and related definitions: agroforestry OR silvoarable OR silvopastoral OR agrosilvopastoral OR "farm woodland*" OR "forest farming*" OR "forest grazing" OR "grazed forest*" OR "isolated trees" OR "scattered tree*" OR "tree outside forest*" OR "farm tree*" OR woodlot* OR "timber tree system" OR dehesa OR montado* OR "oak tree*" OR "olive tree*" OR "fruit tree*" OR pré-verger OR Streuobst OR pomarada* OR Hauberg OR Joualle OR "orchard system" OR "orchard intercropping" OR parkland* OR "alley cropping" OR "wooded pasture*" OR "wood pasture*" OR pollarding OR "fodder tree*" OR pannage OR hedgerow* OR windbreak* OR "riparian woodland*" OR "riparian buffer strip*" OR "buffer strip*" OR "riparian buffer*" OR "shelter belt"
- (2) Ecosystem services and related definitions: "ecosystem service*" OR "ecosystem function*" OR "ecosystem good*" OR "ecosystem benefit*" OR "ecosystem value" OR "ecosystem valuation" OR "environmental service*" OR "environmental function*" OR "environmental good*" OR "environmental benefit*" OR "environmental value"
- (3) Europe and specific countries: Europe* OR EU OR Albania OR Andorra OR Armenia OR Austria OR Azerbaijan OR Belarus OR Belgium OR "Bosnia and Herzegovina" OR Bulgaria OR Croatia OR Cyprus OR Czech* OR Denmark OR Estonia OR Finland OR France OR Georgia OR Germany OR Greece OR Hungary OR Iceland OR Ireland OR Italy OR Kazakhstan OR Latvia OR Liechtenstein OR Lithuania OR Luxembourg OR Malta OR Moldova OR Monaco OR Montenegro OR Netherlands OR Norway OR Poland OR Portugal OR Romania OR Russia OR "San Marino" OR Serbia OR Slovak* OR Slovenia OR Spain OR Sweden OR Switzerland OR Macedonia OR Turkey OR Ukraine OR "United Kingdom" OR England OR Wales OR Scotland

Appendix B. List of the 71 publications included in the review.

1. Alessandro, P., Marta, C., 2012. Heterogeneity of linear forest formations: differing potential for biodiversity conservation. A case study in Italy. *Agrofor. Syst.* 86, 83–93.
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Appendix C. Data extraction variables applied for each publication included in the review. Column Cluster analysis indicates whether the variable was included in the clustering or not.

Variable	Description and/or source	Classes	Reference	Cluster analysis
<i>Publication characteristics</i>				
Author	Author(s)	1 – n		No
Type of publication	Type of publication	Journal Article Book Section		No
Year	Year in which the study was published	1990–2014		No
<i>Study location and context</i>				
Biogeographical region	Biogeographical regions in Europe	Alpine Anatolian Arctic Black Sea Continental Macaronesia Mediterranean Pannonic Steppic Atlantic Boreal Mixed	EEA (2011)	Yes
Country	Country in which the study area is located	Text		No
Number of study sites	Number of study sites considered in the study	1 – n		No
Comparative site	Comparative assessment of ecosystem service(s) in agriculture and forestry systems	Agriculture Forestry Agriculture and forestry Another agroforestry system No		No
<i>Characteristics of agroforestry system</i>				
System border definition	Definition of the limits of the study area(s)	Administrative Bio-physical Both Other	Nieto-Romero et al. (2014)	No
Agroforestry system	Main agroforestry types. Hedgerows includes clear hedgerows, Woodlots and scattered farm trees includes mosaic landscapes where hedgerows can also exist, and Orchards includes fruit tree meadows.	Wood pastures Hedgerows Forest grazing Orchards Woodlots and scattered farm trees Riparian buffer strip Modern Agroforestry systems	Mosquera-Losada et al. (2009), Nerlich et al. (2013)	Yes
Spatial scale of the study	Scale of the study site(s); patch less than 1 km ² , local 1–10 km ² , more than 10 km ²	Patch Local Regional/national		No
Productive management	Type of productive management	Intensive Extensive Organic Mixed N/A Direct	Nieto-Romero et al. (2014)	No
Drivers of change	Natural or anthropogenic factors that directly or indirectly cause an ecosystem change explicitly stated by the authors. Direct (improper management and overexploitation of resources, land use/cover change, climate change, pollution, invasive species), Indirect (socio-political, economic, science and technology, demographic, culture and religion)	Indirect Both N/A	MA (2005), Milcu et al. (2013), Nieto-Romero et al. (2014)	
<i>Methodological approach</i>				
Method	Method for ES identification/elicitation	Quantitative Qualitative Mixed	Milcu et al. (2013)	Yes
Approach	Approach for ES assessment based on three approaches for assessing ecosystem services: biophysical, socio-cultural and monetary (de Groot et al., 2002; Cowling et al., 2008)	Bio-physical Socio-cultural Monetary Mixed approaches	Nieto-Romero et al. (2014)	Yes
Ecosystem service category	Ecosystem services categorised as in MA (2005) typology	Provisioning Regulating Cultural Supporting Mixed	Nieto-Romero et al. (2014), Seppelt et al. (2011)	Yes

