PEGASUS
Public Ecosystem Goods and Services from land management – Unlocking the Synergies

D2.1

TRANSFORMING APPROACHES TO RURAL LAND MANAGEMENT

Stimulating long-lasting improvements in the delivery of social, economic and environmental benefits from EU agricultural and forest land

23/03/2016

Review of approaches and datasets to categorise and map Public Goods and Ecosystem Services at EU level

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Review of approaches and datasets to categorise and map Public Goods and Ecosystem Services at EU level

Executive summary

We present a review of relevant datasets and approaches available at EU level to categorise and map ecosystem services (ES) and public goods (PG). For this, PEGASUS uses the social-ecological system as a conceptual framework. Within this framework, PG and ES are linked to the delivery of environmentally and socially beneficial outcomes (ESBOs) from farming and forestry. ESBOs are defined in PEGASUS D1.2 as part of the conceptual framework. They include a wide range of public benefits provided by agriculture and forestry to society, above and beyond commercial production (of food, fuel, timber, etc.). Therefore, the deliverable does not only focus on indicators and proxies for mapping specific PG/ES, but also includes two chapters describing datasets to describe land management and socio-economic aspects, to allow a comprehensive analysis of the impact that land management and socio-economic drivers play in the delivery of ESBOs. D2.1 is the first step in the process to analyse the patterns and trends of PG/ES occurrence in relation to the diversity of EU farming and forestry systems across Europe (D2.3). The analysis of the data from the D2.1 review will help to identify gaps in data availability at EU level and draw some conclusions on the relevant approaches and datasets to be used in D2.2 (*Develop a coherent database for spatially assessing the delivery of PG/ES by agricultural and forestry systems in different biogeographic, social and economic contexts across Europe*). And in turn D2.2. will underpin the analysis in D2.3.

As regards the mapping of PG/ES, the review shows that we found indicators or proxies to map PG/ES concurring to the supply of 16 out of the 19 ESBOs identified in WP1. Available indicators describe the ecosystem service itself, or the ecosystem function underpinning the service. Moreover, most of the indicators available describe the potential service –the capacity of the ecosystem to deliver a good or service, also called stocks or assets. Only in rare cases available indicators and data allow that the actual service - the flow - is mapped.

We did not identify indicators or proxies at EU level for the ES or PG involved in the delivery of two ESBOs. The reasons are various. “Enhancing the storage/removal of carbon from the atmosphere through maintenance / increase of carbon sinks mitigation of greenhouse gas emissions” is mainly related to carbon sequestration, which is already included as linked to “carbon sequestration/storage”. “Public recreation, education and health” is difficult to map because only one of the three components (public enjoyment supported by the ES outdoor recreation) can be quantitatively described specifically in relation to farming and forestry. It would be possible to map indicators of general public health and well-being (e.g. life expectancy, indices of deprivation) but these would not bear any direct relation to the contribution made by farms and forests to this benefit.

Moreover, it has to be noted that despite the ES and PG indicators underpinning some ESBOs are conceptually clear, many times relevant data are not available and proxies need to be used. For example, the ESBO “Diverse and sufficiently plentiful species and habitats, ecological diversity and functioning” is directly linked to the ES Provision of habitat, of which biodiversity is a key variable. However biodiversity cannot be described in only one way - there is no one-measure-fits-all. Particularly, for agriculture, the only comprehensive measure of (one aspect of) biodiversity is bird surveys. However, the resulting indicators (farmland bird index, forest bird index) are only available at national scale and therefore not usable in a geospatial analysis at EU scale. This explains why biodiversity delivered by agroecosystems is approached through proxies (including pressures) in PEGASUS.

Concerning management, both for agriculture and forestry a good number of indicators is available, especially for agriculture where many data are regularly collected through EU wide farm surveys.

The socio- economic descriptors for farming and forestry are sufficiently populated, though indicators are mostly available at coarse resolutions (NUTS2, NUTS0) and in this case the agricultural section benefits from the fact that being subsidised, its economic aspects are much more closely monitored and modelled than forestry.

Finally, this review is also intended to establish guidance for identifying the dominant PG/ES in the case studies within WP4, the functions that support those goods and services, and the suite of biophysical and socio-economic factors that underpin those functions. The intention is to include feedback from the case study leaders in forthcoming deliverables under WP2 in the course of the PEGASUS project.

CONTENTS

1. Introduction

The overall objective of Deliverable 2.1 (D2.1) is reviewing relevant datasets for categorising and mapping public goods (PG) and ecosystem services (ES) delivered by agriculture and forestry systems in the EU. D2.1 is the first step in the WP2 process to mapping and assessing current and potential PG/ES provision in relation to the diversity of EU primary production systems, depicted in Figure 1. The analysis of the datasets reviewed in D2.1 will help to identify gaps in data availability and draw some conclusions on the relevant approaches and datasets to be used in D2.2 (Develop a coherent database for spatially assessing the delivery of PG/ES by agricultural and forestry systems in different biogeographic, social and economic contexts across Europe). D2.2 will underpin the analysis of patterns and trends of PG/ES occurrence in relation to the diversity of EU farming and forestry systems across Europe (D2.3).

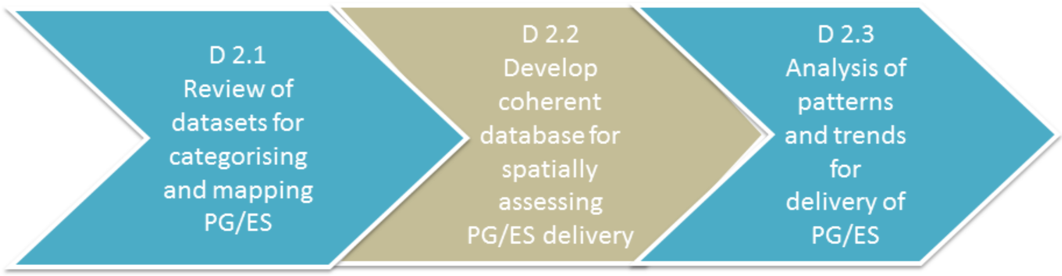

Figure 1: Step-wise process in WP2 to map and assess current and potential PG/ES provision in relation to the diversity of EU.

We link the mapping data and approaches reviewed in D2.1 to the delivery of the environmentally and socially beneficial outcomes (ESBOs) described in Table 1. ESBOs are part of PEGASUS conceptual framework presented in PEGASUS D1.2 Synthesis report. The term ESBO refers to a range of outcomes in the environmental and social spheres that are delivered by agriculture and forestry and which benefit society. These include benefits deriving from ecosystem services (including the underlying functions) that have public goods characteristics, as well as broader social and cultural benefits, delivered by activities in farming and forest ecosystems.

As described in Dwyer et al (2015), the concepts of public goods and ecosystem services have different origins. Whilst PG are identified by combining elements of the economic approach (Cornes and Sandler 1996, Zahrnt et al 2009 and other references cited in Dwyer et al 2015) and the socio-political approach (Ostrom, 1990 and other references cited in Dwyer et al 2015), ES are based on environmental economics. As the concepts are different, we have considered them separately in our D2.1 review. But we recognise that many times PG and ES overlap (e.g. clean air/pollution abatement and regulation of air quality) so the two terms should not be viewed as governing distinct domains in this analysis. Rather, they present different ways of approaching what are often the same essential processes within social-ecological systems. Their similarities and differences will be highlighted throughout the project (particularly in the case studies), and D2.2 and D2.3 will take these into account.

We follow the Ecosystem Services nomenclature of the Common International Classification of Ecosystem Services framework (CICES-V4-3 http://cices.eu/cices-structure/), as this is the official classification for mapping ES agreed by the European Commission. For Public Goods we follow the nomenclature described in PEGASUS Deliverable 1.1. (Dwyer et. al, 2015).

Indicators and proxies for mapping PG/ES are identified according to the project's team best knowledge, which comes from involvement in some of the major EU wide activities on ES mapping and assessment (MAES – Mapping and Assessment of Ecosystem Services, in support of Action 5 of the EU Biodiversity Strategy to 2020; OPERAs project – Ecosystem Science for Policy and Practice; OpenNESS - Operationalisation of natural capital and ecosystem services; MESEU - Mapping of ecosystems and their services in the eu and its member states; TRAIN - Training member states on ecosystem services mapping through hands on workshops; VOLANTE – Visions of Land Use Transitions in Europe etc.).
In particular, the following documents have been taken as reference for the identification of PG/ES indicators and proxies:

- the report "Mapping and Assessment of Ecosystems and their Services - Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020 (http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/ 2ndMAESWorkingPaper.pdf), which contains an overview of indicators to map and assess ecosystem services, which has been consolidated through a common discussion with EU Member States;
- Maes at al., 2012 - A spatial assessment of ecosystem services in Europe - Phase II : Methods, case studies and policy analysis & Synthesis Report. European Commission, Joint Research Centre, 215 p. (PEER Report; No. 4);
- Egoh et al., 2012 - Indicators for mapping ecosystem services: a review. Report EUR 25456 EN. Publications Office of the European Union, Luxembourg;
- Maes et al., 2011 – A European assessment of the provision of ecosystem services. Report EUR 24750 EN. Publications Office of the European Union, Luxembourg;
- EU FP7 OpenNESS Project Deliverable 3.1, M. Pérez Soba, P.A. Harrison, A.C. Smith, G. Simpson, M. Uiterwijk, L. Miguel Ayala, F. Archaux, T. Erős, N. Fabrega, Á.I. György, R. Haines-Young, S. Li, E. Lommelen, L. Meiresonne, L. Mononen, E. Stange, F. Turkelboom, C. Veerkamp and V. Wyllie de Echeverria. Database and operational classification system of ecosystem service - natural capital relationships. European Commission FP7, 2015;
- Cooper et al., 2009 - The Provision of Public Goods Through Agriculture in the European Union. Report prepared for DG Agriculture and Rural Development,

Contract No 30-CE-0233091/00-28. Institute for European Environmental Policy, London;

- ENRD (2010) Public Goods and Public Intervention. A Pan European overview of how Member States approach the delivery of Environmental and Social Public Goods through the 2007-2013 Rural Development Programmes. Final report for the Thematic Working Group 3 on Public Goods and Public Intervention. European Network for Rural Development.

D2.1 has five main chapters: 1) description of mapping approaches; 2) approaches and datasets to map PG/ES; 3) description of the variables to describe land management; 4) description of variables describing socio-economic factors; and 5) synthesis of the review and main conclusions. These elements (PG/ES delivery on one side, management and socio-economic factors influencing their delivery on the other) will be analysed, to derive information on existing links between PG/ES provision in the EU, and its main drivers.

Table 1: Intended social and environmental benefits (ESBOs) from activities in agriculture and forest ecosystems (from PEGASUS D1.2)

Intended beneficial outcomes from agriculture and forest ecosystems that are the focus of PEGASUS				
Broad categories of objectives to be achieved:	**Environmentally and socially beneficial outcomes - ESBOs -** **[and dominant dimension]**	**Description of the beneficial outcome sought**	***Insights from ESS concept*** ***Tells us about the nature of the ESS contributing to the benefit***	***Insights from Public Goods concept*** ***Tells us about whether or not there is a risk that markets alone will not provide an optimal allocation*** ***[private, impure public or pure public characteristics identified in brackets]***
Sustainable and sufficient production of food, timber and energy	1. Food security: Achieving (or maintaining) a sustainable natural resource base to ensure a long term food supply hence security [Economic, social, environmental]	The benefits associated with food security can be: (i) Access to affordable and safe food **--> *not in PEGASUS remit*** (ii) Adequate food supply **--> *not an ESBO*** (iii) Maintenance / increase of a sustainable resource base, as a means to secure the long term capacity of the land to produce food/fibre, etc. **Only the (iii) definition is to be considered relevant for PEGASUS**	*For sustainable resource base (iii) – see ESS involved in all other environmental benefits in this table*	*For sustainable resource base (iii) – see PGs involved in all other environmental outcomes [and their characteristics]*
High water quality and ensuring water availability	2. Water quality: Achieving (or maintaining) good ecological status of surface water and good chemical status of groundwater [Economic, environmental and social]	- Maintenance/increase of areas with surface water of 'good ecological status'*, i.e. with high biological activity in rivers and other water bodies. - Maintenance/increase of areas with surface and groundwater of 'good chemical status'*, i.e. low contamination levels ** Water Framework Directive 2000/60/EC*	*Chemical conditions of freshwaters and salt waters* *Mediation by ecosystems through filtration, sequestration, storage, accumulation of pollutants in freshwaters and salt waters*	*Market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *E.g. Water Framework Directive (2000/60/EC) requirements, private initiatives (e.g. water companies), public incentives.* *[Public good characteristics]*
	3. Water availability:	- Increase / maintenance of sufficient	*Provision of surface and ground*	*Market often does not deliver effectively*

	Achieving (or maintaining) a regular supply of water (i.e. avoidance of water scarcity) [Economic, environmental and social]	volumes ('quantitative status' - Water Framework Directive 2000/60/EC) of groundwater available for drinking and other purposes - Increase/maintenance of the capacity to ensure regular flows of water supply and discharge (i.e. avoiding water scarcity and discharge peaks)	*water for drinking and non-drinking purposes* *Hydrological cycle and water flow maintenance*	*/automatically and therefore alternative mechanisms may need to be put in place to ensure optimal allocation of the resource. E.g. water pricing is in place in some countries; however, pricing frequently only covers the costs of providing the water supply and not the value of water itself. Abstraction licences are required under certain conditions in most MSs.* *[Public good characteristics]*
High air quality	4. Air quality: Achieving (or maintaining) minimised levels of harmful emissions and odour levels [Environmental and social]	- Levels of air pollutants and odours as a minimum to comply with the standards laid down in statutory standards e.g. the Air Quality Directive 2008/50/EC - Improved management of farm resources that lead to harmful emissions and odours - Farm/forestry management to lessen/mitigate pollutants and odour levels found in air	*Partial fit with Atmospheric composition and climate regulation* *Mediation of smell by ecosystems*	*Market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *E.g. regulations are already in place (and under review currently) to limit harmful emissions.* *[Public good characteristics]*
Climate change mitigation objectives	5. GHG emissions: Achieving (or maintaining) minimisation of greenhouse gas emissions [Environmental and social]	- Reduction in /minimisation of emissions of methane, nitrous oxide and carbon dioxide from the agriculture and forest sector (from livestock farming, agricultural machinery, fertiliser use as well as land management and land use change)	*Global climate regulation by reduction of greenhouse gas (GHG) concentrations*	*Some private characteristics where actions would also reduce costs in certain cases, e.g. energy efficient machinery. However overall the market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *E.g. regulations setting targets for GHG reductions; incentive payments.* *[Public good characteristics]*
	6. Carbon sequestration/storage : Achieving (or	- Enhancing the storage/removal of carbon from the atmosphere through maintenance / increase of	*Soil formation and composition notably through fixing processes*	*Some limited private characteristics where carbon stores have an economic value (deep soils, forest biomass). However, in general*

	maintaining) maximisation of carbon sequestration and storage [Environmental]	carbon sinks	*Global climate regulation by reduction of greenhouse gas concentrations*	*the market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *[Private and public good characteristics]*
Climate change adaptation	7. Fire protection: Achieving (or maintaining) a high level of prevention and minimisation of impacts of potential fires [Environmental and social]	- Reduction/minimisation of risk, magnitude and frequency of fire through prevention measures - Improvement/maximisation of resilience of agriculture and forest land to fire	*Partial fit with Atmospheric composition and climate regulation*	*Private characteristics where the control of the fire risk and the costs of damage inflicted are both incurred by private landholders. But generally, the market does not deliver at the wider scale effectively/ automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *E.g. incentive payments* *[Private and public good characteristics]*
	8. Flood protection: Achieving (or maintaining) minimisation of impacts of potential floods [Economic, environmental and social] *Flood protection is also tightly linked to water availability through the management of water flows*	- Increasing the water holding capacity of land - Slowing water flow e.g. by maintaining suitable land cover, structure and management to provide natural protection against floods	*Flood protection* *Hydrological cycle and water flow maintenance*	*Market often does not deliver effectively/automatically and therefore alternative mechanisms often need to be put in place to ensure suitable actions are taken to deliver the desired outcome. It is noted that the frequency and severity of flooding is likely to increase with climate change.* *E.g. flood plans (Floods Directive 2007/60/EC), River Basin Management Plans (Water Framework Directive 2000/60/EC).* *[Public good characteristics]*
Healthy, functioning soils	9. Soil functionality: Achieving (or maintaining) good biological and geochemical	- Maintenance/increase of areas where soils are in good biological and geochemical condition, expressed notably in terms of soil fertility, soil biodiversity, soil	*Mediation of mass flows, including mass stabilisation and control of erosion rates and buffering and attenuation of mass flows*	*Some private characteristics as it is a private resource and it should be in the private interest of the land manager to sustain healthy soils for long term productivity of the land. However, this is not always the*

	condition of soils 10. Soil protection: Achieving (or maintaining) minimisation of soil degradation [Environmental and social] *Soil functionality and protection directly underpin the provision of a number of other objectives: achieving a sustainable resource base for food security, water quality and availability, carbon sequestration and biodiversity.*	nutrient storage capacity and soil structure. As a result, soil is also able to fulfil its functions of weathering, soil formation, decomposition of dead organic material and fixing nutrients. - Avoidance of soil degradation, including erosion, floods and landslides, salinisation, contamination, compaction and sealing, *(c.f. EU Soil Thematic Strategy)*	*Soil formation and composition, including weathering, decomposition and fixing processes*	*case where short term priorities (or lack of knowledge) override longer term considerations. Therefore the market alone does not deliver effectively/automatically and alternative mechanisms are required to ensure suitable actions are taken to deliver the desired outcome.* *E.g. incentive payments, conditions on land management payments, possibilities of carbon markets.* *[Private and public good characteristics]*
High levels of biodiversity	11. Species and habitats: Achieving (or maintaining) the presence of diverse and sufficiently plentiful species and habitats (ecological diversity) 12. Pollination: Achieving (or maintaining) high levels of pollination [Environmental]	- Maintenance/increase in abundance and diversity of species and habitats that comprise biodiversity on farm and forest land, including high levels of crop and livestock genetic diversity (in line with the Birds Directive 2009/147/EC and the Habitats Directive 92/43/EEC) - Maintenance / increase in diversity and abundance of plants that are beneficial to (both wildlife and crop) pollinators - Increase in the abundance and distribution of (both wildlife and crop) pollinators	*Lifecycle maintenance, habitat protection and gene pool protection, notably through pollination and seed dispersal*	*Market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *About pollination, there is some potential to leverage action in the private sector as without crop pollination, productivity can be severely impacted. In spite of this, there is currently no wide-scale incentive for private actors benefiting from pollination to protect and enhance its supply. For wildlife pollination only, the market does not deliver.* *Predominantly [Public good characteristics]*

	Given the importance of the role of pollinators in agriculture (and forestry) activities, this is considered under a separate sub-set within biodiversity			
	13. Biological pest and disease control through biodiversity: achieving (or maintaining) high levels of biological pest and disease prevention and minimisation of the impacts of potential outbreaks using biodiversity [Environmental]	- Maintenance / increase of and use of a diverse biodiversity base for pest and disease biological control, i.e. to reduce the risk of incidence and/or to contain the impacts of pest and disease outbreaks	*Pest and disease control*	*Strong private characteristics where this is within the land managers' control. However, the market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome (i.e. mainly biological control using biodiversity).* *It is noted that in many cases very high levels of pest and disease controls exist, but without using biodiversity as a control tool.* *[Private and public good characteristics]*
Protecting landscape character and cultural heritage	14. Landscape character and cultural heritage: maintaining or restoring a high level of landscape character and cultural heritage [Social and environmental]	- Maintenance of heterogeneous and locally distinctive cultural, archaeological and built heritage, as well as the ecological infrastructure that contributes to the character of the agricultural, forestry and rural landscape in a particular location.	*Spiritual, symbolic and other interactions with biota, ecosystems, and landscapes (environmental settings)*	*Market does not deliver effectively/ automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *[Public good characteristics]*
Public recreation, education and health	15. Outdoor recreation: Achieving (or maintaining) a good level of public access to the countryside to	- Maintenance/increase of access to the countryside and opportunities for sustainable outdoor recreation, including green tourism opportunities, on agriculture and	*Physical use and intellectual/representative interactions with landscapes in different environmental settings* *Experiential use of plants, animals*	*Some private characteristics, particularly where access can be controlled (it is noted that paid access may run counter to a social ideal and it is income-discriminatory). However, where access is open to all, the*

	ensure public outdoor recreation and enjoyment [Social]	forest land.	*and landscapes in different environmental settings*	*market does not deliver effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *[Private and public good characteristics]*
	16. Educational activities: Achieving (or maintaining) a good level of educational and demonstration activities in relation to farming and forestry [Social]	- Enhanced and increased availability of education and demonstration activities on farms and in woodlands	*Physical use and intellectual/representative interactions with landscapes in different environmental settings* *Experiential use of plants, animals and landscapes in different environmental settings*	*Some private characteristics where land managers are economically rewarded for the benefits they provide to those being educated and more generally to society. However, these activities are often not economically sustainable without some form of support and therefore alternative mechanisms need to be put in place to incentivise the actions required to deliver the desired outcome.* *[Private and public good characteristics]*
	17. Health and social inclusion: Achieving (or maintaining) an appropriate level of therapeutic /social rehabilitation activities in relation to farming and forestry [Social]	- Increased use of farming and forest systems to provide therapeutic benefits to improve health, wellbeing and social rehabilitation	*Physical use and intellectual/representative interactions with landscapes in different environmental settings* *Experiential use of plants, animals and landscapes in different environmental settings*	*Some private characteristics where land managers are economically rewarded for the benefits they provide to the patient(s) and more generally to society. However, the market in this area is not well developed and therefore does not deliver automatically. Alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *E.g. Care Farms / Natural Health Service* *[Private and public good characteristics]*
High levels of farm animal welfare	18. Farm animal welfare: achieving (or maintaining) the implementation of high farm animal welfare practices on farms	- Good animal husbandry practices to ensure the avoidance of unnecessary suffering or injury to animals - Access to appropriate living conditions to address animals' physiological and behavioural needs	*Not directly influenced by natural processes*	*Market does not deliver effectively/ automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *E.g. mandatory standards have been put in place at EU level, creation of new markets via certification schemes.*

	[Social and environmental]			*[Private and public good characteristics]*
Preserving and enhancing rural vitality	19. Rural vitality: Achieving (or maintaining) active and socially resilient rural communities [Social]	- Social viability of rural populations through adequate employment and incomes - Sense of community among the rural population - High levels of social capital, trust and cooperation between people (including the promotion of equal opportunity and status for men and women) - Embodying, maintaining and sustaining rich cultural practices, knowledge and traditions - Sense of 'place' and 'territoire'	*Natural processes are not the primary determinant of rural vitality but may be relevant in some cases, e.g. areas prone to flooding*	*Markets have traditionally helped to support and sustain rural communities but in modern developed economies, the market trends may have significant positive or negative impacts upon vitality. The fact that markets do not incorporate social impacts suggests that markets do not delivery effectively/automatically and therefore alternative mechanisms need to be put in place to ensure suitable actions are taken to deliver the desired outcome.* *[Public good characteristics]*

2. Categorisation of mapping approaches

Maps can be seen as multi-purpose tools with a long tradition in human history. The advent of the digital era and the popularisation of GIS and scripting tools have made maps a common day-to-day aspect of our live. A map can be thought as a model representing the whole earth or a certain space (Cauvin et al. (2013)). From this perspective map (model) creation should follow very precise rules, it should follow a methodology including characteristics of reproducibility, validation and uncertainty assessment. In summary, a map can be defined as “a graphic model of the spatial features of reality” (Kraak and Ormeling, 1996), thus allowing communication and further analysis in GIS post-processing and modelling.

Mapping ecosystem services (ES) is an important step in operationalising the ES concept at the landscape level. Mapping provides practical tools contributing to territorial decision making and policies aimed at achieving sustainability targets. More specifically, according to MAES (2013) maps of ES are useful for several purposes:

- Providing spatially explicit representation of synergies and trade-offs among different ES, and between ES and biodiversity;
- As a communication tool to initiate discussions with stakeholders;
- Offering visualisation of the locations where valuable ES are produced or used;
- As tools for communicating the relevance of ES to the public in their territory;
- Aiding the planning and management of biodiversity protection areas and implicitly of their ES at sub-national level;
- Support to decision makers to spatially identify priority areas, and relevant policy measures.

Maps of ES can represent different biophysical dimensions of the services such as flow, potential and demand. Each dimension requires a specific approach and type of data, therefore mapping each dimension of a given ES will produce a different output. Here we present a description mapped in all three dimensions. First, ES flow (supply) refers to the part of the service that is actually used. It is the *de facto* used ES in a particular area within a given time period (Burkhard et al., 2014). Second, ES potential is the maximum potential capacity of an ecosystem, or area, to provide a service independently of being used or not (Burkhard et al., 2014). Third, ES demand is the quantity of a given service desired by people within a given time period (Wolff et al., 2015). In analysing demand it is important to consider scale dependency factors, as some ES are provided at a long distances from the receivers while others are provided much closer to their demand. In addition to the mapping of the biophysical dimensions of ES, mapping of ES values is another option, in which ES are valued, often in monetary terms, across a geographical area, assessing how values vary across space (Schägner et al., 2013).

Maps of ES have become a popular tool for decision-making and policy formulation. In consequence many mapping approaches and categorisations of mapping approaches have been developed in recent years. In this section we present first a review of the literature on mapping approaches; and second a typology of mapping approaches including biophysical and monetary valuation mapping.

A series of approaches has been proposed in recent years for mapping and assessment of ES. Summaries of these approaches are presented in Eigenbrod et al. (2010); Ayanu et al. (2012); Crossman et al. (2012); Egoh et al. (2012); Maes et al. (2012); Martínez-Harms and Balvanera (2012); Crossman et al. (2013); Schägner et al. (2013); and Willemen et al. (2015).

There is a multiplicity of approaches resulting from the combination of data sources and mapping methods. There are two broad categories of data for mapping: primary and secondary. Primary data is derived from field sampling; examples are field data, surveys, interviews or census data. Secondary data is information and maps derived from remotely sensed imagery, socio-economic data, readily available spatially-explicit databases (e.g. soils, climate), and mixed sources (Martínez-Harms and Balvanera, 2012). The method for mapping (or modelling) describes the way that ES are quantified and mapped and the tools necessary to do so. A series of methods has been implemented in the social-ecological domain that in many cases are not mutually exclusive; on the contrary, different methods are often integrated in mapping studies. The approaches can be split in two main categories: biophysical mapping and monetary values mapping. In the next paragraphs we present a typology of the biophysical mapping. We do not include the monetary value mapping as this is out of the scope of the PEGASUS project.

Typology of methods for mapping of biophysical ES supply (figure 1):

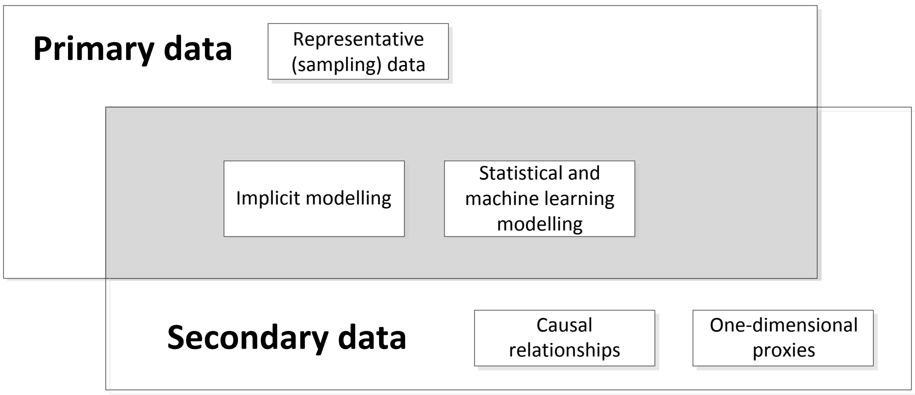

Figure 1. Methods for mapping biophysical ecosystem services supply and type of data source. In light grey the area where methods use both primary and secondary data in a common framework.

Representative (sampling) data uses real world observations to quantify ES supply within a particular spatial unit. The usability of this approach is constrained by the availability of (primary) data and has been used mainly for well-studied small study areas or at large-scale but coarse resolutions. This approach offers the best estimate of observed levels of ES. However, mapping studies based on this approach are limited due to the high costs and difficulty to collect the large amount of data required and have been therefore limited to very few services (e.g. biodiversity, recreation) (Eigenbrod et al., 2010; Schägner et al., 2013).

One-dimensional proxies such as land-cover: This approach uses secondary data and land cover maps as proxies for mapping ES supply. These ES maps use one biophysical variable to map variations of ES supply across space (Schägner et al., 2013). This is a simple approach to derive information on ES directly from land-cover or habitat maps. This approach is appropriate at large scales, for areas where the dominant service relates directly to a particular type of land cover (e.g. crop and timber production) or where data availability or expertise is limited and the focus is on the assumed presence of ES rather than on quantification of the supply (Maes et al., 2012). The information represented in the land cover map is linked to attributes of each land cover category through look-up tables built from literature review or expert knowledge. This approach includes also the option of extrapolating primary data from a study site to the total studied area using look-up tables and land cover maps (Martínez-Harms and Balvanera, 2012). One of the main limitations of this type of approach is that the relationship between ES and land cover (or other proxy) is assumed and does not therefore account for variation within the proxy, such as management changes, shape, scale or other influencing factors.

Causal relationships: This approach incorporates existing knowledge about how different layers of information (usually secondary data) relate to ecosystem processes and services to create a new proxy layer of the ES. The resulting proxy layer is based on logical combination of likely causal relationships between data layers (Eigenbrod et al., 2010; Martínez-Harms and Balvanera, 2012). The causal combinations are usually based on expert knowledge or literature review, and no real world observations on ES supply are used for testing or calibrating model performance (Schägner et al., 2013). Dynamic process-based ecosystem models, e.g. InVEST (Sharp et al., 2015), which estimate ecological production functions, fall within this category.

Statistical and machine learning modelling: This approach employs field data (primary data) of ecosystem services to model the relationship with explanatory variables and proxies (primary or secondary data), such as biophysical data and other sources of information obtained from remote sensing and GIS. One of the strengths of this approach is the ability to provide measures of error/accuracy (Schägner et al., 2013), in some cases in a spatially-explicit way. Common methods within this approach are statistical regression analysis or machine learning tools such as Neural Networks.

Implicit modelling: This approach uses value functions relating the variation in ES values to variations in the characteristics of the ecosystem, context and beneficiaries of the services. Local-level parameter values are inputted into the value function in order to extrapolate spatially the value to other sites of the study area with unknown value information. In applications where the value functions includes biophysical variables that have a causal relationship with the ES supply, the model provides an implicit representation of the ES supply, although the supply is not derived explicitly (Schägner et al., 2013).

3. Approaches and datasets to map Public Goods and Ecosystem Services

The description of indicators and proxies to map PG/ES follows the order of ESBOs in table 1 (from D1.2), maintaining the corresponding nomenclature and numbering. Therefore, the main reference is the ESBOs, to which PG/ES are connected, and consequently the indicators/proxies to mapping them.

When selecting PG/ES indicators, the following criteria are applied:

1) if an indicator describing the PG/ES is available, its metadata is reported in the corresponding section;

2) if an indicator is not available, the closest proxy is sought;

3) if none of the above is existing/available, drivers or pressures are collected as a closest approximation to the description (e.g. landscape fragmentation as a pressure on biodiversity).

3.1. Production of food, timber and/or biomass

3.1.1. Brief description of PG/ES for agriculture

Production of food and biomass with utility for human beings (such as fuel or fibre) is the main provisioning service supplied by agroecosystem and the main goal of agricultural activity. In this document the yearly agricultural production expressed in terms of energy content per hectare is selected as proxy for this ecosystem service. Production of food is a private good, nevertheless due to its importance and impact on other PG/ES, it is described in this section.

