SmartSOIL
Sustainable farm Management Aimed at Reducing Threats to SOILs under climate change


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Summary

This document is the first deliverable from SmartSOIL and attempts to clarify some of the socio economic context and frameworks for developing soil science. A key concept that has attracted considerable interest from scientists and policy makers alike is the ecosystem service approach. In soil science, the use of an ecosystem service approach has been developed in parallel with the concept of soil functions, which also have found their way into EU policy developments such as the proposed EU Soil Framework Directive. We find that soil functions overlap with intermediate services in recent ecosystem service categorisations, such as the one used for the UK National Ecosystem Assessment. The distinction between intermediate and final ecosystem services is crucial in this respect, at least if an ecosystem service approach is supposed to serve as a basis for economic assessments of changes in service delivery due to land use or land management changes.

We further highlight the challenges in understanding the underlying complexity in processes and services and illustrated approaches that could be used to manage this complexity in order to produce results that can be of relevance in practice. This includes clarification of soil stock and (service) flow concepts that motivate (albeit theoretical) questions about the meaning of soil resilience and sustainability. As a main product of this work, we produced a comprehensive overview table that highlights the variety of ecosystem services derived from a lowland arable landscape. Central to this overview is the identification of intermediate service outcomes related to soil that are relevant to final service provision. Such information is particularly useful to identify future research needs in order to quantify and understand crucial links between ‘what soil does and provides’ and the associated final ecosystem services, which are to be valued in monetary terms for assessments of economic impacts of service flow changes due to changes in land use and management.

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1 Introduction

Soil science has long been closely linked with agronomics and silviculture. In the more recent past, The wider importance of soils to fulfil societal needs has been increasingly recognized beyond the support for the production of biomass (Daily 1997, MEA 2003, Lavelle et al. 2006). Land use decisions, for example, have to increasingly consider the demands of a growing urban population with regards to environmental standards, housing, transportation or recreation (Bouma 2001). The emergence of the paradigm of sustainable development on the policy agenda with the Brundtland report (WCED 1987), the integration of 'multifunctionality' in EU agricultural policy (Maier and Shobayashi 2001), and an increasing level of understanding of environmental processes and ecological functioning have certainly contributed to a broader, multifunctional and interdisciplinary perspective on soil, the environment and their importance to fulfil societal needs.

Soil resources can be managed to help mitigate climate change, to expand urbanisation, to increase agricultural production to address food insecurities, to provide recreational services, to maintain reliable water supplies, all while maintaining soil quality and protecting our natural environment. Managing soil resources for multiple benefits and societal needs requires a sound appreciation of the values that people place on the goods and benefits they need and want. Equally, it is necessary to understand the contribution made by soils and ecosystems to the delivery of such benefits. To assess the impacts of (management and land use) decisions, alternative management practices are often being assessed through direct and indirect costs and benefits, ideally considering both spatial and temporal scales. This goes beyond the bounds of soil science and requires an effective interaction between natural and social science disciplines based on a joint conceptual framework.

There has been significant progress in the development of integrated concepts for linking environmental and socio-economic knowledge. The most prominent effort has been the Millennium Ecosystem Assessment (MEA 2003), which aimed to systemise and conceptualise the relationships between humans and nature under the banner of the *ecosystem services* approach which has soil as a central component of terrestrial ecosystems. Several conceptual frameworks and classification systems for an ecosystem services approach have emerged over the years (Daily 1997; de Groot 2002; Wallace 2007; Fisher et al. 2009), but there is still much debate about the ecosystem services concept and how it can be used in practice (e.g. Mace 2012; Johnston and Russell 2011; Balmford et al. 2011). At a national level, many countries, the UK included, are championing an ecosystem service approach "to secure a diverse, healthy and resilient natural environment, which provides the basis for everyone's well-being, health and prosperity now and in the future" (HM Treasury 2007). In the UK, the National Ecosystem Assessment is a large interdisciplinary effort to improve the knowledge base and engage with decision makers on the actual relevance of ecosystem service management considerations in policy and business (UK NEA, 2011).

Several opportunities and risks of applying an ecosystem service approach can be identified (Martin-Ortega in press). Applying an ecosystem service approach can create awareness of wider impacts of policies targeting single environmental goals and support the recognition of values that are not reflected in market prices; improve interdisciplinary dialogue and knowledge exchange, i.e. serve as a powerful communication tool and help to better integrate science into policy decisions. On the other hand, concerns have been raised about the ‘commodification’ of nature (Kosoy and Corbera 2010) and associated neglect of values and beliefs that are often especially pronounced among conservationists. Furthermore, there is a risk that different players (scientists of different disciplines; policy makers) use the same terminology while not sharing a common understanding, which could even exacerbate communication. If an ecosystem service approach is only applied to selected policy contexts, there is a risk that policy guidance and regulation will not be consistently based on the same framework, undermining the advantages of using an ecosystem service approach for consideration of wider policy impacts (Smith et al, under review).

In parallel to the ecosystem service approach, the concept of *soil functions* (Blum 1993) has gained prominence in soil science and now forms the basis for the EU Soil Thematic Strategy and proposed Soil Framework Directive (EC 2006a,b). Again, a number of nations are adopting this approach in developing soil protection strategies (Environmental Protection Agency Ireland 2002; Defra 2004; EC 2006b) and legislation (e.g. Karlaganis 2001).

As policy-making and land management decisions are now converging on multi-functional use of natural resources, the concepts of ecosystems services and soil functions are converging. Ecosystem services have latterly become an important paradigm in soil science research (e.g., indicated by the increasing number of sessions and papers referring to ecosystem services at recent soil conferences such as EUROSOIL).

However, it is unclear how the term ‘ecosystem services’ refers to underlying conceptual frameworks, or if it is simply used interchangeably with the ‘soil function’ concept. Sometimes, aspects of both ecosystem service and soil function frameworks seem to have been mixed (e.g., Rutgers et al., 2012). There are, however, fundamental differences in how the concepts of soil functions and ecosystem services address the relevance of soil to human well-being, which will influence the success of our efforts to assess the relative social, environmental and economic values of soil and in the outcomes from developing soil protection and management policies. It is therefore timely and necessary to review these concepts and propose a way forward for soil science, which identifies linkages between these approaches that can contribute to a harmonised assessment of soil-human relationships and therefore foster effective evaluation of soil within an increasingly all-encompassing and integrated perspective on natural resource use, management and policy development to support human needs and well-being.

Previous efforts to conceptualise soil-related ecosystem services, either as a soil specific framework (e.g., Lavelle et al. 2006; Barrios 2007; Wall et al 2004) or as part of wider (agro-)ecosystems (e.g., Sandhu et al. 2008; Porter et al. 2009) provide a useful starting point in this respect. Robinson and Lebron (2010), Dominati et al. (2010) and Bennett et al. (2010) are probably the most comprehensive frameworks to consistently classify and describe the linkages between soil and its management and resulting impacts on ecosystem services and human welfare. Crucially, Dominati et al. (2010) distinguish ecosystem stocks that make up natural capital from flows. Like any other form of capital, natural capital refers to environmental assets that can be used or invested to yield ecosystem services over time. The environmental assets make up a *stock*, from which *flows* of ecosystem services arise (Maeler et al. 2009). While considerations of natural capital, and their relationship with flows, are particularly important for sustainability assessments of economic activity, ecosystem service assessments are typically concerned with impacts of policy and management on changes in ecosystem service flows, which can be quantified in monetary terms as costs and benefits. This report mainly refers to the latter (flows), while aspects of stocks and natural capital will be dealt with in more detail at later stages of the SmartSOIL project.

The key objective of this report is to conceptually organize known relevant biophysical information in relation to social and economic endpoints. We do this to obtain an improved understanding of how changes to soil management in general, and soil organic carbon (SOC) in particular, influence processes and functions that map onto different social and economic endpoints. In the first part of this report (section 2), we identify the opportunities for soil science to harmonise with the developments of the ecosystem services approach, in particular the interface with social and economic disciplines to support more holistic valuations of fundamentally non-renewable soil resource. To do so, we first review the variety of existing conceptual frameworks, illustrating their advantages and limitations, including the relevance of stock and flow issues in relation to soil. We then explore the relevance of understanding the complexity of human-nature interactions, and to serve as a basis for identifying the relevant links between (soil) processes and human endpoints (section 3). Using lowland agricultural systems in Northern Europe as an example, we develop a comprehensive set of ecosystem services with the aim to identify the relevant influences of changes in (soil) management on service provision and benefits accrued to society (section 4). We close with a summary, highlighting key insights and conclusions from this report.

2 Conceptual developments linking soil and human well-being

2.1 Soil Function concept

The 'soil function' concept emerged in the European soil science community during the early 1970's as approaches to the capability and suitability of land and soil for different human purposes were being developed. This evolved into the definitive paper by Blum (1993) with six functions based on the "ecological" functions of biomass production, protection of humans and the environment and gene reservoir along with the "non-ecological functions" of physical basis of human activities, source of raw materials and geogenic and cultural heritage. In some respects, this paper can be viewed as the first concerted attempt by the soil science community to express what soil contributes to society. The approach had resonance with policy-makers and has been translated into both soil protection strategies, particularly in the British Isles (Environmental Protection Agency Ireland 2002; Defra 2004; Welsh Assembly 2008). In addition, the concept was adopted for the development of the EU Soil Framework Directive with seven key functions that soils perform as a natural resource (EU 2006a). This framework aims at improving "the capacity of soil to perform any of the following environmental, economic, social and cultural functions" (EU 2006a:14):

- production of biomass including the production goods in agriculture and forestry;
- regulatory functions of soil, which comprise of storing, filtering and transforming nutrients, substances and water;
- biodiversity pool, such as habitats, species and genes;
- physical and cultural environment for humans and human activities;
- source of raw materials such as sand, clay or peat;
- acting as carbon pool;
- acting as an archive of geological and archaeological heritage.

If this Framework is eventually adopted by the EU, the concept of soil functions would then be embedded in European and National legislation. A variant of the soil function concept has been recently described by Nortcliff (2009). The basic premise that underpins the soil function concept is that soils can be defined by their inherent capacity to deliver a range of functions and that degradation of inherent soil properties and processes will compromise the delivery of these functions with the sustainable use of soils only possible by a temporal and/or spatial "harmonisation" in soil functions (Blum 2005). This harmonisation requires societal and/or political negotiation processes to choose between alternative options for managing soil or to design policies that target how soils are to be managed to meet a required outcome. On the one hand, these human negotiation processes require information on the natural environment (often termed the "biophysical" environment in socio-economic literature), including soil quality, under different management options. On the other hand, social or economic principles need to be applied in order to consider the impact of changes on the well-being of human society (socio-economic assessment).

In order to assess the suitability of the soil function concept to inform both an assessment guided by ecological criteria and a socio-economic assessment of managing soils, it is useful to take a step back and elaborate on the precise meaning of 'function' in the soil function context. Jax (2005) identifies four primary uses of the term "function" within ecological and environmental sciences[1].

