SOILGUARD

Sustainable soil management to unleash soil biodiversity potential and increase environmental, economic and social well being

Grant Agreement no. 101000371

D1.3 Soil Biodiversity and Wellbeing Framework

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Summary

SOILGUARD addresses the urgent need to conserve and sustainably use soil biodiversity. It aims to advance understanding of how soil biodiversity, in combination with other natural capital assets, underpins the delivery of ecosystem services and human benefits, and how response options, such as sustainable soil management, can enhance such benefits. This requires the collection and integration of evidence establishing links between soil management, soil biodiversity, soil multifunctionality, soil-mediated ecosystem services and human wellbeing across biogeographical regions. The integration of this biophysical, climatic and socio-economic evidence from experiments, modelling and valuation approaches needs to be undertaken using a common holistic approach that is transparent about causal relationships. This will be facilitated using the Soil Biodiversity and Wellbeing Framework (SBWF); a holistic conceptual framework that is easy to communicate to the SOILGUARD stakeholder communities.

The SBWF specifies how the different disciplinary components of the SOILGUARD project interrelate and are affected by drivers and pressures at different scales. It considers: (i) the different components of the biophysical system that affect the delivery of ecosystem services, i.e. the soil natural capital assets that are characterised by soil/ecosystem properties, such as extent, stock, condition and structure, and the soil/ecosystem functions that represent flows or processes; (ii) how the soil natural capital assets combine to produce different ecosystem services (and potentially also disservices); (iii) how the ecosystem services interact resulting in trade-offs and synergies between different types of services; (iv) the different components of the socio-economic system that affect ecosystem service demand, i.e. the attributes of the beneficiaries, including their preferences, location, or other social or economic attributes of the population; and (v) the benefits supplied, how they are economically or socially valued and how this affects different aspects of human wellbeing. The SBWF also takes into account how all these components and interrelationships are affected by different drivers, focusing on climate change and land degradation, and how the resulting impacts on the socio-ecological system may trigger responses, such as policy and management strategies, to maintain or enhance the soil natural capital assets (i.e. soil biodiversity) and hence influence the supply of ecosystem services.

The version of the SBWF reported in this deliverable has been informed by a review of relevant conceptual frameworks from existing projects, initiatives and disciplines. It has also been informed through several cycles of iteration with the SOILGUARD Network of Knowledge to identify, define and agree key terms, project elements and the links between them. As part of building consensus across the project, we have developed an initial glossary of terms to accompany the SBWF, agreed to use the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES) classification of nature's contributions to people (NCP), and undertaken a first mapping of the project elements to the different components of the SBWF. The latter will be extended through the specification of indicators for each component of the SBWF in the analytical part of framework.

This version of the SBWF will be iteratively reviewed and updated during the lifetime of SOILGUARD. A final version of the conceptual and analytical framework will be published at the end of the project that will have the potential to become the global standard for future assessments of soil biodiversity status and its contribution to soil multifunctionality, ecosystem services and human wellbeing.

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1. Introduction

The Soil Biodiversity and Wellbeing Framework (SBWF) provides a holistic approach for structuring the complex evidence from SOILGUARD on the links between soil management, soil biodiversity, soil-mediated ecosystem services (ES) and human wellbeing. Increasing understanding of the links between soil biodiversity and soil-mediated ES enables the quantification of the environmental, economic and social costs of maintaining current unsustainable agricultural and forestry practices, under the increasing severity of climate change. This highlights the importance of promoting the sustainable use of soil biodiversity to protect soil multifunctionality, enhance the delivery of soil-mediated ES and increase economic, social and environmental wellbeing.

This version of the SBWF has been developed to integrate the different disciplinary aspects of the SOILGUARD project. It will be tested and validated throughout the project as methods, data and analyses progress. The SBWF will be re-evaluated and updated at the end of the project based on this learning so that it can be used as guidelines for future assessments of soil biodiversity and its links with soil multifunctionality, ES value and human wellbeing.

The SBWF consists of two components: (i) the conceptual framework that visualises and describes how the different disciplinary components of the project interrelate and are affected by drivers and pressures at different scales; and (ii) the analytical framework that specifies the methodologies and indicators for each component of the conceptual framework. This deliverable reports on the conceptual framework upon which the analytical framework will build.