3.1.2. Summary of the indicator/proxy: challenges and limitations

To take into account the overall biomass produced for any purpose (food, feed, fuel, fibre) by agriculture into a single indicator, the use of energy content is identified as proxy, allowing the application of a single metric to all agricultural outputs. The Energy Content Output (ECO) is defined as the energetic content (burnable calories) of agricultural production, in MJ/hectare. The calculation of ECO is performed using the Common Agricultural Policy Regionalized Impact (CAPRI) model (Kempen et al., 2006). In particular, CAPRI incorporates an energy balance model designed to calculate several energy-related indicators both from the input and output side. All data and calculation are downscaled at the level of HSMU (Homogeneous Spatial Mapping Units). The total ECO is the sum of 4 sub-components: i) ECO of food; ii) ECO of feed; iii) ECO of potential residues of permanent crops; iv) ECO of other non-food biomass, i.e. straw and pruning. Coefficients taken from literatures are used to estimate the maximum potential residues of biomass from permanent crops, straw and pruning, and their energetic content.

The variables needed to compute the ECO are listed in the following table:

Name	Unit	Description
1. Crop Yields (CAPRI code: YILD)	kg	
2. Energy content (ECfo) of the food products	MJ/kg fresh weight	Table containing the energy content of all food crops included in the CAPRI model
3. Energy content (ECfe) of forage or biomass output	MJ/kg fresh weight	Table containing the energy content of all forage crops included in the CAPRI model (silage maize; fodder crop roots; other fodder from arable land; grass)
4. Residue yields of permanent crops (RY)	Ton of dry matter/ ha*year	Table containing average residue harvest ratios per type of permanent crop (Fruit, Nuts fruit and berry plantations, citrus, olives, vineyards)
5. crop share (LEVL) of permanent crops	Ha*1000	Crop share area of permanent crops grown in each Hsmu Source: CAPRI output
6. Energy Content (ECre) of residues of permanent crops	MJ/kg fresh weight	Energy content of residues of the following permanent crops: Fruit, Nuts fruit and berry plantations, citrus, olives, vineyards).
7. Yield of Pruning	Kg/ha	Table containing the yield of pruning of permanent crops type included in CAPRI. Given a crop, the relative yield of pruning is considered constant all over Europe. Source: CAPRI output
8. Yield of straw	Kg/ha	Table containing the yield straw for straw-producing crops type included in CAPRI. Given a crop, the relative yield of pruning is considered constant all over Europe. Source: CAPRI output
9. Share of removable straw	%	Share of straw that can be sustainably removed from straw-producing crops (without negative effects on the soil carbon level (Source: CAPRI database).
10. Energy content of straw and pruning (ECsp)	MJ/kg fresh weight	The value is constant for al crops all over Europe

3.1.3. Metadata info

Indicator	Energy Content Output
Mapping approach (chapt.2)	Statistical and machine learning modelling

Proxy (yes/no)	No
Function/service/benefit	Service
Stock/Potential/flow	Flow
Unit of measure	Mj/hectare
Type of map (point, polygon…)	Raster
Map resolution	1 km
Coordinate system	ETRS 1989 – LAEA
Year of reference	2004 (CAPRI baseline)
Temporal series (if yes, please indicate the period)	No

3.1.4. Gaps

The data provide the actual energy content output of the biomass produced by agricultural land. Whilst it can be assumed that all food-ECO is converted into an actual service for humans (through market or auto-consumption) as far as the share of other biomass (straw, residues from pruning etc.) is concerned, ECO indicates the available energy content regardless of its actual use.

The computation are based on the CAPRI model outputs disaggregated at HSMU level, which are updated as of 2004.

Food, fiber and fuel from agriculture are usually private goods.

3.1.5. Brief description of PG/ES for forestry

Forest ecosystems produce fibres, wood and timber, providing industry with products such as cellulose for paper, fuel-wood, and round wood. These products are the most relevant biomass output from managed forests and are the raison d'être of commercial forest oriented to biomass production. Forest biomass is considered as a private good, nevertheless considering its importance and the impact that forest management may have in other PG/ES e.g. the social importance of carbon sequestration and water and air purification, we have decided to include it in this assessment.

3.1.6. Summary of the indicator/proxy: challenges and limitations

Indicators for forest biomass are grouped in two broad categories: spatially-explicit and administrative level (NUTS) indicators. Available spatially-explicit indicators should ideally describe the amount of biomass that is produced and harvested per time unit. However, such information is not widely available at pan-European level and hence some proxies should be considered. Spatially-explicit proxies for forest biomass have a twofold usability within the scope of this report. First, they serve as an approximation of the amount of carbon sequestered and captured in forest, and second as the available amount of biomass in forest. Indicators for forest biomass that are also used as proxies for carbon sequestration are: 1) Map of forest boreal and temperate carbon stock distribution implemented by Thurner et al. (2014). 2) Map of forest woody biomass increment implemented by Busetto et al. (2014). 3) and 4) Maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements according to Gallaun et al. (2010). A more detailed description of these indicators and the corresponding metadata tables is below in the forest carbon sequestration section.

A further indicator is a map ofthe forest growing stock volume (GSV) produced by Santoro et al. (2011; 2015) retrieved from synthetic aperture radar (SAR) data. Forest GSV data describes the volume of tree stems per unit area and is measured in m3 ha-1. GSV was estimated from multi-temporal observations of the SAR backscattered intensity acquired by Envisat Advanced SAR (ASAR) acquired between October 2009 and February 2011, thus the GSV dataset contains information at 1-km grid size of the year 2010.

An indicator describing specifically wood production was recently implemented by Verkerk et al (2015). They developed an 1 km grid size map of wood production for European forests. Wood production statistics for 29 European countries from 2000 to 2010 as well as a comprehensive set of biophysical and socioeconomic location factors were used as baseline data. Then regression analyses were done to produce maps indicating the harvest likelihood that were used for disaggregating wood production statistics from larger administrative units to the grid cell level.

3.1.7. Metadata info 1

Indicator	Forest growing stock volume (GSV) (Santoro et al., 2011, 2015)
Mapping approach (chapt.2)	Causal relationships: Remote sensing and allometric relationships
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Stock
Unit of measure	m^3 ha^{-1}
Type of map *(point, polygon…)*	Gridded map
Map resolution	0.01° (~1 km) grid cell size
Coordinate system	Geographical latitude/longitude
Year of reference	2010
Temporal series (*if yes, please indicate the period*)	No

3.1.8. Metadata info 2

Indicator	Wood production in European forests (Verkerk et al., 2015)
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Services
Stock/flow	Flow
Unit of measure	m^3 ha^{-1} $year^{-1}$
Type of map *(point, polygon…)*	Gridded map
Map resolution	1 km grid cell size
Coordinate system	Lambert Azimuthal Equal Area (LAEA)
Year of reference	2000-2010
Temporal series (*if yes, please indicate the period*)	No

The second category of indicators for forest biomass, i.e. indicators at administrative level (NUTS), are growing stock, forest harvest and increment. Growing stock, the stem volume of living trees m^3), is a basic variable in national forest inventories. Estimates for growing stock in forests and for the average growing stock density in forests (m^3/ha) provide relevant information for the assessment this ES. Indicators on harvest and increment are useful for assessing the balance between net annual increment (m^3 $year^{-1}$) (NAI) and annual fellings (m^3 $year^{-1}$), one of the most frequently used criterion for assessing forest sustainability (Forest Europe, 2015). NAI is defined as the average annual volume over the given reference period of gross increment (i.e. the total increase of growing stock during a given time period) minus that of natural losses of all trees to a minimum diameter at breast height (DBH) of 0 cm. Fellings is the volume of wood harvested.

Levers et al (2014) implemented indicators synthesising the information on increment and harvesting. They produced two Europe-wide harmonised indicators 1) forest harvest intensity (%) and 2) harvested timber volumes (m^3 ha^{-1}) at NUTS0-3 level. To measure forest harvesting intensity, they related harvested timber volumes to net annual increment for the period 2000–2010 at NUTS level. Data on forest area, net annual increment and harvesting volumes were collected from (sub-)national forest statistics, forestry reports and inventories, and statistical yearbooks and datasets.

Ruiz et al. 2014. calculated available forest biomass as part of bioenergy potentials in Europe. The made an disctiction in stemwood and primary harvest residuals (crown biomass, stumps). The latter is relevant in the light of bioenergy sources. The EFISCEN model (Schelhaas, Eggers et al. 2007) is used to calculate the level of roundwood extraction that can be sustained for a prolonged period, resulting in the data for potentially harvestable stemwood. The input data for running the EFISCEN model is the national forest inventory data providing as detailed information as possible on 'forest available for wood supply' specifying data on area (ha); growing stock volume (m^3/ha overbark); (if available) net annual increment (m^3/ha/yr overbark); if available gross annual increment (m^3/ha/yr overbark) and annual mortality (m^3/ha/yr overbark). The volume of primary forest residues (crown biomass, stumps) were calculated on the base of the EFSOS project and Verkerk et al. 2011. Spatial environmental harvesting constraints were used to assess areas were harvesting level is influenced due to environmental conditions or policy objectives. The following constraints and spatial datasets were used:

- Site productivity, soil surface texture, soil depth and soil bearing capacity (ESDBv2 2006);
- Natural soil susceptibility to compaction (Houšková 2008);
- Slope (TUSGS 1996);
- Natura 2000 sites (DG Environment 2009).

3.1.9. Metadata info 3

Indicator	Average forest harvesting intensity (Levers et al 2014)
Mapping approach (chapt.2)	Representative sampling
Proxy (yes/no)	No, it is based on observed measures
Function/service/benefit	Service
Stock/flow	Flow
Unit of measure	%
Type of map *(point, polygon…)*	Polygon
Map resolution	NUTS0-3
Coordinate system	Lambert Azimuthal Equal Area (LAEA)
Year of reference	2000-2010
Temporal series (*if yes, please indicate the period*)	No

3.1.10. Metadata info 4

Indicator	Harvested timber volumes (Levers et al 2014)

Mapping approach (chapt.2)	Representative sampling
Proxy (yes/no)	No, it is based on observed measures
Function/service/benefit	Service
Stock/flow	Flow
Unit of measure	$m^3 ha^{-1}$
Type of map *(point, polygon…)*	Polygon
Map resolution	NUTS0-3
Coordinate system	Lambert Azimuthal Equal Area (LAEA)
Year of reference	2000-2010
Temporal series (*if yes, please indicate the period*)	No

3.1.11. Gaps

The main gaps are related to the lack of spatially-explicit observational indicators of forest harvest. Some information is available from national forest inventories. But this information is collected from sampling, and thus not spatial explicit on a national scale. This information is usually available at administrative level and a few spatially explicit indicators have been produced, nevertheless the indicators are subject to the uncertainty derived from the methods used for disaggregating administrative statistics to gridded maps.

3.2. Food security

3.2.1 Brief description of PG/ES

Food security is described in PEGASUS through three types of benefits associated to it:

(i) Access to affordable and safe food

(ii) Adequate food supply

(iii) Maintenance / increase of a sustainable resource base, as a means to secure the long term capacity of the land to produce food

of these, only the last one is considered relevant for PEGASUS, and is defined as "Maintenance / increase of a sustainable resource base, as a means to secure the long term capacity of the land to produce food".

Under this definition, there is no single indicator to describe food security, but it is rather the product of an integrated assessment of multiple ecosystem services describing the role of ecosystems in securing land productivity to future generations, coupled to management systems that guarantee the sustainability of production.

Therefore food production is not described here through metadata but will result from the integrated assessment of environmental, management and socio-economic information.

3.3. Water quality

3.3.1 Brief description of PG/ES

The ES identified to contribute to the ESBO "Water quality: achieving (or maintaining) good ecological status of surface water and good chemical status of groundwater" is water quality, which describes the capacity of ecosystems to purify and oxygenate water (e.g. by nutrient retention or translocation) and the availability of cooling water (e.g. for power production).

3.3.2 Summary of the indicator/proxy: challenges and limitations

The pressures reported to affect most surface water bodies are pollution from diffuse sources, in particular from agriculture, causing nutrient enrichment. Hydro-morphological pressures also affect many surface water bodies, mainly from hydropower, navigation, agriculture, flood protection and urban development resulting in altered habitats.

The proxy indicator acquired for water quality of agricultural systems is a map, created by the EEA, showing the 'Proportion of classified river and lake water bodies in different River Basin Districts (RBD) holding less than good ecological status or potential'. It partially reflects the input from bad management in agriculture on the water quality. Limitation is that other sources are also included, such as urban development, etc., thus there is not a direct link to agriculture. Advantages are that the database is recent (2015) and has a high spatial resolution.

Forests can serve as a sediment trap, avoiding erosion and enhancing water quality. Forests can also act as filtering systems, especially riparian forests.

3.3.3 Metadata info

Indicator	Proportion of classified river and lake water bodies in different River Basin Districts (RBD) holding less than good ecological status or potential. Source: http://www.eea.europa.eu/soer-2015/europe/freshwater#tab-based-on-indicators
Mapping approach (chapt.2)	The WISE-WFD database contains data from River Basin Management Plans reported by EU Members States according to article 13 of the Water Framework Directive. The full database is quite complex and not yet made available for public download. However, a number of aggregation queries have been made. These aggregation queries extract data from the database and present it as data tables that can be downloaded in Excel format. Most of the reported data are considered final, however, in some cases they are considered provisional by Member States. The aggregation tables are updated when the underlying WFD Database is updated with new or corrected data. It is therefore important to associate the use of any information in the tables with the date in which data was retrieved. The tables are organised for an access at various levels of overviews versus

	details - aggregated at country, river basin district (RBD) or in some cases even RBD-subunit level. Source: http://www.eea.europa.eu/data-and-maps/data/wise_wfd#tab-european-data
Proxy (yes/no)	Yes. It is not a clear empirical measure but involves classifications and assumptions on ecological status and its potential.
Function/service/benefit	In this case it is more a disservice, as the database reports river and lake water bodies in different River Basin Districts (RBD) holding less than good ecological status or potential, thus bad water quality.
Stock/flow	Stock
Unit of measure	%
Type of map *(point, polygon…)*	Polygon
Map resolution	n.a.
Coordinate system	ETRS-84 LAEC
Year of reference	2015
Temporal series (*if yes, please indicate the period*)	no

3.3.4 Gaps

Some EEA member countries do not report under the Water Framework Directive and some River Basin Districts do not have any data. Another limitation is that there is not direct link to agriculture; other potentially polluting sources are also included, such as urban development, etc.

3.4. Water availability

3.4.1 Brief description of PG/ES

The ES identified to contribute to the ESBO “Water availability: Achieving (or maintaining) a regular supply of water (i.e. avoidance of water scarcity)” is water quantity and describes the availability of a regular supply of water and avoidance of water scarcity. This includes the maintenance of sufficient volumes (“quantitative status”) of water available for drinking and other purposes, and the increase/maximisation of the capacity to maintain regular flows of water supply and discharge (i.e. avoiding water scarcity and discharge peaks). This PG/ES includes both stocks and flows, i.e. availability of surface and ground water for drinking and non-drinking purposes, maintenance of the hydrological cycle and water flow, and water storage and recharge.

3.4.2 Summary of the indicator/proxy: challenges and limitations

Three proxy indicators have been acquired for representing water quantity: the first proxy indicator is annual freshwater availability. This indicator has been implemented by de Roo et al. (2012) using a 21-year (1990-201) record of meteorological data. Daily water fluxes have been computed at 5 x 5 km grid cells with the LISFLOOD model (van der Knijff et al., 2010). Daily water fluxes have been accumulated on an annual basis for producing the average annual freshwater availability in mm/year. The map accounts for precipitation and snowfall minus evapotranspiration and deep groundwater losses. The LISFLOOD model setup has been calibrated and validated using data from around 500 river flow gauging stations. Therefore, the accuracy of the indicator is considered relatively high.

The second and third indicators are the mean annual streamflow (Q) per unit area and the runoff coefficient, both implemented by Beck et al. (2013) and Beck et al. (2015). The runoff coefficient is the estimated ratio of mean annual streamflow to precipitation. This indicator standardises the effect of different precipitation amounts. These indicators were implemented using observed streamflow from 3000 to 4000 small-to-medium-sized catchments around the globe to train neural network ensembles based on climate and physiographic characteristics of the catchments. Among other parameters, the approach used the fraction of forest cover as predictor.

One of the limitations of the three indicators is the coarse spatial resolution of 5 km and 14 km grid size for the first, and second and third indicator respectively. This aspect should be taken into consideration for integrating these indicators with other datasets of higher spatial resolution.

3.4.3 Metadata info 1

Indicator	Annual freshwater availability (de Roo et al., 2012)
Mapping approach (chapt.2)	Causal relationships (hydrological modelling)
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow
Unit of measure	Mm/year
Type of map *(point, polygon…)*	Gridded map
Map resolution	5 Km grid size
Coordinate system	Geographical latitude/longitude
Year of reference	Annual average 1990-2010
Temporal series (*if yes, please indicate the period*)	No

3.4.4 Metadata info 2

Indicator	Mean annual streamflow (Q) per unit area; runoff coefficient (ratio) (Beck et al., 2013; Beck et al., 2015)
Mapping approach (chapt.2)	Causal relationships (neural networks modelling)
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow
Unit of measure	Mm/year; Ratio
Type of map *(point, polygon…)*	Gridded map
Map resolution	0.125° (~14 km at the equator)
Coordinate system	Geographical latitude/longitude
Year of reference	Annual average 1960-2000
Temporal series (*if yes, please indicate the period*)	No

3.4.5 Gaps

A limitation of these indicators is that they were implemented using a series of predictor variables where information on forest and agriculture management is not present. This might pose some limitations for assessing local level effects of management activities in water provision.

3.5. Air quality

3.5.1 Brief description of PG/ES

The ecosystem service linked to the ESBO "Air quality: Achieving (or maintaining) minimised levels of harmful emissions and odour levels" is "air quality regulation". It is a regulating ecosystem service provided by trees or other plants by removing pollutants from the atmosphere. The clean air resulting is a public good. Using the CICES terminology, air quality regulation is considered under the division 'Mediation of waste, toxics and other nuisances', group 'Mediation by ecosystems', class 'Filtration/sequestration/storage/accumulation by ecosystems' and to describe it two indicators are proposed: Proportion of green areas in the high density area of cities (%); and Removal of NO2 by urban vegetation (ton ha^{-1} $year^{-1}$). These two indicators show that the highest service of the trees/vegetation is expected in urban areas where the concentrations of air pollutants and the number of affected population are high. This also explains why most of available literature refers to role of green in urban areas. However, this regulating capacity can be extrapolated to any situation where air pollution takes place, considering all the mechanisms summarised below.

3.5.2 Summary of the indicator/proxy: challenges and limitations

In principle there are three mechanisms by which air quality is influenced by green infrastructure:

1) Increase in deposition of pollutants. Several model studies investigate the influence of increased deposition of pollutants caused by green on air quality (among others Nowak et al., 2006 and Yang et al., 2008). These studies assume that the dry deposition of a pollutant is a function of the deposition velocity, the height to which the pollutant is well mixed, and the pollutant concentration. The higher the deposition velocity, the more deposition, and the lower the concentration of a pollutant in the air will become. The pollutant concentration itself also influences the deposition, the higher the concentration the more deposition. Thus some studies suggest to place green infrastructure at locations where the emissions, and thereby also the concentration of pollutants, are high (Nowak et al., 2006). They estimated that the air quality improvement in ten American cities due to removal of pollutant by urban trees was 1 % or less. For the city of Portland, with 42% of tree cover, the air quality was 0.003% improved for CO, 0.6% for NO2, 0.8% for O3, 1% for PM10, and 0.7% for SO2. Although the improvement is small, using other designs than green might worsen the air quality. It must be noted that part of the removed pollutants can be re-suspended into the atmosphere. This re-suspension is mainly driven by wind. The study of Nowak et al. (2013) assumes that the deposited PM2.5 are removed from green surfaces when rain intensity exceeds their storage capacity, which was calculated as 0.2 x leaf area index.

2) Altering the wind flow. To what extent the wind flow in an urban environment is altered due to green, depends on the type of green infrastructure (trees, shrubs, or grass), the lay-out of the urban environment, and the wind direction.

3) Emitting biogenic volatile compounds and pollen. Biological sources also emit biogenic volatile organic compounds (VOCs). The majority of VOCs are produced by plants. A major class of VOCs is terpenes. Emissions are affected by a variety of factors, such as temperature, which determines rates of volatilization and growth, and sunlight, which determines rates of biosynthesis. Emission occurs almost exclusively from the leaves, the stomata in particular. The VOCs can react with nitrogen oxides and carbon monoxide to form ozone, which is a photochemical reaction (i.e., occurs when there is sunlight). Thereby, green might increase the concentration of O_3 in cities, especially in summertime. Nowak et al. (2000) modelled the consequence of green on O_3 concentrations above a city, and found that in urban areas the O_3 concentrations decreased when green infrastructure is added. However, the average O_3 concentration over the overall domain increased. It is advisable to use diverse plant types to ensure that the O_3 does not increase due to planting green infrastructure. Besides biogenic volatile organic compounds green also emit pollen, which has a negative effect on the health of people with hay fever symptoms.

However, it is important to note that experimental data on the influence of green on air quality in an urban environment is still lacking. Weijers et al. (2007) did investigate experimentally the influence of a green strip on the air quality (PM and NOx) near a motorway. They found that immediately behind the green strip the concentrations of PM2.5 and PM10 were lowered. No such relation was found for NO and NO_2. A similar study was carried out by Erbrink et al. (2009) along a motorway. They found higher concentrations of NO and NOx close by the road when vegetation was planted. However, the concentrations of NO_2 were lower when vegetation was planted due to the less mixing in of O_3. For fine dust they did not find that the concentration decreased when vegetation was planted.

In conclusion, the assessment of the air regulating capacity by vegetation (in agriculture ir forest areas) should be carefully done considering:

- the species and the season: in principle conifer trees are best in removing fine dust, because the dust are deposited on the needles and on the branches. Furthermore, these trees in general stay green throughout the winter, making it possible to remove fine dust all year round. For gases, deciduous trees with leaves with large stomatal openings remove most pollutants. However, in winter the uptake of pollutants by plants are minimal;
- the size, growth, form, and health condition of an individual plant (Jim and Chen, 2008)
- management: the overall health of urban green is also important to ensure optimal pollutant removal. Timely pruning, watering on dry days, and pest monitoring and control, could improve plants health and thus their intensities of photosynthesis and respiration (Yang, 1996 cited in Jim and Chen, 2008).

The assessment will clearly depend on the scale (e.g. forests at EU level, and individual trees at local/city level). At pan European scale, we propose two indicators:

1. for all areas: the forest% share of land area (if possible distinguishing between conifer and deciduous trees)
2. for urban areas: removal of NO_2 by urban vegetation

3.5.3 Metadata info 1

Indicator	Forest% share of land area
Mapping approach (chapt.2)	Based on both Earth Observation data and recent forest statistical information. It applies a previously developed calibration method to produce a comprehensive and complete European map on forest area.
Proxy (yes/no)	yes
Function/service/benefit	Function/service (if linked to air quality information) and benefit (if linked to population density)
Stock/flow	stock
Unit of measure	Forest % share of land area
Type of map *(point, polygon…)*	grid
Map resolution	1 x 1 km^2 resolution
Coordinate system	
Year of reference	EU27, AL, BA, CH, HR, ME, MK, NO, RS, TR: Forest/non-forest map 2006 (beta version) prepared by the EC Joint Research Centre, aggregated to 1km resolution. Based on IRS-P6 LISS-III, SPOT4 (HRVIR) and SPOT5 HRG satellite data of 2006; Statistical data: National forest inventory statistics (ranging from 1994-2008 depending on te country); State of Europe's Forests country statistics 2011.
Temporal series (*if yes, please indicate the period*)	no
Availability	Map comes from EFI. The map can be accessed free of charge after completing a simple registration process.

3.5.4 Metadata info 2

Indicator	Removal of NO_2 by urban vegetation
Mapping approach (chapt.2)	The calculation of the air purification model is based on the calculation of three different indicators: average concentrations of NO2, deposition velocity, and removal capacity. Those indicators are evaluated at European

	scale by using simple GIS map algebra operations.
Proxy (yes/no)	yes
Function/service/benefit	service
Stock/flow	stock
Unit of measure	Index (0,1)
Type of map *(point, polygon…)*	grid
Map resolution	100m
Coordinate system	
Year of reference	2010
Temporal series (*if yes, please indicate the period*)	no
Availability	JRC

3.5.5 Gaps

The calibration of Forest share of land area indicator achieves an overall fit of the map with the statistics at regional and country level, i.e. when summing up all forest area in a country the result corresponds to the respective statistics. However, at the local level the map might differ from the real situation due to uncertainties in the applied remote sensing products and the changes introduced by the calibration procedure. Uncertainties are higher for Belarus, Ukraine, Moldova and Russia, since the input map used for these areas is of much lower resolution (1000m) than the one used for the rest of Europe (25m).

The removal of NO_2 by urban vegetation map focuses on urban areas but could be expanded to peri-urban and rural areas. A total of 1769 and 3035 monitoring sites for the year 2000 and 2010 respectively from the AirBase database , were considered for the analysis. Those sites were meant to be representative of different type of areas (urban, suburban and rural sites) and different types of impact (or absence) of nearby emissions (industrial, traffic and background stations) according to the Guidance for the Implementing Decision on Air Quality Reporting (6) (2011/850/EU). Regarding the predictor variables, some of them reflect sources or sinks for air pollution such as the road network, different types of land use and population density. Population density was also considered a proxy for traffic flow levels since no complete information on this is currently available.

3.6. GHG emissions

Greenhouse gas emissions from agriculture contribute with 9.6 % to EU-28 total greenhouse gas emissions (Eurostat, 2015). Although GHG emissions from agriculture have decreased by 20% since 1990, further efforts are possible and will be required to meet the ambitious EU energy and climate agenda.

The main ecosystem function linked to the GHG mitigation is C sequestration, which mainly happens in forest ecosystems, and it is already included in the next subsection and therefore not discussed here.

It is interesting to notice that farm and forestry management have also a role in the abatement of GHG emissions. For example improved nitrogen management on arable farms, improved animal genetics and both on-farm and centralised anaerobic digestion are considered as being cost-effective measures (Moran et al. 2010). Furthermore, the abatement potential of any stand-alone measure will be influenced by the simultaneous adoption of other measures. For example, if a farm implements biological fixation, then less nitrogen fertiliser will be required.

We will consider these management factors, as far as data are available, in the analysis of the patterns and trends of PG/ES occurrence in relation to the diversity of EU farming and forestry systems.

3.7. Carbon sequestration/storage (forest)

3.7.1 Brief description of PG/ES

Carbon sequestration describes the capacity of forest for removing and storing carbon from atmosphere. Carbon removed from forest is stored in live and dead biomass and in forest soils. Forests contribute to global climate regulation by carbon sequestration and storage.

3.7.2 Summary of the indicator/proxy: challenges and limitations

The first indicator identified as proxy for forest carbon sequestration is the map of forest boreal and temperate carbon stock distribution that is a proxy for carbon sequestration. The methodology was implemented by Thurner et al. (2014) to infer a forest carbon density map at 0.01° (~1 km) resolution, based on remotely sensed radar imagery of boreal and temperate forests and covering the Northern hemisphere. This map was developed modelling with allometric relationships the forest growing stock volume map measured in m^3 ha^{-1} (Santoro et al., 2011; Santoro et al., 2013), recently retrieved from radar observation data acquired by Envisat Advanced SAR (ASAR) between October 2009 and February 2011. The map was then masked using the GLC2000 global land-cover map (JRC, 2003) to exclude non-forested areas. In addition, the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009) and the JRC GHG-AFOLU Biomass Compartment Database (JRC, 2009) were used and aggregated to the level of leaf forest type: broadleaved, deciduous conifer and evergreen conifer forests. The resulting map quantifies the forest carbon density measured in kg C m-2. It has been tested at a regional scale using inventory-based data from Russia and USA. In Europe the EFI (2005) national statistics at country scale were adopted, resulting a significant agreement ($r^2 = 0.7$, RMSE = 0.87 kg C m-2). The input factors (growing stock volume, wood density, allometric relationships) used for the computation of the map contributed to develop an uncertainty map estimated for each grid cell.

The second indicator, forest woody biomass increment, was implemented by Busetto et al. (2014) using remotely sensed data of Gross Primary Productivity (GPP) from MODIS (NASA Product MOD17A3) adjusted with GPP data derived from upscaling FLUXNET observations using the Model Tree Ensemble (MTE) technique implemented by Jung et al. (2011) to derive a 1-km resolution woody biomass increment map. The map was validated using regional National Forest Inventory (NFI) data. Specifically the indicator measures above ground woody forest biomass increment i.e., the yearly increase of the biomass stored in forests in their woody above-ground tissues, i.e. excluding leaves and roots.

The indicator shows a reasonable good agreement with the validation information from NFI, nevertheless the applicability at local level (grid-cell level) might be subject to local effects and not well captured by the remotely sensed data used for implementing the indicator. Thus, caution is needed when assessing the indicator at local level. Nevertheless, information from the indicators at regional level is in-line with the information from NFI.

The third and fourth indicators are growing stock and above-ground biomass in forests based on remote sensing and field measurements. National forest inventory data were combined with remotely sensed data to produce pan-European maps on growing stock and above-ground woody biomass for the two species groups ‘‘broadleaves’’ and ‘‘conifers’’. An automatic up-scaling approach made use of satellite remote sensing data and field measurement data was applied for EU-wide mapping of growing stock and above-ground biomass in forests. The approach was based on sampling and allows the direct combination of data with different measurement units such as forest inventory plot data and satellite remote sensing data. For the classification, data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were used. Comprehensive field measurement data from national forest inventories for 98,979 locations from 16 countries were used for which tree species and growing stock estimates were available. The classification results were evaluated by comparison with regional estimates derived independently from the classification from national forest inventories. The validation at the regional level shows a high correlation between the classification results and the field based estimates with correlation coefficient r = 0.96 for coniferous, r = 0.94 for broadleaved and r = 0.97 for total growing stock per hectare. The mean absolute error of the estimations is 25 m^3/ha for coniferous, 20 m^3/ha for broadleaved and 25 m^3/ha for total growing stock per hectare. Biomass conversion and expansion factors were applied to convert the growing stock classification results to carbon stock in above-ground biomass.

3.7.3 Metadata info 1

Indicator	Carbon stock in forest (Thurner et al., 2014)
Mapping approach (chapt.2)	Causal relationships: Remote sensing and allometric relationships
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Stock
Unit of measure	Kg C m^{-2}
Type of map *(point, polygon…)*	Gridded map
Map resolution	0.01° (~1 km) grid cell size

Coordinate system	Geographical latitude/longitude
Year of reference	2010
Temporal series (*if yes, please indicate the period*)	No

3.7.4 Metadata info 2

Indicator	Forest woody biomass increment (Busetto et al., 2014)
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow
Unit of measure	Ton dry matter/ha yr
Type of map *(point, polygon…)*	Gridded map
Map resolution	1-km
Coordinate system	Lambert Azimuthal Equal Area (ETRS89/ETRS-LAEA)
Year of reference	Annual average 2000-2010
Temporal series (*if yes, please indicate the period*)	No

3.7.5 Metadata info 3

Indicator	Growing stock and above-ground biomass in forests Gallaun, H., G Zanchi , GJ Nabuurs, G Hengeveld, M Schardt, PJ. Verkerk. 2010 EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements. Forest Ecology and Management 260 (2010) 252–261
Mapping approach (chapt.2)	National forest inventory data were combined with remotely sensed data to produce pan-European maps on growing stock and above-ground woody biomass for the two species groups ‘‘broadleaves’’ and ‘‘conifers’’. An automatic up-scaling approach made use of satellite remote sensing data and field measurement data was applied for EU-wide mapping of growing stock and above-ground biomass in forests
Proxy (yes/no)	Yes
Function/service/benefit	Function/Service
Stock/flow	Stock
Unit of measure	tonnes/ha/year

Type of map *(point, polygon…)*	Gridded map
Map resolution	10 Km grid size
Coordinate system	Geographical latitude/longitude
Year of reference	1995-2005
Temporal series (*if yes, please indicate the period*)	No

3.7.6 Gaps

The main data gap of the indicators on *Carbon stock in forest* and *Forest woody biomass increment* is the lack of plot level data available for validation of the datasets. This aspect could limit local level assessments where high accuracy of the estimates are necessary. Both indicators were validated using regional level datasets and despite a reasonably good correspondence, their usability at local level should be verified. Also, the maps do not contain information about soil carbon stocks or flows.