1. *Functions used as a synonym for processes*. Function is used in a purely descriptive manner to illustrate state changes in time between living or inanimate 'objects'. Processes are described with or without consideration of cause-effect relationships (e.g., *cation-exchange capacity, function of clay minerals, decomposition of organic matter*)
2. *Function used to mean the function(ing) of a system*. Processes are part of a 'whole'. The use of the term 'functioning' refers to the complex interactions between processes and components, and how they contribute to the state a system is in. (e.g., *the functioning of a nutrient cycle such as* carbon and nitrogen)
3. *Functions used as a synonym for roles*. The focus moves from the interaction between objects to the objects themselves. Objects now *have* an ascribed role that describes their position within the system. Different objects can have the same function or role. (e.g., *the function of humus in water retention, the function of earthworms, the function of methanotrophic microbes*)
4. *Functions as services*. This use of function describes particular characteristics of the whole system that are of practical use for humans or other living beings. (e.g., *nutrient availability for crop growth, sequestration of carbon from the atmosphere, water retention preventing flooding, physical medium for plant growth, reservoir of biodiversity with conservation value*)

The soil function concept is mainly applied to capability and suitability assessments of land/soil for different human purposes. This information is of practical use to humans: decision makers can draw on this information for making choices on land use and management. Generally, the *'outputs'* of applying the soil function concept refer to category 4, functions as services. Capability and suitability assessments of land and soil are based on findings grounded in objective science and seek to explain functions as processes, in system functioning and as roles. This refers to categories 1-3, which are the areas where most soil

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[1] See also Dominati et al. (2010, 1859), who briefly touch upon the controversy around the use of the terms 'process' and 'function' in a soil science context.

scientists currently operate. The 'biophysical' information that serves as *'input'* into applications of the soil function concept is being evaluated by experts, often soil scientists, to deliver information that is of practical use to humans. This evaluative step – call it expert judgment – usually shows little consideration of the ultimate consequences of decisions on soil and land management to human well-being. It lacks reference to the actual values, or 'end-products', delivered by soil either as tangible or as intangible costs and benefits.

The combination of objective biophysical information and expert judgment to inform decision making can be called *ecological assessment* (of management options). Ecological assessments are likely to be guided by principles of the *environmental or ecological dimension of sustainability* (c.f. de Groot et al. 2002, 403). It can be defined as "the natural limits set by the carrying capacity of the natural environment (physically, chemically and biologically), so that human use does not irreversibly impair the integrity and proper functioning of its natural processes and components" (de Groot et al. 2002, FN2). Guiding principles for ecological sustainability therefore include concepts such as irreversibility, resilience, self-organising capacity, ecosystem health, and ecosystem integrity. For example, threshold values of critical loads could be defined, or intervals, based on measured data, could be created that indicate whether soil would perform a certain function "better" or "worse", or whether soil is exposed to a "high" or "low" risk, or whether a contamination is "tolerable" or "non-tolerable" for the environment.

An example of an 'output' of the soil function concept is the Land Capability for Agriculture (LCA) classification (Bibby et al. 1982), developed during the 1970s and still in wide use. It consists of a series of guidelines that allows a soil specialist to classify an area of land based on assessments of climate, soil, topography, wetness and vegetation and arrive at a judgement of the capability of that land for agriculture (a component of the biomass production soil function). The guidelines have been constructed by a number of experts and these are subsequently applied to objective biophysical information by similar experts. Indeed the assumptions that underpin the guidelines state explicitly that social and economic factors are <u>not</u> part of the assessment procedure. LCA has been used widely in planning, features in property sales and its use in policy revision and agricultural subsidy distribution has been examined (Wright et al. 2006, Scottish Government 2008, Buchan et al 2010); it is widely trusted and accepted by a range of stakeholders. It has also been used to examine how this function of soil might change under a warming climate (Brown et al 2008).

Figure 1 demonstrates the climatic component of the classification. Climate across the UK is allocated to a LCA class (1-7) based on *expert appraisal* of the interaction between the two variables (Potential Soil Moisture Deficit (P) and Accumulated Temperature (A) along the X and Y axes respectively) and how this manifests itself in imposing climatic limitations on agricultural use. In essence, the warmer and drier the climate, the greater the potential flexibility of agricultural land use. The positions of the class boundaries are based solely on the consensus of experts. Similar procedures have been developed for the other attributes in the classification.

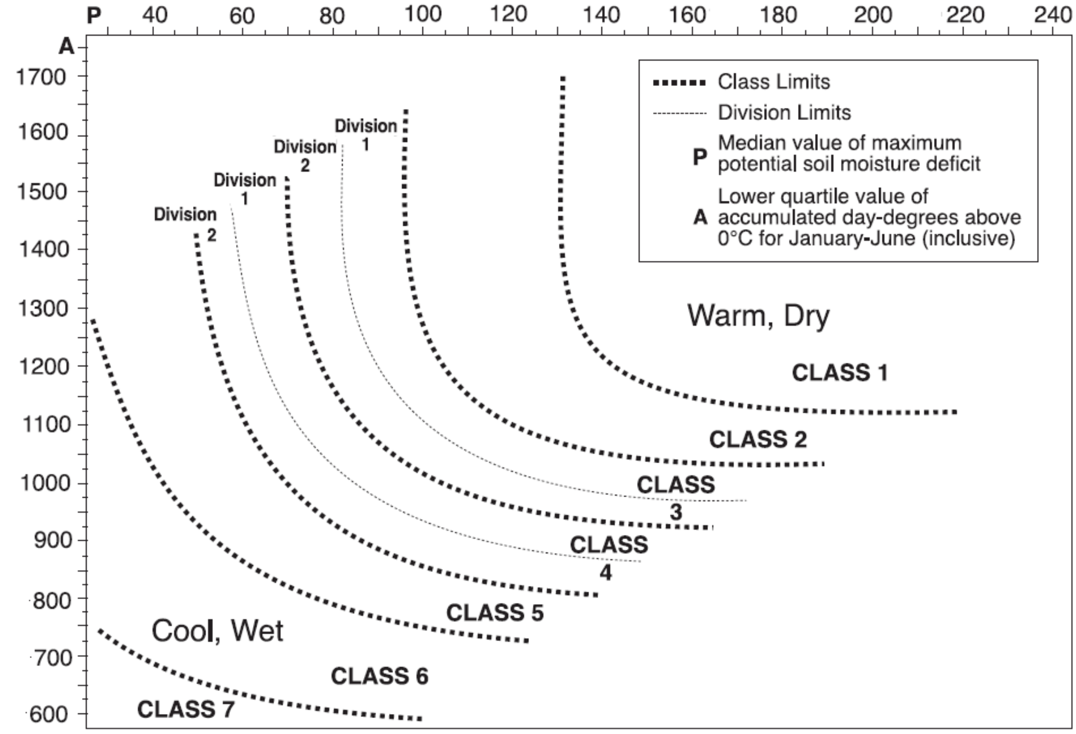

Figure 1 The climate of the UK allocated into different LCA classes (see Table 1 for an explanation of classes)

The classification itself comprises a series of descriptions outlining the range of crops and agricultural activities that are possible at a site or within an area (Table 1). These descriptions describe the biophysical potential of the land to produce agricultural outputs, but do not contain explicit references to the actual 'end-product(s)' or benefit(s) derived from those outputs. The LCA classification and other similar assessment procedures provide robust indications of the *capacity* of soil processes and components, in tandem with other factors such as climate to provide ecosystem services that satisfy human needs. They therefore fulfil a valuable role in decision making, but are only part of the overall process of what society is seeking from soils and the wider environment. Importantly, such information may be particularly useful for the development of robust indicators of ecosystem *stocks*, from which ecosystem service flows arise – but not to characterise or quantify ecosystem service flows and related benefits per se. We will return to the issue of stocks and flows in section 2.2.6.2.

Table 1 The Land Capability for Agriculture (LCA) classification (see also Figure 1)

Class	*Biophysical Limitations*	*Class description (abbreviated)*
Class 1	None or very minor	Very wide range of crops with consistently high yields
Class 2	Minor	Wide range of crops, except those harvested in winter
Class $3._1$	Moderate	Moderate range of crops, with good yields for some (cereals and grass) and moderate yields for others (potatoes, field beans, other vegetables)
Class 3_2	Moderate	Moderate range of crops, with average production, but potentially high yields of barley, oats and grass
Class 4_1	Moderately-severe	Narrow range of crops, primarily ley grassland with some forage crops and cereals.
Class 4_2	Moderately-severe	Narrow range of crops, primarily grassland with some limited potential or other crops.
Class 5	Severe	Improved grassland, with mechanical intervention possible to allow seeding, rotation or ploughing
Class 6	Very Severe	Rough grazing pasture only
Class 7	Extremely Severe	Very limited agricultural value

2.1.1 A note on the soil function concept

Because soil scientists and ecologists have a strong association with a process type definition of the term ‘function’ and social scientists and policy makers with a ‘service’ definition of ‘function’, it is important to identify potential sources of interdisciplinary misconception regarding the soil function concept in the light of linking it with an ecosystem service approach.

That the soil function concept refers to ecological processes when describing the soil functions in greater detail (e.g. filtering, buffering and transformation) may be one such source of misunderstanding. It should be clear that the soil function concept specifically focuses on ecosystem processes if and only if they can actually be related ‘end-products’ i.e. the satisfaction of human needs.

Confusion can also arise from distinguishing two categories of soil functions: ecological and non-ecological functions. This strong dichotomy poses the unintended risk of conceiving it as a clear distinction between ecological processes and human use. However, a distinct boundary cannot be placed between the two categories. Ecological functions have a stronger underpinning with classical ecological processes related to nutrient cycling, filtering, buffering and interactions within and between the domains of soil organisms. Non-ecological functions are dominated by the human use perspective, and using land for non-ecological functions will “exclude the three ecological functions” (Blum 1993, 40). However, non-ecological functions are essentially also characterised by a set of soil (i.e. ecological) processes. As an aside, any attempt to draw a clear line between the two would be complicated by the fact that non-ecological functions depend on the processes related to ecological functions, however on a different spatial and a very large time scale. In the EU Framework document (EC 2006a), no distinction has been made between the “ecological and non-ecological functions”; the purpose is to ‘establish a framework for the protection of soil and the preservation of the capacity of soil to perform any of the following functions: environmental, economic, social and cultural. Nortcliff’s (2009) interpretation of soil functions also clearly refers to the social role of environmental interactions. We believe that the removal of this artificial separation represents an improvement in the development of the soil function concept.

According to Blum (2005), soil functions encompass the role of soils for both society and the environment. This is another source of potential misunderstanding. The role of soil for the environment is usually discussed in the ecological and soil science literature in terms of environmental interactions and processes, and is at the heart of soil science. A scientist aims to design their research for assessing the role soil has for the environment with objectivism. How do soils develop under different land cover? How do the physical and chemical properties of soil interact with the hydrological cycle? The natural environment, excluding human beings, will not make decisions on the relative importance of soil functions. We cannot ask the environment, for example, about its preferences for land use patterns associated with different levels of ‘performance’ of different soil functions. Ultimately, the role soil has or does not have is defined by an anthropocentric perspective. Therefore, any function soil performs for society fully captures all relevant soil functions *sensu* Blum for the environment. Understanding the role of soil for the environment is often a precondition to understand the role soil has for society. If the human-soil relationship is conceptualised, a distinction between the role of soils for society and for the environment is not necessary.

2.2 Ecosystem services

2.2.1 Background

Because the concept of ecosystem services has been explicitly developed to improve our understanding of the human-environment relationship, we may expect to find some insights to better integrate capability assessments such as the LCA with information on the social and economic consequences of land use and soil management decisions. Given that there is constant and mutual interaction between the natural environment and humans, a better integration may also improve the capability to assess the consequences of changes covered by both environmental (e.g. climate) and direct human (e.g. land use change) drivers of change.