The development of the conceptual part of the SBWF has involved a short scoping review of existing, relevant conceptual frameworks to ascertain those elements that may be useful for SOILGUARD. This was used to create a first draft SBWF that was presented to the SOILGUARD Network of Knowledge at the project kick-off meeting (June 2021) and at a WP1 Workshop (July 2021). Both events involved all members of the SOILGUARD consortium. The aim of the latter workshop was to identify and agree the main components that need to be represented in the framework and the links between them. Participants mapped their contributions to SOILGUARD to the different elements of the draft SBWF and provided general feedback to improve the framework. The SBWF was then revised based on this feedback and iterated for a final round of feedback to WP leaders. This final round of feedback focused on clarifying what aspects of the framework would be measured or modelled in SOILGUARD and hence, paved the way for the analytical part of the framework.

The analytical part of the SBWF is composed of: (i) the indicators selected for the assessment of soil biodiversity and multifunctionality (WP2-WP3); (ii) the list of indicators for the economic and socio-cultural valuation of ES benefits (WP4); (iii) categories of human wellbeing to which those benefits contribute (WP5); and (iv) the methodologies used to assess and/or value each indicator. These will be reported separately in the deliverables from WPs 2 to 5, and brought together in the final update to the SBWF (Deliverable 1.4) as the analytical framework is refined during the project lifespan with stakeholders from the WP1 Action Groups, particularly Action Group 1 (cross-biome network of sites).

This deliverable also discusses appropriate ES classifications and definitions for key terms related to the SBWF and SOILGUARD in general. Agreements on starting points for the project are given that help foster consistency in understanding and use across the project, but these may be further developed as needs arise during the project lifespan.

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2. Review of conceptual frameworks

Conceptual frameworks are generally developed to address a specific question or set of questions. For SOILGUARD, key questions include:

- How does soil biodiversity, in combination with other natural capital assets, underpin ES and human benefits?
- What land and soil management practices enhance soil biodiversity and the delivery of human benefits from ES?
- How do threats, such as land degradation, unsustainable soil management and climate change, affect soil biodiversity, soil-mediated ES and human benefits?
- What responses improve the sustainable use of soil biodiversity, protect soil multifunctionality and increase economic, social and environmental wellbeing?

Several existing conceptual frameworks were reviewed and matched to our key questions to identify those elements of existing frameworks that might be worth taking forward into the SBWF. The review was specifically limited to existing studies that had developed conceptual frameworks that focus on the links between biodiversity and/or natural capital, ES and societal benefits/human wellbeing.

2.1. Millennium Ecosystem Assessment conceptual framework

The Millennium Ecosystem Assessment created one of the earliest conceptual frameworks linking biodiversity, ES, human well-being and drivers of change (MA 2005) (Figure 2.1). The framework portrays the interlinkages between indirect (e.g. demographic, economic, technological, political and cultural drivers) and direct (e.g. land use change, climate change, resource use) drivers of biodiversity change, and how these result in changes to ES (provisioning, regulating, cultural and supporting services), which in turn affect human well-being (e.g. health, security, basic materials for a good quality of life). The framework also illustrates that these interactions can take place across different spatial and temporal scales, and that different strategies and interventions can be applied at many points in this framework to enhance human well-being and conserve ecosystems (MA 2005).

2.2. UK National Ecosystem Assessment conceptual framework

The conceptual framework of the UK National Ecosystem Assessment (UKNEA; Mace & Bateman 2011) built on the Millennium Ecosystem Assessment, but also incorporated advances in representing the economics of ES (TEEB; see section 2.5) and valuation (Ring 2010; Fisher and Turner 2008) (Figure 2.2). It includes elements which would yield information on valuation for economists and recognises the importance of considering policy-led changes (through changes in direct and indirect drivers of change) over a defined time period. The conceptual framework emphasises the role of ecosystems in providing services that bring improvements in well-being to people. The UKNEA considered three broad categories of human well-being defined in terms of different value types: economic value, health value and shared (social) value.