Appendix C. (Continued)

Variable	Description and/or source	Classes	Reference	Cluster analysis
Ecosystem service	Ecosystem service by MA typology	P1 Food P2 Fresh water P3 Fuel P4 Fiber P5 Biochemicals, natural medicines and pharmaceuticals P6 Genetic resources P7 Ornamental species R1 Climate regulation R2 Air quality maintenance R3 Water regulation R4 Erosion control R5 Water purification and waste treatment R6 Regulation of human diseases R7 Biological control R8 Pollination R9 Storm protection R10 Fire hazard prevention C1 Cultural diversity C2 Spiritual and religious values C3 Knowledge systems (traditional and formal) C4 Educational values C5 Inspiration C6 Aesthetic values C7 Social relations C8 Sense of place C9 Cultural heritage values C10 Recreation and ecotourism S1 Soil formation and retention S2 Nutrient cycling S3 Primary production S4 Water cycling S5 Production of atmospheric oxygen (photosynthesis) S6 Provisioning of habitat	MA (2005)	No
Number of ecosystem services assessed	Defined by authors and based on the defined classification for the review, the authors of an article might use an alternative classification system	1-n	Nieto-Romero et al. (2014), Seppelt et al. (2011)	No
Data source	Data source (main)	Field measurements Surveys/questionnaires Interviews Aerial photographs Satellite images Cartographical data Statistics Census data Other official databases Participatory observation Participatory fieldwork Focus group/workshop	Nieto-Romero et al. (2014), Seppelt et al. (2011)	Yes
Applied indicator	Indicators used for the assessment: Bio-physical (bio-physical quantities e.g. kilogram/year pollen transported by pollinators, tonnes/year sediment lost by erosion), ranking (e.g. which ecosystem service has been rated highest by experts/policy makers/the general public), monetary (monetary value for the service produced)	Bio-physical Ranking Monetary Policy Mixed	Seppelt et al. (2011)	Yes
Monetary valuation	Undertake and applied method for economic valuation	Contingent valuation Market price and cost approaches Travel cost method Hedonic pricing Benefits transfer Choice experiment Deliberative valuation None	Milcu et al. (2013)	No
Non-monetary valuation	Undertake of non-economic valuation	Yes No	Milcu et al. (2013)	No

Appendix C. (Continued)

Variable	Description and/or source	Classes	Reference	Cluster analysis
ES mapping	Undertake of ES mapping	Yes No	Milcu et al. (2013)	No
ES trade-off analysis	Undertake of ES trade-off analysis	Yes No	Milcu et al. (2013)	No
ES bundle analysis	Undertake of analysis of ES bundles	Yes No	Milcu et al. (2013)	No
Scenario analysis	Undertake of and applied approach for scenario analysis: Policy scenarios, behavioural scenarios (which assume a behavioural change by the people using the service or threatening the service, e.g. a change of the fishing strategy or a change in the intensity of land use), demographic scenarios and climate change scenarios	Policy scenario Behavioural scenario Demographic scenario Climate change scenario Mixed No	Nieto-Romero et al. (2014), Seppelt et al. (2011)	No
Stakeholder involvement	Actively involving stakeholders (e.g. residents or institutions in the study area) in the design, implementation or analysis of the scientific research regarding ES	Yes No	Milcu et al. (2013), Nieto-Romero et al. (2014), Seppelt et al. (2011)	No

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