Since its early developments in the mid 1960s and early 1970s (King 1966; Helliwell 1969; SCEP 1970; Odum & Odum 1972; cited in Mooney & Ehrlich 1997 and de Groot et al. 2002), the basic idea behind ecosystem services remains largely unaltered: human life depends on the existence of a finite natural resource base, and nature contributes to the fulfilment of human needs. How human needs and well-being interact with quantities and qualities of the finite natural resource base, and how changes to the natural environment impact on human activities and vice versa are key questions underlying the conceptual development of an ecosystem service framework.

We generally acknowledge the presence of temporal and spatial dynamics within the human-environment system, and the importance of considering these aspects in ecosystem service assessments (Fisher et al. 2011; Bateman et al. 2011). However, the framework illustrated in Section 2.2.2 is not conceived as an exact diagrammatic representation of the human-environment system but as a mental map to facilitate orientation between ways of thinking about soil, and ecosystems, bounded by disciplinary perspectives.

2.2.2 The ecosystem service approach

We present a simple overview of an ecosystem service framework adapted from Bateman et al. (2011) and based on previous conceptual developments in Fisher et al. (2009) and Turner et al. (2010). What follows is a brief description of central components of the framework as illustrated in Figure 2.

Boundary conditions of ecosystems comprise of natural external conditions of the ecosystem such as climate and geology/geomorphology. Importantly, these boundary conditions usually cannot be easily altered by changing the management of the specific ecosystem. Ecosystem structure refers to structural properties such as plant composition, soil texture and soil depth, or slope. Physical, chemical and biological structural ecosystem components interact in ecosystem processes. In this respect, soil processes are the interactions of the chemical, physical and biological properties of the pedosphere. Examples of soil processes are infiltration and storage of water in soil pore systems, organic matter decomposition and humification, carbon cycles in soil and biomass. These processes can be divided into a hierarchy of processes and contributing components. For example, soil invertebrates contribute to soil formation by bioturbation and particle selection. Knowledge on ecosystem properties and processes are the concern of natural science, irrespective of human needs or desires.

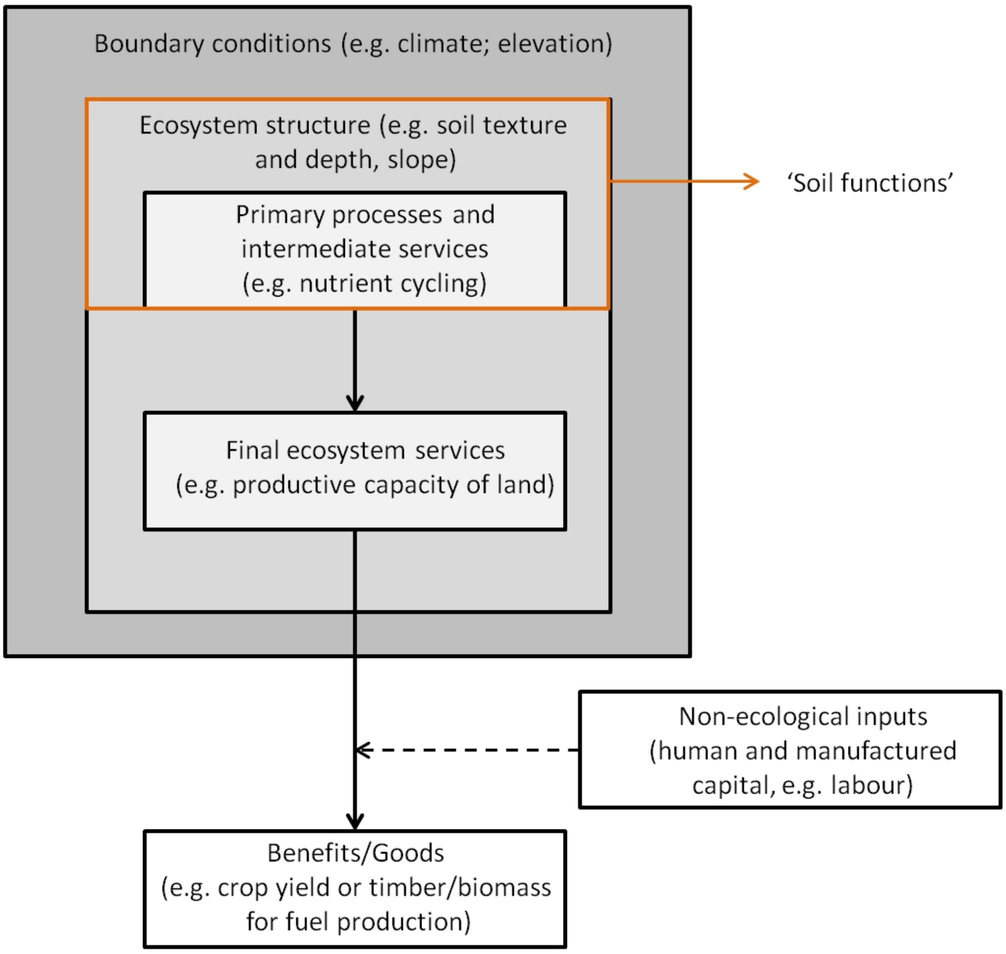

Figure 2 Basic conceptual links between ecosystem structures, processes and intermediate services, final ecosystem services and goods (human values) (adapted from Bateman et al. 2011) ; the proposed role of the soil function concept is to develop ecological assessments of processes and structures that are *potentially* of benefit to humans

If the aim is to assess human-soil relationships, it is conceptually helpful to identify and describe those soil properties and processes that *potentially* impact on human well-being. Within an ecosystem service approach, a condensed set of ecosystem properties and processes that describe the capacity of ecosystems to deliver ecosystem services has initially been denoted 'ecosystem functions'. They represent "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly and indirectly" (de Groot et al. 2002, 394) and include aspects of gas regulation, water regulation, soil retention, soil formation, food, raw materials and genetic resources, or information functions such as cultural and artistic, spiritual and historic information. One can think of ecosystem functions with respect to soil as those processes that are directed towards a specific use that is defined by human needs. The analogue to ecosystem functions in the ecosystem service framework outlined by Fisher et al. (2009) are '*intermediate services*'. Intermediate services describe those structures and (bundles of) processes that do not yield *direct* benefits to humans, but only indirectly via effects on other – final – ecosystem services. 'Final ecosystem services' are then those biophysical outcomes of ecosystems that directly impact on human well-being (cf. Fisher et al. 2009). Both natural and human external drivers (e.g., climate change; agricultural land management) can impact on the structure and properties of the ecosystem, and hence directly or indirectly affect primary processes and intermediate services.

The distinction between intermediate and final ecosystem services has mainly been drawn for one main reason: to ensure that the contribution of a single ecosystem condition or process to human well-being is counted only once for each person or group of persons who obtain benefits (beneficiaries). This can be achieved by only summing up final ecosystem service values for (economic) ecosystem service assessments, while the value of intermediate services only represents their marginal contribution to the final service. For example, counting both the value of nutrient cycling and the productive capacity of land would double count the contribution of nutrient cycling, because nutrient cycling contributes to productive capacity of land. This contribution could be equally captured in valuations of nutrient cycling.

It is, however, crucial to identify final ecosystem services specifically from a beneficiary perspective. That is, what constitutes an intermediate or a final service depends on the beneficiary. For example, a commercial fisherman may mainly be interested in fish catch – the amount and type of fish that can be harvested from a water body. Water quality (e.g. compromised by eutrophication) would be an intermediate service to the fisherman, because it only affects her welfare indirectly through effects on the food web and hence the fish population. In other words, if fish catch and all other factors remained constant but water quality were to change, this would not affect the fisherman's welfare. Compare this with a recreational fisherman (or the same fisherman in a recreational role), who derives pleasure from a variety of factors associated with the fishing experience (for example, the scenic beauty of the fishing spot; or the presence of a larger variety of fish species). To this fisherman, both catch and water quality are intermediate services. The final ecosystem service may be the attractiveness of a particular water body to recreational fishing, which is influenced by both water quality, catch and a variety of additional factors. The fact that the definition of final and intermediate services is beneficiary-specific illustrates that it is not useful to resort to generalised a priori classifications or 'lists' of ecosystem services that are applied without adjustments to the specific context (see Johnston and Russell 2011 for a comprehensive discussion of this issue).

Finally, final ecosystem services may be combined with human or manufactured capital to produce benefits. The UK National Ecosystem Assessment (UK NEA 2011) and Bateman et al. (2011) refer to the products of final ecosystem services and non-ecological inputs as 'goods'. Goods here comprise of both market and non-market goods, the latter including aspects of nature contributing to well-being without being linked to any direct or indirect use (non-use values arising, for example, from the pure knowledge that a species or habitat are preserved); and valued aspects of ecosystems that are difficult or impossible to monetise such as the attachment of spiritual values to nature. The distinction between final ecosystem services and benefits or 'goods' is important to indeed measure nature's contribution to human well being; and to avoid the impression that market prices are necessarily reflecting ecosystem service values.

2.2.3 Soil functions and the ecosystem service approach

Soil functions and ecosystem services concepts are used in fundamentally different ways. As described in Section 2.1. using the LCA classification example, the resulting outputs of capability and suitability assessments generally provide decision makers with information on how 'good' or 'bad' a given function is performed by a given soil at a certain point in space and time. In ecological assessments, natural scientists set the boundaries: in essence they define the thresholds between 'good' and 'bad' performance of a soil function. Environmental assessments of management options are characterised by the limited consideration of the actual 'end-products', or final ecosystem services, delivered by soil, and therefore also the ultimate consequences to human well-being. They are not reaching out to the actual end-products of nature and are therefore limited in their scope to provide an answer to the question of what we actually want from soil. Because this question is a key issue to social science investigation in the human-soil relationship, the soil function concept *alone* is likely to fail to yield the level of transdisciplinary integration needed to improve our understanding of the links between humans and the environment.

There is an obvious position where outputs related to the soil function concept can sit in an ecosystem service framework: they can comprise and describe elements of intermediate services (see Figure 2). They were described as those structures and (bundles of) processes that do not yield *direct* benefits to humans, but only indirectly via effects on other – final – ecosystem services. This is exactly the kind of information on which ecological assessments following the soil function concept are based upon. Because soil function assessments relate to intermediate ecosystem services, there is a risk that soil science research dedicated to investigating soil processes gets labelled as being relevant to 'ecosystem services' without trying to be explicit about where in an ecosystem service approach the studied processes are located; if they refer to intermediate or final services; and how exactly the process is expected to be linked to human benefits ('goods').

Therefore, in order to actually benefit from the conceptual integration, both natural and social scientists should start to identify the final ecosystem services affected by decisions on land use and soil management; and then to identify how final ecosystem service delivery is related to underlying intermediate services, encompassing relevant soil processes and properties. Depending on soil type, location and management, some of the intermediate services and processes may contribute more or less to a final ecosystem service, i.e. they may require more or less attention for an assessment of impacts of environmental change. Soils, and the roles they play within an ecosystem, are often one of many inputs for the provision of final ecosystem services, and the same soil-related intermediate services (i.e. bundles of processes relevant to final service delivery) contribute to more than one final service at the same time (see Kibblewhite et al. 2008; Lavelle et al. 2006, who use the de Groot et al. (2002) process-function-service terminology).