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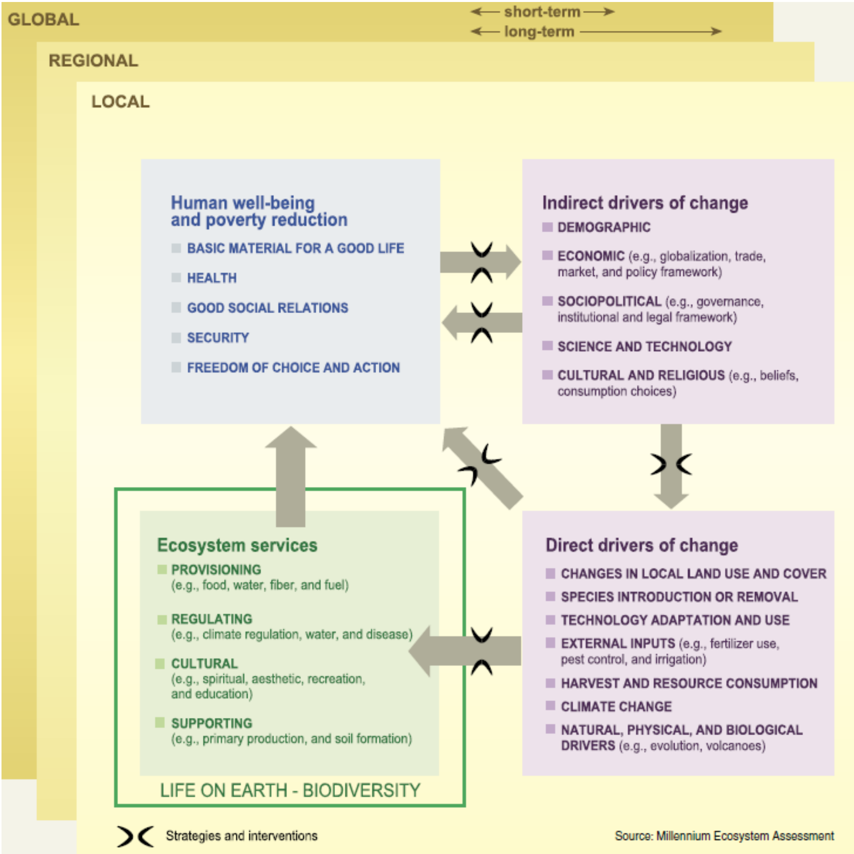

Figure 2.1: Conceptual framework for the Millennium Ecosystem Assessment showing links between indirect and direct drivers, ES and human well-being (MA 2005).

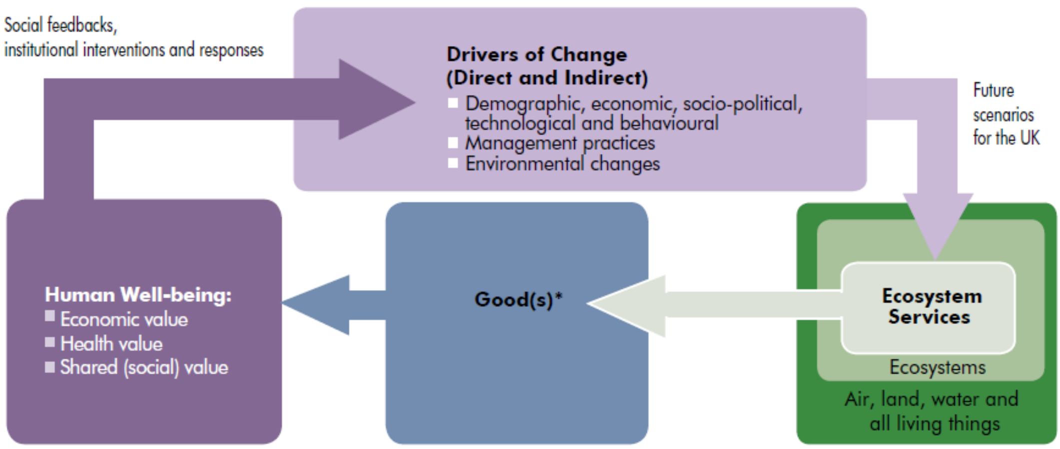

Figure 2.2: Overall conceptual framework for the UKNEA showing links between ecosystems, ES, good(s), valuation, human well-being, change processes and scenarios (Mace & Bateman 2011).