3.8. Fire protection

3.8.1 Brief description of PG/ES

As in any other natural hazard (e.g. soil erosion), also in fire management it makes sense to include "fire protection" as an ecosystem service given the variability in the spatial distribution of fire susceptibility (Bajocco and Ricotta, 2008; Fernandes, 2009; Moreira et al., 2009; Verde and Zêzere, 2010), particularly in the presence of fire-friction landscapes, which change fire behavior and minimize its effects on the ecosystem (Azevedo et al., 2013; Fernandes, 2013; Fernandes et al., 2010). Highlighting the effect of landscape structure, ecosystems and active land management in controlling fire size, intensity and severity are requirements to manage fire regimes more suitable to maintain biodiversity and ecological processes in the landscape (Fitzsimons et al., 2012; Guiomar et al., 2015), thus maintaining ecological resilience as a strategy for conserving biodiversity and ecosystem services throughout global change (Rist and Moen, 2013).

3.8.2 Summary of the indicator/proxy: challenges and limitations

To assess the provision of fire protection services is critical to analyze the data enabling the characterization fire regimes, such as the spatial distribution of the burned areas, the number of fires, fire frequency (recurrence) and the occurrence of large and mega-fires (Fréjaville and Curt, 2015; Moreno and Chuvieco, 2013; Pausas and Keeley, 2014; San-Miguel-Ayanz et al., 2013a; Santana et al., 2014; Tedim et al., 2013).

The EFFIS (European Forest Fire Information System) has been developed jointly by the European Commission services (Directorate General Environment and the Joint Research Centre) and the relevant fires services in the countries (San-Miguel-Ayanz et al., 2013b). EFFIS provides information to over 37 countries in the European and Mediterranean regions, through its main components (San-Miguel-Ayanz et al., 2012): European Fire Database, Active Fire Detection, Rapid Damage Assessment, Fire Danger Forecast, and post-fire modules dealing with the analysis of land cover damages, post-fire soil erosion, emissions estimates and dispersion of the smoke plume, and the monitoring of vegetation recovery in large burnt areas.

The European Fire Database is the largest repository of information on individual fire events in Europe containing over 2 million individual wildfire event records, of which about 1.66 million are classified as forest fires, and reflecting (today) the efforts of the 22 contributing countries that have been regularly supplying fire data (San-Miguel-Ayanz et al., 2012): Bulgaria, Croatia, Cyprus, Czech, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and Turkey. The four main types of information collected are: time of fire, location of fire, size of fire, and cause of fire. Rodrigues et al. (2013) used data from this database to assess temporal trends in number of fires and in burned area between 1985 and 2009 in the EU-Mediterranean region at three different spatial scales: (1) at regional (supranational) level, considering the Euro-Mediterranean region as a whole; (2) at country level; (3) at NUTS3 level.

Rapid Damage Assessment (RDA) module provides harmonized daily estimates of the areas affected by forest fires during the fire season, based on 250 m spatial resolution bands provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) (Sedano et al., 2013). The spatial resolution of the MODIS data permits the accurate mapping of fires of approximately 40 ha or larger, although smaller fires are often detected and mapped, and the information on the perimeters of these fires is updated twice daily and available in the "Current Situation" page of EFFIS (San-Miguel-Ayanz et al., 2012; Vilar et al., 2015).

European fire danger index is based on the Canadian Fire Weather Index (FWI) (van Wagner, 1987), which, in turn, has been applied in several studies conducted in Europe (Bedia et al., 2012; Cane et al., 2008; Carvalho et al., 2008; Dimitrakopoulos et al., 2011; Rainha and Fernandes, 2002; Šturm et al., 2011). The FWI System has six components rating fuel moisture content and potential fire behavior in a common fuel type (i.e., mature pine stand) and in no slope conditions. The three moisture codes carry different useful information as indicators of the ease of ignition and flammability of fine fuels (Fine Fuel Moisture Code - FFMC), fuel consumption in medium-size woody material and moderate duff layers (Duff Moisture Code - DMC), fuel consumption in large logs and amount of smoldering in deep duff layers (Drought Code - DC) (Alexander, 2008). The remaining codes of the FWI are fire behavior indices rating the expected rate of fire spread (Initial Spread Index - ISI), the fuel available for combustion (Build Up Index - BUI), and the fire line intensity (Fire Weather Index - FWI) (Alexander, 2008; van Wagner, 1987). Fire danger assessment is done in EFFIS with weather forecasts from the Météo-France and the Deutsche Wetter Dienst (DWD), and with observed synoptic weather data of air temperature, relative humidity, wind speed and previous 24-h precipitation. In the current EFFIS implementation of the FWI, the 5 fire danger classes are defined through a geometric progression (San-Miguel-Ayanz et al., 2012).

More recently EFFIS has made available on the "Current Situation" the spatial distribution of fire severity in each fire event. In the face of what has been previously reported, these data are even more relevant than the more common indicators of fire regime. Lee et al. (2015) determined ecosystem service losses by assessing fire burn severity, translating this severity into an initial quantifiable loss in terms of acre-years, and summing the losses over the ecosystem recovery period. As the above-mentioned indicators of fire regime, fire severity data can be used as a proxy for assessing ecosystem services related to fire protection. However it can also be tested in an approach similar to that in Guerra et al. (2014) and adopted by Maes et al. (2015). Currently the severity data are presented in four classes and are not available (detailed) information on their calculation. However, assuming that the severity data can be translated in a ratio of biomass consumed depending on the biomass available, these fire severity can be compared with the Buildup Index (BUI) of the FWI system (used in this context as the Structural Impact in the sense of Guerra et al. (2014)), since BUI is a relative measure of the total amount of fuel available for combustion.

3.8.3 Metadata info 1

Indicator	**Burned areas from *Rapid Damage Assessment*** http://forest.jrc.ec.europa.eu/effis/ References: San-Miguel-Ayanz et al. (2013b, 2012, 2009); Vilar et al. (2015)
Mapping approach (chapt.2)	
Proxy (yes/no)	Yes
Function/service/benefit	
Stock/flow	
Unit of measure	-
Type of map *(point, polygon…)*	Polygon
Map resolution	40ha (minimum map unit)
Coordinate system	
Year of reference	
Temporal series (*if yes, please indicate the period*)	

3.8.4 Metadata info 2

Indicator	**Burned areas from *European Fire Database*** http://forest.jrc.ec.europa.eu/effis/ References: San-Miguel-Ayanz et al. (2013b, 2012, 2009); Vilar et al. (2015)
Mapping approach (chapt.2)	
Proxy (yes/no)	Yes
Function/service/benefit	
Stock/flow	
Unit of measure	-
Type of map *(point, polygon…)*	Polygon
Map resolution	
Coordinate system	
Year of reference	
Temporal series (*if yes, please indicate the period*)	1980-2015

3.8.5 *Metadata info 3*

Indicator	**Burned areas from *European Fire Database*** http://forest.jrc.ec.europa.eu/effis/ References: San-Miguel-Ayanz et al. (2013b, 2012, 2009); Vilar et al. (2015)
Mapping approach (chapt.2)	
Proxy (yes/no)	Yes
Function/service/benefit	
Stock/flow	
Unit of measure	-
Type of map *(point, polygon…)*	Point
Map resolution	
Coordinate system	
Year of reference	
Temporal series (*if yes, please indicate the period*)	1980-2015

3.8.6 *Metadata info 4*

Indicator	**Fire severity** http://forest.jrc.ec.europa.eu/effis/
Mapping approach (chapt.2)	
Proxy (yes/no)	Yes
Function/service/benefit	
Stock/flow	
Unit of measure	Categorical (5 classes)
Type of map *(point, polygon…)*	Vector
Map resolution	40ha (minimum map unit)
Coordinate system	
Year of reference	
Temporal series (*if yes, please indicate the period*)	

3.9. <u>Flood protection</u>

3.9.1 Brief description of PG/ES

Flood protection describes the capacity of ecosystems to reduce runoff and discharge rates. Woodlands and wetlands can for example serve as water retention areas and have the capacity to slow down water flows.

3.9.2 Summary of the indicator/proxy: challenges and limitations

We haven't found a map for the EU as a whole, of flood protection related to agricultural land or forests. There are records of some national flood protection maps: flood protection/water retention based on a land use, slope and soil maps in Croatia; potential flood mitigation/protection by peatland, based on conservation status, land use, drainage system and forest management maps, in Lithuania.

For Europe there are/will be maps available on:

Flood hazard maps, showing the extent and expected water depths/levels of an area flooded in a couple of scenarios, varying in probability (return period).

Flood risk maps, shall also be prepared for the areas flooded under these scenarios showing potential population, economic activities and the environment at potential risk from flooding, and other information that Member States may find useful to include, for instance other sources of pollution.

(Source: http://ec.europa.eu/environment/water/flood_risk/flood_atlas/)

Furthermore, there are two maps available on the water-retention potential of Europe's forests, one map for the potential in wintertime and one for the potential in summertime. For these maps, an analysis was conducted of the relationships between forest and water retention for the whole of Europe. It is based on available data at European level from the EEA Water Accounts Production Database, as well as on information on forest land use and cover from forest statistics and CORINE LC. The selected indicators did not always provide the same level of signals for the same territory due to different soil, climatic or forest stand reasons, as well as because of data precision issues. Therefore, the classification method focuses on computing an index by summing-up the results obtained from three main indicators: run off coefficient, surface run-off coefficient and run off irregularity coefficient. This classification should be interpreted as an attempt to quantify the water retention potential of forests in a very generalised way. However, such a classification is helpful to provide an overview at European level of the influence of forests on water retention. The study resulted in a classification of European forests into those with high, medium and low water retention potentials. Water retention is a time-dependent process. Seasonality is very important where water retention of forests is concerned. Therefore, the water retention potentials of European forests have been estimated separately for winter and summer months rather than providing annual averages that might be misleading when making conclusions. Water retention potential across Europe varies significantly between winter and summer. The analysis revealed few forest areas in winter that had high retention potential, due to the different rainfall regime. The rest of Europe presented mainly medium or low levels of water retention during the winter. In contrast, forests play a significant role in retaining water during summer months, thus expanding high water retention potentials across Europe. High water retention potentials occur mostly in the lowlands of the Atlantic, Continental, and Boreal regions and in the Alpine region.

Source: http://www.eea.europa.eu/publications/water-retention-potential-of-forests

3.9.3 Metadata info

Indicator	Water retention potential by forests, winter and summer Source: http://www.eea.europa.eu/publications/water-retention-potential-of-forests map 4.1
Mapping approach (chapt.2)	A European overview of the role of forests in water retention, based on the Water Accounts Production Database developed at the EEA. The results represent 287 sub-basins hosting more than 65,000 catchments across Europe. The impact of forests on water retention is measured according to three parameters/characteristics: forest cover (measured in hectares), forest types (coniferous, broad-leaved, mixed), and the degree of management of the forests ('protected' versus unprotected/commercial forests). The estimation of the water-retention potential is derived from the relationships between input (rainfall) and output (water run-off into rivers and lakes) as affected by these three forest characteristics.
Proxy (yes/no)	yes
Function/service/benefit	service
Stock/flow	stock
Unit of measure	Qualitative (low, medium, high)
Type of map *(point, polygon…)*	polygon
Map resolution	n.a.
Coordinate system	ETRS-84 LAEC
Year of reference	2015
Temporal series (*if yes, please indicate the period*)	no

3.9.4 Gaps

The water retention potential of forests is not calculated for some NUTS areas, because these areas have a forest coverage < 10% or the hydrological data is not available.

3.10. Soil functionality

3.10.1 Brief description of PG/ES

Soil sustains the delivery of a range of land-based services that support life on the planet (Barrios, 2007; Brevik et al., 2015; Calzolari et al., 2016; Dominati et al., 2010; Lavelle et al., 2006; McBratney et al., 2014; Nielsen et al., 2015; Pascual et al., 2015; Pulleman et al., 2012; Wagg et al., 2014; Wall et al., 2012). Widespread soil degradation, leading to a decline in the ability of soil to carry out its ecosystem services, is largely caused by non-sustainable uses of the land. In an ecosystem services management framework, although recognising and taking account of inherent soil properties (e.g. slope, depth, cation exchange capacity, clay types), the manageable properties (e.g. soluble phosphate, mineral nitrogen, organic matter contents, macroporosity) assume more practical importance as they provide the opportunity for agronomists, farmers and other stakeholders to optimise the provision of ecosystem services from soils (Dominati et al., 2010). Biodiversity in the soil is a regulator of ecosystem processes playing an important role in ecosystem service delivery (Díaz et al., 2006; Lavelle et al., 2006; Mace et al., 2012). The dynamics of many soil nutrient cycles are determined by the composition of biological communities in the soil (Bradford et al., 2002; Hector et al., 2000), resilience to pests and environmental change is also increased in more diverse biological communities (Cardinale et al., 2003) and, in many contexts, higher biodiversity is related with increased ecosystem functions (Balvanera et al., 2006; Barrios, 2007; Hooper et al., 2005; Lavelle et al., 2006; Naeem and Wright, 2003; Pascual et al., 2015; Srivastava and Bell, 2009; Wagg et al., 2014; Worm and Duffy, 2003). A complete overview of soil threats in Europe is given in Stolte et al., 2015.

3.10.2 Summary of the indicator/proxy: challenges and limitations

Maes et al. (2015) assessed the trends in soil formation and composition through the Gross Nitrogen Balance which was also suggested in the 2nd MAES report on indicators for services delivered by agro-ecosystems (Maes et al., 2014). Gross nitrogen balance is an agri-environment indicator and provides an indication of the potential surplus of nitrogen (N) on agricultural land (kg N ha^{-1} $year^{-1}$). According to Jones et al. (2012) excess nitrogen in the soil from high fertiliser application rates and/or low plant uptake can cause an increase in the mineralisation of organic carbon, which in turn leads to an increased loss of carbon from soils. Maximum nitrogen values are reached in areas with high livestock populations, intensive fruit and vegetable cropping, or cereal production with imbalanced fertilisation practices.

Based on the work of Jones et al. (2012), the Theoretical Ecosystem Potential (TEP) was proposed as an indicator of the role played by ecosystems in sustaining the soil's biological activity, physical structure, composition, diversity and productivity (EEA, 2014; Liquete et al., 2015). This indicator results from the spatial overlay of two soil threats, Soil Compaction (Panagos et al., 2012) and Soil Erosion (Kirkby et al., 2008; Panagos et al., 2015e; van der Knijff et al., 2000), with good soil management practices or preservation measures with positive effects on Top-soil Organic Carbon (Jones et al., 2005; Panagos et al., 2013, 2012; Rusco et al., 2001; Zdruli et al., 2004). According to Liquete et al. (2015), which used TEP as a proxy of the capacity of natural systems to maintain soil structure and quality, the layers were ranked into four classes from 1 (very high susceptibility to compaction, >50 t/ha/yr of erosion, 0–2% of organic carbon content) to 4 (low susceptibility to compaction, null erosion, >8% organic carbon). These data were used to create an integrative indicator about the theoretical TEP for each pixel *i*:

$$TEP_i = SC_i + SE_i + SOC_i$$

where the three parameters are reclassified as explained above, and TEP gets values between 3 (minimum) and 12 (maximum). Regions with high TEP scores are considered to provide good ecosystem functions for maintaining good soil structure and quality.

Soil compaction results mainly of agricultural mechanization and livestock trampling (Ball et al., 2012; Coulouma et al., 2006; Hiltbrunner et al., 2012; Picchio et al., 2012; Polge de Combret-Champart et al., 2013), and affects soil structural and chemical properties by increasing bulk density and decreasing macropores (Lipiec and Hatano, 2003; Mossadeghi-Björklund et al., 2016; van Dijck and van Asch, 2002; Voorhees et al., 1979), reducing saturated and near-saturated hydraulic conductivity (Schwen et al., 2011), reducing soil physical fertility (Hamza and Anderson, 2005), influencing both nitrification and denitrification and mineralization of soil organic carbon (Ball et al., 2008; Bhandral et al., 2007; Hansen et al., 1993), reducing water infiltration-rate and increasing erosion risk by accelerating run-off (Morvan et al., 2014; Vervoort et al., 2001).

Between the supporting processes included in the conceptual framework proposed by Dominati et al. (2010), soil biota activity and diversity are essential to soil structure, nutrient cycling, and detoxification, being in the core of soil formation (pedogenesis), and building up the physical, biological and chemical stocks of soils. Hence, soil degradation by erosion, contamination, salinisation and sealing all threaten soil biodiversity by compromising or destroying the habitat of the soil biota (Jones et al., 2012). According with the same authors, management practices that reduce the deposition or persistence of organic matter in soils, or bypass biologically mediated nutrient cycling, also tend to reduce the size and complexity of soil communities (Jones et al., 2012). In this context, Orgiazzi et al. (2015) assessed soil threats at European level through knowledge-based rankings of potential threats to different components of soil biodiversity.

3.10.3 Metadata info 1

Indicator	**Natural susceptibility to compaction** http://esdac.jrc.ec.europa.eu/content/natural-susceptibility-soil-compaction-europe References: Panagos et al. (2012)

Mapping approach (chapt.2)	This map shows the natural susceptibility of agricultural soils to compaction if they were to be exposed to compaction. The evaluation of the soil's natural susceptibility is based on the creation of logical connections between relevant parameters (pedotransfer rules). The input parameters for these pedotransfer rules are taken from the attributes of the European soil database, e.g. soil properties: type, texture and water regime, depth to textural change and the limitation of the soil for agricultural use. Besides the main parameters auxiliary parameters have been used as impermeable layer, depth of an obstacle to roots, water management system, dominant and secondary land use. It was assumed that every soil, as a porous medium, could be compacted.
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	
Unit of measure	Categorical (6 classes)
Type of map *(point, polygon…)*	Raster
Map resolution	1km
Coordinate system	ETRS89 Lambert Azimuthal Equal Area
Year of reference	2000
Temporal series (*if yes, please indicate the period*)	No

3.10.4 Metadata info 2

Indicator	**Topsoil Organic Carbon Content** http://esdac.jrc.ec.europa.eu/content/octop-topsoil-organic-carbon-content-europe References: Jones et al. (2005); Panagos et al. (2013, 2012)
Mapping approach (chapt.2)	ESDAC makes available the Maps of Organic carbon content (%) in the surface horizon of soils in Europe
Proxy (yes/no)	Yes
Function/service/benefit	Benefit
Stock/flow	Stock
Unit of measure	%
Type of map *(point, polygon…)*	Raster
Map resolution	1km
Coordinate system	ETRS89 Lambert Azimuthal Equal Area (?)
Year of reference	2004 (?)
Temporal series (*if yes, please indicate the period*)	No

3.10.5 *Metadata info 3*

Indicator	**Potential threats to soil biodiversity in Europe** http://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe References: Orgiazzi et al. (2015)
Mapping approach (chapt.2)	Knowledge-based rankings of potential threats to different components of soil biodiversity were developed in order to assess the spatial distribution of threats on a European scale. A list of 13 potential threats to soil biodiversity was proposed to experts with different backgrounds in order to assess the potential for three major components of soil biodiversity: soil microorganisms, fauna, and biological functions. This approach allowed us to obtain knowledge-based rankings of threats. These classifications formed the basis for the development of indices through an additive aggregation model that, along with ad-hoc proxies for each pressure, allowed us to preliminarily assess the spatial patterns of potential threats. Intensive exploitation was identified as the highest pressure. In contrast, the use of genetically modified organisms in agriculture was considered as the threat with least potential. The potential impact of climate change showed the highest uncertainty. Fourteen out of the 27 considered countries have more than 40% of their soils with moderate-high to high potential risk for all three components of soil biodiversity. Arable soils are the most exposed to pressures. Soils within the boreal biogeographic region showed the lowest risk potential. The majority of soils at risk are outside the boundaries of protected areas. First maps of risks to three components of soil biodiversity based on the current scientific knowledge were developed. Despite the intrinsic limits of knowledge-based assessments, a remarkable potential risk to soil biodiversity was observed. Guidelines to preliminarily identify and circumscribe soils potentially at risk are provided. This approach may be used in future research to assess threat at both local and global scale and identify areas of possible risk and, subsequently, design appropriate strategies for monitoring and protection of soil biota.
Proxy (yes/no)	Yes
Function/service/benefit	
Stock/flow	
Unit of measure	Categorical (5 classes)
Type of map *(point, polygon…)*	Raster
Map resolution	500m
Coordinate system	ETRS89 Lambert Azimuthal Equal Area
Year of reference	2015
Temporal series (*if yes, please indicate the period*)	No

3.10.6 *Metadata info 4*

Indicator	**Water Retention Index** http://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe References: Orgiazzi et al. (2015)
Mapping approach (chapt.2)	

Proxy (yes/no)	Yes
Function/service/benefit	
Stock/flow	
Unit of measure	
Type of map *(point, polygon…)*	Raster
Map resolution	1km
Coordinate system	
Year of reference	
Temporal series (*if yes, please indicate the period*)	No

3.11. Soil protection

3.11.1 Brief description of PG/ES

The proxy identified to describe ES providing the ESBO "Soil protection: Achieving (or maintaining) minimisation of soil degradation" is soil erosion.

Soil erosion is one of the major and most widespread forms of soil degradation in Europe, showing negative effects on economic and ecosystem services provided by soils (Farkas et al., 2013). Moreover, this process can be significantly accelerated by human activities such as agricultural practices, deforestation, overgrazing and construction activities (García-Ruiz and Lana-Renault, 2011; García-Ruiz, 2010; Nunes et al., 2011), and considering the climate change scenarios it can worsen considerably. Thus the need to quantify the susceptibility to erosion, as well as determine their spatial distribution throughout Europe, has long been a concern (Kirkby et al., 2008; Panagos et al., 2015e; van der Knijff et al., 2000). According to Huber et al. (2008) with the very slow rate of soil formation, any soil loss of more than 1 ton/ha/yr can be considered as irreversible within a time span of 50–100 years.

3.11.2 Summary of the indicator/proxy: challenges and limitations

Erosion control is an important service provided by vegetation, which can reduce the speed of runoff water and thus regulate water flows and avoid soil erosion. In this context, soil erosion control is a key service supply by terrestrial ecosystems, mainly provided by vegetation cover. In the frame of ESTIMAP (Ecosystem Services Mapping) project (Zulian et al., 2014), Maes et al. (2015) assessed the erosion control service in ecosystems by means of two indicators under the conceptual framework of the Revised Universal Soil Loss Equation (Wischmeier, 1978; Renard, 1997):

$$A = R \times K \times LS \times C \times P$$

where *A* is the amount of soil loss ((t ha^{-1} yr^{-1}); *R* is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}); *K* is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}; *L* is the slope-length factor and *S* is the slope factor (dimensionless); *C* is dimensionless vegetation cover factor; and *P* refers to the soil conservation and management practice aimed at erosion control.

In the framework proposed by Guerra et al. (2014), which compares modelled soil erosion with and without the presence of vegetation, *C* and *R* factors are considered dynamic factors whereas *P*, *LS* and the *K* factors will keep static:

- To estimate the rainfall erosivity parameter, both Maes et al. (2015) and Guerra et al. (2014) followed the model proposed by Diodato and Bellocchi (2010) for Mediterranean conditions, but Maes et al. (2015) estimated the annual erosivity of rainfall while Guerra et al. (2014) determined its monthly variation. Panagos et al. (2015a) estimated the R-factor based on the model of Brown and Foster (1987) at the European scale and concluded that the spatial distribution of the R-factor values were similar to the results that were obtained by Diodato (2014);

- *LS*-factor and *K*-factor were estimated for Europe by Panagos et al. (2015b) and Panagos et al. (2014) respectively;
- The *C*-factor (yearly average) was determined using the CORINE Land Cover Map for 2006 reclassified to a smaller number of land cover classes, and vegetation cover was monthly estimated using the relation between the Normalized Difference Vegetation Index (NDVI; calculated from 2009 MODIS 16 days NDVI composites with a 250 meters pixel resolution) and the USLE *C*-Factor (Renard et al., 1997; Wischmeier and Smith, 1978) proposed by van der Knijff et al. (2000, 1999). The original *C*-factor data was stratified using the environmental zones from Metzger et al. (2005), and zonal statistics were calculated to obtain the average monthly value of the *C*-factor present in each land cover class. Then, a monthly snow cover data set (Dosio and Paruolo, 2011; Dosio et al., 2012) was included to mask the obtained *C*-factor. More recently, Panagos et al. (2015c) proposed a map with the *C*-factor at European level.
- Maes et al. (2015) didn't use the *P*-factor due to lack of data (assigning a constant value equal to 1), a gap that has since been overtaken by the work developed by Panagos et al. (2015d).

To assess erosion control service of ecosystems Maes et al. (2015) adapted the empirical USLE equation to compute two indicators under the conceptual ecosystem services framework proposed by Guerra et al. (2014):

- The first dimensionless indicator measures the *Capacity of Ecosystems to Avoid Soil Erosion* assigning values ranging from 0 to 1 at pixel level, covering the EU-28 territory. This indicator is related to the capacity of a given land cover type to provide soil protection.

- The second indicator, *Soil Retention*, is calculated as soil loss without vegetation cover (*Structural Impact* in the sense of Guerra et al. (2014), referred to the potential soil erosion including rainfall erosivity, soil erodibility and topography) minus soil loss including the current land use/cover pattern. In other words, soil retention (actual ecosystem service provision) is the difference between the structural impact and the mitigated impact, measured in ton ha^{-1} $year^{-1}$. Specifically, this indicator takes into account climate data (observed measurements for rainfall and modelled for snow), topographic aspects, soil properties and the presence or not of the vegetation cover.

According to Maes et al. (2015), *Soil Retention* (ton ha^{-1} $year^{-1}$) is considered as a suitable indicator to quantify soil erosion control. However it is important to upgrade this layer according to the most recent publications on the estimates of soil loss at European level (Panagos et al., 2015e) and of its different components (Panagos et al., 2015a, 2015b, 2015c, 2015d, 2014).

Also as regards of soil threats, it is important to stress the estimates of the European level of soil erosion by the wind (Borrelli et al., 2014a), and the assessment of susceptibility to landslides (Günther et al., 2014a, 2014b).

3.11.3 Metadata info 1

Indicator	**Soil erosion by water (RUSLE2015)** http://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015 Rainfall erosivity (R-factor), Soil Erodibility (K-factor), Topography (LS-factor), Cover Management (C-factor), Support Practices (P-factor) data are also available for download in the corresponding pages. References: Panagos et al. (2015a, 2015b, 2015c, 2015d, 2015e, 2014)
Mapping approach (chapt.2)	At a resolution of 100m, this is the most detailed assessment yet of soil erosion by water for the EU. The study applied a modified version of the Revised Universal Soil Loss Equation (RUSLE) model, RUSLE 2015, which delivers improved estimates based on higher resolution (100 m compared to 1 km) peer-reviewed inputs of rainfall, soil, topography, land use and management from the year 2010 (the latest year for which most of the input factors are estimated). The model can be used to predict the effect of a range of policy scenarios. It is also replicable, comparable and can be extended to model other regions. All the input layers (Rainfall erosivity, Soil Erodibility, Cover-Management, Topography and Support Practices) have been peer reviewed and published as well.
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow
Unit of measure	ton/ha/yr
Type of map *(point, polygon…)*	Raster
Map resolution	100m
Coordinate system	ETRS89 Lambert Azimuthal Equal Area
Year of reference	2010
Temporal series (*if yes, please indicate the period*)	No

3.11.4 Metadata info 2

Indicator	**Pan European Soil Erosion Risk Assessment - PESERA** http://esdac.jrc.ec.europa.eu/content/pan-european-soil-erosion-risk-assessment-pesera References: Kirkby et al. (2008)
Mapping approach (chapt.2)	Soil erosion estimates (t/ha/yr) by applying the PESERA GRID model at 1km, using the European Soil Database, CORINE land cover, climate data from the MARS Project and a Digital Elevation Model. The resulting estimates of sediment loss are from erosion by water. The PESERA model produces results that depend crucially on land cover as identified by CORINE and the accuracy of the interpolated meteorological data.

Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow
Unit of measure	ton/ha/yr
Type of map *(point, polygon…)*	Raster
Map resolution	1km
Coordinate system	ETRS89 Lambert Azimuthal Equal Area (?)
Year of reference	2004 (?)
Temporal series (*if yes, please indicate the period*)	No

3.11.5 Metadata info 3

Indicator	**Soil Retention** References: Maes et al. (2015)
Mapping approach (chapt.2)	Soil Retention, is calculated as soil loss without vegetation cover (*Structural Impact*), referred to the potential soil erosion including rainfall erosivity, soil erodibility and topography) minus soil loss including the current land use/cover pattern. In other words, soil retention (actual ecosystem service provision) is the difference between the structural impact and the mitigated impact.
Proxy (yes/no)	Yes
Function/service/benefit	Service
Stock/flow	Flow
Unit of measure	ton/ha/yr
Type of map *(point, polygon…)*	
Map resolution	
Coordinate system	
Year of reference	2010
Temporal series (*if yes, please indicate the period*)	No

3.11.6 Metadata info 4

Indicator	**Index of Land Susceptibility to Wind Erosion (ILSWE) and Wind-erodible fraction of soil (EF) for Europe** http://esdac.jrc.ec.europa.eu/content/index-land-susceptibility-wind-erosion-ilswe-and-wind-erodible-fraction-soil-ef-europe

	References: Borrelli et al. (2014)
Mapping approach (chapt.2)	A limited number of key parameters which can express the complex interactions between the variables controlling wind erosion should be considered. The ILSWE is based on the combination of the most influential parameters, i.e. climate (wind, rainfall and evaporation), soil characteristics (sand, silt, clay, CaCO3, organic matter, water-retention capacity and soil moisture) and land use (land use, percent of vegetation cover and landscape roughness). The spatial and temporal variability of factors are appropriately defined through Geographic Information System (GIS) analyses. Harmonised dataset and a unified methodology were employed to suit the pan- European scale and avoid generating misleading findings that could result from heterogeneous input data. The selected soil erosion parameters were conceptually divided into three groups, namely (i) Climate Erosivity, (ii) Soil Erodibility and (iii) Vegetation Cover and Landscape Roughness. Sensitivity to the contributing group of factors was calculated using the fuzzy logic technique, which allows the sensitivity range of each factor in Europe to be unambiguously defined.
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow
Unit of measure	Categorical (5 classes)
Type of map *(point, polygon…)*	Raster
Map resolution	500m
Coordinate system	ETRS89 Lambert Azimuthal Equal Area
Year of reference	1981-2010
Temporal series (*if yes, please indicate the period*)	No

3.11.7 Metadata info 5

Indicator	**European Landslide Susceptibility Map (ELSUS1000) v1** http://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus1000-v1 References: Günther et al. (2014a, 2014b)
Mapping approach (chapt.2)	ELSUS1000 version 1 shows levels of spatial probability of generic landslide occurrence at continental scale. It covers most of the European Union and several neighbouring countries. Basically, the map has been produced by regionalizing the study area based on elevation and climatic conditions, followed by spatial multi-criteria evaluation modelling using pan-European slope gradient, soil parent material and land cover spatial datasets as the main landslide conditioning factors. In addition, the location of over 100,000 landslides across Europe, provided by various national organizations or collected by the authors, has been used for model calibration and validation.
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Flow

Unit of measure	Categorical (5 classes)
Type of map *(point, polygon…)*	Raster
Map resolution	1km
Coordinate system	ETRS89 Lambert Azimuthal Equal Area
Year of reference	2013 (?)
Temporal series (*if yes, please indicate the period*)	No

3.12 Species and habitats

3.12.1 Brief description of PG/ES describing biodiversity in agroecosystems

The ESBO "Species and habitats: achieving (or maintaining) the presence of diverse and sufficiently plentiful species and habitats (ecological diversity)" is related to biodiversity, which is a public good, but not an ecosystem service per se. Species and habitat diversity is a biotic component of the ecosystem that supports the maintenance of its functions, which can lead to many ecosystem services (and public goods) in turn delivering a range of benefits. According to the Convention of Biological Diversity (CBD), agricultural biodiversity is a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems, also named agro-ecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes. Agricultural biodiversity is the outcome of the interactions among genetic resources, the environment and the management systems and practices used by farmers. This is the result of both natural selection and human inventive developed over millennia. There is no indicator describing the complexity of biodiversity in agroecosystems and, most importantly, no indicator available at a suitable resolution derived from field surveys (the farmland bird indicator is an exception but its current resolution –NUTS0- does not make it suitable for use in PEGASUS analysis). Therefore two proxies are proposed (conservation status of agriculture related habitats and high nature value farmland) and some information on pressures (see following metadata info).