Ecosystem services are defined as the end-products of nature (or benefits humans obtain from (the use of) nature). Compared to Blum's soil functions, an ecosystem services approach is therefore better suited to offer a systematic way of integrating information on soil processes and properties with end-products and human values and to facilitate an assessment of management options and resulting environmental changes across disciplinary boundaries. Figure 3 serves to illustrate this. Knowledge on biophysical impacts is a precondition to assess impacts of change, both in socio-economic terms or as an ecological assessment. 'Raw' biophysical information is unlikely to directly find its way into socio-economic assessments. Social scientists will struggle to meaningfully interpret and utilise findings on soil processes *per se*. The output of applications of the soil function concept (capability assessments such as the LCA) is a useful basis for guiding decisions based on biophysical criteria.

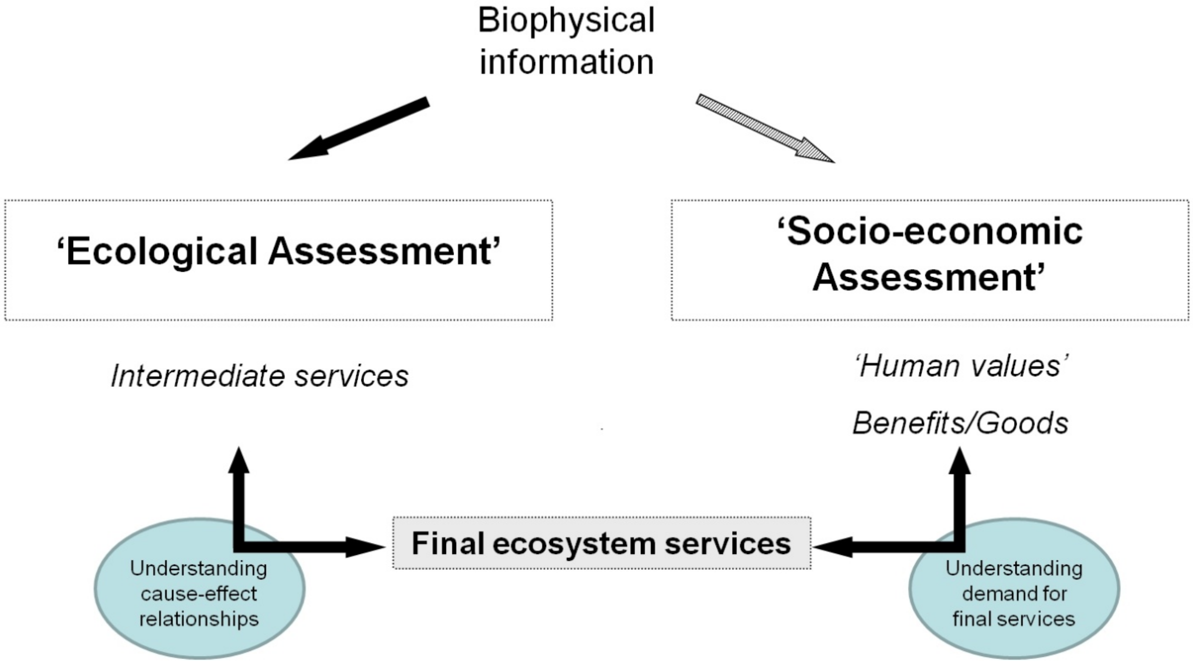

Figure 3 The ecosystem service concept can provide useful links to facilitate socio-economic assessments of changes to soil-related ecosystem services

If a clear link can be made between outputs such as the LCA to a final ecosystem service (e.g. productive capacity of land) and the goods or benefits consumed to yield well-being, then such information or data may be used as inputs into economic analysis. For example, farmers and land managers care about soil quality. Andrews et al. (2003) have reported a good agreement between farmers' perceptions of soil quality and soil quality indices based on indicators selected by expert opinion. There have also been attempts to quantify and value the magnitude of "care" by assessing the impact of soil characteristics on land market prices. Fofana et al. (unpublished) applied the hedonic pricing method to examine the relationship between market price for farmland and its individual attributes, including the LCA classes the farmland falls into. The empirical analysis drew on data compiled from the Register of Scotland (ROS) database. The data included sale date, land size (acres), price paid, date of purchase, extent of property, proprietors, postal code, and geographical coordinates on the location of land, which allowed identification of the LCA class associated with a particular market transaction. 1,337 farmland transactions ranging in size from 0.5 to 7,847 hectares (1.3 to 19,391 acres) for the period 2003 to 2007 were used in the analysis. Price per acre was used as the dependent variable. The explanatory variables included the seven Scottish LCA classes; an index of cereal prices to capture the importance of cereal crops in Scotland's farming system in determining farmland prices; population density to account for the influence of farmland prices on nearness to market and urban centres; and a variable to assess whether EU single-farm payment have any significant impact on farmland prices in Scotland. LCA classes were found to be significant determinants of land prices, with higher LCA classes (reduced land capability for agricultural activity) being associated with lower land prices.

Mapping capability assessments against the actual end-products or ecosystem services can improve the accessibility of biophysical information to evaluate the impact of environmental changes to human well-being. Especially if change is driven by direct human causes, knowledge on human values can provide useful insights about trade-offs among different (final) ecosystem services, which may inform research on competing soil functions/intermediate services (Mayr et al. 2008). The ecosystem services approach therefore serves to mediate and translate between ecological assessments based upon biophysical information and socio-economic assessments based upon human preferences and values.

2.2.4 Ecosystem service frameworks for different objectives

The Millennium Ecosystem Assessment (MEA 2003) defines ecosystem services (and goods) as the benefits humans obtain from ecosystems which include provisioning, regulating, and cultural services that directly affect people and supporting services needed to maintain the other services. Another definition by Boyd & Banzhaf (2007) refers to ecosystem services as end-products of nature that are "directly enjoyed, consumed or used to yield human well-being", while Daily (1997) refers to ecosystem services as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. Fisher et al. (2009) distinguish between intermediate and final ecosystem services, as illustrated in 2.2.2.

As can be seen, there is no consensus on how exactly ecosystem services should be defined and classified, and there is an ongoing discussion on the implications for applying an ecosystem service approach (Johnston and Russell 2011; Barkmann et al. 2008). Research on ecosystem services is evolving. It is important to be aware of the consequences that arise from the use of different definitions for both research and policy making. Major differences arise from the *purpose* the ecosystem service concept is expected to serve (Fisher and Turner 2008; Fisher et al. 2009). A purely *descriptive* objective, for example in terms of illustrating human-nature relationships, can do with the most generic and broad definitions, such as the ones given by the MEA (2003) and Daily (1997). For the specific purpose of creating an ecosystem service or "green" inventory that can be balanced against economic national accounts – and therefore an *evaluative* use of an ecosystem service concept –, it is useful to think beyond aspects that are 'valued' and define ecosystem services more narrowly, for example in line with Boyd & Banzhaf (2007) as end-products of nature that are directly enjoyed, consumed or used. The similar definition by Fisher et al. (2009) introduced in 2.2.2 draws on ideas of Boyd and Banzhaf (2007) and has found a lot of resonance with environmental economists (e.g., Bateman et al. 2011).

It should therefore be emphasised that 'lists' of identified ecosystem services will differ depending on the specific descriptive or evaluative objectives behind such a task (see Fisher et al. 2009, 651). Instead of drawing upon extensive lists such as the ones published in the Millennium Ecosystem Assessment, the selection and definition of relevant ecosystem services should be conducted on a project-by-project basis to avoid a mismatch of purpose and underlying conceptual framework; and to ensure that final ecosystem services are identified from the perspective of beneficiaries (see Section 2.2.2). It should also be clarified in research papers, which concept and therefore underlying purpose the term 'ecosystem service' refers to.

2.2.5 Evaluating changes in ecosystem service provision: acknowledging value pluralism

Because ecosystem services arise from human demand, hence they reflect human values and therefore issues predominantly covered by social sciences. The term value in this respect can be broadly understood as "the contribution of an action or object to goals, objectives and conditions defined by users" (Farber et al. 2002, 375). The user-defined objectives and conditions represent preferred (end-) states of the world. One basic question is to evaluate the contribution of final ecosystem services and *changes* in their provision to aspects of human well-being, which we term *socio-economic assessment*. This responds to a need for better understanding of trade-offs between different ecosystem goods and services associated with the use and management of natural resources. Human values can be assessed from various perspectives that reflect social and economic guiding principles such as efficiency and social welfare, life satisfaction and quality of life, equity and fairness or social capital. The use of an ecosystem service approach is therefore not constrained to an economic understanding of value, but can appeal to a broad range of social science disciplines. For an illustration of the plurality of human endpoints in an ecosystem service approach, we refer the reader to MEA (2003, 78).

How can soil science contribute to socio-economic assessments? One crucial input into any evaluation process consists of information on the cause-effect relationship of changes in the natural environment on the provision of ecosystem services. In this respect, the contribution of soil science for improving the valuation of the ecosystem's contribution to goods is two-fold. First, a prerequisite to perceive something as beneficial in the first place is the awareness of the existence of a relevant impact of soils on human well-being. Awareness in turn is initiated by recognition, which requires prior identification of what is to be recognised. Some impacts are well-known, but others remain largely unknown. A good example for this is the role of soil biodiversity in moderating the provision of ecosystem services (Daily et al. 1997; Lavelle et al. 2006; Huguenin et al. 2006). Indeed, there are considerable gaps in understanding soil-related cause-effect relationships or response functions; and how they are associated with a variety of final ecosystem services.

The second aspect concerns the establishment of a knowledge base that links information on soil processes with ecosystem services. Because soil has a central position in most terrestrial ecosystems and interacts with many other components and processes that take place in ecosystems, this will require soil scientists to integrate knowledge from other disciplines such as hydrology or ecology. Such a process also needs input and guidance from social sciences in order to make sure that the information provided matches the information requirements for valuation. A close collaboration of soil scientists, other natural scientists, economists and other social scientists is therefore needed to enable evaluation and to improve their accuracy and usefulness. This becomes especially relevant if the evaluation task targets goods related to a service that involves complex interactions of ecosystem processes, which is the case for many services that rely on regulatory-type ecosystem functions such as, for example, water quality (see Section 3).

If all that mattered to society was to apply socio-economics to assess the positive and negative impacts of environmental changes to human well-being, this would mean that ecological sciences should be evaluated by their potential to provide information that is useful for valuation and economic analysis. Certainly, this is not the case. An economic approach that is often championed to evaluate ecosystem changes (e.g., ADAS 2006; Defra 2007) is taking a pragmatic route aimed at making sure that the importance and relevance of managing our ecosystems is reflected in the decision making process. This should not be viewed in opposition but in coexistence to 'holistic' ways of thinking about nature such as, for example, expressed in Aldo Leopold's famous essay "Thinking like a mountain" (Leopold 1949). In this essay, Leopold was criticising himself for not having considered impacts on larger time and spatial scales in his earlier programmes of wolf eradication. To think like a mountain expresses the need to consider the complexity of ecological and social systems that underlie changes and impacts. Economic valuation is limited in its capacity to reflect this complexity. Therefore, the role of ecological sciences for evaluation of ecosystem changes extends beyond the supply of causal relationships of ecosystem functions and services as outlined above. "Learning to think like a mountain is learning to think pluralistically: it is not to stop thinking economically, but it is to start thinking in terms of long-term ecological dynamics in addition to economic analysis" (Norton & Noonan 2007, 672). This calls for a dual approach with regards to evaluating environmental change based on a deep ecological knowledge base. It also suggests a way of thinking that doesn't put "the soil" at the centre of any ecological or socio-economic analysis, but rather focuses on "what soil does" both in interaction with other components of ecosystems and with human activity.