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2.3. Framework for Ecosystem Service Provision

The Framework for Ecosystem Service Provision (FESP) is based on the Drivers-Pressures-State-Impact-Response (DPSIR) framework (Figure 2.3) (Rounsevell et al. 2010). It provides detailed definitions of the DPSIR components for ES assessments and includes the role and attributes of ES beneficiaries in addition to the attributes relevant to ES supply. It also incorporates mechanisms of either mitigation or adaptation to environmental change through the effect of response strategies acting on specific pressure or state variables (Rounsevell et al. 2010).

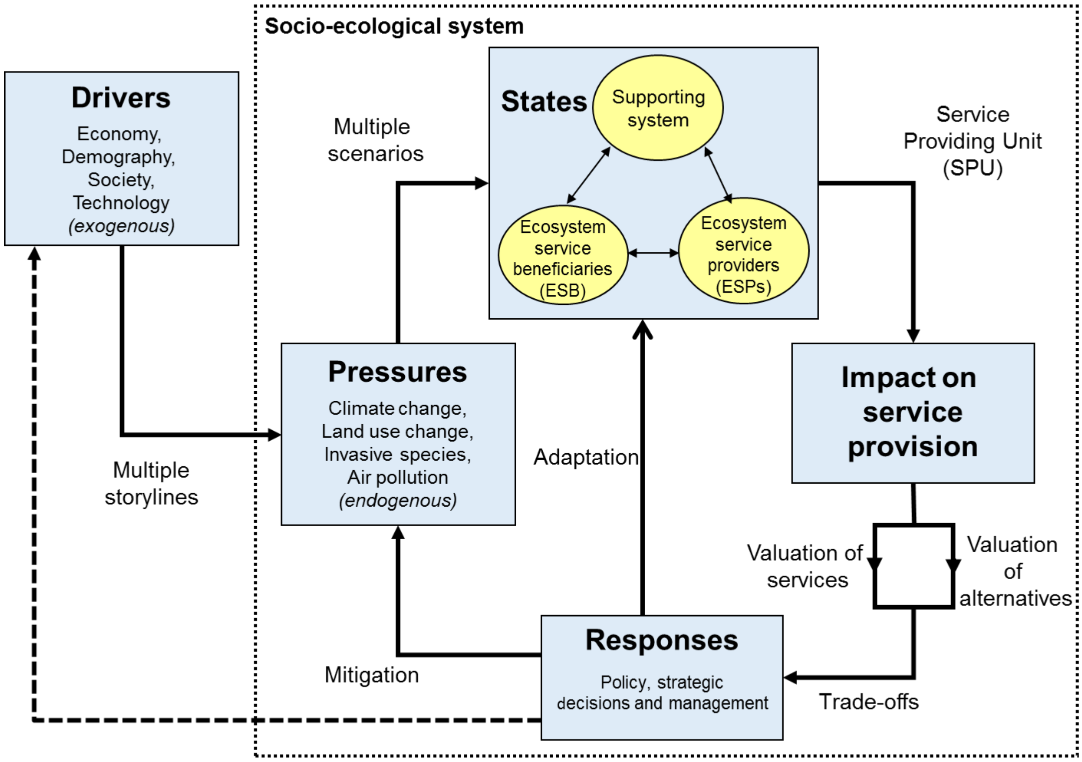

Figure 2.3: Framework for Ecosystem Service Provision (FESP) based on a modified Driver-Pressure-State-Impact-Response (DPSIR) framework (Rounsevell et al. 2010).

2.4. The ecosystem service cascade framework

The ES cascade framework (Figure 2.4a) links ecological processes with elements of human well-being following a pattern similar to a production chain. It was first developed by Haines-Young and Potschin (2007). The framework shows a cascade of linkages between different elements of relevance in ES assessments; ecosystem properties (biophysical structure or stock) produce ecosystem functions (flows), which provide ES that have benefits for humans, to which a value (economic/socio-cultural) can be attributed (Potschin and Haines-Young 2011). A function provides a service if it produces a benefit for humans, which can vary by spatial and socio-economic context.