3.12.1.1 Summary of the indicator/proxy: challenges and limitations

Several habitats of European importance depend on agricultural management and their existence and functioning is associated, in particular, to low-intensive farming. A study by Halada et al (2011), identified 63 habitat types that partly or fully depend on agriculture in that: i) their existence depends on the continuation of appropriate agricultural activities; ii) their existence is maintained or spatially enlarged by agricultural activities blocking or reducing secondary succession; iii) the habitat type contains both natural and semi-natural habitats, the second ones requiring agricultural management for their existence.

Cessation of agriculture or major changes in management would negatively affect habitat structure and species composition. A typical example is cessation of grazing that would lead to a transition from meadows to a shrub or woodland habitat type. Habitats status in Europe is monitored by Member States pursuant art. 17 of the Habitats Directive 43/92/EC. Habitats status is classified as either 'Favourable', 'Unfavourable-inadequate' and 'Unfavourable-bad' by evaluating 4 parameters: i) range, ii) area, iii) structure and functions, iv) future prospects.

Based on the most recent habitats assessment carried out for the period 2007-2012 (EEA, 2015), Masante et al. (2015) elaborated a spatially explicit representation of the number and conservation status of agriculture-related habitats. A numeric value was assigned to habitats assessments: favourable = 1; unfavourable-inadequate = 2; Unfavourable-bad = 3; then the mean value of all habitats occurring in each cell of 10 km x 10 km was calculated. The resulting index provides an indication of the average conservation status of habitats associated to agricultural activity, which resulted overall worse compared to the rest of habitats (Masante et al, 2015).

Agricultural intensification and land abandonment are two of the main pressures on biodiversity linked to agro-ecosystems in Europe (EEA, 2010). Decreases in the diversity of crops, the simplification of cropping methods, use of fertilisers and pesticides and the homogenisation of landscapes all have negative effects on biodiversity in agricultural areas (INRA, 2008). Land abandonment causes the loss of specialised species and the deterioration of habitats associated with extensively farmed agro-ecosystems (Moreira et al., 2005 in EEA, 2010). When mapping, it is interesting to note the impact of agriculture at different spatial scales as this can help to select the appropriate indicators:

- At the plot level, fertilisation, tillage and pesticides are environmental disturbances that have an overall negative effect on agricultural biodiversity.
- At the landscape level, negative effects are caused by the disappearance of semi-natural environments at the edge of agricultural areas (such as woodland, semi-natural grassland and hedge and field margins), resulting in a homogenisation of land use. The same applies for the homogenisation of crops and the synchronisation of practices (such as harvesting and mowing dates). The loss of biodiversity in agro-ecosystems through agricultural intensification and habitat loss negatively affects the maintenance of pollination systems and causes the loss of pollinators (TEEB, 2009; http://www.eea.europa.eu/publications/eu-2010-biodiversity-baseline).

The following proxy indicators are proposed:

- The first indicator map proposed is a proxy for agricultural intensity and connects to the fact that many European habitats and landscapes considered to be of high nature conservation value, are intimately associated with the continuation of specific low-intensity farming systems. Any resulting intensification or abandonment of such farming systems would adversely impact on the associated high nature value (HNV).
- The second indicator map is an aspect of land abandonment as a pressure on agricultural biodiversity. It is created by the EEA and shows the 'The percentage of loss of agricultural land to artificial surfaces 1990-2000'.
- The third proxy is related to the level of homogenisation of either land use or cropping pattern, which can be expressed by the Shannon evenness index, a measure for diversity. The indicator map shows the landscape diversity of Europe, expressed by the Shannon evenness index, calculated by NUTS 2 regions from the land use.
- The fourth indicator map shows the diversity in cropping pattern, again expressed by the Shannon evenness index, but now calculated from the variation in main crop categories (14 in total for the EU).

3.12.1.2 Metadata info 1

Indicator	Conservation status of agriculture-related habitats
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Attribute of the stock
Unit of measure	Dimensionless index, range 1-3, where 1= favourable conservation status and 3 Unfavourable-Bad conservation status
Type of map (point, polygon…)	Polygon (standard EEA square grid), shapefile format
Map resolution	10 km
Coordinate system	ETRS 1989 – Lambert Azimuthal Equal Area
Year of reference	2012 (habitats assessments)
Temporal series (if yes, please indicate the period)	No

3.12.1.3 Metadata info 2

Indicator	High Nature Value farmland in the EU-27 – the likelihood of HNV farmland presence Source: http://agrienv.jrc.ec.europa.eu/publications/pdfs/HNV_Final_Report.pdf page 37
Mapping approach (chapt.2)	The basic mapping steps were the following: 1) selection of relevant land cover classes in the different environmental zones in Europe 2) refinement of the draft land cover map on the basis of additional expert rules (e.g. relating to altitude, soil quality) and country specific information 3) addition of the biodiversity data layers with European coverage 4) addition of national biodiversity data sets 5) upscaling of original data to a suitable level of detail in order to provide a harmonized result
Proxy (yes/no)	Yes, although real biodiversity data is used
Function/service/benefit	function
Stock/flow	stock
Unit of measure	% likelihood of HNV farmland presence
Type of map *(point, polygon…)*	grid

Map resolution	1 km x 1km
Coordinate system	ETRS-84 LAEC
Year of reference	2007/2008
Temporal series (*if yes, please indicate the period*)	no

3.12.1.4 *Metadata info 3*

Indicator	The percentage of loss of agricultural land to artificial surfaces 1990-2000 Source: http://www.eea.europa.eu/data-and-maps/figures/loss-of-agricultural-land-to
Mapping approach (chapt.2)	Mapping of land use changes from agriculture to artificial surface between 1990 and 2000
Proxy (yes/no)	yes
Function/service/benefit	The indicator is a pressure
Stock/flow	Land use change is a flow, percentage change is a stock
Unit of measure	% difference to European mean value
Type of map *(point, polygon…)*	polygon
Map resolution	n.a., but probably depending on Corine
Coordinate system	ETRS-84 LAEC
Year of reference	2006, 2011
Temporal series (*if yes, please indicate the period*)	Derived from maps of 1990 and 2000

3.12.1.5 *Metadata info 4*

Indicator	Landscape diversity expressed by the Shannon evenness index, by NUTS2 regions, 2012 Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Land_cover_and_land_use_(LUCAS)_statistics
Mapping approach (chapt.2)	When the LUCAS surveyors walk a 250m transect, they are requested to register all the land cover changes they observe. The degree of homogeneity or heterogeneity of land cover can be analysed by measuring the number of different land cover types in each transect and their relative abundance (in other words, whether the same type of land cover reoccurs in the transect). The Shannon evenness index (SEI) can be used to evaluate landscape diversity and takes

	into consideration both the number of different land cover types observed and their relative abundance; the index is based on values within the range of 0–1, with zero representing a landscape with no diversity (only one land cover type) and a value of one representing the maximum diversity (in other words, featuring all types of land cover in equal amounts). If a landscape is characterised by all different types of land cover being found in equal abundance then the Shannon evenness index will tend towards the value of one; conversely, if there is only one dominant type of land cover then the index will tend towards zero. Shannon evenness index = $-\sum_{i}^{m}(Pi * \ln(Pi))\cdot/\cdot\ln(m)$ where the relative abundance of land cover types is denoted by Pi and the different types of land cover are denoted by m.
Proxy (yes/no)	yes
Function/service/benefit	The indicator is a pressure
Stock/flow	stock
Unit of measure	index, range = 0–1; with a value of zero representing a landscape with no diversity (only one land cover type) and a value of one representing the maximum diversity (in other words, all types of land cover in equal amounts)
Type of map *(point, polygon…)*	polygon
Map resolution	n.a., but probably depending on Corine
Coordinate system	ETRS-84 LAEC
Year of reference	2012
Temporal series (*if yes, please indicate the period*)	no

3.12.1.6 Metadata info 5

Indicator	Cropping pattern – Shannon index crop variation arable area Source:http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Cropping_pattern_-_Shannon_index_crop_variation_arable_area,_EU-27,_IS,_NO,_CH,_ME_and_HR,_2010,_NUTS2_English.png
Mapping approach (chapt.2)	Cropping patterns are described on the basis of data from the Farm structure survey (FSS). Data on land use are also available from crop statistics. To estimate the Shannon index at NUTS 0 and NUTS 2 level the different crops on arable land were categorised in 14 different categories. In the formula S is the total number of different crops on arable land in a certain region, and p is the proportion of crop i in the total area of arable land in a certain region. The Shannon equitability index EH (or Shannon evenness index) shows the Shannon index in proportion to the maximum diversity index possible for the region. The index is of course dependent on the categorisation of species (crops). The Shannon index has been calculated using the following categorisation of crops

	on arable land with data from the Farm structure survey: • cereals (excluding rice and grain maize), • maize (grain maize and green maize), • rice, • legumes (pulses and soya), • root crops (potatoes, sugar beet, fodder roots and brassica's), • sunflower, • rape (Rape and turnip), • oilseed and fibre crops (cotton, other oilseed and fibre crops), • tobacco, • other industrial crops (hops, aromatic, medicinal and culinary plants, industrial crops not mentioned elsewhere), • vegetables (Fresh vegetables, melons, strawberries, seeds and seedlings, other crops on arable land), • flowers (flowers and ornamental plants), • grass (temporary grassland, Other green fodder excluding green maize), • fallow land.
Proxy (yes/no)	yes
Function/service/benefit	The indicator is a pressure
Stock/flow	stock
Unit of measure	index, range = 0–1; with a value of zero representing a landscape with no crop diversity (only one crop category) and a value of one representing the maximum diversity (in other words, all crop categories in equal amounts)
Type of map *(point, polygon…)*	polygon
Map resolution	n.a., but probably depending on Corine
Coordinate system	ETRS-84 LAEC
Year of reference	2010
Temporal series (*if yes, please indicate the period*)	no

3.12.1.7 Gaps

Only for the High Nature Value map, real biodiversity data is used to test and upscale expert rules to the European level. The Shannon evenness index maps for the diversity of land use and cropping patterns would profit from such comparison or refinement with biodiversity data.

3.12.2 Brief description of PG/ES describing biodiversity in forest ecosystems

Forests are biologically diverse ecosystems that provide habitat for a multiplicity of plants, animals and micro-organism and are home to much of the European terrestrial biodiversity. The Convention of Biological Diversity (CBD) defines forest biodiversity as all life forms found within forested areas and their ecological roles. Forest biodiversity is studied at different levels, including the ecosystem, landscapes, species, populations and genetics.

3.12.2.1 Summary of the indicator/proxy: challenges and limitations

Four indicators on forest biodiversity are available.

The first indicator provides information on vascular plant and tree species, and will be sourced from the BioSoil Project database (Durrant et al., 2011). The BioSoil project collected systematically information of a series of forest parameters. The BioSoil project was a demonstration study showing how to achieve harmonised soil and biodiversity data contributing to research and forest related policies. The information was collected by observational sampling in around 3,400 plots across Europe in 2006-2007. Species richness is simply a count of the total number of species in the plot. However, despite the simplicity of this measure, indicators of vascular plant species and tree species are considered proxies for forest biodiversity. There is correlation between vascular plant species and vertebrate richness (Mutke and Barthlott, 2005; Qian and Ricklefs, 2008; Jetz et al., 2009; Kier et al., 2009), and insect diversity (Gaston, 1996). There are also positive relationships between tree species richness and other biodiversity components (Gamfeldt et al., 2013).

The number of tree species found in the plots varied from 1 to 13 with nearly half of all plots recording only one or two tree species. Regarding vascular plant species a total of 2,302 species were recorded across Europe with the greatest numbers of species being recorded in Alpine areas where the average number of species per plot was around 24.

The second indicator for biodiversity in forests is the plant species richness dataset developed by Kalwij et al. (2014). This dataset counts the number of vascular plant species presence for each grid cell, as extracted from two large-scale Atlas covering Europe: (1) the Atlas Florae Europaeae (AFE) published in 13 volumes (Jalas and Suominen, 1972-1994; Jalas et al., 1996; Jalas et al., 1999; Kurtto et al., 2004) that provides 4,123 species distribution maps; (2) the Atlas of North European Vascular Plants North of the Tropic of Cancer (ANEVP) published by Hultén and Fries (1986) providing 2,605 species distribution maps.

This species richness dataset followed the spatial resolution of Universal Transverse Mercator (UTM) grid already used in AFE maps, which is built by 4652 square tiles 50x50 km with some deviating sizes in the overlapping areas of the UTM zones. Instead, species presence maps of ANEVP have been digitalised into a vector geodatabase, then the presence polygons have been combined into the UTM grid, assigning the presence in a tile with entire or partial overlapping. The species richness values have been evaluated through a regression analysis and a t-test of the difference in range sizes for those species mapped in both atlases. Finally a Jaccard index has been calculated for each cell in order to determine the geographical similarity. The whole dataset contains 5,221 unique species, which represents around 38% of the 13,650 plant species estimated in Europe.

Limitations: AFE sampling intensity varies among countries and the extent of this space variation is unknown.

The third indicator is the amount of dead wood. Dead wood not only provides habitat for many plant- and animal species, but can also be used as indicator for the management intensity of the forest. An advantage is that this indicator it also applicable at the European scale.

The fourth indicator is tree species distribution. In order to map the spatial distribution of twenty tree species groups over Europe at 1 km x 1 km resolution, the ICP-Forest Level-I plot data were extended with the National Forest Inventory (NFI) plot data of eighteen countries. The NFI grids have a much smaller spacing than the ICP grid. In areas with NFI plot data, the proportions of the land area covered by the tree species were mapped by compositional kriging. Outside these areas, these proportions were mapped with a multinomial multiple logistic regression model. A soil map, a biogeographical map and bio-indicators derived from temperature and precipitation data were used as predictors. Both methods ensure that the predicted proportions are in the interval [0,1] and sum to 1. The estimated overall accuracy of this map was 43%. In areas with NFI plot data, overall accuracy was 57%, outside these areas 33%. This gain was mainly attributable to the much denser plot data, less to the prediction method.

3.12.2.2 Metadata info 1

Indicator	BioSoils database: Vascular plants richness and tree species richness (Durrant et al., 2011)
Mapping approach (chapt.2)	Representative data
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Stock
Unit of measure	Species richness
Type of map *(point, polygon…)*	Plot level data (point)
Map resolution	Plot level data
Coordinate system	Lambert Azimuthal Equal Area (ETRS89/ETRS-LAEA)
Year of reference	2006-2007

Temporal series (*if yes, please indicate the period*)	No

3.12.2.3 Metadata info 2

Indicator	Plant species richness (Kalwij et al., 2014)
Mapping approach (chapt.2)	Representative sampling
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Stock
Unit of measure	Number of species
Type of map *(point, polygon…)*	Polygon
Map resolution	~50x50 km UTM grid
Coordinate system	Albers equal-area conic
Year of reference	1972-2004
Temporal series (*if yes, please indicate the period*)	No

3.12.2.4 Metadata info 3

Indicator	Amount of dead wood in forests (Verkerk et al. 2011) Verkerk,P.J., P.J. M. Lindner, G. Zanchi S. Zudin, 2011. Assessing impacts of intensified biomass removal on deadwood in European forests Ecological Indicators 11 (2011) 27–35 doi:10.1016/j.ecolind.2009.04.004
Mapping approach (chapt.2)	The amount of deadwood is calculated with the dynamic model EFISCEN (Nabuurs et al. 2007). In EFISCEN, the state of the forest is described as an area distribution over age- and volume-classes in matrices, based on forest inventory data. Transitions of area between matrix cells during simulation represent different natural processes and are influenced by management regimes and changes in forest area. Growth dynamics are simulated by shifting area proportions between matrix cells. In each 5-year time step, the area in each matrix cell moves up one age-class to simulate ageing. Part of the area of a cell also moves to a higher volume-class, thereby simulating volume increment. Growth dynamics are estimated by the model's growth functions whose coefficients are based on inventory data or yield tables.
Proxy (yes/no)	Yes.
Function/service/benefit	Function/Service

Stock/flow	Stock
Unit of measure	tonnes / ha
Type of map *(point, polygon…)*	Polygon (NUTS 2)
Map resolution	n.a.
Coordinate system	Longitude/latitude
Year of reference	2005
Temporal series (*if yes, please indicate the period*)	no

3.12.2.5 Metadata info 4

Indicator	Tree species distribution D. J. Brus, G. M. Hengeveld, D. J. J. Walvoort, P. W. Goedhart, A. H. Heidema, G. J. Nabuurs, K. Gunia 2012. Statistical mapping of tree species over Europe. Eur J Forest Res (2012) 131:145–157
Mapping approach (chapt.2)	In order to map the spatial distribution of twenty tree species groups over Europe at 1 km x 1 km resolution, the ICP-Forest Level-I plot data were extended with the National Forest Inventory (NFI) plot data of eighteen countries. The NFI grids have a much smaller spacing than the ICP grid. In areas with NFI plot data, the proportions of the land area covered by the tree species were mapped by compositional kriging. Outside these areas, these proportions were mapped with a multinomial multiple logistic regression model.
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/flow	Stock
Unit of measure	Nr of species/km2
Type of map *(point, polygon…)*	Gridded map for 20 tree species
Map resolution	1 Km grid size

3.12.2.6 Gaps

One limitation of the BioSoils database is that it does not provide maps; on the contrary, the information is provided at plot level. This implies further analysis for making the plot level information comparable with other spatially explicit datasets (maps). Another limitation is the effect of national methodologies for collecting data, this may have an effect the accounting of species observations during the field surveys. A consequence of this effect is that in some case the analysis should be implemented at the country level and then aggregated in an harmonised way for producing comparable results (see: Durrant et al., 2011 p. 73).

Some gaps are present in the indictor on plant species richness, the unfinished AFE project follows the Englerian taxonomic sequence, started from pteridophytes and gymnosperms up to a part of Rosaceae in the latest volume. Thus, there is a systematic under-representation of plant species in southern Europe as many Mediterranean families are not published yet. In addition, ANEVP is biased towards northern Europe in its species list, and it does not provide information on the endemic species of central European mountainous areas and the Mediterranean zone.

3.12.3 Brief description of PG/ES describing genetic diversity in forest ecosystems

Forest genetic diversity is defined as the diversity in genetic material (DNA) available in forests from wild plants, algae and animals for biochemical industrial and pharmaceutical processes e.g. medicines, fermentation, detoxification, and for bio-prospecting activities e.g. wild species used in breeding programmes.

(Source: MAES - http://biodiversity.europa.eu/maes/common-international-classification-of-ecosystem-services-cices-classification-version-4.3)

3.12.3.1 Summary of the indicator/proxy: challenges and limitations

There have been several European initiatives to map the genetic diversity in forest species (e.g. Oaks, Black poplar, Ash): ***http://www.forestry.gov.uk/fr/infd-65qd6w***

For example, within the FAIROAK project, the level of diversity in the Q. petraea and Q. robur species and its geographic variation have been evaluated, by sampling large size populations and using hypervariable markers (exhibiting numerous alleles).

Source: ***http://www.pierroton.inra.fr/Fairoak/***

3.12.3.2 Metadata info

Indicator	level of diversity in the Q. petraea and Q. robur species and its geographic variation http://www.pierroton.inra.fr/Fairoak/Maps/ToutEurop.jpg
Mapping approach (chapt.2)	Maps of cpDNA haplotypes were produced using the software MapInfo Professional version 3.5 (Figure 1.1, 1.2 and Annexes 1.1 to 1.22). Symbols of different sizes were used to indicate the level of reliance in the authochthony of each population. The largest symbols indicate populations fixed for a given haplotype; smaller symbols were used for populations represented by a single haplotype; still smaller symbols were used for indicating populations that comprised

	other haplotypes than the one considered; finally, populations considered *a priori* of dubious autochthony were represented with the smallest symbols
Proxy (yes/no)	Yes for forestry as a whole
Function/service/benefit	Service
Stock/flow	Stock
Unit of measure	level of reliance in the authochthony of each population
Type of map *(point, polygon…)*	point
Map resolution	n.a.
Coordinate system	n.a.
Year of reference	2000
Temporal series (*if yes, please indicate the period*)	no

3.12.3.3 Gaps

The map mentioned above is made only for one species group, depending on point measurements of genetic diversity. Gathering this information is a time-consuming process and cannot be generalized for all species.

Important indicators for genetic diversity in forests are e.g. criteria for a core network (e.g. depending on forest patch areas and connectivity) and migration barriers (exhausted vertical buffers). These indicators can be input to spatial population models.

Source:
http://www.euforgen.org/fileadmin/templates/euforgen.org/upload/Publications/PDF/EUFORGEN_FGR_and_Climate_change_web.pdf

3.12.4 Brief description of PG/ES describing genetic diversity in agroecosystems

Genetic diversity in agricultural systems is defined as the genetic material (DNA) available in agricultural systems from wild plants, algae and animals for biochemical industrial and pharmaceutical processes e.g. medicines, fermentation, detoxification, and for bio-prospecting activities e.g. wild species used in breeding programmes.

(Source: MAES - ***http://biodiversity.europa.eu/maes/common-international-classification-of-ecosystem-services-cices-classification-version-4.3***)

3.12.4.1 Summary of the indicator/proxy: challenges and limitations

Global distribution of crop wild relatives (CWR) of 81 assessed crop genepools. Crop wild relatives contain a multitude of genes of potential value for plant breeding. Among these are many traits that are relevant for climate change adaptation. Many CWR are threatened in the wild by habitat modification, the modernization of agricultural areas, and invasive species, among other factors, and climate change is likely to exacerbate their vulnerability.

The species richness map acquired as a proxy for agricultural genetic diversity displays the concentration of all assessed CWR species, regardless of final priority category. The yellow-orange-red regions indicate geographic areas where very large numbers of CWR species exist, which are largely in the traditionally recognized centers of crop genetic diversity, particularly the Mediterranean and Near East.

Source: http://www.cwrdiversity.org/gap-analysis-results/

3.12.4.2 Metadata info

Indicator	Crop wild relatives species richness for all crop genepools combined Source: http://www.cwrdiversity.org/gap-analysis-results/ Figure 3
Mapping approach (chapt.2)	The Harlan and de Wet Crop Wild Relative Inventory used here uses both genepool concepts as well as documentation of CWR species that have been successfully used in breeding in the past to provide a priority list of 1400 CWR species, along with key ancillary data such as their regional and national occurrence, seed storage behavior and herbaria housing major collections of CWR.
Proxy (yes/no)	yes
Function/service/benefit	service
Stock/flow	stock
Unit of measure	Number of taxa
Type of map *(point, polygon…)*	Possibly polygon
Map resolution	n.a.
Coordinate system	n.a.
Year of reference	n.a.
Temporal series (*if yes, please indicate the period*)	no

3.12.4.3 Gaps

The map described above is based on a worldwide assessment. A comparable mapping for Europe only might be more specific, looking only at crops relevant for Europe.

3.13. Pollination

3.13.1. Brief description of PG/ES

Pollination is the bio-physical process by which the male microgametophytes of seed plants, contained in the pollen grains, are transported to the female reproductive organs of the same plant or of another one, to enable fertilization and reproduction. This transfer may be mediated by abiotic factors (e.g. wind) or by living organisms, mainly insects. Many agricultural crops worldwide depend on pollination by wild pollinators, the most important ones being wild bees. The direct (regulating) value of pollination services to humans is the marginal increase (qualitative and/or quantitative) in production of crops, fibre, forage, timber and non-timber forest products resulting from animal pollination. The indirect (supporting) value is the marginal increase, due to animal pollination, in reproduction of wild plants that play a role in other ecosystem services (Kremen at el, 2007).

Animal-mediated pollination is a mobile-agent based service, thus it is delivered at the local scale, but it is influenced by factors acting both at local and broader (landscape) scale, such as land use/cover and management, habitat quality and loss, fragmentation/connectivity. The influence and interrelations of such factors is highly context-dependent.

3.13.2. Summary of the indicator/proxy: challenges and limitations

An indicator of pollination potential at the European scale has been developed and mapped by Zulian et al, 2013, building on the conceptual framework proposed by Lonsdorf (2009). The model scores land cells according their potential to host pollinators and provide forage, and generates an index of their relative abundance in a landscape sector. Scores are primarily determined by land covers complemented, in the EU model, by more refined data on agricultural land management (CAPRI model), High resolution layers on forest covers, presence of semi-natural vegetation in agricultural land, riparian zones and roadsides.

Pollinators' behaviour is mimicked by considering a species-specific foraging range, within which pollinators can fly in search of feed. The intensity (or probability) of foraging in a certain cell is assuming to decline exponentially with distance from the nesting site.

Each land parcel is assigned two different scores for its nesting suitability and floral availability. The first score reflect the capacity of a land parcel to host pollinators, whilst the second one measures the potential availability of nectar and pollen, hence its attractiveness for pollinators as source of food. Scores are assigned based on expert judgements and depend on the pollinator species considered.

Given a determined foraging range for a specific species (e.g. 200 m for wild bees), the (potential) abundance of individuals in any cell of the landscape is determined by considering the landscape composition within the foraging range. Since both nest suitability and floral availability limit pollinators abundance in a given cell, their product is computed to determine the total intrinsic suitability of that cell. For any single cell in a landscape, pollinators abundance is determined by summing up the contributions of all cells within the foraging range (moving window approach), giving an exponentially decreasing weight to distant cells.

Once the presence of pollinators has been computed for all cell in the study area, their (potential) visiting rate to any cell in the landscape is determined again by resorting to the same moving window approach. It is assumed that each cell receives a certain number of visit, thus a certain amount of service, from all other cells within the foraging range, proportionally to the abundance of pollinators in those cell and inversely proportional to their distance (according to the same negative exponential function used to determine abundance).

A refinement to the Londsdorf model introduced by Zulian et al (2013), to run it at a continental scale, is that bees' activity (time spent outside the nest) is not constant, but depends on the ambient temperature. The model assumes that solitary wild bees increase their activity linearly with temperature after a certain threshold is reached (a behaviour observed for social bees). Using data provided by the JRC MARS climate database on temperature and solar radiation, the pollination potential was adjusted accordingly. The resulting macro spatial pattern at the continental scale is thus a decrease of the overall pollination potential along a South-North gradient.

The main limitations are that the model calculates the relative pollination potential, not the actual service delivered (e.g. actual share of production obtained thanks to wild-bees pollinations) and that so far the index has been calculated at the EU level only for one pollinators species, i.e. solitary wild bees. To estimate the overall pollination potential, the contribution of several other species (e.g. *Bombus spp*) shall be considered.

3.13.3. Metadata info

Indicator	Relative Pollination Potential
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Pollination (regulating service)
Stock/Potential/Flow	Potential
Unit of measure	Dimensionless index normalized to [0-1], where 0 = no pollination potential and 1= maximum pollination potential.
Type of map *(point, polygon…)*	Raster
Map resolution	Cell size: 100 m
Coordinate system	ETRS 1989 - LAEA
Year of reference	2006 for Corine Land Cover, 2004 for CAPRI data

Temporal series (*if yes, please indicate the period*)	No

3.13.4. Gaps

Suitability scores of different land covers are assigned based on expert judgements and not on real observations; the model likely underestimates pollination potential in cropland as information on the presence of semi-natural vegetation in agricultural areas is still not accurate and small scale features such as herbaceous linear elements, flower strips or hedgerows – which provide valuable habitats to pollinators – are currently not detectable at the EU scale.

The model could also be refined with data on pollinators species occurrence in across Europe, but consistent field observations covering the EU territory are currently not available, particularly as regards Mediterranean countries. Pollination abundance was estimated based mainly on land cover data, crops share and presence of other landscape elements (riparian zones, semi-natural vegetation); however, management practices (not considered in the model) may also significantly affect pollinators abundance (e.g. pesticide application, implementation of agri-environmental measures).

3.14. Biological pest and disease control

3.14.1. Brief description of PG/ES

Weeds and animal pests can significantly reduce crop yields and require additional inputs from farmers in the form of pesticides and/or labour to avoid or reduce infestations. Some organisms naturally present in agro-ecosystems (including vertebrates, spiders, parasitic wasps/flies and lady bugs) are natural predators of pests and can contribute to keep them below harmful thresholds. Beyond contributing to diminish yield losses, biological control is considered beneficial also to the stabilization and enhancement of the whole agro-ecosystem as it avoids relying solely on chemical control that in turn can lead to the emergence and spread of resistant pests.

The ecological interactions between natural enemies and pests are however complex and seems to depend on the landscape -rather than the local - context. In general, predators' species diversity, composition and abundance are considered to increase the pest suppressions services, and are associated to more complex landscape structures, but the underlying biological mechanisms are still not fully understood and further research is needed.

3.14.2. Summary of the indicator/proxy: challenges and limitations

Given the knowledge gaps highlighted above, very few if any examples of models and indicators for biological control have been developed so far at the European scale.

The number of terrestrial vertebrate species providing natural control of invertebrate and rodent pests has been used as a proxy of biological control by Mouchet et al (2014) in the frame of VOLANTE Project. The main assumption was that the higher the number of species, the greater the expected natural control of pests. This is based on literature showing that a more diverse community of natural enemies is able to control a greater richness of pests on diverse crops (e.g. Cardinale et al. 2003, Perfecto et al. 2004).

110 species of European terrestrial vertebrates were identified by Civantos et al. (2012) as pest control providers and grouped into two service-providing unit : invertebrate-pest-control and rodent-pest-control groups. Species' extents of occurrence was mapped from the global assessments (e.g. Global Mammals Assessment) and literature surveys. Each species' suitability to global land cover classes was assessed through literature review to refine species' distributions. Finally, we the potential distributions of the species was overlaid with service-providing units. The resulting maps provide a spatial representation of the potential species richness within each pest-control service-providing unit.

Another approach to build a spatially explicit model of biological pest control at the European scale is currently under development in the framework of FP7 research project QUESSA (http://www.quessa.eu/). The model will be based on real data observations of level of pest predation by beneficial organisms in different landscape contexts. By resorting to a statistical and machine learning modelling approach, primary field data are related to explanatory variables like land uses/covers and presence of semi-natural habitats adjacent to the studied field and in the surrounding landscape. Results from this first modelling exercise carried out at the landscape scale will be then up-scaled at the European level by adapting and customizing the obtained models to use input layers covering the whole EU territory as proxies of the explanatory variables identified at the lower scale.

3.14.3. Metadata info

Indicator	Number of terrestrial vertebrate species providing natural control of invertebrate and rodent pests
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Service
Stock/Potential/flow	Potential
Unit of measure	Number of species/Areal Unit
Type of map (point, polygon…)	Raster
Map resolution	1 km
Coordinate system	ETRS Lambert Azimuthal Equal Area
Year of reference	
Temporal series (if yes, please indicate the period)	No

3.14.4. Gaps

The indicator proposed by Mouchet et al. (2014) only considers terrestrial vertebrate species, whilst pest control is provided by different classes of invertebrates, notably including insects and spiders. Plus, other relevant aspects affecting biological pest control such as landscape structure are not taken into account.

3.15. Landscape character and cultural heritage

3.15.1. Brief description of PG/ES

Agrarian landscapes in Europe are the result of the long-standing and mutually constitutive relations between human activity and the natural environment. Farmers play a key role in preserving the great variety of rural landscapes across Europe through adequate land management, often entailing extensive management practices and application of local knowledge. Landscape shall include in this context also the ensemble of human-made infrastructures related to agricultural activity, such as buildings, ditches, terraces, paths and so on.