2.2.6 Evaluating changes in ecosystem service flows: economic perspective

2.2.6.1 Valuing changes in flows

As mentioned in previous sections, the ecosystem service concept carries an inherently anthropocentric notion that motivates economic analysis and assessments of ecosystem services (Bateman et al., 2011). Values of ecosystem service flows can enter a cost-benefit analysis, which can be used to guide decisions on policy developments and land and soil management. For economic valuation of ecosystem services, we follow the definition by Fisher et al. (2009): services are those outputs of the ecosystem that contribute directly to human well-being.

Importantly, monetary valuation of ecosystem services is concerned with assessing social welfare changes resulting from a change in ecosystem service provision levels. Service provision levels in before and after situations, or business-as-usual with an alternative situation after policy interventions, are compared and the change is valued in monetary terms. That change in provision results from a change in how the ecosystem is managed, but will also be affected by changes in external conditions (e.g., related to climate change or related to policy drivers). For instance, in the case of carbon valuation, it is not the value of the total carbon stock (e.g. soil organic carbon (SOC) content) that is of interest, but the annual flow of ecosystem services related to a change in the stock (change in productive capacity of land following management change linked to SOC).

Economists value aim to assess how welfare changes in response to marginal changes in ES production/delivery. 'Marginal' changes refer to 'relatively' small changes in ecosystem service provision, or to changes in an 'additional unit' of ecosystem service provision. What considered marginal depends on the scale of the policy level of interest (Fisher et al. 2008), e.g. changes may be considered substantial (non-marginal) at the local scale, yet marginal at the national scale. In such a case, economic valuation can still be meaningful at the national scale. For example, the complete loss of topsoil due to erosion (and hence the loss of most of the SOC) may be considered marginal at a national scale if the area of that site is small relative to the total area of land within a country, but represent a non-marginal change at the local scale.

Marginal values for changes in ecosystem service flows do not have to be constant over provision levels or stocks (Bateman et al., 2011). Indeed, values of ecosystem services should reflect the relative scarcity of their supply: the more of a service can be consumed or enjoyed, the less the value of consuming or enjoying an additional unit of that service. Marginal values associated with, for example, impacts of land management on water quality may decline as the absolute magnitude of service flows and the associated stocks, related to soil organic carbon (SOC) or other ecosystem components, increase. For example, Glenk et al. (2011) found that Scottish citizens' demand for improving water quality in Scottish rivers and lochs decreases with an increasing supply of water bodies in the highest quality category. McVittie and Moran (2010) also found evidence of diminishing marginal values in a study of preferences for marine conservation; relative to a counterfactual of continued decline in marine biodiversity values for halting that decline were higher than values for increasing biodiversity despite this being a 'better' outcome. Marginal values might also be sensitive to scale with a one unit change in service provision at landscape or catchment level being valued less than the same change at field or farm level, although evidence of such sensitivity to scale is often contradictory.

On the other hand, in the context of climate change mitigation, the marginal value of avoiding the emission of an additional unit of GHGs to the atmosphere can be plausibly assumed not to differ much between the first and the last ha of land added to a soil carbon management programme covering a certain area. Given that the total impact of managing all of Europe's soils with the objective to minimise net GHG emissions will be a relatively small contribution to reducing climate change induced damage worldwide (in other words, the contribution is marginal at a global scale), the value associated with reduction in GHGs is not diminishing considerably with increasing levels of provision. The distinction between constant and diminishing marginal values matters, because constant marginal values can simply be multiplied with associated ecosystem service units to arrive at a total value to be used in cost-benefit analysis, while non-constant (diminishing) marginal values require integration over ecosystem service provision levels.

To enter cost-benefit analysis, costs and benefits need to be valued in monetary terms. Monetary valuation of changes in ecosystem service flows involves addressing a number of questions. A starting point is to understand which ecosystem services are provided by the ecosystem, and how they are affected by management change. This requires a sound biophysical analysis of changes to ecosystem service provision against a baseline, considering spatial and temporal effects. Secondly, the directional flows of ecosystem services should be identified – i.e. are service flows contained to the area under management change or flow beyond its boundaries. It further needs to be determined if there are other, non-ecological inputs (human or manufactured capital) that are combined with final ecosystem services to yield goods. While knowing where ecosystem services flow in the landscape may facilitate the identification of beneficiaries, sometimes beneficiaries may reside far away from the actual service flow. Also, as illustrated above, the definition of a final ecosystem service is dependent on the perspective of the beneficiary. Hence, it must be clarified who the beneficiaries are and where they are, also setting boundaries for the economic analysis (i.e. whose benefits and costs should count?). Benefits and costs related to ecosystem service flows need then to be valued and related to each other.

The underlying ecosystem processes, mechanisms and functions need to be understood in the biophysical modelling of ecosystem change to be able to quantify outputs, i.e. the final ecosystem services and goods. Ideally, these outputs are quantified in units that are time and location specific. Hence, valuation is highly reliant on a thorough biophysical understanding of the ecosystem services provided by the ecosystem under various scenarios (the supply side). The costs of ecosystem service provision (supply) need to be understood. The costs of ecosystem service supply vary with the mechanism or policy used across space and time. Equally, the socio-demographics of the beneficiaries (the demand side) needs to be understood, to be able to assess the (monetary) value of changes in ecosystem service provision and eventually to evaluate which policy decision would generate highest net social benefits.

2.2.6.2 Natural capital and stocks

The nomenclature used to locate soil functions, services and values in the ecosystem approach has another useful analogue in economic frameworks used to define and measure sustainability, albeit at a more macroeconomic scale of national income (wealth or wellbeing) accounting. Since the latter has been the recent focus of considerable political debate, it is insightful to draw out this link as a means to motivating further inquiry across the SmartSOIL consortium.

Briefly, soil components as natural assets are part of a natural capital stock. The ways in which soil components combine either with or without non ecological (i.e. man made) input give rise to *flows* of services and ultimately goods. Deconstructing this functionality can motivate a number of questions about measuring soil sustainability that have some relevance to how we manage soil organic carbon (SOC).

The first question relates to ways in which ecological inputs can substitute for each other while still maintaining a plurality of function and service flows that generate goods. Thus, what does increasing SOC content (albeit with human agency) mean for the generation of other non carbon services? The second question relates to the substitutability of ecological and non ecological inputs. Specifically, when or how can man-made capital inputs partly or fully substitute for natural elements? This trade off question is reminiscent of the distinction between weak and strong sustainability and related discourses (cf Neumayer 2003). In the case of strong sustainability, there may be fundamental limits to the substitutability between soil elements. Limits, particularly with respect to non-renewable elements, define thresholds that limit soil function and resilience if they are breached. Ultimately, such thresholds will exist, but within them there may be some substitutability between soil elements that does not compromise service flows. Thus within limits, a form of weak sustainability holds. This implies greater flexibility in the ways we manage soils. For example, the ways in which management might choose to increase SOC.

The weak and strong sustainability distinction leads to useful questions about the relationship between an asset stock and the related service flows. What constitutes (and what should we be recording as) an asset stock and how can we manage and substitute across natural and man-made elements of that stock to optimise service flows? This is similar to the question addressed by Bond and Farzin (2004) who consider soil in a resource theory framework, recognising thresholds implicit in the fact that soil elements have both renewable and non-renewable properties (implicitly there is some non substitutability).

Bond and Farzin (2004) consider soils as a multi-pool portfolio with a particular limiting mobile nutrient (e.g. nitrogen). This specification allows for fertilizer to directly enter the active pool, while tillage initially affects the decadal pool, reflecting the realities of agricultural production. Under these circumstances, it is instructive to define and examine the properties of the steady-state (the stock) and the time paths of the optimal solutions (the flows). Together, these define sustainability criteria of farm-level agricultural practices.

Resource theory determines the socially optimal extraction and accretion rates of soil elements for a given desired service flow. This defines the basis for a resource account that changes year on year and which is one step removed from a wellbeing account for the monetary value of goods and services derived from soil.

This theoretical perspective motivates the question of whether there is some aggregate accounting protocol that the project might choose to adopt to define stocks and flows and as a basis for reconciling the main scientific inputs within a macro (i.e. country or continent

–wide) indicator framework. Such an account essentially converts the ecosystem approach into a sustainability assessment that might be made operational at a range of scales.

3 Understanding complexity

The preceding discussion of soil functions and their relationship to the broader concepts of ecosystem functions/processes and services within an ecosystem services framework has not explicitly acknowledged the complex nature of these relationships. As Dominati et al. (2010) note, some studies (e.g., Sandhu et al. 2008; Porter et al. 2009) have significantly reduced the underlying complexity of ecological processes within soil and interactions with the wider ecosystems. In these examples Dominati et al. (2010) note that each identified ecosystem service was linked to a single underlying ecosystem process or function; consequently economic valuation needs only be based on a single indicator.

In reality ecosystem services and final goods/benefits arise from the complex interactions of multiple processes, both soil and non-soil related. Each final service will result from multiple intermediate services and in turn may contribute to several goods/benefits. Taking an example of intermediate and final ecosystem services linkages from Bennett et al. (2010), the complexity can be illustrated (Figure 4). This figure only identifies where relationships between services exist not what the nature of these relationships are both in the sense of the functional relationship between intermediate and final services (and goods) and also the synergies or trade-offs between services (e.g. food production and habitat provision). Further, we have not indicated where inputs from other non-soil systems, natural and man-made, are required to produce goods/benefits from final ecosystem services. Relevant natural capital stocks and physical properties such as slope, aspect and climate are also omitted.

These complex relationships are compounded by the range of beneficiaries for the final goods/benefits. Some of these are clearly private benefits that will accrue to land owners or managers (i.e. farmers) and provide immediate incentives for relevant management interventions. Other benefits may also be private in nature but are external to land management decisions (e.g. water quality impacts on drinking water treatment costs, flood damage), although mechanisms could be created to reduce external burdens through management agreements such as payments for ecosystem services (PES) schemes. Further benefits may have public good characteristics requiring government intervention to ensure socially optimal supply. In each of these cases there will also be issues of scale, both spatial and temporal, to consider and account for between intermediate services and goods/benefits.

Clearly the application of economic valuation will be affected by the degree of complexity. Values for final goods/benefits can be derived from the range of available market (price and costs) and non-market (revealed and stated preference) approaches. The subsequent use of these values for purposes such as ecosystem service or natural accounting, or designing PES schemes is more difficult. This is an ongoing field of research (e.g. relevant Valuing Nature Network studies[2]) where attempts are being made to characterise species pathways of management interventions, intermediate services, final services and goods/benefits. These studies are adopting approaches such as Bayesian Belief Networks to draw together quantitative and qualitative knowledge of how ecosystems operate to explore how values are affected by changes in management and physical states. However, inherent in these approaches is a necessary simplification of some aspects of the system in order to capture interactions of interest.

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[2] http://www.valuing-nature.net/projects/agricultural-management; http://www.valuing-nature.net/projects/stocks-flows

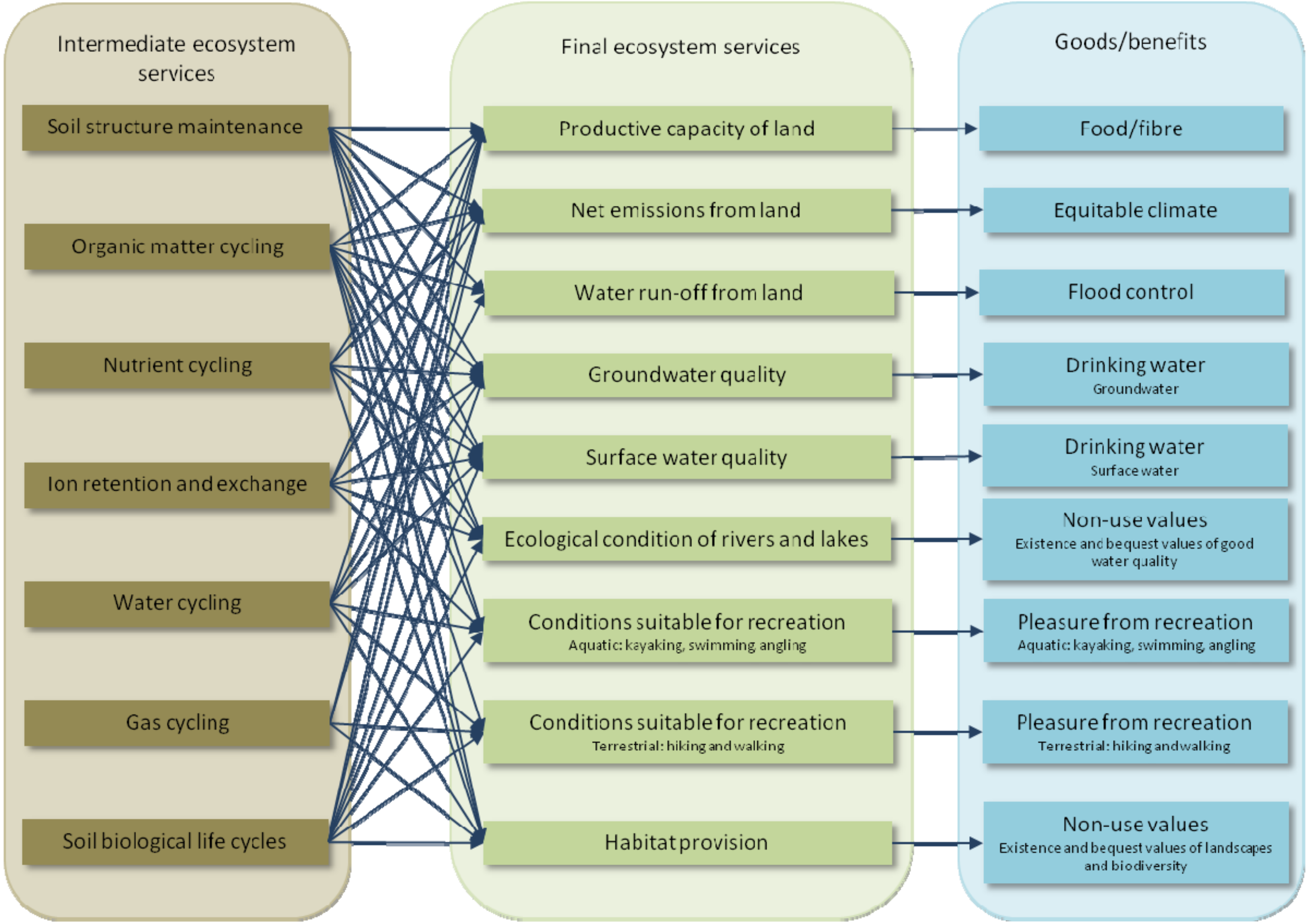

Figure 4 Soil ecosystem service complexity (intermediate and final service links adapted from Bennett et al., 2010)

4 Soil and soil organic carbon (SOC) in an ecosystem service approach

4.1 Approach

In this section, we draw on the conceptual framework outlined in section 2.2.2 to exemplify where soil and SOC are located within an ecosystem service framework. We acknowledge the complexity of interactions between various ecosystem components and processes as described in section 3, but here rather focus on soil-related ecosystem services as illustrated in Figure 5, and therein on the identification of outcomes of soil-related intermediate services to final service provision.

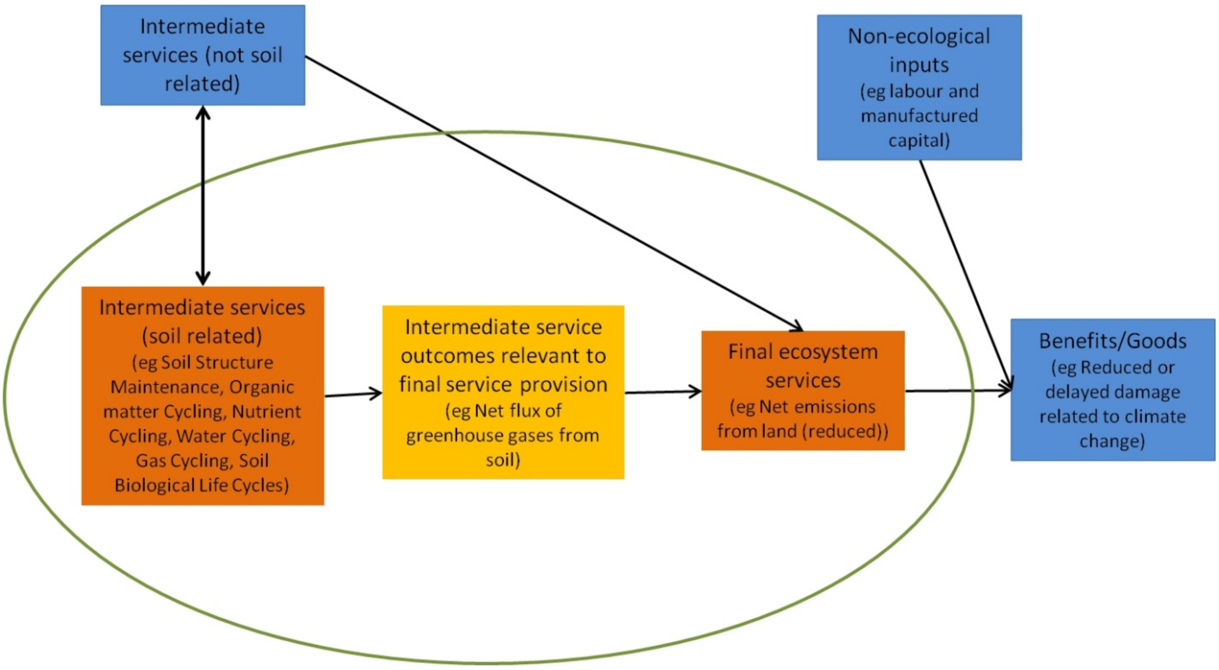

Figure 5 Identification of outcomes of soil-related intermediate services to final service provision

These characterise outcomes of bundles of (soil) processes (using the categorisation of Bennett et al. 2010) for which quantifiable measures exist or can be developed. This is motivated by the need to establish quantifiable dimensions of intermediate service provision in order to better understand and quantify their contribution to final service provision; and to monitor and evaluate changes over time. Ideally, changes in final ecosystem service provision could be described as a function of changes in these measures, and outcomes of other intermediate service outcomes that are not directly linked to soil. If final ecosystem services can be quantified as costs and benefits in monetary terms, this would theoretically enable a consistent assignment of marginal values to soil-related outcomes. Note, however, that a value assigned in this way would relate only to the particular final ecosystem service investigated, because additional effects (trade-offs and synergies) on the provisioning of other final ecosystem services are not considered. Hence it would *not* reflect the value of the change in an intermediate ecosystem service outcome *per se*, but only its marginal contribution to a single final ecosystem service. Also, it is important to consider potential interactions between the quantified intermediate service outcomes when assessing their contribution to final ecosystem service provision.

Furthermore, quantities of a measure of intermediate ecosystem service outcomes could be mapped against changes in SOC levels to determine the sensitivity of intermediate service outcomes to significant changes in SOC levels(and vice versa). This is a key element of the (experimental) soil science research in SmartSOIL. SOC is the key component of soil organic matter, which is at the centre of many soil-related processes and intermediate services (Figure 6).

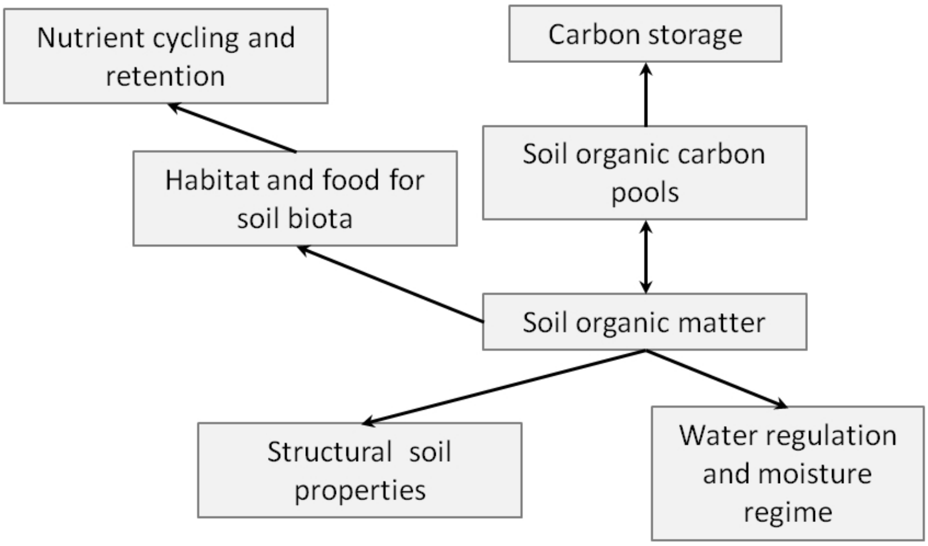

Figure 6 Soil organic carbon (SOC) and soil organic matter (SOM) are at the centre of soil processes

SOM is formed by the biological, chemical and physical decay of organic materials originating from above ground (e.g. litter) and below ground (e.g. roots) organic materials, and SOM formation is influenced by, amongst other factors, temperature, moisture regime, the soil’s physical and chemical properties and their interaction with soil biota. Importantly, the level of SOM formation and decomposition; and the level of SOC accumulation can be influenced by land management. Therefore, we expect the relevance of SOC management to intermediate service outcomes to be generally considerable. However, whether SOC management is equally important for final service delivery depends, amongst other things, on the dependency and immediacy of final service provision with respect to soil-related intermediate ecosystem services, and the availability to influence final service provision via alternative means rather than through SOC management.

4.2 Case study application: lowland agricultural (arable) ecosystem

As discussed in Section 2, an ecosystem service approach is inherently case-study specific. The ecological conditions for service provision differ, and importantly the definition of final ecosystem services is dependent on the perspective of beneficiaries. To illustrate in principle how soil and SOC can be embedded in an ecosystem service approach, we compiled a list of final ecosystem services with a lowland arable agro-ecosystem in North-West Europe in mind. We do not claim here that our list encompasses all possible services that such ecosystems deliver. Despite focusing on a particular agro-ecosystem in one part of Europe, we think that the compiled list can be readily adjusted to other contexts.

We report the following categories associated with each final ecosystem service in a table (Appendix A), which also constitutes the main outcome of this research report:

1) is (biophysical) service provision spatially specific?
2) who are the beneficiaries?
3) what are the related goods (benefits)?
4) which generic categories following the terminology used in the UK National Ecosystem Assessment do the goods (benefits) fall into?
5) what can be said about the potential to substitute final ecosystem services with non-ecological inputs to yield goods (benefits)?
6) what other, non-ecological inputs are possibly combined with final ecosystem services to produce goods (benefits)?
7) which soil processes (intermediate services) are related to final service delivery?
8) what are quantifiable 'outcomes' of intermediate services related to soil that are most relevant to final service provision?
9) how sensitive are these outcomes to changes in SOC levels and management?
10) how sensitive is final ecosystem service provision to changes in (soil-related) intermediate services?
11) what other, non-soil related intermediate services contribute to final service provision?