Landscape can be considered a paradigmatic instance of public good, with many if all cultural ecosystem services are associated to, or dependent on, landscape preservation and presenting the characteristics of public goods. Benefits of landscape preservation also include touristic attractiveness in different form (cultural and eno-gastronomical tourism, outdoor recreation etc.) and are linked to rural vitality (see section 3.20).

3.15.2. Summary of the indicator/proxy: challenges and limitations

Despite the interest towards landscape indicators has been growing steadily during the last decade, the majority of the indicators proposed in the literature concerns the local or regional scale. Bottom-up approaches are mostly based on case specific studies and contingent valuation and therefore are not up-scalable at the EU level. In the following, information is provided on the three components of the indicator that has been developed and implemented (mapped) at the European scale, namely: "Landscape state and diversity" developed by Paracchini and Capitani (2011), which is included in the list of the 28 "Agri-Environmental Indicators (AEI) developed to monitor the environmental effects of the Common Agricultural Policy (COM(2006)508)

The broad conceptual assumptions behind AEI n. 28 is that the agrarian landscape is the results of drivers and characteristics that can be grouped into three main components (figure 2):

1. the natural potential of the land, given by its **natural components** (geology, topography, vegetation etc.) and the **anthropic influence** exerted by society through agricultural activities and management;
2. the **physical structure** of the agricultural landscape, intended as land cover and its spatial organisation as a product of land management;
3. the **societal awareness** of the agrarian landscape, i.e. how the society perceives, assesses and values landscape quality and plans, manages, and uses the landscape for productive or non-productive purposes.

The fist component is measured through the hemeroby index, which classifies areas according to the degree of artificiality or, conversely, the distance from a pure natural condition. Nine classes were identified, from "natural" or "Ahemerobe" (pristine habitats such as tundras or unmanaged forests) to artificial or “Metahemerobe” (sealed surfaces). It is based on land cover (Corine Land Cover 2006) integrated with information of management intensity in agricultural land (Nitrogen input and livestock density) derived from the CAPRI model and other ancillary information on tree species coverages and presence of natural vegetation.

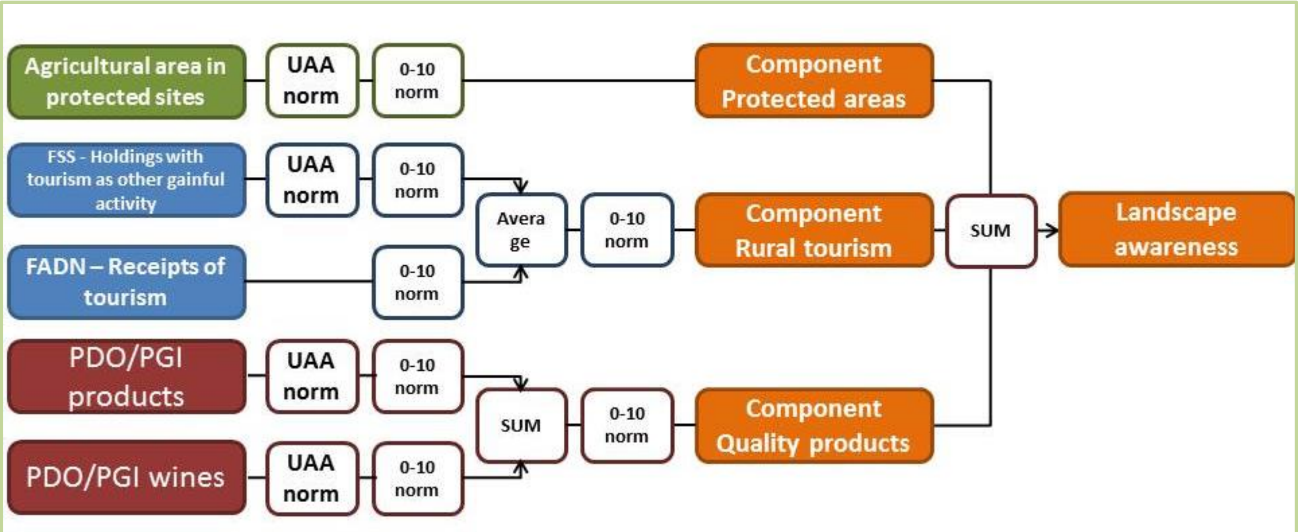

Figure 2: Aggregation scheme of the societal awareness of agricultural landscape indicator. (Source: Paracchini et al, 2015)

The second component concerns **the physical structure** of the agrarian landscape and measures the agricultural landscape dominance and fragmentation in the matrix of non-agricultural background and the degree of diversity of the agrarian landscape. Landscape dominance is measured by resorting to the Largest Patch Index, defined as the percentage of the largest patch of agricultural area in each reference cell of 10 km X 10 km. Diversity is assessed through the number of crops categories in the unit area (derived by the CAPRI model). Each of these two components is classified in three categories (low, medium and high), the combination of which defines 9 structural classes in total.

The third component measures the level of **societal awareness** of agrarian landscape, i.e. the recognition of landscape value by society as a whole. It is in turn the aggregation of three sub-indexes considered as proxies of the ways society interacts with the agrarian landscape:

1) society values certain agrarian landscapes as common resources and protect them through legislation;
2) society consumes landscape *in situ* by using the recreational services provided;
3) society through the legislator provides the legal framework for creating added value to local products linked to specific landscape, consumes the products of the landscape *ex situ* and provides a market for such products

The proxies used to measures the three components are:

- Protected (agrarian) landscapes: surface of agricultural land within protected areas (Natura2000 sites, World Heritage Unesco sites related to agricultural landscape, European nationally designated areas, and IUCN (International Union for Conservation of Nature) category V – World Protected Areas.
- In situ consumption: number of holdings in NUTS 2 regions reporting “tourism” as “Other gainful activity”, by NUTS2 regions in the EU Farm Structure Survey, and “ receipts of tourism, including returns from board and lodging, campsites, cottages, riding facilities, hunting and fishing and excluding value of products produced on the holding used for catering” in the FADN database.
- Ex situ consumption: number (per each NUTS2 region) of agricultural products under EU schemes PDO (protected designation of origin) and PGI (protected geographical indication) with a specific link to landscape, plus and hectares of UAA allocated to the production of wine labelled as VQPRD (Vin de Qualité Produit dans des Régions Déterminées).

The first two main dimensions of the composite indicators, physical structure and degree of naturalness, are the most consolidated ones, as extensive literature exists on these aspects. The societal awareness of landscape is the most novel one and in need of refinements. A downscaling exercise was carried out to test the indicator’s consistency at NUTS 2 and LAU1/2 (municipal) scale and to identify other input data to improve it. (Paracchini et al, 2012; Paracchini et al, 2015). Stakeholders were also consulted to assess the perceived utility of the indicators. The main identified limitations are: agricultural land in nationally designated areas should be considered as well; NUTS2 regions appear to be a too coarse level of representation as landscape societal awareness can strongly vary within them; the importance attached to the three different components varies across regions; the indicator used for tourism account only for a fraction of the total rural tourism.

3.15.3. Metadata info

Metadata are provided separately for each of the three main components of the “Landscape Character and State” indicator: i) degree of naturalness; ii) physical structure; and iii) societal awareness

Indicator	Degree of naturalness of the agrarian landscape
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Function
Stock/Potential/Flow	Stock
Unit of measure	Dimensionless categorical index (9 classes)

Type of map *(point, polygon…)*	Raster
Map resolution	100 m
Coordinate system	ETRS 1989 – LAEA_52_10
Year of reference	2011
Temporal series (*if yes, please indicate the period*)	No

Indicator	Landscape Physical structure
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Not applicable
Stock/Potential/Flow	Not applicable
Unit of measure	Dimensionless categorical index (9 classes)
Type of map *(point, polygon…)*	Raster
Map resolution	10 km
Coordinate system	ETRS 1989 – LAEA_52_10
Year of reference	2011
Temporal series (*if yes, please indicate the period*)	No

Indicator	Societal awareness of agricultural landscape
Mapping approach (chapt.2)	Causal relationships
Proxy (yes/no)	Yes
Function/service/benefit	Not applicable
Stock/Potential/Flow	Stock
Unit of measure	Dimensionless score (Range 0-30)
Type of map *(point, polygon…)*	Polygons
Map resolution	NUTS2
Coordinate system	ETRS 1989 – LAEA_52_10
Year of reference	2011
Temporal series (*if yes, please indicate the period*)	No

3.15.4. Gaps

As for tourism, FSS data are missing for the following regions: Eastern and South Western Scotland, Highlands and Islands in the United Kingdom and Île-de-France in France. FADN data are not available for Romania and Bulgaria. Other tourism indicators that would improve the composite index (numbers of tourists, accommodation density) are not available at the EU level. In some regions, the normalization of the number of holdings with tourism to UAA may be misleading as there are many holdings with small agricultural area. As for certified products related, the UAA allocated to each scheme could be a better proxy than the number of products, but this information is not available.

3.16. Outdoor recreation

3.16.1. *Brief description of PG/ES*

Outdoor recreation is a cultural ecosystem service including activities generating benefits in daily life (day leisure visits), encompassing walking, hiking, biking, short trips with the sole purpose to enjoy nature and spend some time in an healthier environment (compared to large cities). There are multiple benefits associated to such activities, from pure mental enjoyment and relaxation to health benefits of increased physical activity and consequent reduction of occurrences of certain diseases. Analyses of visitor surveys and literature identified recurrent elements in the choice of destinations for outdoor recreation, primarily linked to the presence of sites characterised by a medium to high degree of naturalness (water bodies included).

3.16.2. *Summary of the indicator/proxy: challenges and limitations*

An index of potential outdoor recreation has been developed and implemented for the whole EU by Paracchini et al (2014). This was obtained by considering three main factors:

- potential provision of the service (recreation potential);
- accessibility of recreation sites
- degree of remoteness of recreation sites.

The recreation potential is linked to the degree of naturalness of a certain area and it is measured thorough the hemeroby index (see section 3.14) incremented by the presence of water bodies (in terms of proximity to marine and inland coasts) and natural protected areas as proxies both for a high degree of naturalness and availability of recreation facilities and opportunities. The three components (naturalness, water, protected areas) are assumed to have equal weight and are summed to obtain the Recreation Potential Index, as schematised in figure 3.

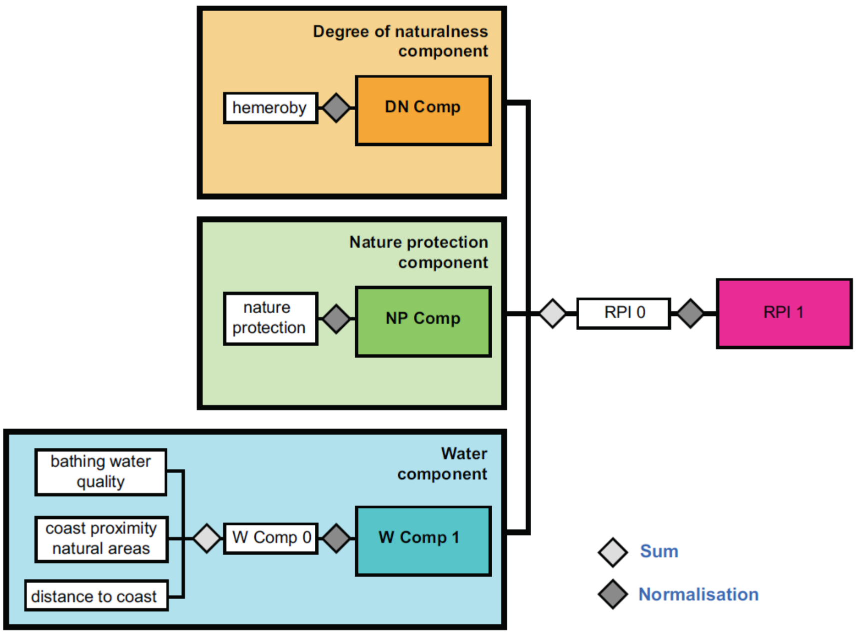

Figure 3 Flowchart of the procedure to obtain recreation potential (W: water; NP: nature protection areas; DN: degree of naturalness; RPI: recreation potential index). Source: Paracchini *et al*, 2014

Remoteness and accessibility have been addressed by using as proxies distance from roads and from residential areas. Through expert judgements, thresholds for distances from roads and urban areas were identified, and each combination was assigned a label among the following five: neighbourhood, proximity, far, remote, very remote, as shown in Figure 4.

Distance from urban areas (km)	Distance from road (km)			
	< 1	1-5	5-10	> 10
< 5	1	2	2	4
5-10	2	2	2	4
10-25	3	3	3	4
25-50	3	4	4	4
> 50	4	4	4	5

1	Neighborhood
2	Proximity
3	Far
4	Remote
5	Very Remote

Figure 4 Classes of the accessibility/remoteness index. **Source: Paracchini *et al*, 2014**

The first two indexes are cross-tabulated to obtain the final Recreation Opportunity Spectrum (ROS). The Recreation Potential Index is classified in three classes of high-medium-low provision by defining thresholds derived from statistical analysis; similarly, information on remoteness and accessibility has been aggregated in three classes by merging “Neighbourhood” and “Proximity” classes, and “Remote” and “Very remote” classes. The final

Proximity model	Recreation Potential		
	< 0.19	0.19-0.25	> 0.25
1 Neighborhood	1	4	7
2 Proximity	1	4	7
3 Far	2	5	8
4 Remote	3	6	9
5 Very Remote	3	6	9

1	Low provision - easily accessible
2	Low provision - accessible
3	Low provision - not easily accessible
4	Medium provision - easily accessible
5	Medium provision - accessible
6	Medium provision - not easily accessible
7	High provision - easily accessible
8	High provision - accessible
9	High provision - not easily accessible

Figure 5: The Recreation Opportunity Spectrum classes. **Source: Paracchini *et al*, 2014**

ROS is thus a 9 classes index derived by the combination of (3x3) classes, as depicted in figure 5.

3.16.3. Metadata info

Indicator	Recreation Opportunity Spectrum
Mapping approach (chapt.2)	Causal Relationship
Proxy (yes/no)	
Function/service/benefit	Service
Stock/flow	Flow
Unit of measure	Dimensionless class index
Type of map *(point, polygon…)*	Raster
Map resolution	100 m
Coordinate system	ETRS 1989 – LAEA
Year of reference	2006 (Corine Land Cover)
Temporal series (*if yes, please indicate the period*)	No

3.16.4. Gaps

Input data were lacking for Bulgaria and Romania. The index measures the overall potential provision and how this matches potential demand, but does not include individual preferences for destinations within the travelling distance. Other identified limitations are that there are comparatively few studies of people's attitudes in southern EU countries; access denied to visitors in private property and inaccessible areas could not be taken into account; aspects such as scenic beauties, vantage points, or presence of infrastructure for outdoor recreation (paths, bike trails etc.) could not be mapped.

3.17. Educational activities

No PG/ES indicator or proxy in support of this ESBO has been identified.

3.18. Health and social inclusion

No PG/ES indicator or proxy in support of this ESBO has been identified.

3.19. Animal welfare

3.19.1 Brief description of PG/ES

Improving husbandry conditions and animal welfare increases the overall health of animals, decreases the risk of diseases due to psychic-physical stress and thus the need of pharmacological treatments. High level of animal welfare can ultimately improve the quality and quantity of animal products. Therefore it can be considered as a public good. There are no ES directly linked to this ESBO, as it depends exclusively on the farm management. Several factors affects husbandry conditions, including:

- the type and size of cattle sheds, the presence of outdoor spaces, the type of paving and litters
- micro-climatic conditions: control of temperature and humidity, adequate ventilation and lighting
- improved feeding and watering system to guarantee access to all animals and avoid competition
- periodic veterinarian checks for common diseases, disinfestations, systems of isolation of infected animals.

3.19.2 Summary of the indicator/proxy: challenges and limitations

Improving the animal welfare is among the objectives of the European Rural Development Policy. During the 2007-2013 programing period, a specific measure was envisaged to implement actions aimed at ameliorating husbandry conditions. The amount of approved grants can be used as a proxy for the public good.

3.19.3 Metadata info

Indicator	Animal welfare payments – CAP Pillar 2, Axis 2, measure 215
Mapping approach (chapt.2)	
Proxy (yes/no)	Yes
Function/service/benefit	
Stock/Potential/Flow	
Unit of measure	Euros. Can be normalized to UAA, n. of holdings, n. of heads.
Type of map *(point, polygon…)*	Polygons
Map resolution	NUTS2 for Italy and Spain, NUTS1 for Germany, NUTS0 for all other countries.
Coordinate system	ETRS 1989 - LAEA
Year of reference	Total expenditure for the CAP 2007-2013 programming period

Temporal series (*if yes, please indicate the period*)	No

3.19.4 Gaps

It must be noted that this indicator does not represent per se the actual information on the implementation of high animal welfare practices on farms. It rather an indication of the interest that some Member States or regions show on this issue.
Information is available at NUTS2 or NUTS1 level only in Italy, Spain and Germany. At members State level only, this indicators are also available beyond total expenditure: number of applications approved, number of farm holdings supported and number of contracts.

3.20. Rural vitality

3.20.1. Brief description of PG/ES

Rural vitality is a broad concept encompassing social, cultural and economic dimensions; according to the ENRD (2010) it arises when there is a sufficient critical social mass to sustain valued and place-based rural customs, to maintain the services and infrastructures relied upon by rural populations as well as serving as a repository of skills and knowledge which help to keep alive rural cultures. It can be seen also as a benefit for urban population that can find in vibrant rural communities a place for leisure and relaxation from the urban life. It can be considered as a public good and many ecosystem services can underpin it if embedded in the appropriate socio-economic context.

Rural vitality is also a precondition for the continuation of farming/forestry activity in marginal rural areas, which in turn is essential to maintain many ecosystems and related services, as well as the features and structures of certain valuable landscapes. The Alpine pasture system is a clear example of that: the alpine landscape composed of patches of forests and grasslands is the results of the cattle-breeding activity that has been taking place for centuries in these mountain areas. The abandonment of such activity would have consequences not only on the landscape physical structure, with natural succession replacing grassland with pioneer woods, but also on the whole complex of human buildings and artefacts related to that activity, as well as practices and traditions.

3.20.2. Summary of the indicator/proxy: challenges and limitations

Given the multidimensional nature of this ESBO, there is probably no single indicator able to grasp the different facets of rural vitality, which therefore may be better described by considering multiple sub-indicators and/or composite indexes. To the authors' knowledge, no such exercise has been carried out so far at the European scale. In the following, an overview of possible indicators or proxies of rural vitality is provided, together with a proposal of development of a composite indicator.

Whichever definition of vibrant rural communities is assumed, rural vitality opposes to marginalisation of rural areas, depopulation and land abandonment. All those aspects are considered by the EU Agri-environmental indicator (AEI) no. 14 "Risk of Land abandonment", intended to measure the likeliness of a cessation of agricultural activities on a given surface of land which leads to undesirable changes in biodiversity and ecosystem services. A full description of the indicator is provided by Terres et al (2013); the inverse of this indicator can be considered a first proxy of rural vitality. Moreover, land abandonment has been found to impact not only on biodiversity but also to influence several ecosystem functions and the related provision of Ecosystem Services – fire risk mitigation, nutrient cycling, carbon sequestration, water balance – as well as cultural landscape values (Benayas et al., 2007)

As land abandonment can be caused by different drivers (economic, social, cultural, geographic), the final indicator is actually a composite index made-up by different indicators that captures different aspects of rural marginalisation/vitality. The considered drivers are classified into low farm stability and viability, and the regional context. The first group include low income, farmers' age and qualification, level of farm investments, small farm size and farm enrolment in specific schemes. The second comprise weakness of the land market, previous trend of farmland abandonment, remoteness and low population density. The full list of indicators is provided in table 2 along with a short description of the rationale for their selection (for details, see Terres *et al*, 2013 and references therein).

However, not all drivers/indicators were included in the computation of the final composite indicators following an assessment of their relevance and data quality/availability. Discarded drivers/indicators are indicated in the table.

Table 2: indicators and datasets used to build the composite indicator "Risk of land abandonment". UAA= Utilised agricultural area ; FADN= Farm accountancy data network; FSS= Farm structure survey. Source (adapted from Terres *et al*, 2013)

Driver description	Indicators/proxies used	Data source	Resolution	Included in final indicator
Weak land market: the land price is considered a good indicator of marginalization, as it expresses the demand for land and a weak land market is a good proxy for a higher risk of land abandonment.	Weighted average of the rental price (€/ha)	FADN database, DG AGRI,	NUTS 2	Yes
	Share of the rented UAA (%)	FADN database, DG AGRI,	NUTS 2	Yes
Low farm income: farm viability strongly depends on the farm's economic situation and the risk of abandonment increases as the farm income (compared to the average national income) decreases. FADN variable 'Farm net value added' expressed per annual work unit (AWU) is used to express income. The ratio agricultural income/National GDP is then computed. Holdings belonging to the first quintile (ratio <0.58) are considered at high risk of abandonment.	Agricultural income/National GDP (%)	FADN database, DG AGRI EUROSTAT (GDP)	NUTS 2	Yes
Low farm dynamism/adaptation capacity. Farm investments are a good proxy of dynamism, adaptation, innovation capacity and attractiveness of rural areas.	Average level of investment per holding (€/ha)	FADN database	NUTS 2	yes
Ageing farmer population. Farmland abandonment is more likely to occur when farmer population is old and close to retirement). Furthermore, young farmers are more open to innovations and more adaptable, which relates to rural vitality. The indicator is the ration between farm holders above 65 years and the total number of farm holders.	Share of old (>65) farmers (%)	EUROSTAT – FSS	NUTS 2	yes

Low farmer qualification: trained and qualified farmers are more able to adapt to changing circumstances and maintain the farming activity. The use of farm advisory services is used as a proxy.	Share of farmers with practical experience only (%)	FSS	NUTS2	no
Previous trend of farmland abandonment previous trends in rural areas are likely to influence their future evolution: areas where land abandonment has been occurring in recent time are likely to be more fragile and at higher risk.	Loss of agricultural land	DG Agriculture and Rural Development	NUTS2	no
Remoteness and low population density: distance from social services (schools, hospitals) as well as from markets, retailers and suppliers, increase the risk of land abandonment. Proximity to urban centres increases the possibility of finding second or complementary jobs.	Share of remote agricultural area, where remote areas (LAU2) are >60 min from an urban centre and with < 50 inhabitants/km2	agricultural and urban areas from CLC 2006, UMZ, UA; population from SIRE; road network from ERM	NUTS2	yes
Small farm size: small farms often experience more difficulties in keeping their activity viable and can have difficulties in accessing credit and subsides. Conversely, large farms generally benefits from economies of scale and are more prone to innovations.	Share of small farms	DG Agriculture and Rural Development	NUTS2	no
Farm enrolment in specific schemes: support received for specific agri-environmental schemes related to land management and continuation of activity for a certain period of time prove to contrast the risk of land abandonment.	Share of farms under organic farming scheme	FSS	NUTS2	no

Other dimensions of rural vitality that are recurrently cited in literature and policy documents include **Diversification** of farm activities and the presence of **social capital**.

Diversification of activities and income source is considered to contrast land abandonment and foster rural vitality. Datasets and indicators available at the EU level that can be used to measure diversification are:

- No. of holdings declaring other gainful activities (tourism, processing, handcraft)
- Expenditure on measures of Axis 3 of Rural Development Programs aimed at fostering farm diversification, namely:

M311-Diversification into non-agricultural activities
M312-Support for business creation and development
M313-Encouragement of tourism activities
M321-Basic services for the economy and rural population
M322-Village renewal and development
M323-Conservation and upgrading of the rural heritage
M331-Training and information

Social capital: also central to ensuring rural vitality is the development of capacity within rural communities to build human capital and increase the skills and knowledge base to enable them to adapt and change to the pressures facing rural areas (ENRD, 2010). In a broader sense, social and institutional capital refer to the ability of farmers, local authorities and stakeholders in a territory to establish partnerships and networks for the proposal and implementation of local development projects. This is the rationale behind the LEADER (*Liaison Entre Actions de Développement de l'Économie Rurale*) approach launched by the European Commission in the early nineties and financed under Axis 4 of Rural Development Program in the programming period 2007-2013.

The aspect of farmers' qualification (assessed by FSS questionnaires) is already incorporated in the conceptual definition of the indicator "Risk of Land abandonment". However, the quality for this item wan considered low by Terres et al (2015) in building the indicator of land abandonment.
Other data that can be exploited to this purpose are again those derived by the monitoring of Rural Development Programs' expenditures. For each RDP, data on programmed and realized expenditure is available, at NUTS 2 or Member Sates level depending on the countries. The following measures might be considered:

M111-Vocational training and information actions;
M114-Use of advisory services
M124-Cooperation for development of new products, processes and technologies in agriculture, the food sector and in forestry

As for the establishment of partnerships and local projects, similar figures are available for expenditures under Axis 4:

M411–Competitiveness
M412-Environment/land management

M413-Quality of life/diversification

3.20.3. Metadata info

Metadata in the following table refer only to AEI no. 14 “Risk of land abandonment”

Indicator	Risk of land abandonment
Mapping approach (chapt.2)	Causal relationship
Proxy (yes/no)	Yes: several sub-indicators are considered as proxies
Function/service/benefit	Inverse proxy for rural vitality
Stock/flow	Not applicable
Unit of measure	Dimensionless composite indicator normalized to [0-1], where = minimum risk and 1= maximum risk. Each sub component is normalized and subsequently they are linearly aggregated by sum, with equal weights.
Type of map *(point, polygon…)*	Polygons
Map resolution	NUTS2 (NUTS1 for Germany and UK, NUTS0 for Slovenia, Cyprus, Estonia, Malta, Luxemburg)
Coordinate system	ETRS 1989 - LAEA 52 10
Year of reference	Average 2006-2008 (FADN)
Temporal series (*if yes, please indicate the period*)	no

3.20.4. Gaps

As a general limitation, FADN data only covers farms above a minimum size thresholds, which leads to under-representations of small farms, which are in turn relevant for land abandonment.

Data for the drivers Concerning the driver “Previous trend of farmland abandonment”, UAA trends shall be calculated at local LAU2 level; however, this data was not available at this resolution and the indicator has not been calculated so far.

Data for the indicators “Level of farm investments”, “enrolment in organic farming” “small farm size”, “Low farmer qualification” are available but were assessed as of low quality/accuracy and/or the overall relevance of the indicators was considered low, so they were not included in the final composite indicator.

Income level is measured considering farm income only, whilst other sources of income (tourism, external income by partners, second jobs etc.) could be important. However, this information is not available in the FADN database.

Finally, environmental conditions and natural constraints also influence the risk of land abandonment, but they are not currently included in the indicator.

3.21. Synthesis table

In table 3 we synthesise the link between PG/ES and ESBOs, together with corresponding indicator/proxy availability. This summary table is the first attempt to map such links within PEGASUS and needs further elaboration in order to identify the correct terminology. Moreover, some indicators may be used as proxies for different ecosystem services, but are currently mapped only under one.

Table 3 shows that the variables identified to describe PG/ES in most cases are proxies. The resolution is variable but mostly in the range 100 m to 10 km, and in 50% of the cases the data are available within the consortium, in the other cases they can be retrieved in other institutions.

Table 3: Synthesis table linking PG/ES to ESBOs and indicator/proxy availability

Broad categories of objectives to be achieved:	Environmentally and socially beneficial outcomes - ESBOs -[and dominant dimension]	Public good	Ecosystem service	Indicator	proxy	resolution	availability
	1. Food security: Achieving (or maintaining) a sustainable natural resource base to ensure a long term food supply hence security	Food security					see section 3.2
High water quality and ensuring water availability	2. Water quality: Achieving (or maintaining) good ecological status of surface water and good chemical status of groundwater	Water quality	Bio-remediation by micro-organisms, algae, plants, and animals Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals Filtration/sequestration/storage/accumulation by ecosystems Dilution by atmosphere, freshwater and marine ecosystems Chemical condition of freshwaters		Proportion of classified river and lake water bodies in different River Basin Districts (RBD) holding less than good ecological status or potential	polygon	
	3. Water availability: Achieving (or maintaining) a regular	Water availability	Hydrological cycle and water flow maintenance		Annual freshwater availability	5 km	

	supply of water (i.e. avoidance of water scarcity)				Mean annual streamflow (Q) per unit area; runoff coefficient (ratio)	0.125°	
High air quality	4. Air quality: Achieving (or maintaining) minimised levels of harmful emissions and odour levels	Air quality	Micro and regional climate regulation		Forest share of land area	1 km	
					Removal of NO2 by urban vegetation	100 m	
			Mediation of smell/noise/visual impacts				
Climate change mitigation objectives	5. GHG emissions: Achieving (or maintaining) minimisation of greenhouse gas emissions	Climate stability	Global climate regulation by reduction of greenhouse gas concentrations				
	6. Carbon sequestration/storage: Achieving (or maintaining) maximisation of carbon sequestration and storage		Global climate regulation by reduction of greenhouse gas concentrations		Carbon stock in forest	0.01° (~1 km)	
					Forest woody biomass increment	1 km	
					Growing stock and above-ground biomass in forests	10 km	
Climate change adaptation	7. Fire protection: Achieving (or maintaining) a high level of prevention and	Resilience to fire			Burned areas from Rapid Damage Assessment	polygon	

	minimisation of impacts of potential fires				Burned areas from European Fire Database	polygon	
					Burned areas from European Fire Database	point	
					Fire severity	vector	
	8. Flood protection: Achieving (or maintaining) minimisation of impacts of potential floods	Resilience to flooding	Flood protection by appropriate land coverage		Water retention potential by forests	polygon	
Healthy, functioning soils	9. Soil functionality: Achieving (or maintaining) good biological and geochemical condition of soils	Soil functionality	Maintenance of bio-geochemical conditions of soils including fertility, nutrient storage, or soil structure; includes biological, chemical, physical weathering		Natural susceptibility to compaction	1 km	
					Topsoil Organic Carbon Content	1 km	
					Potential threats to soil biodiversity in Europe	500 m	
					Water Retention Index	1 km	

			Maintenance of bio-geochemical conditions of soils by decomposition/mineralisation of dead organic material, nitrification, denitrification etc.), N-fixing				
	10. Soil protection: Achieving (or maintaining) minimisation of soil degradation		Mass stabilisation and control of erosion rates		Soil erosion by water	100 m	
					Pan European Soil Erosion Risk Assessment - PESERA	1 km	
					Soil Retention	1 km ?	
					Index of Land Susceptibility to Wind Erosion (ILSWE) and Wind-erodible fraction of soil (EF) for Europe	500 m	
					European Landslide Susceptibility Map (ELSUS1000) v1	1 km	
High levels of biodiversity	11. Species and habitats: Achieving (or maintaining) the presence of diverse and sufficiently plentiful	Biodiversity	Maintaining nursery populations and habitats		Conservation status of agriculture-related habitats	10 km	

	species and habitats (ecological diversity)			High Nature Value farmland	1 km	
				IUCN Red List Species	10 km	
				The percentage of loss of agricultural land to artificial surfaces 1990-2000		
				Landscape diversity expressed by the Shannon evenness index		
				Cropping pattern		
				Vascular plants richness and tree species richness	plot	
				Plant species richness	50 km	
				Amount of dead wood in forests	NUTS2	
				Statistical mapping of tree species over Europe	1 km	
				level of diversity in the Q. petraea and Q. robur	point	

					species		
					Crop wild relatives species richness for all crop genepools combined		
	12. Pollination: Achieving (or maintaining) high levels of pollination		pollination and seed dispersal		landscape pollination potential	100 m	
	13. Biological pest and disease control through biodiversity: achieving (or maintaining) high levels of biological pest and disease prevention and minimisation of the impacts of potential outbreaks using biodiversity		pest control		Number of terrestrial vertebrate species providing natural control of invertebrate and rodent pests	1 km	
Protecting landscape character and cultural heritage	14. Landscape character and cultural heritage: maintaining or restoring a high level of landscape character and cultural heritage	Agricultural landscapes			societal awareness of agricultural landscape	NUTS2	
					Landscape physical structure	10 km	
					Degree of naturalness of the agrarian landscape	100 m	

	15. Outdoor recreation: Achieving (or maintaining) a good level of public access to the countryside to ensure public outdoor recreation and enjoyment		Physical and experiential interactions: physical use of land-/seascapes in different environmental settings		Recreation Opportunity Spectrum	100 m	
Public recreation, education and health	16. Educational activities: Achieving (or maintaining) a good level of educational and demonstration activities in relation to farming and forestry		Intellectual and representative interactions: education				
	17. Health and social inclusion: Achieving (or maintaining) an appropriate level of therapeutic /social rehabilitation activities in relation to farming and forestry						
High levels of farm animal welfare	18. Farm animal welfare: achieving (or maintaining) the implementation of high animal welfare practices on farms	Farm animal welfare and animal health			Animal welfare payments – CAP Pillar 2, Axis 2, measure 215	NUTS2 for Italy and Spain, NUTS1 for Germany, NUTS0 for all other countries	
Preserving and enhancing rural vitality	19. Rural vitality: Achieving (or maintaining) active and socially resilient rural communities	Rural vitality			Inverse of risk of land abandonment	NUTS2 (NUTS1 for Germany and UK, NUTS0 for	

						Slovenia, Cyprus, Estonia, Malta, Luxemburg)	

data available in-house
data available but to be collected outside the consortium
data existing but not available
data not existing

4. Datasets to describe land management

4.1 Agriculture

The table in this section summarises data and indicators on agricultural management, needed to analyse the causal relation between PG/ES provision and management. Variables include both well-known descriptors of agricultural activities in the strict sense such as cropping patterns, fertilisers input, irrigation, and descriptors of environmental variables impacting agricultural management (agroecological zoning, areas with natural constraints, Natura 2000 network).