Table 2 summarises 3), 4), 8), 9) and 10) for all the identified final ecosystem services. The table supports the fact that generally soil contributes to the production of a variety of goods and benefits from which humans derive well-being; and that soil itself, or even the relevant soil outcomes, rarely provide a direct link to the final ecosystem service under consideration. An exception is reducing net emissions from land, which is directly influenced by changes in the net flux of greenhouse gases from soil. Also, it is noteworthy that many final services can be – to some degree – substituted with non-ecological inputs

Table 2 Goods/benefits, final ecosystem services and soil-related intermediate services – case study example

Goods/benefit categories adopted from UK NEA	*Good/benefit*	*FS - Final ecosystem Service (desirable condition)*	*IS - Intermediate service (soil related) outcomes relevant to FS provision*	*Sensitivity of FS provision levels to IS (soil related) outcomes*	*Sensitivity of IS outcomes to changes in SOC levels*
Food / Fibre	Income from production and sale of crop yield (or timber or biomass for fuel production) - 2 main pathways for improved SOC management: changes in yield (increase); changes in fertiliser use efficiency (less inputs required)	Productive capacity of land (high)	Provision of plant available nutrients, control of erosion/loss of topsoil, provision of a platform for (root) growth, provision of a moisture regime that is suitable for plant growth, biological diversity influencing pest/disease control (+/-), provision of a habitat for soil-based pollinators	high	high
Equable climate	Reduced or delayed damage related to climate change	Net emissions from land (reduced)	Net flux of greenhouse gases from soil	very high	very high
Flood control	Reduced damage due to flooding	Water run-off from land (reduced or slowed down)	Water flow moderation and water storage capacity of soil	medium	high
Drinking water	High quality drinking water from groundwater sources	Groundwater quality (high)	Water flow moderation, groundwater recharge, nutrient leaching	high	high
Drinking water	High quality drinking water from surface water sources	Surface water quality (high)	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	medium-high	high
Energy	Electricity	Sedimentation of reservoirs/dams used for electricity production (reduced)	Control of sedimentation/erosion (loss of topsoil), water flow moderation	medium-high	high
Existence value associated with aquatic habitat	Knowing that rivers and lakes are and will be in good condition for future generations (or others living at present)	Ecological condition of rivers and lakes (good condition)	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	medium-high	high
Recreation/Tourism	Pleasure and fulfilment derived from fishing	Availability of locations suitable for fishing / fishing certain fish species, including aspects of fish availability, water quality and aesthetic/landscape components (high availability to serve demand locally)	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	low-high	high
Food	Fish catch	Fish catch (high)	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	low-medium	high
Recreation/Tourism	Pleasure and fulfilment derived from swimming	Availability of conditions suitable for swimming (high availability to match demand locally)	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	low	high
Recreation/Tourism	Pleasure and fulfilment derived from kayaking	Availability of conditions suitable for kayaking (high availability to match demand locally)	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	low	high
Recreation/Tourism	Pleasure and fulfilment derived from hiking and walking	Provision of a natural platform for hiking and walking (question is what people perceive as important ecosystem features that would enhance their experience)	Soil in a state that enables recreation activity; soil enables habitat growth that is perceived as relevant for the recreational experience; avoiding potential thresholds for loss of culturally important landscapes (e.g dustbowls, soil erosion)	low-medium	low-medium
Non-use value (bequest motives) for aquatic habitat	Knowing that agricultural landscapes provide habitat also for future generations (or others living at present)	Habitat provision supporting certain species compositions (present)	Soil enables (demanded) habitat growth; avoiding potential thresholds for loss of culturally important landscapes (e.g dustbowls, soil erosion)	low to very high	low to very high
Aesthetic/Inspiration	Landscape benefits (different paths: soil as visual component; soil as platform for landscapes)	Not definable - the 'landscape' itself is final ecosystem service	Avoiding potential thresholds for loss of culturally important landscapes (e.g dustbowls, soil erosion)	probably not very high	probably not very high
Recreation/Tourism ; Food	Pleasure and fulfilment derived from hunting and 'field sports'	Availability of hunted species (high)	Soil enables habitat growth; this may include considerations about the food web of the hunted species	low	low to very high
Medicine	New products/pharmaceuticals based on genetic material found in soils	Genetic variability in soils across space (high)	Soil genetic diversity	very high	high
Pollution control	Depends on designated use of land; e.g. property values, which may be compromised by contamination	Bio-remediation (high)	Filtering and buffering capacity w/r to specific pollutants, biological capacity to contain contaminants	high	high

(manufactured capital) to produce benefits. This points to (weak versus strong) sustainability issues that need to be uncovered to better understand the implications of allowing the soil resource to degrade while keeping the level of goods/benefit production constant through replacement of soil-related services by non-ecological inputs. Indeed, from a whole systems and life cycle (optimal control) perspective, it is questionable whether the use of some substitutes will provide outcomes that are socially desirable.

The importance of SOC management to relevant intermediate service outcomes has been judged to be fairly high, underscoring the central role of SOC in many soil processes. The picture is much more mixed for evaluations of the contribution of soil-related intermediate service outcomes to final service provision. For example, we do not expect fish catch related to commercial fishing to be very sensitive to small changes in erosion control and reduced nutrient run-off. It may be of relevance for some particularly sensitive commercial species, but often there is a large degree of non-ecological inputs and man-made engineering involved in such enterprises.

The identification of intermediate service outcomes related to soil that are relevant to final service provision is particularly useful to identify future research needs with respect to understanding and quantifying crucial links between 'what soil does and provides' and the associated final ecosystem services. This is a key outcome of this report to soil science research and the SmartSOIL project. Thinking around outcomes of bundles of (soil) processes for which quantifiable measures exist or can be developed instead of soil processes themselves can help to re-focus research to provide better integration with socio-economic analysis and assessment. (Systematic) reviews of experimental and field research investigating the relationships between the identified outcomes and proxies for final ecosystem services or goods (e.g. yield or biomass production) would be a useful task to pursue. Such systematic reviews could help to establish key knowledge gaps, describe limits to generalising findings across ecosystem types and bio-climatic zones, and characterise the level of uncertainty associated with impacts of changes in intermediate service outcomes on final service provision.

In Table 2, the intermediate service outcomes relevant to final service provision are described without providing specific and appropriate measures for them. The development of appropriate measures is another natural step in moving this work forward. Additionally, it is worth investigating how developed measures would relate to indicators of soil stocks and natural capital.

Another avenue for further research is to map the interactions between outcomes that have been associated with final ecosystem services. This would be particularly important for making the ecosystem service approach a practical tool for assessment of flow changes arising from to land use and management changes. Smith et al. (under review) have conducted an analysis along this line by relating key outcomes (services) of soil to an

Millennium Ecosystem Assessment (MEA, 2003) inspired classification of ecosystem services. Their work illustrates the numerous inter-linkages and emphasises the need to recognise them in order to identify trade-offs and synergies, and potential 'win-win' situations to be endorsed by land managers and policy makers.

5 Conclusions

The ecosystem service approach has attracted considerable interest from scientists and policy makers alike. In soil science, the use of an ecosystem service approach has been developed in parallel with the soil function concept, which has found its way into EU policy developments such as the proposed EU Soil Framework Directive. There is thus a need to clearly align both approaches from a conceptual perspective. In the first part of this report, we have made some concrete suggestion how this can be achieved. As a key message, soil functions should be viewed as (bundles of) soil processes that are providing input into the delivery of (valued) final ecosystem services. In this respect, they overlap with intermediate services in more recent ecosystem service categorisations.

The distinction between intermediate and final ecosystem services is important, if an ecosystem service approach is intended to serve as a basis for the economic assessment of changes in service delivery due to land use or land management changes. Ecosystem service (and associated goods/benefits) provision is underpinned by complex interactions of multiple processes, both soil and non-soil related. It is important to understand the underlying biophysical complexity of service delivery in order to establish a sound scientific underpinning for valuation; and in order to identify the range of trade-offs and synergies associated with the ecosystem response to alternative land management. However, approaches aimed at capturing complexity in service delivery ultimately require that some aspects of the system are simplified in order to capture interactions of interest.

The identification of intermediate service outcomes related to soil that are relevant to final service provision is particularly useful to help identify future research needs in order to quantify and understand crucial links between 'what soil does and provides' and the associated final ecosystem services. The SmartSOIL project aims to investigate the impacts of SOC and soil management on the productive capacity of land, either improving the growth conditions of crops and therefore yields, or by increasing fertiliser use efficiency, related to a reduced level of fertiliser input required for optimal plant growth. Measuring SOC content and monitoring greenhouse gas fluxes associated with alternative soil management regimes will ultimately contribute to a better understanding of the role of SOC in the provisioning of other important ecosystem services. The case study approach taken in this report to localise SOC within an ecosystem service approach may be used as a template to define other ecosystem service impacts of SOC management practices and – at least qualitatively – assess associated trade-offs and synergies in intermediate and final service provision.

It is important to understand the economic implications of changes in soil management: monetary valuation is concerned with changes in ecosystem service flows that are related to changes in stocks or natural capital. While values of changes in flows provide input into cost-benefit assessments of, for example, policy interventions aimed at increasing SOC levels, they do on their own not provide the information required to assess the sustainability of such interventions and management changes. The latter requires information on stocks of ‘soil assets’ and the degree of substitutability of natural and man-made elements of stocks to optimise service flows over time.

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Appendix

Appendix A. Ecosystem services of a lowland arable agro-ecosystem in North-West Europe: links between soil-related ecosystem service and benefits