Variable	Description	Units	Spatial resolution	Source	Rationale for selecting the variable
Crop shares	areas of: arable crops (cereals, pulses and protein crops, root crops, industrial crops, oilseeds, fibre crops, clover/lucerne/other green harvested crops, fresh vegetables, fruit, etc) permanent crops including kitchen gardens (grapes, olives, nurseries, pome fruits etc) permanent grassland / meadow fallow land within crop rotations unutilised land and other areas	1,000 ha	NUTS2 1 km2 level	Eurostat (data from farm structure survey FSS) (agr_r_acs) (from 2000 onwards)[1] CAPRI disaggregated data at 1km2 level	Arable, permanent crops and permanent grassland are broadly associated with different capacities to deliver regulating ES and public goods (e.g. carbon storage or soil protection), with delivery highly dependent on how they are managed. Particular crops are likely to be associated with particular environmental impacts associated with their management (e.g. pesticide use intensity, nitrogen fertilizer application, tillage practices), although cropping intensities vary locally, regionally and nationally, and overall impacts depend on the overall cropping system and crop rotation(s) used on the farm holding.
Active, fallow or (temporarily) abandoned farmland	area of active, fallow, and temporarily abandoned farmland NB fallow land category in LUCAS includes agricultural land not used for the entire year for crop production or as part of a field rotation; land which has been set-aside from production for the long term; and bare land for agricultural use in other years (LUCAS 2009). This broadly corresponds to the FSS category 'unutilised land and other areas'.	ha	NUTS2 individual sample points for LUCAS	Eurostat (data from LUCAS survey) - Data from 2009 (EU-23)[2], 2012 (EU-27)	Fallow can have positive effects on regulating ESS and public goods associated with negative agricultural externalities such as water pollution. Under-management or abandonment can have negative or positive impacts on biodiversity, landscape aesthetics and other ESS/public goods. Fallow land tends to dominate in dryland areas (ES, PT, IT) where it is part of arable rotations to maintain soil fertility and reduce pressure on water courses. Spatial analysis of the interplay between fallow in these areas and irrigated land may give an indication on ESS provision.

[1] NB Between individual Member States, there are some discrepancies within the data, particularly for Austria, Slovenia, Poland, the Netherlands and Portugal, which is to be expected given the different definitions, time series and sampling approach (Hart et al, 2013)

[2] LUCAS 2009 http://ec.europa.eu/eurostat/web/lucas/data/primary-data/2009

	NB land is not often truly abandoned, but may be temporarily out of agricultural use, underused (semi-abandonment or hidden abandonment), or being used for a non-agricultural activity (eg recreation, hunting)				
Livestock density	no of cattle, horses, donkeys, pigs, sheep, goats, converted into standard livestock units per farm	livestock standard units (LSU) per farm holding, per UAA (regional averages)	NUTS2	Eurostat (data from farm structure survey) - Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	High livestock density is associated with intensive farm management and is therefore correlated with nitrogen input on grassland etc. Livestock density is broadly correlated with greenhouse gas emissions (ammonia & methane), contributing to climate change, and nitrogen emissions into soil and water from manure and slurry, which negatively affect water quality (Leip et al, 2015). Minimum livestock densities required to maintain grazing on semi-natural habitats and natural grassland are generally low to very low, in the range of 0.8 to 0.1 LSU/ha (European Commission, 2014). It is not possible to assess the degree to which minimum grazing that benefits biodiversity is being maintained, as the data do not reveal abandonment of specific habitats, although strong declines in the regional average may indicate possibility of abandonment.
Crop production and yields	for more than 100 crop products	1000 tonnes or 100 kg/ha	NUTS 2 (but FR and DE only NUTS1)	Eurostat (annual statistics from 2000 onwards for EU-15 to EU-28)	Higher yields are usually associated with higher input use (fertiliser, pesticide, irrigation, etc) and therefore with the likelihood of negative environmental externalities. Lower yield is broadly associated with natural constraints affecting the capacity of soil and landscape to produce crops.
Nitrogen input		Kg/ha	1 sqkm	CAPRI	The level of nitrogen application is broadly associated with farming intensity. Nitrogen fertilization on semi-natural grasslands tends to reduce plant species richness (Stevens et al, 2010) and/or plant

					functional diversity, with negative effects on invertebrate diversity (Oeckinger et al, 2006) and grassland-breeding birds (Donald et al, 2002; Wilson et al, 2009), whilst increasing biomass production. Nitrogen fertilisation in arable crops is associated with increased crop density and vigour, which tends to reduce arable weed abundance and diversity (Kovács-Hostyánszki et al, 2011), with food chain impacts on wildlife, whilst increasing soil cover during the growing season, which can decrease overall soil erosion rates. Nitrogen fertilisation is associated with greenhouse gas emissions (nitrous oxides and/or ammonia, depending on fertiliser type). Fertilisation (both N and P) stimulates soil microbial activity which affects soil organic matter levels – generally resulting in a decrease in SOM, but by addition of manure or compost can increase SOM in some cases (Sradnick et al, 2013).
Nitrogen surplus		Kg/ha	1 sqkm	CAPRI	Nitrogen surplus indicates an increased likelihood of greenhouse gas emissions and run-off to water, negatively affecting water quality and freshwater biodiversity (Dise, 2011). These impacts are likely to be located both near the farm holding and/or downstream within the catchment. It is very difficult to attribute the impacts of diffuse agricultural water pollution to particular originating farms.
Pesticide consumption	Annual pesticide sales in EU countries from 2011 onwards are available as kg active substances sold per pesticide major group (herbicides haulm destructors & mosskillers, fungicides & bactericides,	kg active substances of pesticide major groups sold per year	Member State level (NB detailed use statistics available in UK and Germany)	Eurostat (data from Member State reporting 2011-2013; data from European Crop Association 2003-2009)	The data are broadly associated with intensity of agricultural production, but only at a very general level. The data are a poor indicator of the actual use of pesticides in field crops as they do not indicate where the pesticides are being used or when (whether in agriculture or not, on what crops etc). Weight data are very

	insecticides & acaricides, molluscicides, plant growth regulators, other) NB in the UK and Germany, pesticide active substance use data are available broken down to active substance, annual usage on specific crop, region, in frequency of application and quantity (weight) of substance used. All Member States are obliged to collect and report data on treated area and treatment frequency from 2016, but it is not yet known when these data will actually be available.				heavily influenced by use of potato desiccators and by use of certain herbicides. The data are not recommended for use as a proxy for environmental impact of pesticides. The data are a poor indicator of actual environmental impact, because environmental impact varies greatly between different active substances, different situations of use (arable, horticultural, grassland, sealed surfaces etc), and different use practices (maintenance of safe distances to water courses, formulation etc).
Irrigation		Irrigation intensity (%)	10 sqkm	Wriedt et al., 2009 - A European irrigation map for spatially distributed agricultural modelling. Agricultural Water Management 96: 771-789	Modern irrigation systems tend to be associated with highly intensive agriculture with some high negative environmental externalities (Villanueva et al, 2014). In some cases the installation of irrigation systems has resulted in the loss of semi-natural habitats with high biodiversity value, eg central Spain (De Frutos et al, 2015). In some catchments, irrigation is associated with groundwater and/or surface water scarcity. This has negative impacts on water-related ecosystem services and biodiversity in the locations where the water is abstracted and also downstream, if ecological flows are not maintained. In contrast, traditional irrigation systems can be associated with high landscape aesthetic values and benefits for wildlife.
Other inputs: phosphorus fertilisation	Mineral Fertilizer Consumption, Phosphorous It is calculated based on data from Fertilizers Europe and Member States, allocated to	Kg P/ha	HSMU (1 km2)	CAPRI model	Phosphorus (P) fertilisation on semi-natural grasslands causes a long term reduction in plant species richness (Ceulemans et al, 2014) and/or plant functional diversity (Helsen et al, 2014). Therefore P fertilisation is broadly

	crops and regions through a statistical estimator				associated with greater biomass production and lower biodiversity of grasslands, and lower production of associated ecosystem services and public goods. On arable land, the relationship between P fertilisation and crop production intensity is less marked as most soils in the EU have accumulated a P surplus, and use of P fertilizers is currently falling without noticeably affecting production.
Energy input in agriculture	The indicator is the sum of the energy input due to labour, machinery, irrigation, fertilisation, seeds.	Mj/ha	1 sqkm	Perez-Soba et al., 2015 - Agricultural biomass as provisioning ecosystem service: quantification of energy flows. EUR 27538 EN. Publication Office of the European Union, Luxembourg	Energy input is a measure of the modification of the ecosystem due to agricultural activities. In the case of cereals and grasslands, it is strongly related to an increase in energy content in the yields.
Organic farming	no of organic farms (certified & in conversion); area of organic farming; livestock units of organic farm holdings; area of farm types that are organic; no of holdings of farm types that are organic; organic crop production	no of holdings; area (ha UAA) per region; LSU; area of crop (ha UAA)	NUTS2	Eurostat (data from farm structure survey) - Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	Organic farming is often associated with greater farm-scale structural diversity (eg with more trees and field margins) and wildlife diversity (Smith et al, 2011; Tuomisto et al, 2012) - but not in all cases, and the farm-scale impact depends on the structural diversity of the surrounding landscape (Dänhardt et al, 2010; Fischer et al, 2011; Gabriel et al, 2010; Smith et al, 2010). Organic farms may form isolated patches in a landscape of intensive conventional farms, or may be dotted around in areas where mixed farming is common (and which may correspond with HNV areas), but not large blocks. Organic farming may be associated with greater production of other public goods such as social or cultural services - but the impact depends on the attitude, values and situation of the farmer rather than on the organic certification *per se* (Dinis et al, 2015).
Natura 2000	Area of Natura 2000 network	size of each	site level	EEA Natura 2000 Access database (data for EU-	The Natura 2000 network contains 9.4% of

	per Member State (net area of designated sites accounting for SCI/SPA overlap); individual site areas (not accounting for overlap) NB Natura 2000 areas are often (but not always) a protected area under one or more national or international designations (national park, nature reserve, landscape park, Ramsar site etc). The Natura 2000 site may be part of a larger protected area, or larger than the protected area, or overlapping in part.	SCI or SPA site in ha[3] (spatial boundary data available as shape files plottable in GIS) net coverage of Natura 2000 sites by Member States	Member State level	27 from 2012) EEA Natura 2000 barometer	the EU's agricultural area[4] (10.9% including natural grasslands, some of which require grazing or cutting), although it is important to note that only a part of this area is actually eligible for CAP payments. Natura 2000 sites contain a large proportion of extensive / HNV but also some intensive agriculture systems. Agricultural production within Natura 2000 sites is influenced (through both obligatory and voluntary measures) by the conservation objectives and measures necessary to maintain and restore the EU habitats and species for which the site is designated. Therefore, at least theoretically, they are associated with a higher abundance of rare habitats and species of conservation concern. Farm holdings within Natura 2000 sites are therefore more likely to be delivering a range of regulating and cultural ecosystem services and public goods. In addition, as many Natura 2000 sites are also nationally or regionally protected areas, they are generally associated with cultural ecosystem services such as recreation, nature tourism, and valued landscapes.
Biophysical constraints determining	The spatial distributions of bio-physical limitations on rain-fed agricultural land have been			Global Agro-Ecological Zoning methodology applied to EU datasets (e.g. IIASA Global Agro-	Areas of biophysical constraint(s) on agricultural production are broadly associated with lower agricultural production potential,

[3] SCI (Site of Conservation Interest) designated under the EU Habitats Directive and SPA (Special Protection Area) designated under the EU Birds Directive, jointly known as Natura 2000 sites

[4] European Commission DG AGRI (2014) CAP Context Indicators 2014-2020 34. Natura 2000 areas December 2014. Available at http://ec.europa.eu/agriculture/cap-indicators/context/2014/c34_en.pdf

agricultural land use	assessed using soil and terrain maps (Allen et al, 2015). Areas of Natural Constraint qualifying for CAP payments must now be defined according to objective criteria and thresholds for climate, terrain and soil (low temperature, dryness, excess soil moisture, limited soil drainage, unfavourable texture and stoniness, shallow rooting depth, poor chemical properties, steep slope) specified in the regulation[5]. Methodologies, data availability, and threshold uncertainties of the CAP ANC criteria were reviewed by JRC (Terres et al, 2014).			ecological Zones (GAEZ) system) Descriptions of how Member States/regions have defined ANCs including local unit level are available in Rural Development Programmes[6] Terres et al., 2014, Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints. Report EUR 26940 EN, Publication office of the European Union, Luxembourg.	and therefore generally include more extensively managed farms, although they also include some intensively managed farms (for example, which have invested in drainage or soil improvement). The extensively managed farms are often associated with a range of ecosystem services and public goods but also with economically marginal farms, in some cases even loss-making farms and farmland abandonment. This can be associated with declining rural vitality through population decline and the departure of the younger generation, decline in farming incomes, employment and investment. There is a broad overlap with HNV. The JRC review identified three critical problems in utilising EU data to delineate areas of natural constraint (Terres et al, 2014): agriculture in the EU encompasses a wide range of crops that have different soil and climate requirements – it would therefore be very complex to present one single suitability map encompassing the huge variety of crops and their possible combinations across the EU 28; many soil and climate characteristics co-determine suitability and mutually interact, and it is a complex exercise to define, quantify and match all relevant criteria with the multitude of possible crops across the EU 28;

[5] Annex III in Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005.

[6] In accordance with Annex I Part 1 paragraph 8(e)12 of Commission Implementing Regulation (EU) No 808/2014 of 17 July 2014 laying down rules for the application of Regulation (EU) No 1305/2013 of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD).

					delimitation of zones is conditioned by available data, for example point observations (eg from LUCAS) must be converted to gradients of change across space.
High Nature Value Farmland	High Nature Value farmland comprises those areas in the EU where agriculture is a major (usually dominant) land use and where that agriculture supports or is associated with either a high species and habitat diversity, and/or the presence of species of European, and/or national, and/or regional conservation concern or both (Beaufoy and Cooper, 2008; Cooper et al, 2007; Oppermann et al, 2012). Within this definition, three types of HNV farmland are identified: (1) farmland with a high proportion of semi-natural vegetation; (2) farmland with a mosaic of low density agriculture and natural and structural elements; (3) farmland supporting rare species or a high proportion of European or world populations. HNV identification and targeting must consider land cover, biodiversity and farming characteristics together, as any one of these characteristics alone is not sufficient to identify HNV (Keenleyside et al, 2014). HNV farming systems can be divided into (Keenleyside et al, 2014): • whole-farm HNV (low intensity management of	% likelihood of HNV presence	1 sqkm	EU-wide map of likelihood of presence of HNV (Paracchini et al, 2008) HNV maps in individual Member States, described in (Keenleyside et al, 2014)	High Nature Value farmland is associated with low (fuel, fertiliser etc) input but relatively labour intensive farming systems, with traditional farming landscapes, crops and animals (in particular permanent grazing systems), and with higher abundance and species richness of wildlife and habitats associated with agriculture. It is therefore associated with a range of ecosystem services and public goods, including biodiversity, aesthetically valued landscapes, cultural traditions such as transhumance, extensively managed landscapes that provide hunting, wild food, recreation, and other opportunities for public uses. HNV farmland includes mainly low input mixed farming systems, but also includes some low intensity arable systems and some intensive grassland systems with a high occurrence of bird populations of EU or global importance. HNV farmland also includes a high proportion of economically marginal farms and a close overlap with ANC areas, see ANC comment above. It should be noted that an unknown but significant area of HNV farming is not receiving any CAP subsidies.

	all land) • partial HNV (some HNV alongside more intensive land) • remnant HNV (small patches or fields no longer functionally/economically related to intensive farming system)				
Common land grazing		ha	NUTS0	http://ec.europa.eu/eurostat/statistics-explained/index.php/Common_land_statistics_-_background	There is a close overlap between common land ownership, grazing systems based on commoners rights, HNV farmland, Areas of Natural Constraint, and Natura 2000 areas. See comments above.

Data gaps

The main limitation of the identified datasets and proxies is that they are available in a coarse resolution (NUTS2 – NUTS0). This will reduce the possibilities for i.e. multivariate analysis to detect trends between PG/ES and management variables.

4.2 Forestry

In this section we list relevant spatial and statistical datasets to describe forestry systems and management. Forestry involves the science, art and business of managing forest for human benefit (Seymour and Hunter, 1999). In agreement with the EU Forest Strategy (European Commission, 2013) current forestry practices are oriented in many circumstances to multifunctional forests. However, the spectrum of forest management approaches (FMAs) ranges from intensive forest practices following an agricultural-like paradigm to maximise timber production, to conservation forestry oriented to biodiversity protection or to spontaneous natural processes. Between these two extremes there is an extended range of approaches with intermediate objectives between pure timber production,nature conservation and other objectives such as outdoor recreation or water production .

To differentiate FMAs in the field is not easy because silvicultural practices, which define FMAs, produce a continuum where the distinciton between approaches is often not evident. Different options exist for tree species selection, site preparation, planting, tending or thinning. All this options depends on the approach adopted and they are often not mutually exclusive. In consequence there is no a unique and unequivocal classification that can be mapped using observational or field methods. Therefore using proxies describing the main features of each FMA is a suitable option.

Recently Duncker et al. (2012) proposed a conceptual classification of FMAs of European forestry systems. Their classification system includes five approaches following a scale of management intensity from passive to intensive:

Passive – Unmanaged forest-nature reserve: Is an area where the main aim is protection of valuable habitats and biodiversity. Natural processes and natural disturbances are in place without management intervention.

Low – Close-to-nature forestry: The objective of this system is to manage forest stands emulating natural processes without excluding economic output. Management interventions must look to enhance or conserve forest ecosystem functions.

Medium – Combined objective forestry: In this approach various management objectives are combined for satisfying diverse needs. Economic and environmental objectives play a major role including timber production, habitat, water and soil protection, and other services.

High – Intensive even-aged forestry: The main objective of this approach is timber production under an even-aged monoculture stand distribution. Environmental objectives are considered if they do not represent much income loss.

Intensive – Short rotation forestry: The objective of this approach is to produce the highest amount of timber or wood biomass, while ecological aspects have a minor importance.

The classification of Duncker et al. (2012) was operationalized by Hengeveld et al. (2012) by producing a spatially-explicit European map describing the likely distribution of the five approaches on each 1-km grid cell. Despite some limitations the map is the first product of these characteristics implemented at pan-European level and could be used as reference for FMA mapping within the scope of PEGASUS project.

Within production forest an important parameter is management intensity that describe the amount of timber produced in relation to forest productivity. One indicator describing management intensity is forest harvesting intensity (HI) which is defined as the relation between the outputs from forestry (i.e. harvest) to forest ecosystem productivity (i.e. net increment). Levers et al. (2014) implemented a European map of HI at the NUTS-3 level (polygons). This dataset make it possible to compare forest HI across large regions, however its non-spatially-explicit character could result in some limitations for integrating this dataset with other fine-grained datasets such as National Forest Inventory plot level data or gridded datasets, for example, carbon stock indicators.

The table in this section summarises a series of proxies for forest management. These proxies are useful to describe the relations between forest PG/ES provision and potential forest management approaches.

Variable	Description	Units	Spatial resolution	Source	Rationale for selecting the variable
Forest management approach	Forest management approach described using five categories	Categories	1-km grid size	Duncker et al. (2012); Hengeveld et al. (2012)	This dataset provides the first harmonised pan-European map of potential forest management to inform policy, land use modelling and forest resources projections. The dataset describes the suitability of each grid-cell to five forest management approaches based on a series of proxy factors.
Forest harvest intensity [See also increment and felling ratios]	% and harvested timber volumes		NUTS2 level		Forest harvest intensity is used to describe the relationship between the rate of fellings compared to the annual increment. As fellings approach the level of increment one can assume that the management intensity of the forest has increased with associated potential risks to ESS delivery. It could therefore be assumed that as FHI increases, ESS delivery is likely to decrease. This will likely be a non-linear relationship and depend on the methods used within different forestry systems and within different geographical contexts of the EU.
Naturalness	Naturalness: Area of forest and other wooded land classified as “undisturbed by man”, “semi-natural” or “plantations”, each by forest type	ha or %	??	Indicator 4.3 from SoEF, 2015 NFI - MS reporting presumably	Similar rationale to the above with the level of natural ecosystem function (and therefore balance) being greater in undisturbed forests than plantations or high intensity management areas.
Dead wood	Volume of standing deadwood and of lying deadwood in forest and other wooded land classified by forest type	m^3 / ha	NUTS2 level	Indicator 4.5 from SoEF, 2015 NFI - MS reporting presumably	Deadwood is an important substrate for a large number of forest species, including vertebrates, invertebrates, algae, bryophytes, vascular plants, fungi, slime moulds and lichens. Deadwood contributes to the structural stability of soils, e.g. on slopes, and it helps in the retention of organic matter, carbon, nitrogen and water.
Genetic Resources	*Area managed for the conservation and utilization of forest tree genetic resources (*in situ *and* ex situ *genetic conservation) and area managed for seed production*	Unclear	Point information	Indicator 4.6 from SoEF, 2015 European Information System on Forest Genetic Resources	The conservation and use of forest genetic resources is a vital component of sustainable forest management. Genetic diversity ensures that forest trees can survive, adapt and evolve under changing environmental conditions. Genetic diversity is also needed to maintain the vitality of forests and cope with pests and diseases. Forest management in

				(EUFGIS)	Europe is largely based on the management of wild or semi-wild tree populations; the establishment of new forests through artificial or natural regeneration always involves the deployment of genetic material.
Carbon stock	*Carbon stock of woody biomass and soil in forest another wooded land*	Mt C and %	1 km grid size	Indicator 1.4 from SoEF, 2015	A direct proxy for the amount of carbon sequestered in forest. Could be used as a proxy for carbon sequestration if combined with FHI measurements, and overall carbon sink status.
Soil condition	The condition of soils under forest with consideration of SOC and pH		Probably NUTS2	Indicator 2.2 from SoEF, 2015 LUCAS soil survey	As a proxy for soil carbon sequestration + other ESS.
Production and use of non-wood goods and services, provision of speciality recreation	Qualitative indicator reporting changes or trends only.		Not mappable other than at country level		
Protective forests – soil, water and other ecosystem functions	*Area of forest and other wooded land designated to prevent soil erosion, to preserve water resources, or to maintain other forest ecosystem functions, part of MCPFE Class "Protective Functions"*	ha and %	Country – possibly NUTS 1 or 2	Indicator 5.1 from SoEF, 2015	Proxy for the protection of ESS in other areas provided by forests.
Protective forests - infrastructure and managed natural resources	*Area of forest and other wooded land designated for the protection of infrastructure and managed natural resources against natural hazards, part of MCPFE Class "Protective Functions"*	ha and %	Country – possibly NUTS 1 or 2	Indicator 5.2 from SoEF, 2015	Proxy for the protection of ESS in other areas provided by forests.
Other potentially relevant indicators of ESBO/ESS/PG					
Forest landscape pattern	The forest spatial pattern can be described by: (1) the spatial distribution of the forest cover; (2) the landscape mosaic composition in the forest surroundings, in terms how, by	Usually %		Indicator 4.7 from SoEF, 2015 Interpreted from Corine Land Cover forest map for	This indicator would describe the ability of forest ecosystems to function as a collective unit, as an effective singular unit, and describe how species could move between individual units.

	what and how much the forest cover is fragmented; and (3) the connectivity of forest cover, which also specifies how far apart forest areas are and which types of land separate them from the perspective of functional groups of forest species.			2012	
Tree species distribution	Tree species groups can be calssified by the most important tree species from such groups (birch, oak, beech, pine etc.)	ha	1-km grid size		Tree species distribution can be used as indirect proxy for biodiversity and cultural services. It gives some information on the habitat and type of management. And also on tree species related wild species (e.g. birds).
Tree species composition	Area of forest and other wooded land, classified by number of tree species occurring and by forest type			Indicator 4.1 from SoEF, 2015	
Forest area	Total forest area by type	ha			Not a direct proxy for ESS, but certainly has bearing on the ability of forests to deliver services / possibly a better indicator is forest patch size for example. In countries like UK, BE, NL, forest area is crucial for function.
Services	Five categories of indicators for ecosystem services – see pg 123 of SoEF, 2015	% and € value of services to society	Country level?	Indicator 3.4 from SoEF, 2015	Direct proxy for ESS.

Data gaps

The main gap regarding information to describe forestry systems and management is the lack of an observational dataset at pan-European level. This gap may have implications in the methodology for exploring the relations and trade-off between PG/ES and forestry systems. The table in this section shows a list of proxies useful for describing management approaches. Nevertheless, each proxy has its advantages and limitations that should be considered in the mapping and assessment tasks. Some of the proxies are rough estimations provided at administrative units, thus further limiting its usability for assessing spatially explicit (gridded maps) information.

5. Socio-economic variables

In the frame of PEGASUS is has been proposed (D1.1 - Public Goods and Ecosystem Services from Agriculture and Forestry – a conceptual approach) that Socio-Ecological Systems (SES) become the reference framework "*to better understand how ecological and social attributes and values, and their provision in farming and forestry alongside the production of food, fuel or fibre, interconnect*". The following tables contain a selection of indicators to characterise SES, which goes beyond management and includes, for agriculture, information on farm structure, farm types, ownership, income, CAP subsidies, demography, education.

5.1 Agriculture

Variable	Description	Units	Spatial resolution	Source	Reference year(s)	Rationale for selecting the variable
Farm size (economic – agricultural output)	Average monetary value of the agricultural output of the farm holding[7] at farm gate price (combined €/ha crops and €/head of livestock)	million €/farm holding/year in size classes (NUTS2 total)	NUTS2[8]	Eurostat (data from farm structure survey)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	Economic farm size is an indicator of farm contribution to the national economy, but is only partially related to contribution to the local rural economy, as farms differ greatly in their level of integration into the local and regional economy. Economic farm size is also only partially related to farm food production as some farms are specialised in high economic value products with relatively low importance or volume as food (such as wine or quality cheese). Economic farm size is highly skewed within the EU, within MS and within regions: around half of EU agricultural economic output comes from 2.4% of holdings with output above €250,000, whilst 40.2% of holdings (4.4 million) have a standard output below €2000 and contribute 1% of EU agricultural economic output.
Farm type	Farm specialisation in crops (field or permanent), or grazing livestock, or granivore	No of farm holdings of each farm type (NUTS2 total); area of each	NUTS2	Eurostat (data from farm structure survey) (product code: ef_oluft)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	Mixed farming can be related to more balanced on-farm nutrient cycles and greater landscape diversity, which may be linked to a greater supply of

[7] The statistical unit observed is the agricultural holding (a single unit, both technically and economically, which has a single management and which produces agricultural products), which has: an utilised agricultural area of 1 ha or more (before 2010) and 5 ha or more (from 2010 onwards), an utilised agricultural area less than 1 ha if it market produce on a certain scale or if its production units exceed certain natural thresholds.