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
#	**Comment**	**Spatial location**	**Spatially specific (Yes/No)**	**Beneficiary**	**Goods/benefit categories adopted from UK NEA**	**Good/benefit**	**Potential to substitute final ecosystem services with non-ecological inputs to yield goods (benefits)**	**Final ecosystem Service (desirable condition)**	**Non-ecological inputs**	**Sensitivity of final service provision levels to intermediate service (soil related) outcomes**	**Sensitivity of intermediate service outcomes to significant changes in SOC levels**	**Intermediate service (soil related) outcomes relevant to final service provision**	**Intermediate services - soil**	**Intermediate services - non-soil**
				Individual or group of individuals who benefit	based on UK NEA, Chapter 2, Figure 2.3	detailed description of the market and non-market goods		'Final ecosystem services' are then those biophysical outcomes of ecosystems that directly impact on human well-being (benefits)	Final ecosystem services may be combined with human or manufactured capital to produce goods (benefits)	Do small to moderate changes in 13 affect 9? The more they affect 9, the higher the sensitivity; based on expert judgment	Do small to moderate changes in SOC levels affect 13? The more they affect 13, the higher the sensitivity; based on expert judgment	These characterise outcomes of bundles of (soil) processes for which quantifiable measures exist or can be developed; changes in these measures could then be related to changes in final ecosystem services	Intermediate services describe those structures and (bundles of) processes that do not yield direct benefits to humans, but only indirectly via effects on other – final – ecosystem services.	
1	a,b,c,d	Local	Y	Farmer / land manager	Food / Fibre	Income from production and sale of crop yield (or timber or biomass for fuel production) - 2 main pathways for improved SOC management: changes in yield (increase); changes in fertiliser use efficiency (less inputs required)	drops in productive capacity can be countered by increases in inputs to some degree at a cost; depends on the relative scarcity of substitutes (e.g. fertilisers); limited possibility to replace soil/land as growth substrate	Productive capacity of land (high)	labour, capital, technology, pesticides, fertiliser	high	high	Provision of plant available nutrients, control of erosion/loss of topsoil, provision of a platform for (root) growth, provision of a moisture regime that is suitable for plant growth, biological diversity influencing pest/disease control (+/-), provision of a habitat for soil-based pollinators	SSM, OC, NC, IE, WC, GC, BC (indeed this would also include aspects related to the retention of fertile top soil; and aspects of regulation of soil-borne diseases and pests)	abstracted water designated for irrigation; maybe pollinators; fixed quantity inputs: climate (temperature, precipitation, etc.); plant cultivars used
2		Global	N	Global community	Equable climate	Reduced or delayed damage related to climate change	numerous other options to mitigate climate change that are not land-based exist	Net emissions from land (reduced)	this depends on how reduced net emissions can be achieved; may require labour and manufactured capital	very high	very high	Net flux of greenhouse gases from soil	SSM, OC, NC, GC, BC, WC --> N2O	very specific to land use and management
3		Catchment	Y	Downstream population	Flood control	Reduced damage due to flooding	structural hard-engineering solution to flood management are available at a cost up to a certain severity of run-off events	Water run-off from land (reduced or slowed down)	labour, capital (implementation and maintenance of structures aimed at reducing/slowing down run-off; or aimed at reducing flood damage (eg flood walls etc))	medium	high	Water flow moderation and water storage capacity of soil	SSM, OC, NC, BC,WC (improving 'buffering' capacity of land; structural barriers to fast run-off such as buffer strips and wetlands)	biomass production (in case of biological structural barriers and buffers); all services contributing to buffering capacity of land
4	e	Catchment	Y	Water utilities (and eventually their consumers)	Drinking water	High quality drinking water from groundwater sources	water can be treated up to a certain degree of contamination at a cost - removal of some pollutants, however, difficult if certain thresholds are crossed	Groundwater quality (high)	labour, capital, infrastructure and everything else needed to treat water (eg chemicals and treatment infrastructure)	high	high	Water flow moderation, groundwater recharge, nutrient leaching	SSM, OC, NC, IE, WC, BC (eg via infiltration and sub-soil)	all services related to water flow moderation above ground
5	e	Catchment	Y	Water utilities (and eventually their consumers)	Drinking water	High quality drinking water from surface water sources	water can be treated up to a certain degree of contamination at a cost (but technical problems e.g. when colouring due to DOC exceeds certain threshold)	Surface water quality (high)	labour, capital, infrastructure and everything else needed to treat water (eg chemicals and treatment infrastructure)	medium-high	high	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	SSM, OC, NC, IE, WC, BC (eg via reduced soil transport into the water systems above ground)	all services related to water flow moderation above ground
6	e,f	Catchment	Y	Electricity utilities using water power (and eventually their consumers)	Energy	Electricity	no substitutes (maybe build reservoirs/dams in catchments with low sedimentation rates)	Sedimentation of reservoirs/dams used for electricity production (reduced)	labour, capital, infrastructure needed to procduce electricity from water flows	medium-high	high	Control of sedimentation/erosion (loss of topsoil), water flow moderation	SSM, OC, NC, IE, WC, BC (eg via reduced soil transport into the water systems above ground)	biomass production (plant cover reducing run-off/erosion and impacting on soil structural properties)
7	e	Local/regional/ national	N	Everyone with an interest/value derived from non-use of waterbodies (rivers and lakes)	Existence value associated with aquatic habitat	Knowing that rivers and lakes are and will be in good condition for future generations (or others living at present)	no substitutes	Ecological condition of rivers and lakes (good condition)	none	medium-high	high	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	SSM, OC, NC, IE, WC, BC (eg via reduced soil erosion and transport of chemicals into the water systems above ground)	biomass production (plant cover reducing run-off/erosion and impacting on soil structural properties); all services related to the buffering functions of rivers and lakes themselves
8	e,g	Catchment	Y	Recreational fishermen	Recreation/Tourism	Pleasure and fulfilment derived from fishing	depends on local conditions and relative scarcity of suitable locations	Availability of locations suitable for fishing / fishing certain fish species, including aspects of fish availability, water quality and aesthetic/landscape components (high availability to serve demand locally)	capital (transport, gear etc.); infrastructure (access)	low-high	high	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	SSM, OC, NC, IE, WC, BC (contributing to water quality and quantity)	all services related to the buffering functions of rivers and lakes; and services that enable a functioning food web in rivers and lakes; everything related to landscape aspects
9	e	Catchment	Y	Commercial fishermen	Food	Fish catch	no substitutes	Fish catch (high)	labour, capital, farmed fish: technology and inputs such as feedstock, hormones or pharmaceuticals	low-medium	high	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	SSM, OC, NC, IE, WC, BC (contributing to water quality and quantity)	all services related to the buffering functions of rivers and lakes; and services that enable a functioning food web in rivers and lakes
10	e,g	Catchment	Y	Water-based sports: swimming	Recreation/Tourism	Pleasure and fulfilment derived from swimming	depends on local conditions and relative scarcity of suitable locations	Availability of conditions suitable for swimming (high availability to match demand locally)	capital (transport, gear etc.); infrastructure (access)	low	high	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	SSM, OC, NC, IE, WC, BC (contributing to water quality and quantity - assuming that more pleasure is derived from swimming in 'clean' water)	all services related to the buffering functions of rivers and lakes; and services; everything related to landscape aspects
11	e,g	Catchment	Y	Water-based sports: canoeing and kayaking	Recreation/Tourism	Pleasure and fulfilment derived from kayaking	depends on local conditions and relative scarcity of suitable locations	Availability of conditions suitable for kayaking (high availability to match demand locally)	capital (transport, gear etc.); infrastructure (access)	low	high	Control of sedimentation/erosion, reduced nutrient run-off, water flow moderation	SSM, OC, NC, IE, WC, BC (contributing to water quality and quantity - assuming that more pleasure is derived from kayaking in 'clean' water)	all services related to the buffering functions of rivers and lakes; and services; everything related to landscape aspects
12	h	Landscape	Y	People hiking and walking in the countryside	Recreation/Tourism	Pleasure and fulfilment derived from hiking and walking	depends on local conditions and relative scarcity of suitable locations	Provision of a natural platform for hiking and walking (question is what people perceive as important ecosystem features that would enhance their experience)	labour, capital (installation and maintenance of hiking paths and other infrastructure, e.g. related to access)	low-medium	low-medium	Soil in a state that enables recreation activity; soil enables habitat growth that is perceived as relevant for the recreational experience; avoiding potential thresholds for loss of culturally important landscapes (e.g dustbowls, soil erosion)	SSM, OC, NC, IE, WC, GC, BC (but depends if changes in these factors influence hiking or walking experience)	highly locally specific
13	h	Local/regional/ national	N	Everyone with an interest/value derived from non-use (bequest motives) of agricultural landscapes	Non-use value (bequest motives) associated with aquatic habitat	Knowing that agricultural landscapes provide habitat also for future generations (or others living at present)	depends on local conditions and relative scarcity of demanded habitats	Habitat provision supporting certain species compositions (present)	this depends on what kind of habitat/species people want; where they want it; and in which quantities relative to other habitats/species	low to very high	low to very high (depending on habitat)	Soil enables (demanded) habitat growth; avoiding potential thresholds for loss of culturally important landscapes (e.g dustbowls, soil erosion)	SSM, OC, NC, IE, WC, GC, BC (everything needed to supply the habitat people want)	all services related to the provision of the valued habitat type
14	h	Landscape	Y	Local population/visitors (use values), everyone with an interest/value derived from non-use of agricultural landscapes	Aesthetic/Inspiration	Landscape benefits (different paths: soil as visual component; soil as platform for landscapes)	depends on the availability of similar landscapes	Not definable - the 'landscape' itself is final ecosystem service	this depends on what kind of landscape people want; where they want it; and in which quantities relative to other landscapes	probably not very high	probably not very high	Avoiding potential thresholds for loss of culturally important landscapes (e.g dustbowls, soil erosion)	SSM, OC, NC, IE, WC, GC, BC (everything needed to supply the landscape people want)	all services associated with the provision of the demanded landscapes
15		Local	Y	Land owners and users	Recreation/Tourism; Food	Pleasure and fulfilment derived from hunting and 'field sports'	depends on relative scarcity of hunting grounds	Availability of hunted species (high)	capital (transport, gear etc.); infrastructure (access)	low	low to very high (depending on habitat)	Soil enables habitat growth that supports demanded hunting species; this may include considerations about the food web of the hunted species	SSM, OC, NC, IE, WC, GC, BC (but depends if on habitat requirements for hunted species)	all services related to the provision of the hunted species
16		Local/regional/ national	N	Global community, research community	Medicine	New products/pharmaceuticals based on genetic material found in soils	no substitutes	Genetic variability in soils across space (high)	knowledge,R&D	very high	high	Soil genetic diversity	SSM, OC, NC, IE, WC, GC, BC	all services that interact with soil influencing soil genetic diversity
17		Local/regional	Y	Land owners and users	Pollution control	Depends on designated use of land; e.g. property values influenced by the possibility to use land for specific purposes, which may be compromised by contamination	some substitutes (e.g. chemicals; removal of contaminated soil) available depending on degree of contamination and pollutant	Bio-remediation (high)	Non-ecological inputs to alter physical or biological state	high	high	Filtering and buffering capacity w/r to specific pollutants, biological capacity to contain contaminants	SSM, OC, NC, IE, (WC, GC), BC	probably highly locally specific

Comments:

a: farmers may have a set of farming objectives unrelated to income maximisation; here we assume that maximising income from land is the predominant driver of farmers'/land managers' activities
b: there may also be benefits to consumers related to maintaning or increasing food production locally, at present and into the future; we would argue that the final service for this benefit would also be productive capacity of land, possibly adding 'maintained or increased' to emphasise the relevance of the time scale
c: instead of focusing on the (mean) productive capacity of land as a final service, it would also be possible to consider if land/soil/SOC mangement would impact on the variance of productive capacity over time. The related benefit to farmers would stem from a reduced risk premium of farming activities
d: for livestock systems with any own fodder production, productive capacity of land contributes to income from livestock or dairy sales
e: 4, 5 and 6 as well as 7-11, have an important quantity dimension, too, in areas where water quantity is a limiting factor. Quantity and quality issues may be linked, for example due to greater dilution of pollutants, or because water flows impact on ecology, which in turn impacts on 5 (non-use values) or 6-9 (use values). Hence, sufficent water quantity is a limiting condition for water quality
f: another benefit related to reduced sedimentation and moderation of water flows could be enabling riverine transportation via the final service (reduced) sedimentation requiring less dredging
g: generally one can assume that water quality requirements are lower for kayaking/canoeing than for swimming, and recreational fishing; however, there may be a lot of individual heterogeneity regarding the infuence of water quality on demand for these activities
h: a key issue related to soil here is the avoidance of system shifts; for example, losing peatland habitat/landscape due to severe erosion or conversion to other landuse (eg agriculture)

Abbreviation	**Description**
SSM	Soil structure maintenance
OC	Organic matter cycling
NC	Nutrient cycling
IE	Ion retention and exchange
WC	Water cycling
GC	Gas cycling
BC	soil biological life cycles

taken from Bennett et al. 2010, Agriculture, Ecosystems and Environment 139