[8] NB Farm Structure Survey data from basic surveys are available in a three-level geographical breakdown of the whole country, the regions and the district; while data from intermediate surveys are only available at the two-levels of country and regions.

	holdings. Farms with mixed livestock or crop-livestock. Non-classifiable holdings.	farm type (NUTS2 total)				regulating and cultural ESS, but this is not always the case. Both mixed and specialised farms differ widely in their level of production intensity, but farm types can be used to locate a possible undersupply of certain ESS often associated with certain crop types (e.g. vineyards and soil erosion, cereal arable farms and wildlife, horticulture and water quality).
Legal status of farm holding	Sole holder, legal entity (e.g. company), group holdings (e.g. common land association) NB: legal status does not specify public and private ownership division	No of farm holdings in each legal type / area of each legal type (NUTS2 total)	NUTS2	Eurostat (data from farm structure survey) (product code: ef_kvaareg)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	The legal status of a farm holding may influence the way in which a holding can adapt the farming system to provide more ESS or public goods. However, the connections are likely to be complex and case-specific.
Farms in public ownership						Publically owned farms may have greater opportunity to influence land management decisions as compared to privately owned farms
Farmer age	Age of person registered as farm manager or holder	Less than 35 years; from 35 to 44 years; from 45 to 54 years; from 55 to 64 years; 65 years or older (NUTS2 totals)	NUTS2	Eurostat (data from farm structure survey) (product code: ef_kvage)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	Older farmer age is broadly correlated to lower farm investment and lower economic value of farm production (Carbone and Subioli, 2008), and to greater supply of regulating and cultural ESS in more marginally productive farming landscapes (Schmitzberger et al, 2005). However, the connections are indirect and not generally applicable.
Farmer agricultural training	Basic training; practical experience only; full agricultural training Expenditures on training courses under CAP Pillar 2	no of farmers trained in each category (NUTS2 totals) Euros/year/country or region	NUTS2 NUTS0 (in some cases (NUTS2)	Eurostat (data from farm structure survey) (product code: ef_mptrainecs) ENRD (European Network for Rural Development)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28) Totals for CAP programming period 2007-2013	If the agricultural training was relatively recently acquired, it is likely to have included some aspects relevant to the production of ESS or public goods associated with environmental or cultural benefits. However the choices to implement those beneficial management practices will still likely come down to individual opinion and

						economic choices. Expenditures for farmers training is an indication of rural vitality and capacity building for innovation
labour force directly employed on the farm (family or not)	No of people who work regularly on farm holding(s), gender, and whether they belong to the holder's family	persons and annual working units[9] (NUTS2 total)	NUTS2	Eurostat (data from EU labour force survey (LFS)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	Labour force is related to the contribution of farming to the economy, so it can contribute to rural vitality. It is possible to calculate net additional full-time equivalent jobs created, labour productivity (change in Gross Value Added per full-time equivalent. Whether the number of people who work on the farm is directly correlated to the environmental management of the farm is unclear. In most EU MS, farming is predominantly a family activity using family labour. Non-regular (seasonal) labour represents between 10% and 20% of the total labour input in some MS.
part-time / full time business (secondary activities)	main or subsidiary non-agricultural activities directly related to the holding using the resources and/or products of the holding (main holder and spouse)	no of holdings with main other gainful activity; subsidiary; no other; not applicable (NUTS2 total)	NUTS2	Eurostat (data from farm structure survey) (data: ef_ogaaa)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013 (EU-28)	Part-time farming may be associated with other farm activities that provide ESS or public goods (e.g. on-farm recreation and tourism offers, conservation farming, social enterprises). However, when interpreting this indicator, part-time farming may also mean that the farmer has other gainful income and farming merely represents a hobby and thus investment in ESS decisions may not be paramount.
organic farming	no of organic farms (certified & in conversion); area of	no of holdings; area (ha UAA) per region; LSU; area of	NUTS2	Eurostat (data from farm structure survey)	Data from 2005 (EU-27), 2007 (EU-27), 2010 (EU-27), 2013	Organic farming is often associated with greater landscape and wildlife diversity - but not in all cases, and the impact

[9] where one AWU corresponds to the work performed by one person occupied on a full-time basis

	organic farming; livestock units of organic farm holdings; area of farm types that are organic; no of holdings of farm types that are organic; organic crop production	crop (ha UAA)			(EU-28)	depends on the structural diversity of the surrounding landscape. Organic farming may be associated with greater production of other public goods such as social or cultural services - but the impact depends more on the attitude and situation of the farmer than on the organic certification *per se*.
CAP subsidies – I pillar: Common Market Organisations	payments to CMOs such as dairy marketing boards, fruit & vegetable producer organisations		region or Member State level			Payment levels may indicate the relative importance of the supported food production sector in the region or MS.
CAP subsidies – I pillar: direct farm payments	single farm payment or single area payment	annual direct payment per ha UAA	region or Member State level			Payment level may reflect historic production levels in the EU-15 (although payments are being progressively evened out to set regional levels by 2017) Information on payments received by individual farms is not generally publicly available
CAP subsidies – II pillar: agri-environment-climate measure	schemes under agri-environment-climate payment	annual payment per ha UAA under contract	region or Member State level (depending on rural development planning level)	Rural Development Programmes 2014-2020 (planned payment rates, target areas) ex-post assessments of RDPs 2007-2013 (not available until end 2016)	planned payments and target areas for 2014-2020 actual payments and areas in 2007-2013 (once ex-post assessments become available)	As the agri-env-climate measure is obligatory, payments are made in every RDP region or MS. However, the schemes vary widely in the types of measures they support, and therefore in the ESS and public good provision they promote. Unless detailed payment information is obtainable for specific targeted schemes, it is not possible to conclude much about ESS or public goods provision.
CAP subsidies – II pillar: organic measure	payments to organic farms in conversion or to certified organic farms	annual payment per ha UAA under contract	region or Member State level (depending on rural development planning level)	as above	as above	see organic farming information above
CAP subsidies – II pillar: ANC measure	payments to Areas of Natural Constraint or other constraints	annual payment per ha UAA in qualifying areas	region or Member State level (depending on rural	as above	as above	Payments under the measure do not specify nature conservation management requirements and for

			development planning level)			habitats and species and therefore do not provide incentives for positive effects for EU protected habitats and species. However, they will benefit many farms with High Nature Value and may prevent abandonment of semi-natural grassland management.
CAP subsidies – II pillar: other measures	payments under other area-based measures	annual payment per ha UAA under contract	region or Member State level (depending on rural development planning level)	as above	as above	Some of the other Pillar II measures involve areas-based payments; however, it is generally not possible to link subsidies with ESS or public good provision. The Natura 2000 payments measure is directly connected to protected areas, but is only used by some MS/regions and only for a subset of Natura 2000 sites.
Gross net margin plus CAP Pillar I revenues	Gross Value Added - the difference between revenues from sales and the value of the intermediate inputs used in the production process, summed to CAP Pillar I revenues	Euros/ha	1 sqkm	CAPRI		
% of total employment in agriculture	Agricultural labour statistics – absolute figures	1000 annual working units	NUTS0	Eurostat	Available yearly 1973 - 2015	Labour statistics on agriculture can be related to similar statistics for the other sectors in order to have an indication of the vitally of the agricultural sector in a Country/region
net migration						
extent of rural broadband	Data not available					
tourism infrastructure in rural areas	Farms declaring tourism as "other gainful activity"	Nr of farms	NUTS2	Eurostat – Farm Structure Survey	Latest info available in 2010 FSS	Information on tourism activity in farms is both a measure of rural vitality and farm business diversification
social services in rural areas	Data not available					Information on social services in rural areas is a measure of rural vitality

(physical & mental health services, child services, pensioner services)						
life-long learning services in rural areas	Data not available					

Data gaps

A main limitation is that data are available at NUTS2 level or above. This limits the possibilities for analysis in conjunction with environmental data. A main gap in the data concerns tourism and accommodation facilities. Such information is not available or not easily retrievable. For example, in the Farm Structure Survey there is a field "farm declaring tourism as other gainful activity", which is per se a useful information but it concerns only the farms. No data are available on tourism infrastructure or touristic fluxes in rural areas. Potentially, data available i.e. on Google Earth on accommodation facilities would allow calculating the density of accommodation facilities per cell of i.e. 10 km x 10 km. Data on social services and broadband coverage are equally lacking.

5.2 Forestry

This section summarises a series of socio-economic variables known to influence forest management and indirectly the provision of PG/ES. The socio-economic context at local/regional level actuates as one of the drivers guiding decisions of forest managers regarding management approaches and forestry intensity. Therefore, these decisions have a potential effect in the provision of PG/ES as consequence of the management approach implemented.

Variable	Description	Units	Spatial resolution	Source	Time series	Rationale for selecting the variable
GDP PPP	Gross domestic product - Purchasing Power Parities (for international comparison)	€	NUTS-2; NUST-3	EUROSTAT http://ec.europa.eu/eurostat/web/regions/overview http://ec.europa.eu/eurostat/web/regions/data/database		Unclear how this could relate to Forest ESS provision more accurately than GVA
GVA	Gross value added in sector A (agriculture, forestry, fishing)[10] The total value of products produced (output) minus the value of the goods and services consumed as inputs during production (intermediate consumption).	€	NUTS-3	EUROSTAT http://ec.europa.eu/eurostat/web/regions/data/database Note: the SoEF indicator 6.2 (contribution of forest sector to GDP) covers a broader suite of forest related industries that relate to demand drivers for forest management i.e. the addition of value in forestry, the wood industry, and the pulp and paper industry.		GVA is a component part of GDP and reflects to some extent the efficiency of forestry management (a loose proxy). GVA and GDP are influences by the provision of other ESS from forests, such as recreational tourism etc.
Net revenue in forestry	Net revenue of forest enterprise	€		Indicator 6.3 in SoEF, 2015 MS Reporting, SoEF data, ISCC/NACE		The net revenue of forestry is an important indicator of the degree of economic sustainability of forest management and could influence management decisions relating to forests.
Unemployment	Unemployment rates[11]	%	NUTS-2	EUROSTAT		Unclear why this is relevant to the ability of forests to provide services?

[10] Gross value added at basic prices by NUTS 3 regions

[11] Unemployment rates by sex, age and NUTS 2 regions (%)

				http://ec.europa.eu/eurostat/web/regions/data/database		Could relate to the lack of use of forest and therefore forests tending towards a state of natural management or with limited intervention. However unemployment could mean a high degree of mechanisation requiring lower rates of manual labour for a given intensity of forest management
Labour	Labour force in sector A (agriculture, forestry, fishing)[12]	%	NUTS-2	EUROSTAT http://ec.europa.eu/eurostat/web/regions/data/database See also - **Indicator 6.5 (SoEF) Forest sector workforce** *Number of persons employed and labour input in the forest sector, classified by gender and age group, education and job characteristics.*		Possible proxy for the importance of forestry to local quality of life) based on earnings. Care needed in interpreting this indicator, particularly if labour is imported.
Heating oil prices	Heating oil prices	€	Country level	EC, DG-Energy http://ec.europa.eu/energy/en/statistics/weekly-oil-bulletin		Heating oil prices will influence to some extent the rate at which forest harvesting is undertaken in a given area. Consumers with the ability to heat their homes using timber may choose to do so with cheaper timber resources, either gathered from

[12] Employment by age, economic activity and NUTS 2 regions (NACE Rev. 2)

						forests or from commercial energy wood production (split wood, chips and pellets)
Timber	Timber prices	US $	Country level	FAOSTAT http://faostat.fao.org/site/630/Forestry.aspx Note: could be linked to Indicator 6.7 (SoEF) Wood consumption (Per capita consumption of wood and products derived from wood) to provide trend analysis to establish causal relationships. Also Indicator 6.8 Trade (SoEF) (Imports and exports of wood and products derived from wood)		Timber prices will influence to some extent the rate at which forest harvesting is undertaken in a given area. For any given area there will be a tipping point at which the forest becomes economic to extract timber and below which it isn't. Trade will also be an important factor with relationships to paper pulp prices in China for example (a significant destination country for EU timber)
Population density	Population density disaggregated with Corine land cover 2000	Inh/ha	100 m	JRC-EEA http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2#tab-gis-data		This indicator gives an indication of the ability of individuals who might wish to use forests for recreational purposes can do due to proximity. See also travel time to population centres.
Urban-rural	Urban-rural typology	Categories	NUTS-3	EUROSTAT http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban-rural_typology		This indicator classifies the EU regions in three main classes: predominantly urban, intermediate, predominantly rural. It gives information on which are the regions which are potentially major providers of PG/ES from agriculture and forestry
Forest	Proportion of forest	%	NUTS-2	Pulla et al. 2013; EFI (upon request)		Ownership is assumed to be a key

ownership	land in private ownership			http://www.eea.europa.eu/data-and-maps/figures/proportion-of-forest-land-in also - Indicator 6.1 from SoEF, 2015		factor that influences forest land management and protection (Siry et al. 2010).
Travel time to cities	Estimated travel time to the nearest city of 50,000 or more people in year 2000	Hours, days	30 arc seconds (~1 km)	JRC http://forobs.jrc.ec.europa.eu/products/gam/download.php		This indicator gives an indication of the ability of large population centres to access forests for the purpose of recreation. Note: This proxy needs to account also for a large but dispersed rural population that may live within close proximity (or indeed within) the forest; the ability to access forests (i.e. whether they are private or not); and the speed at which travel can be made, such as motorways or not. It would also be interesting to map public transport distances to forests. Whilst forests may be in close proximity to urban centres, lack of public transport may be a significant barrier for many citizens.
Forest undisturbed by man	Areas of forest that have never been harvested or are inaccessible for commercial forestry operations	ha	polygon or NUTS level aggregation	MCPFEE / SoEF		Linked to the above (Travel time) and below (Env protection) indicators. The areas of forest undisturbed by man can indicate a level of naturalness to enable certain ESS to be delivered optimally. However, these inaccessible areas may be difficult to reach by the general public and this have limited potential

						to deliver socio-economic services to society.
Environmental protection	Protected areas – Natura 2000 network of protected sites	Categories	Polygons	EEA http://www.eea.europa.eu/data-and-maps/data/natura-6		This indicator provides an indication of the level of protection placed on forests and thus the potential for that forest to avoid over exploitation or damage, and thus maintain ESS function. Note: care needs to be taken when making causal relationships between a protected forest and its ability to provide ESS, particularly if the protection excludes public access or if the area has been protected due to damage rather than optimal fuction.
Accessibility for recreation	*Area of forest and other wooded land, to which the public has a right of access for recreational purposes, and indication of the intensity of such use*	%	Unclear	Indicator 6.10 of SoEF, 2015		A proxy for the ability of citizens to use forests and therefore benefit from certain ESS.
% of forestry on total employment						Possible proxy for the importance of forestry to local quality of life) based on earnings. Care needed in interpreting this indicator, particularly if labour is imported.
Expenditure for services	Total expenditures for long-term sustainable services from forest	€ by type	NUTS level probably	Indicator 6.4 in SoEF, 2015 MS reporting through SoFE		Indicator 6.4 includes all government expenditures on forest-related activities. Hence, it measures all

						expenditures made by governments for maintaining and increasing the capacity of forests to produce goods and services. Indeed, in the absence of adequate government funding, the benefits that forests can provide can easily decline. The indicator also includes all government revenue collected from the domestic production and trading of forest products and services. This revenue provides the economic incentive for governments to spend on forest-related activities (SoEF, 2015)
Cultural and spiritual values	Number of sites within forest and other wooded land designated as being of cultural or spiritual values	No. Sites		Indicator 6.11 in SoEF, 2015		Direct proxy for the provision of socio economic services.

Data gaps

The main data gaps identified are related with the lack of fine-grained spatially explicit socio-economic data. Most of the variables are available at regional or country level thus posing some methodological limitations for its analysis. This may have implications for the methodology of the analysis tasks of this work package, where gridded information on the provision of PG/ES is to be integrated with regional socio-economic data.

6. References

Alexander, M.E., 2008. Proposed revision of fire danger class criteria for forest and rural areas in New Zealand. Wellington.

Allen, B, Maréchal, A, Nanni, S, Prazan, J, Baldock, D and Hart, K (2015) Data sources to support land suitability assessments for bioenergy feedstocks in the EU - a review. Institute for European Environmental Policy (IEEP), London.

Ayanu, Y. Z., Conrad, C., Nauss, T., Wegmann, M., and Koellner, T. (2012) Quantifying and Mapping Ecosystem Services Supplies and Demands: A Review of Remote Sensing Applications, Environmental Science & Technology, 46, 8529-8541.

Azevedo, J.C., Possacos, A., Aguiar, C.F., Amado, A., Miguel, L., Dias, R., Loureiro, C., Fernandes, P.M., 2013. The role of holm oak edges in the control of disturbance and conservation of plant diversity in fire-prone landscapes. For. Ecol. Manage. 297, 37–48.

Bajocco, S., Ricotta, C., 2008. Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer? Landsc. Ecol. 23, 241–248.

Ball, B., Crichton, I., Horgan, G., 2008. Dynamics of upward and downward N2O and CO2 fluxes in ploughed or no-tilled soils in relation to water-filled pore space, compaction and crop presence. Soil Tillage Res. 101, 20–30.

Ball, B.C., Cameron, K.C., Di, H.J., Moore, S., 2012. Effects of trampling of a wet dairy pasture soil on soil porosity and on mitigation of nitrous oxide emissions by a nitrification inhibitor, dicyandiamide. Soil Use Manag. 28, 194–201.

Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J.-S., Nakashizuka, T., Raffaelli, D., Schmid, B., 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol. Lett. 9, 1146–1156.

Barrios, E., 2007. Soil biota, ecosystem services and land productivity. Ecol. Econ. 64, 269–285.

Beaufoy, G and Cooper, T (2008) The Application of the High Nature Value Indicator. Guidance Document to the Member States. Report for DG Agriculture. European Evaluation Network for Rural Development. http://ec.europa.eu/agriculture/rurdev/eval/hnv/guidance_en.pdf

Beck, H. E., van Dijk, A. I. J. M., Miralles, D. G., de Jeu, R. A. M., Bruijnzeel, L. A., McVicar, T. R., and Schellekens, J. (2013) Global patterns in base flow index and recession based on streamflow observations from 3394 catchments, Water Resources Research, 49, 7843-7863.

Beck, H. E., de Roo, A., and van Dijk, A. I. J. M. (2015).Global Maps of Streamflow Characteristics Based on Observations from Several Thousand Catchments, Journal of Hydrometeorology, 16, 1478-1501.

Bedia, J., Herrera, S., Gutiérrez, J.M., Zavala, G., Urbieta, I.R., Moreno, J.M., 2012. Sensitivity of fire weather index to different reanalysis products in the Iberian Peninsula. Nat. Hazards Earth Syst. Sci. 12, 699–708.

Benayas, J.M.R., Martins, A., Nicolau, J.M., Schulz, J.J., 2007. Abandonment of agricultural land: an overview of drivers and consequences. CAB Rev.:Perspect. Agric. Vet. Sci. Nutr. Nat. Resour. 2, 1–14

Bhandral, R., Saggar, S., Bolan, N., Hedley, M., 2007. Transformation of nitrogen and nitrous oxide emission from grassland soils as affected by compaction. Soil Tillage Res. 94, 482–492.

Borrelli, P., Ballabio, C., Panagos, P., Montanarella, L., 2014. Wind erosion susceptibility of European soils. Geoderma 232-234, 471–478.

Bradford, M.A., Jones, T.H., Bardgett, R.D., Black, H.I.J., Boag, B., Bonkowski, M., Cook, R., Eggers, T., Gange, A.C., Grayston, S.J., Kandeler, E., McCaig, A.E., Newington, J.E., Prosser, J.I., Setälä, H., Staddon, P.L., Tordoff, G.M., Tscherko, D., Lawton, J.H., 2002. Impacts of soil faunal community composition on model grassland ecosystems. Science (80-.). 298, 615–618.

Brevik, E.C., Cerdà, A., Mataix-Solera, J., Pereg, L., Quinton, J.N., Six, J., Van Oost, K., 2015. The interdisciplinary nature of SOIL. Soil 1, 117–129.

Brown, L.C., Foster, G.R., 1987. Storm erosivity using idealized intensity distributions. Trans. ASAE 30, 379–386.

Brus D.J., G. M. Hengeveld, D. J. J. Walvoort, P. W. Goedhart, A. H. Heidema, G. J. Nabuurs, K. Gunia 2012. Statistical mapping of tree species over Europe. Eur J Forest Res (2012) 131:145–157

Burkhard, B., Kandziora, M., Hou, Y., and Müller, F.: Ecosystem Service Potentials, Flows and Demand – Concepts for Spatial Localisation, Indication and Quantification, Landscape Online, 34, 1-32, 2014.

Busetto, L., Barredo, J. I., and San-Miguel-Ayanz, J.: Developing a spatially-explicit pan-European dataset of forest biomass increment, 22nd European Biomass Conference and Exhibition - EU BC&E 2014, Hamburg, 23-26 June 2014, 2014.

Calzolari, C., Ungaro, F., Filippi, N., Guermandi, M., Malucelli, F., Marchi, N., Staffilani, F., Tarocco, P., 2016. A methodological framework to assess the multiple contributions of soils to ecosystem services delivery at regional scale. Geoderma 261, 190–203.

Cane, D., Ciccarelli, N., Gottero, F., Francesetti, A., Pelfini, F., Pelosini, R., 2008. Fire Weather Index application in north-western Italy. Adv. Sci. Res. 2, 77–80.

Carbone, A and Subioli, G (2008) *The generational turnover in agriculture: The ageing dynamics and the EU support policies to young farmers*. Paper prepared for the 109th EAAE Seminar " THE CAP AFTER THE FISCHLER REFORM: NATIONAL IMPLEMENTATIONS, IMPACT ASSESSMENT AND THE AGENDA FOR FUTURE REFORMS". Università della Tuscia, Viterbo, Italy.

Cardinale, B.J., Harvey, C.T., Gross, K., Ives, A.R., 2003. Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. Ecol. Lett. 6, 857–865.

Carvalho, A., Flannigan, M.D., Logan, K., Miranda, A.I., Borrego, C., 2008. Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System. Int. J. Wildl. Fire 17, 328–338.

Cauvin, C., Escobar, F., and Serradj, A.: Thematic Cartography and Transformations, John Wiley & Sons, Inc., London, 450 pp., 2013.

Ceulemans, T, Stevens, C J, Duchateau, L, Jacquemyn, H, Gowing, D J G, Merckx, R, Wallace, H, van Rooijen, N, Goethem, T, Bobbink, R, Dorland, E, Gaudnik, C, Alard, D, Corcket, E, Muller, S, Dise, N B, Duprè, C, Diekmann, M and Honnay, O (2014) Soil phosphorus constrains biodiversity across European grasslands. Global Change Biology No 20 (12), pp3814-3822.

Chave J, Coomes DA, Jansen S, Lewis SL, Swenson NG, Zanne AE (2009) Towards a worldwide wood economics spectrum. Ecology Letters 12(4): 351-366

Civantos E, Thuiller W, Maiorano L, Guisan A, Araujo MB (2012) Potential impacts of climate change on ecosystem services in Europe: the case of pest control by vertebrates. BioScience 62: 658-666. doi: 10.1525/bio.2012.62.7.8

Cooper, T, Arblaster, K, Baldock, D and Beaufoy, G (2007) Guidance document to the Member States on the application of the HNV impact indicator. Institute for European Environmental Policy, London.

Cooper, T, Hart, K and Baldock, D (2009) The Provision of Public Goods Through Agriculture in the European Union . Report prepared for DG Agriculture and Rural Development, Contract No 30-CE-0233091/00-28. Institute for European Environmental Policy, London.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., and Turner, R. K.: Changes in the global value of ecosystem services, Global Environmental Change, 26, 152-158, 2014.

Coulouma, G., Boizard, H., Trotoux, G., Lagacherie, P., Richard, G., 2006. Effect of deep tillage for vineyard establishment on soil structure: a case study in Southern France. Soil Tillage Res. 88, 132–143.

Cornes, R and Sandler, T (1996) The Theory of Externalities, Public Goods and Club Goods. 2nd edition edition, Cambridge University Press, Cambridge.

Crossman, N. D., Burkhard, B., and Nedkov, S.: Quantifying and mapping ecosystem services, International Journal of Biodiversity Science, Ecosystem Services & Management, 8, 1-4, 2012.

Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., et al.: A blueprint for mapping and modelling ecosystem services, Ecosystem Services, 4, 4-14, 2013.

Dänhardt, J, Green, M, Lindström, Å, Rundlöf, M and Smith, H G (2010) Farmland as stopover habitat for migrating birds - effects of organic farming and landscape structure. Oikos No 119 (7), pp1114-1125.

De Frutos, A, Olea, P P and Mateo-Tomás, P (2015) Responses of medium- and large-sized bird diversity to irrigation in dry cereal agroecosystems across spatial scales. Agriculture, Ecosystems & Environment No 207, pp141-152.

de Roo, A., Bouraoui, F., Burek, P., Bisselink, B., Vandecasteele, I., Mubareka, S., et al.: Current water resources in Europe and Africa Matching water supply and water demand, European Commission - Joint Research Centre, Luxembourg, 41, 2012.

Díaz, S., Fargione, J., Chapin, F.S., Tilman, D., 2006. Biodiversity loss threatens human well-being. PLoS Biol. 4, 1300–1305.

Dimitrakopoulos, A.P., Bemmerzouk, A.M., Mitsopoulos, I.D., 2011. Evaluation of the Canadian fire weather index system in an eastern Mediterranean environment. Meteorol. Appl. 18, 83–93.

Dinis, I, Ortolani, L, Bocci, R and Brites, C (2015) Organic agriculture values and practices in Portugal and Italy. Agricultural Systems No 136, pp39-45.

Dise, N B (2011) Nitrogen as a threat to European terrestrial diversity, in M A Sutton, C M Howard, J W Erisman, G Billen, A Bleeker, P Grennfelt, H van Grinsven, & B Grizzetti (eds) The European Nitrogen Assessment, Chapter 20. Cambridge University Press, Cambridge. http://www.nine-esf.org/sites/nine-esf.org/files/ena_doc/ENA_pdfs/ENA_c20.pdf

Diodato, N., 2014. Spatial pattern probabilities exceeding critical treshold of annual mean storm-erosivity in Euro-Mediterranean areas, in: Diodato, N., Bellocchi, G. (Eds.), Storminess and Environmental Change. Springer, Dordrecht, pp. 79–99.

Diodato, N., Bellocchi, G., 2010. MedREM, a rainfall erosivity model for the Mediterranean region. J. Hydrol. 387, 119–127.

Dominati, E., Patterson, M., Mackay, A., 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecol. Econ. 69, 1858–1868.

Donald, P F, Evans, A D, Muirhead, L B, Buckingham, D L, Kirby, W B and Schmitt, S I A (2002) Survival rates, causes of failure and productivity of Skylark Alauda arvensis nests on lowland farmland. Ibis No 144 (4), pp652-664.

Dosio, A., Paruolo, P., 2011. Bias correction of the ENSEMBLES high-resolution climate change projections for use by impact models: evaluation on the present climate. J. Geophys. Res. 116, D16106.

Dosio, A., Paruolo, P., Rojas, R., 2012. Bias correction of the ENSEMBLES high resolution climate change projections for use by impact models: analysis of the climate change signal. J. Geophys. Res. 117, D17110.

Duncker, P. S., Barreiro, S. M., Hengeveld, G. M., Lind, T., Mason, W. L., Ambrozy, S., and Spiecker, H.: Classification of Forest Management Approaches: A New Conceptual Framework and Its Applicability to European Forestry, Ecology and Society, 17, 2012.

Durrant, T., San-Miguel-Ayanz, J., Schulte, E., and Suarez Meyer, A.: Evaluation of BioSoil Demonstration Project: FOREST BIODIVERSITY - Analysis of Biodiversity module, European Commission - Joint Research Centre, Luxembourg, 138, 2011.

Dwyer, J, Short, C, Berriet-Solliec, M, Gael-Lataste, F, Pham, H-V, Affleck, M, Courtney, P and Déprès, C (2015) Public goods and ecosystem services from agriculture and forestry - a conceptual approach. PEGASUS Deliverable 1.1. PEGASUS project consortium.

Egoh, B., Drakou, E. G., Dunbar, M. B., Maes, J., and Willemen, L., 2012. Indicators for mapping ecosystem services: a review, European Commission - Joint Research Centre, Luxembourg.

Eigenbrod, F., Armsworth, P. R., Anderson, B. J., Heinemeyer, A., Gillings, S., Roy, D. B., Thomas, C. D., and Gaston, K. J.: The impact of proxy-based methods on mapping the distribution of ecosystem services, Journal of Applied Ecology, 47, 377-385, 2010.

ENRD (2010) Public Goods and Public Intervention. A Pan European overview of how Member States approach the delivery of Environmental and Social Public Goods through the 2007-2013 Rural Development Programmes. Final report for the Thematic Working Group 3 on Public Goods and Public Intervention. European Network for Rural Development.

Erbrink, H., Hofschreuder, P., Jansen, S., Kuypers, V.H.M., Maerschalck, B. de, Ruyten, F., Vries, E.A. de, Wolff, J. de. (2009) Flora - Vegetation for a better air quality. Rijkswaterstaat Dienst Verkeer en Scheepvaart, Delft, Rapportnummer DVS-2009-013. (In Dutch).

European Commission: COM(2013) 659 final: A new EU Forest Strategy: for forests and the forest-based sector, European Commission, 2013.

European Commission (2014) Farming for Natura 2000. Guidance on how to integrate Natura 2000 conservation objectives into farming practices based on Member States good practice experiences. Guidance and annexes. European Commission, Brussels. http://ec.europa.eu/environment/nature/natura2000/management/docs/FARMING%20FOR%20NATURA%202000-final%20guidance.pdf

European Environment Agency (2010). Assessing biodiversity in Europe — the 2010 report. EEA Report 5/2010. Luxembourg: Office for Official Publications of the European Union

European Environment Agency (2014). Spatial analysis of green infrastructure in Europe. Luxembourg.

European Environment Agency (2015) Technical Report n. 2/2015. State of nature in the EU Results from reporting under the nature directives 2007–2012. Luxembourg: Publications Office of the European Union. ISBN 978-92-9213-586-7. ISSN 1725-2237. doi:10.2800/603862. Available at: http://www.eea.europa.eu/publications/state-of-nature-in-the-eu

European network for Rural Development - ENRD (2010) Thematic Working Group 3 Public Goods and Public Intervention. Final Report, December 2010. Available at: http://enrd.ec.europa.eu/app_templates/filedownload.cfm?id=260BDAAE-0BDA-C671-41E7-31CED794278A

Farkas, C., Beldring, S., Bechmann, M., Deelstra, J., 2013. Soil erosion and phosphorus losses under variable land use as simulated by the INCA-P model. Soil Use Manag. 29, 124–137.

Fernandes, P.M., 2009. Combining forest structure data and fuel modelling to classify fire hazard in Portugal. Ann. For. Sci. 66, 415.

Fernandes, P.M., 2013. Fire-smart management of forest landscapes in the Mediterranean basin under global change. Landsc. Urban Plan. 110, 175–182.

Fernandes, P.M., Luz, A., Loureiro, C., 2010. Changes in wildfire severity from maritime pine woodland to contiguous forest types in the mountains of northwestern Portugal. For. Ecol. Manage. 260, 883–892.

Fischer, C, Flohre, A, Clement, L W, Batáry, P, Weisser, W W, Tscharntke, T and Thies, C (2011) Mixed effects of landscape structure and farming practice on bird diversity. Agriculture Ecosystems and Environment No 141 (1-2), pp119-125.

Fitzsimons, J., Russell-Smith, J., James, G., Vigilante, T., Lipsett-Moore, G., Morrison, J., Looker, M., 2012. Insights into the biodiversity and social benchmarking components of the Northern Australian fire management and carbon abatement programmes. Ecol. Manag. Restor. 13, 51–57.

FOREST EUROPE, 2015: State of Europe’s Forests 2015. Ministerial Conference on the Protection of Forests in Europe, FOREST EUROPE Liaison Unit Madrid.

Fréjaville, T., Curt, T., 2015. Spatiotemporal patterns of changes in fire regime and climate: defining the pyroclimates of south-eastern France (Mediterranean Basin). Clim. Change.

Gabriel, D, Sait, S M, Hodgson, J A, Schmutz, U, Kunin, W E and Benton, T G (2010) Scale matters: the impact of organic farming on biodiversity at different spatial scales. Ecology Letters No 13 (7), pp858-869.

Gallaun, H., G Zanchi , GJ Nabuurs, G Hengeveld, M Schardt, PJ. Verkerk. 2010 EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements. Forest Ecology and Management 260 (2010) 252–261

García-Ruiz, J.M., 2010. The effects of land uses on soil erosion in Spain: a review. Catena 81, 1–11.

García-Ruiz, J.M., Lana-Renault, N., 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region – A review. Agric. Ecosyst. Environ. 140, 317–338.

Gamfeldt, L., Snall, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., et al.: Higher levels of multiple ecosystem services are found in forests with more tree species, Nature Communications, 4, 1-8, 2013.

Gaston, K. J.: Biodiversity: A Biology of Numbers and Difference, Blackwell Science, Oxford, 1996.

Guerra, C.A., Pinto-Correia, T., Metzger, M.J., 2014. Mapping soil erosion prevention using an ecosystem service modeling framework for integrated land management and policy. Ecosystems 17, 878–889.

Guiomar, N., Godinho, S., Fernandes, P.M., Machado, R., Neves, N., Fernandes, J.P., 2015. Wildfire patterns and landscape changes in Mediterranean oak woodlands. Sci. Total Environ. 536, 338–352.

Günther, A., Hervás, J., van den Eeckhaut, M., Malet, J.-P., Reichenbach, P., 2014a. Synoptic pan-European landslide susceptibility assessment: the ELSUS 1000 v1 map, in: Sassa, K., Canuti, P., Yin, Y. (Eds.), Landslide Science for a Safer Geoenvironment, Vol. 1. Springer, Cham, pp. 117–122.

Günther, A., van den Eeckhaut, M., Malet, J.-P., Reichenbach, P., Hervás, J., 2014b. Climate-physiographically differentiated pan-European landslide susceptibility assessment using spatial multi-criteria evaluation and transnational landslide information. Geomorphology 224, 69–85.

Halada, L., Evans, D., Romão, C., & Petersen, J.E. (2011). Which habitats of european importance depend on agricultural practices? Biodiversity and Conservation, 20(11), 2365-2378

Hamza, M.A., Anderson, W.K., 2005. Soil compaction in cropping systems. Soil Tillage Res. 82, 121–145.

Hansen, S., Mæhlum, J.E., Bakken, L.R., 1993. N2O and CH4 fluxes in soil influenced by fertilization and tractor traffic. Soil Biol. Biochem. 25, 621–630.

Hart, K, Allen, B, Lindner, M, Keenleyside, C, Burgess, P J, Eggers, J and Buckwell, A (2013) Land as an environmental resource. Report prepared for DG Environment, Contract No ENV.B.1/ETU/2011/0029. Institute for European Environmental Policy, London.

Hector, A., Beale, A.J., Minns, A., Otway, S.J., Lawton, J.H., 2000. Consequences of the reduction of plant diversity for litter decomposition: effects through litter quality and microenvironment. Oikos 90, 357–371.

Helsen, K, Ceulemans, T, Stevens, C J and Honnay, O (2014) Increasing soil nutrient loads of European semi-natural grasslands strongly alter plant functional diversity independently of species loss. Ecosystems No 17 (1), pp169-181.

Hengeveld, G. M., Nabuurs, G.-J., Didion, M., van den Wyngaert, I., Clerkx, A. P. P. M., and Schelhaas, M.-J.: A Forest Management Map of European Forests, Ecology and Society, 17, 2012.

Hiltbrunner, D., Schulze, S., Hagedorn, F., Schmidt, M.W.I., Zimmmermann, S., 2012. Cattle trampling alters soil properties and changes soil microbial communities in a Swiss sub-alpine pasture. Geoderma 170, 369–377.

Hooper, D.U., Chapin III, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setãlã, H., Symstad, A.J., Vandermeer, J., Wardle, D.A., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol. Monogr. 75, 3–35.

Huber, S., Prokop, G., Arrouays, D., Banko, G., Bispo, A., Jones, R.J.A., Kibblewhite, M.G., Lexer, W., Möller, A., Rickson, R.J., Shishkov, T., Stephens, M., Toth, G., van den Akker, J.J.H., Varallyay, G., Verheijen, F.G.A., Jones, A.R., 2008. Environmental assessment of soil for monitoring. Volume I: indicators & criteria. Ispra.

Hultén, E., and Fries, M.: Atlas of north European vascular plants north of the Tropic of Cancer, Koeltz Scientific Books, Königstein, Germany, 1986.

Jalas, J., and Suominen, J.: Atlas Florae Europaeae, The Committee for Mapping the Flora of Europe and Societas Biologica Fennica, Helsinki, Finland, 1972-1994.

Jalas, J., Suominen, J., and Lampinen, R.: Atlas Florae Europaeae, The Committee for Mapping the Flora of Europe and Societas Biologica Fennica, Helsinki, Finland, 1996.

Jalas, J., Suominen, J., Lampinen, R., and Kurtto, A.: Atlas Florae Europaeae, The Committee for Mapping the Flora of Europe and Societas Biologica Fennica, Helsinki, Finland, 1999.

Jetz, W., Kreft, H., Ceballos, G., and Mutke, J.: Global associations between terrestrial producer and vertebrate consumer diversity, Proceedings of the Royal Society of London B: Biological Sciences, 276, 269-278, 2009.

Jim, C.Y. and Chen, W.Y., 2008. Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China), Journal of Environmental Management 88, 665–676

Jones, A., Panagos, P., Barcelo, S., Bouraoui, F., Bosco, C., Dewitte, O., Gardi, C., Erhard, M., Hervás, J., Hiederer, R., Jeffery, S., Lükewille, A., Marmo, L., Montanarella, L., Olazábal, C., Petersen, J.-E., Penizek, V., Strassburger, T., Tóth, G., van den Eeckhaut, M., van Liedekerke, M., Verheijen, F., Viestova, E., Yigini, Y., 2012. The state of soil in Europe. A contribution of the JRC to the European Environment Agency's Environment State and Outlook Report–SOER 2010. Ispra.

Jones, R.J.A., Hiederer, R., Rusco, E., Montanarella, L., 2005. Estimating organic carbon in the soils of Europe for policy support. Eur. J. Soil Sci. 56, 655–671.

JRC: Global Land Cover 2000 database, 2003.

JRC: The Biomass Compartment Database of the GHG-AFOLU project of the European Commission, 2009.

Jung, M., Reichstein, M., Margolis, H. A., Cescatti, A., Richardson, A. D., Arain, M. A., et al.: Global patterns of land-atmosphere fluxes of carbon dioxide, latent heat, and sensible heat derived from eddy covariance, satellite, and meteorological observations, Journal of Geophysical Research: Biogeosciences, 116, G00J07, 2011.

Kalwij, J. M., Robertson, M. P., Ronk, A., Zobel, M., and Pärtel, M.: Spatially-Explicit Estimation of Geographical Representation in Large-Scale Species Distribution Datasets, PLoS ONE, 9, e85306, 2014.

Keenleyside, C, Beaufoy, G, Tucker, G M and Jones, G (2014) High Nature Value farming throughout EU-27 and its financial support under the CAP. Final report and annexes. Report prepared for DG Environment, Contract No ENV B.1/ETU/2012/0035. Institute for European Environmental Policy &

European Forum on Nature Conservation and Pastoralism, London. http://www.ieep.eu/work-areas/agriculture-and-land-management/public-goods-and-agriculture/2014/05/high-nature-value-farming-throughout-eu-27-and-its-financial-support-under-the-cap

Kempen, M., Heckelei, T., Britz, W., 2006. An econometric approach for spatial dis-aggregation of crop production in the EU. In: Arfini (Ed.), Modelling AgriculturalPolicies: State of the Art and New Challenges. Proceedings of the 89th Seminar of the EAAE, pp. 810–830.

Kier, G., Kreft, H., Lee, T. M., Jetz, W., Ibisch, P. L., Nowicki, C., Mutke, J., and Barthlott, W.: A global assessment of endemism and species richness across island and mainland regions, Proceedings of the National Academy of Sciences, 106, 9322-9327, 2009.

Kirkby, M.J., Irvine, B.J., Jones, R.J.A., Govers, G., 2008. The PESERA coarse scale erosion model for Europe. I. - Model rationale and implementation. Eur. J. Soil Sci. 59, 1293–1306.

Kovács-Hostyánszki, A, Batáry, P, Báldi, A and Harnos, A (2011) Interaction of local and landscape features in the conservation of Hungarian arable weed diversity. Applied Vegetation Science No 14 (1), pp40-48.

Kraak, M. J., and Ormeling, F. J.: Cartography, the Visualization of Spatial Data, Addison Wesley Longman, London, 222 pp., 1996.

Kremen C, Williams NM, Aizen MA, et al. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecol Lett 10: 299–314.

Kurtto, A., Lampinen, R., and Junikka, L.: Atlas Florae Europaeae, The Committee for Mapping the Flora of Europe and Societas Biologica Fennica, Helsinki, Findland, 2004.

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P., Rossi, J.-P., 2006. Soil invertebrates and ecosystem services. Eur. J. Soil Biol. 42, S3–S15.

Lee, C., Schlemme, C., Murray, J., Unsworth, R., 2015. The cost of climate change: ecosystem services and wildland fires. Ecol. Econ. 116, 261–269.

Leip, A, Billen, G, Garnier, J, Grizzetti, B, Lassaletta, L, Reis, S, Simpson, D, Sutton, M A, de Vries, W, Weiss, F and Westhoek, H (2015) Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environmental Research Letters No 10 (11), 115004-http://iopscience.iop.org/1748-9326/10/11/115004.

Levers, C., Verkerk, P. J., Müller, D., Verburg, P. H., Butsic, V., Leitão, P. J., Lindner, M., and Kuemmerle, T.: Drivers of forest harvesting intensity patterns in Europe, Forest Ecology and Management, 315, 160-172, 2014.

Lipiec, J., Hatano, R., 2003. Quantification of compaction effects on soil physical properties and crop growth. Geoderma 116, 107–136.

Liquete, C., Kleeschulte, S., Dige, G., Maes, J., Grizzetti, B., Olah, B., Zulian, G., 2015. Mapping green infrastructure based on ecosystem services and ecological networks: a Pan-European case study. Environ. Sci. Policy 54, 268–280.

Lonsdorf E, Kremen C, Ricketts T, Winfree R, Williams N, Greenleaf S. Modelling pollination services across agricultural landscapes. Ann. Bot. 2009, 103, 1589–1600

Mace, G.M., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends Ecol. Evol. 27, 19–26.

MAES: Mapping and Assessment of Ecosystems and their Services - An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020, Publications office of the European Union, Luxembourg, Technical Report - 2013 - 067, 57, 2013.

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., et al.: Mapping ecosystem services for policy support and decision making in the European Union, Ecosystem Services, 1, 31-39, 2012.

Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Ivits, E., Polce, C., Vandecasteele, I., Marí, I., Guerra, C., Castillo, C.P., Vallecillo, S., Baranzelli, C., Barranco, R., Batista, F., Trombetti, M., Lavalle, C., 2015. Mapping and assessment of ecosystems and their services. Trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. Ispra.

Maes, J., Teller, A., Erhard, M., Murphy, P., Paracchini, M.L., Barredo, J.I., Grizzetti, B., Cardoso, A., Somma, F., Petersen, J.-E., Meiner, A., Gelabert, E.R., Zal, N., Kristensen, P., Bastrup-Birk, A., Biala, K., Romao, C., Piroddi, C., Egoh, B., Fiorina, C., Santos, F., Naruševičius, V., Verboven, J., Pereira, H., Bengtsson, J., Kremena, G., Marta-Pedroso, C., Snäll, T., Estreguil, C., San Miguel, J., Braat, L., Grêt-Regamey, A., Perez-Soba, M., Degeorges, P., Beaufaron, G., Lillebø, A., Malak, D.A., Liquete, C., Condé, S., Moen, J., Östergård, H., Czúcz, B., Drakou, E.G., Zulian, G., Lavalle, C., 2014. Mapping and assessment of ecosystems and their services. Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Publications office of the European Union, Luxembourg.

Maes , J , Hauck , J , Paracchini, M L , Ratamäki, O , Termansen , M , Perez-Soba , M , Kopperoinen , L , Rankinen , K , Schägner , J P , Henrys , P , Cisowska , I , Zandersen , M , Jax , K , La Notte , A , Leikola, N , Pouta , E , Smart , S , Hasler , B , Lankia , T , Andersen , H E , Lavalle , C , Vermaas , T , Alemu , M H , Scholefield , P , Batista , F , Pywell , R , Hutchins , M , Blemmer , M , Fonnesbech-Wulff , A , Vanbergen , A , Münier , B , Baranzelli , C , Roy , D , Thieu , V , Zulian , G , Kuussaari , M , Thodsen , H , Alanen , E-L , Egoh , B , Sørensen , P B , Braat , L & Bidoglio , G 2012 , A spatial assessment of ecosystem services in Europe - Phase II : Methods, case studies and policy analysis & Synthesis Report . European Commission, Joint Research Centre . PEER Report , no. 4 .

Maes J., Paracchini M.L., Zulian G., 2011. A European assessment of the provision of ecosystem services. EUR 24750 EN, Publication Office of the European Union, Luxembourg.

Martínez-Harms, M. J., and Balvanera, P., 2012. Methods for mapping ecosystem service supply: a review, International Journal of Biodiversity Science, Ecosystem Services & Management, 8, 17-25.

Masante D., Rega C., Cottam A., Dubois G., Paracchini M.L. (2015). Indicators of biodiversity in agroecosystems: insights from Article 17 of the Habitat Directive and IUCN Red List of Threatened Species. JRC Technical Report EUR 27536 EN. European Union.

McBratney, A., Field, D.J., Koch, A., 2014. The dimensions of soil security. Geoderma 213, 203–213.

Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mücher, C.A., 2005. A climatic stratification of the environment of Europe. Glob. Ecol. Biogeogr. 14, 549–563.

Moreira, F., Vaz, P., Catry, F.X., Silva, J.S., 2009. Regional variations in wildfire susceptibility of land-cover types in Portugal: implications for landscape management to minimize fire hazard. Int. J. Wildl. Fire 18, 563–574.

Moreno, M.V., Chuvieco, E., 2013. Characterising fire regimes in Spain from fire statistics. Int. J. Wildl. Fire 22, 296–305.

Morvan, X., Naisse, C., Malam Issa, O., Desprats, J.F., Combaud, A., Cerdan, O., 2014. Effect of ground-cover type on surface runoff and subsequent soil erosion in Champagne vineyards in France. Soil Use Manag. 30, 372–381.

Mossadeghi-Björklund, M., Arvidsson, J., Keller, T., Koestel, J., Lamandé, M., Larsbo, M., Jarvis, N., 2016. Effects of subsoil compaction on hydraulic properties and preferential flow in a Swedish clay soil. Soil Tillage Res. 156, 91–98.

Mouchet M., Lavorel S., Maes J., Paracchini M.L., Plutzar C., Schulp C.J.E., Stuerck J., Verburg P., Verkerk H., Zulian G. (2014). Spatially explicit assessment of current ecosystem service supply for Europe - Deliverable 8.2, Volante Project. Available at http://www.volante-project.eu/images/stories/DELIVERABLES/VOLANTE_D8.2_Spatially_explicit_assessment_of_current_ecosystem_service_supply_for_Europe.pdf

Mutke, J., and Barthlott, W.: Patterns of vascular plant diversity at continental to global scales, in: Plant diversity and complexity patterns - Local, regional and global dimensions. Proceedings of an International Symposium held at the Royal Danish Academy of Sciences and Letters in Copenhagen, Denmark, 25-28 May, 2003, edited by: Friis, I., and Balslev, H., Royal Danish Academy of Sciences and Letters, Copenhagen, Denmark, 521-537 2005.

Nabuurs, G.J., Pussinen, A., van Brusselen, J., Schelhaas, M.J. 2007. Future harvesting pressure on European forests. European Journal of Forest Research 126(3): 391-400

Naeem, S., Wright, J.P., 2003. Disentangling biodiversity effects on ecosystem functioning: deriving solutions to a seemingly insurmountable problem. Ecol. Lett. 6, 567–579.

Nielsen, U.N., Wall, D.H., Six, J., 2015. Soil biodiversity and the environment. Annu. Rev. Environ. Resour. 40, 63–90.

Nowak, D.J., Hoehn, R., Hirabayashi, S., Bodine, A., 2013. Modeled PM 2.5 removal by trees in ten U.S. cities and associated health effects. Environmental Pollution, 2013, Vol.178, pp.395-402

Nowak , D.J. ; Crane , D.E. ; Stevens , J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. Urban forestry & urban greening, 2006, Vol.4(3), pp.115-123

Nowak, D.J, Civerolo, K.L, Trivikrama Rao, S., Sistla, G. Luley, C.J.,Crane, D.E., 2000. A modeling study of the impact of urban trees on ozone. Atmospheric Environment, 2000, Vol.34(10), pp.1601-1613

Nunes, A.N., de Almeida, A.C., Coelho, C.O.A., 2011. Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Appl. Geogr. 31, 687–699.

Oeckinger, E, Hammarstedt, O, Nilsson, S G and Smith, H G (2006) The relationship between local extinctions of grassland butterflies and increased soil nitrogen levels. Biological Conservation No 128 (4), pp564-573.

Oppermann, R, Beaufoy, G and Jones, G (eds) (2012) High Nature Value Farming in Europe. 35 European Countries - Experiences and Perspectives. verlag regionalkultur, Ubstadt-Weiher.

Orgiazzi, A., Panagos, P., Yigini, Y., Dunbar, M.B., Gardi, C., Montanarella, L., Ballabio, C., 2015. A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity. Sci. Total Environ. 545-546, 11–20.

Ostrom, E (1990) Governing the Commons: The Evolution of Institutions for Collective Action. Political Economy of Institutions and Decisions, Cambridge University Press, Cambridge.

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva, S., Tadić, M.P., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Beguería, S., Alewell, C., 2015a. Rainfall erosivity in Europe. Sci. Total Environ. 511, 801–814.

Panagos, P., Borrelli, P., Meusburger, K., 2015b. A new european slope length and steepness factor (LS-factor) for modeling soil erosion by water. Geosciences 5, 117–126.

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., Montanarella, L., 2015c. Estimating the soil erosion cover-management factor at the European scale. Land use policy 48, 38–50.

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J., Alewell, C., 2015d. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environ. Sci. Policy 51, 23–34.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015e. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 54, 438–447.

Panagos, P., Hiederer, R., van Liedekerke, M., Bampa, F., 2013. Estimating soil organic carbon in Europe based on data collected through an European network. Ecol. Indic. 24, 439–450.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C., 2014. Soil erodibility in Europe: a high-resolution dataset based on LUCAS. Sci. Total Environ. 479-480, 189–200.

Panagos, P., van Liedekerke, M., Jones, A., Montanarella, L., 2012. European Soil Data Centre: response to European policy support and public data requirements. Land use policy 29, 329–338.

Paracchini ML, Correia TP, Loupa-Ramos I, Capitani C, Madeira L. (2015) Progress in indicators to assess agricultural landscape valuation: How and what is measured at different levels of governance. Land Use Policy doi:10.1016/j.landusepol.2015.05.025

Paracchini, M.L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J.P., Termansen, M., Zandersen, M., Perez-Soba, M., Scholefield, P.A., Bidoglio, G. (2014). Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. Ecological Indicators, 45, 371-385

Paracchini M.L., Capitani C., Schmidt A.M., Andersen E., Wascher D.M., Jones P.J., Simoncini R., Carvalho Ribeiro S., Griffiths G.H., Mortimer S.R., Madeira L., Loupa Ramos I. and T. Pinto Correia (2012). Measuring societal awareness of the rural agrarian landscape: indicators and scale issues. EUR Report 25192 EN, Luxembourg: Publications Office of the European Union, 130 pp.

Paracchini ML, Capitani C (2011). Implementation of a EU wide indicator for the rural-agrarian landscape. EUR 25114 EN, Luxembourg: Publications Office of the European Union, p. 89. Available at http://agrienv.jrc.ec.europa.eu/publications/pdfs/EUR_25114.pdf.

Paracchini, M L, Petersen, J-E, Hoogeveen, Y, Bamps, C, Burfield, I and van Swaay, C (2008) High Nature Value Farmland in Europe - An Estimate of the Distribution Patterns on the Basis of Land Cover and Biodiversity Data. JCR Scientific and Technical Reports EUR 23480 EN. Office for Official Publications of the European Union, Luxembourg. http://agrienv.jrc.ec.europa.eu/publications/pdfs/HNV_Final_Report.pdf

Pascual, U., Termansen, M., Hedlund, K., Brussaard, L., Faber, J.H., Foudi, S., Lemanceau, P., Jørgensen, S.L., 2015. On the value of soil biodiversity and ecosystem services. Ecosyst. Serv. 15, 11–18.

Pausas, J.G., Keeley, J.E., 2014. Abrupt climate-independent fire regime changes. Ecosystems 17, 1109–1120.

Perez-Soba, M, Elbersen, B, Kempen, M, Braat, L, Staristky, I, Van der Wijngaart, R, Kaphengst, T, Andersen, E, Germer, L, Smith, L, Rega, C and Paracchini, M L (2015) Agricultural biomass as provisioning ecosystem service: quantification of energy flows. JRC Institute for Environment and Sustainability. Publications Office of the European Union, Luxembourg. http://publications.jrc.ec.europa.eu/repository/handle/JRC97764

Perfecto, I., Vandermeer, J.H., Bautista, G.L., Nunez, G.I., Greenberg, R., Bichier, P., et al. (2004). Greater predation in shaded coffee farms: the role of resident neotropical birds. Ecology, 85, 2677–2681.

Picchio, R., Neri, F., Petrini, E., Verani, S., Marchi, E., Certini, G., 2012. Machinery-induced soil compaction in thinning two pine stands in central Italy. For. Ecol. Manage. 285, 38–43.

Polge de Combret-Champart, L., Guilpart, N., Mérot, A., Capillon, A., Gary, C., 2013. Determinants of the degradation of soil structure in vineyards with a view to conversion to organic farming. Soil Use Manag. 29, 557–566.

Pulleman, M., Creamer, R., Hamer, U., Helder, J., Pelosi, C., Pérès, G., Rutgers, M., 2012. Soil biodiversity, biological indicators and soil ecosystem services—an overview of European approaches. Curr. Opin. Environ. Sustain. 4, 529–538.

Qian, H., and Ricklefs, R. E.: Global concordance in diversity patterns of vascular plants and terrestrial vertebrates, Ecology Letters, 11, 547-553, 2008.

Rainha, M., Fernandes, P.M., 2002. Using the Canadian Fire Weather Index (FWI) in the Natural Park of Montesinho, NE Portugal: calibration and application to fire management, in: Viegas, D.X. (Ed.), Forest Fire Research & Wildland Fire Safety. Millpress, Rotterdam, pp. 1–6.

Renard, K.G., Foster, G.R., Weesies, D.K., McCool, D.K., Yoder, D.C., 1997. Predicting soil erosion by water: a guide to conservation planning with the revised Universal Soil Loss Equation (RUSLE). Washington DC.

Rist, L., Moen, J., 2013. Sustainability in forest management and a new role for resilience thinking. For. Ecol. Manage. 310, 416–427.

Rodrigues, M., Miguel, J.S., Oliveira, S., Moreira, F., Camia, A., 2013. An insight into spatial-temporal trends of fire ignitions and burned areas in the European Mediterranean countries. J. Earth Sci. Eng. 3, 497–505.

Rusco, E., Jones, R., Bidoglio, G., 2001. Organic matter in the soils of Europe: present status and future trends. Ispra.

San-Miguel-Ayanz, J., Pereira, J.M.C., Boca, R., Strobl, P., Kucera, J., Pekkarinen, A., 2009. Forest fires in the European Mediterranean region: mapping and analysis of burned areas, in: Chuvieco, E. (Ed.), Earth Observation of Wildland Fires in Mediterranean Ecosystems. Springer, Berlin, Heidelberg, pp. 189–203.

San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., Strob, P., Liberta, G., Giovando, C., Boca, R., Sedano, F., Kempeneers, P., McInerney, D., Withmore, C., Oliveira, S.S., Rodrigues, M., Durrant, T., Corti, P., Oehler, F., Vilar, L., Amatulli, G., 2012. Comprehensive monitoring of wildfires in Europe: the European Forest Fire Information System (EFFIS), in: Tiefenbacher, J. (Ed.), Approaches to Managing Disaster - Assessing Hazards, Emergencies and Disaster Impacts. InTech, pp. 87–108San-Miguel-Ayanz, J., Moreno, J.M., Camia, A., 2013a. Analysis of large fires in European Mediterranean landscapes: lessons learned and perspectives. For. Ecol. Manage. 294, 11–22.

San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., 2013b. The European Forest Fire Information System in the context of environmental policies of the European Union. For. Policy Econ. 29, 19–25.

Santana, V.M., Alday, J.G., Baeza, M.J., 2014. Effects of fire regime shift in Mediterranean Basin ecosystems: changes in soil seed bank composition among functional types. Plant Ecol. 215, 555–566.

Santoro, M., Beaudoin, A., Beer, C., Cartus, O., Fransson, J. E. S., Hall, R. J., et al. (2015). Forest growing stock volume of the northern hemisphere: Spatially explicit estimates for 2010 derived from Envisat ASAR, Remote Sensing of Environment, 168, 316-334.

Santoro, M., Beer, C., Cartus, O., Schmullius, C., Shvidenko, A., McCallum, I., Wegmüller, U., and Wiesmann, A. (2011). Retrieval of growing stock volume in boreal forest using hyper-temporal series of Envisat ASAR ScanSAR backscatter measurements, Remote Sensing of Environment, 115, 490-507.

Santoro, M., Cartus, O., Fransson, J., Shvidenko, A., McCallum, I., Hall, R., Beaudoin, A., Beer, C., and Schmullius, C. (2013). Estimates of Forest Growing Stock Volume for Sweden, Central Siberia, and Québec Using Envisat Advanced Synthetic Aperture Radar Backscatter Data, Remote Sensing, 5, 4503.

Schägner, J. P., Brander, L., Maes, J., and Hartje, V.: Mapping ecosystem services' values: Current practice and future prospects, Ecosystem Services, 4, 33-46, 2013.

Schmitzberger, I, Wrbka, T, Steurer, B, Aschenbrenner, G, Peterseil, J and Zechmeister, H G (2005) How farming styles influence biodiversity maintenance in Austrian agricultural landscapes. Agriculture, Ecosystems & Environment No 108 (3), pp274-29

Schwen, A., Hernandez-Ramirez, G., Lawrence-Smith, E.J., Sinton, S.M., Carrick, S., Clothier, B.E., Buchan, G.D., Loiskandl, W., 2011. Hydraulic properties and the water-conducting porosity as affected by subsurface compaction using tension infiltrometers. Soil Sci. Soc. Am. J. 75, 822–832.

Sedano, F., Kempeneers, P., San-Miguel, J., Strobl, P., Vogt, P., 2013. Towards a pan-European burnt scar mapping methodology based on single date medium resolution optical remote sensing data. Int. J. Appl. Earth Obs. Geoinf. 20, 52–59.

Seymour, R. S., and Hunter, M. L.: Principles of ecological forestry, in: Maintainig biodiversity in forested ecosystems, edited by: Hunter, M., Cambrige University Press, Cambridge, UK, 22-61, 1999.

Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., et al.: InVEST 3.2.1 User's Guide, The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund., Stanford, 2015.

Smith, J, Wolfe, M, Woodward, L, Pearce, B and Lampkin, N (2011) Organic farming and biodiversity: a review of the literature. Organic Centre Wales, Aberystwyth. http://www.canolfanorganigcymru.org.uk/uploads/biodiversity_review_2011.pdf

Smith, H, Dänhardt, J, Lindström, Å and Rundlöf, M (2010) Consequences of organic farming and landscape heterogeneity for species richness and abundance of farmland birds. Oecologia No 162 (4), pp1071-1079.

Sradnick, A, Murugan, R, Oltmanns, M, Raupp, J and Joergensen, R G (2013) Changes in functional diversity of the soil microbial community in a heterogeneous sandy soil after long-term fertilization with cattle manure and mineral fertilizer. Applied Soil Ecology No 63, pp23-28.

Srivastava, D.S., Bell, T., 2009. Reducing horizontal and vertical diversity in a foodweb triggers extinctions and impacts functions. Ecol. Lett. 12, 1016–1028.

Stevens, C J, Duprè, C, Dorland, E, Gaudnik, C, Gowing, D J G, Bleeker, A, Diekmann, M, Alard, D, Bobbink, R, Fowler, D, Corcket, E, Mountford, J O, Vandvik, V, Aarrestad, P A, Muller, S and Dise, N B (2010) Nitrogen deposition threatens species richness of grasslands across Europe. Environmental Pollution No 158 (9), pp2940-2945.

Stolte J., Tesfai M., Øygarden L., Kværnø S., Keizer J., Verheijen F., Panagos P., Ballabio C., Hessel R. (2016). Soil threats in Europe; EUR 27607 EN; doi:10.2788/488054 (print); doi:10.2788/828742 (online)

Šturm, T., Fernandes, P.M., Šumrada, R., 2011. The Canadian fire weather index system and wildfire activity in the Karst forest management area, Slovenia. Eur. J. For. Res. 131, 829–834.

Tedim, F., Remelgado, R., Borges, C., Carvalho, S., Martins, J., 2013. Exploring the occurrence of mega-fires in Portugal. For. Ecol. Manage. 294, 86–96.

TEEB: The Economics of Ecosystems and Biodiversity: Ecological and economic foundation, Earthscan Cambridge, 2010.

Terres, J M, Hagyo, A, Wania, A, Confalonieri, R, Jones, B, van Diepen, K and Van Orshoven, J (2014) Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints. JRC Science and Policy Report EUR 26940 EN. Publications Office of the European Union, Luxembourg. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC92686/lbna26940enn.pdf

Terres, J.M., Nisini, L., Anguiano, E. (2013): Assessing the risk of farmland abandonment in the EU - Final Report. EUR 25783 EN

Thurner, M., Beer, C., Santoro, M., Carvalhais, N., Wutzler, T., Schepaschenko, D., et al.: Carbon stock and density of northern boreal and temperate forests, Global Ecology and Biogeography, 23, 297-310, 2014.

Tuomisto, H L, Hodge, I D, Riordan, P and Macdonald, D W (2012) Does organic farming reduce environmental impacts? - A meta-analysis of European research. Journal of Environmental Management No 112, pp309-320.

Van der Knijff, J. M., Younis, J., and De Roo, A. P. J.: LISFLOOD: a GIS-based distributed model for river-basin scale water balance and flood simulation, International Journal of Geographical Information Science, 24, 189-212, 2010.

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 1999. Soil erosion risk assessment in Italy. Ispra.

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 2000. Soil erosion risk assessment in Europe. Ispra.

Van Dijck, S.J.E., van Asch, T.W.J., 2002. Compaction of loamy soils due to tractor traffic in vineyards and orchards and its effect on infiltration in southern France. Soil Tillage Res. 63, 141–153.

Van Wagner, C.E., 1987. Development and structure of the Canadian Forest Fire Weather Index System. Toronto.

Verde, J.C., Zêzere, J.L., 2010. Assessment and validation of wildfire susceptibility and hazard in Portugal. Nat. Hazards Earth Syst. Sci. 10, 485–497.

Verkerk,P.J., M. Lindner, G. Zanchi S. Zudin, 2011. Assessing impacts of intensified biomass removal on deadwood in European forests Ecological Indicators 11 (2011) 27–35 doi:10.1016/j.ecolind.2009.04.004

Verkerk PJ, Levers C, Kuemmerle T, Lindner M, Valbuena R, Verburg PH, Zudin S (2015) Mapping wood production in European forests Forest Ecol Manag, 357: 228-238. doi:http://dx.doi.org/10.1016/j.foreco.2015.08.007

Vervoort, R.W., Dabney, S.M., Ro, M.J.M., 2001. Tillage and row position effects on water and solute infiltration characteristics. Soil Sci. Soc. Am. J. 65, 1227–1234.

Villanueva, A J, Gómez-Limón, J A, Arriaza, M and Nekhay, O (2014) Analysing the provision of agricultural public goods: The case of irrigated olive groves in Southern Spain. Land Use Policy No 38, pp300-313.

Vilar, L., Camia, A., San-Miguel-Ayanz, J., 2015. A comparison of remote sensing products and forest fire statistics for improving fire information in Mediterranean Europe. Eur. J. Remote Sens. 48, 345–364.

Voorhees, W.B., Young, R.A., Lyles, L., 1979. Wheel traffic considerations in erosion research. Trans. ASAE 22, 786–790.

Wagg, C., Bender, S.F., Widmer, F., van der Heijden, M.G.A., 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proc. Natl. Acad. Sci. U. S. A. 111, 5266–5270.

Wall, D.H., Bardgett, R.D., Behan-Pelletier, V., Herrick, J.E., Jones, T.H., Ritz, K., Six, J., Strong, D.R., van der Putten, W.H., 2012. Soil ecology and ecosystem services. Oxford University Press, Oxford.

Weijers, E.P., G.P.A. Kos, W.C.M. van den Bulk, A.T. Vermeulen, 2007. Research on the air quality around a vegetation strip alongside the motorway. ECN rapport nr. ECN-E--07-011. (In Dutch).

Willemen, L., Burkhard, B., Crossman, N., Drakou, E. G., and Palomo, I.: Editorial: Best practices for mapping ecosystem services, Ecosystem Services, 13, 1-5, 2015.

Wilson, J D, Evans, M G and Grice, P V (2009) Bird Conservation and Agriculture. Ecology, Biodiversity and Conservation, Cambridge University Press, Cambridge, UK.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses – A guide to conservation planning. Washington DC.

Wolff, S., Schulp, C. J. E., and Verburg, P. H.: Mapping ecosystem services demand: A review of current research and future perspectives, Ecological Indicators, 55, 159-171, 2015.

Worm, B., Duffy, J.E., 2003. Biodiversity, productivity and stability in real food webs. Trends Ecol. Evol. 18, 628–632.

Wriedt, G, Van Der Velde, M, Aloe, A and Bouraoui, F (2009) A European irrigation map for spatially distributed agricultural modelling. Agricultural Water Management No 96 (5), pp771-789.

Yang, J., Yu, Q., Gong, P., 2008. Quantifying air pollution removal by green roofs in Chicago. Atmospheric Environment, 2008, Vol.42(31), pp.7266-7273

Yang, S., 1996. Urban Ecology. Science Press, Beijing, 141pp. (in Chinese).

Zahrnt, V and et al (2009) A Common Agricultural Policy for European public goods. 2009 declaration by a group of leading agricultural economists. Online document at http://www.reformthecap.eu/posts/declaration-on-cap-reform

Zandersen, M., Termansen, M., and Jensen, F. S.: Evaluating approaches to predict recreation values of new forest sites, Journal of Forest Economics, 13, 103-128, 2007.

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., et al.: Data from: towards a worldwide wood economics spectrum, 2009.

Zdruli, P., Jones, R.J.A., Montanarella, L., 2004. Organic matter in the soils of southern Europe. Ispra.

Zulian, G., Maes, J., & Paracchini, M. L. (2013). Linking land cover data and crop yields for mapping and assessment of pollination services in Europe. *Land*, 2(3), 472-492.

Zulian, G., Polce, C., Maes, J., 2014. ESTIMAP: a GIS-based model to map ecosystem services in the European Union. Ann. di Bot. 4, 1–7.