Potschin and Haines-Young updated the framework to include pressures and to demonstrate how it fits with the Common International Classification of Ecosystem Services (CICES; Figure 2.4b) (Potchin and Haines-Young 2016).

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Several researchers have used and adapted the cascade framework, incorporating intermediate and final ES (see Section 2.7), ES dis-benefits, and defining different aspects of human well-being (Saarikoski et al. 2015; Hernandez-Morcillo et al. 2013; Rendon et al. 2019) (Figure 2.5).

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(b)

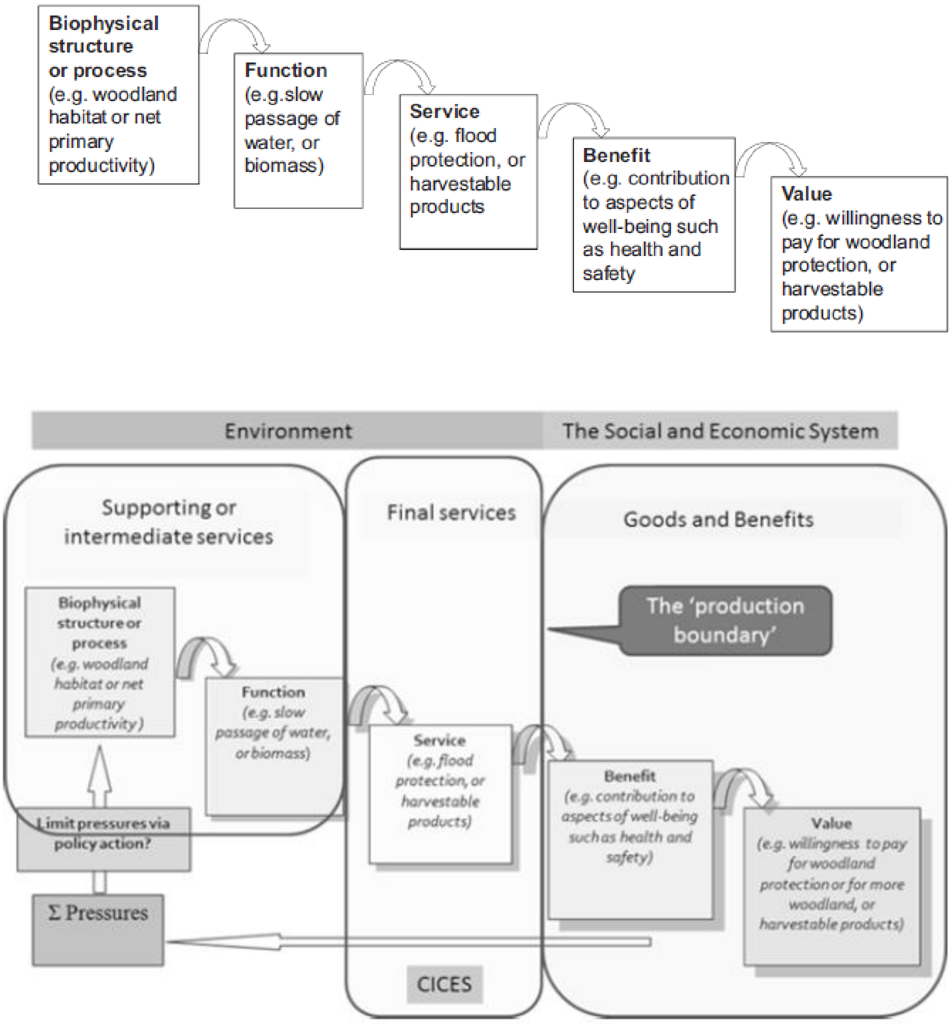

Figure 2.4: The ES cascade framework: (a) original version of Potschin and Haines-Young (2011); and (b) updated version of Potchin and Haines-Young (2016) supporting CICES.

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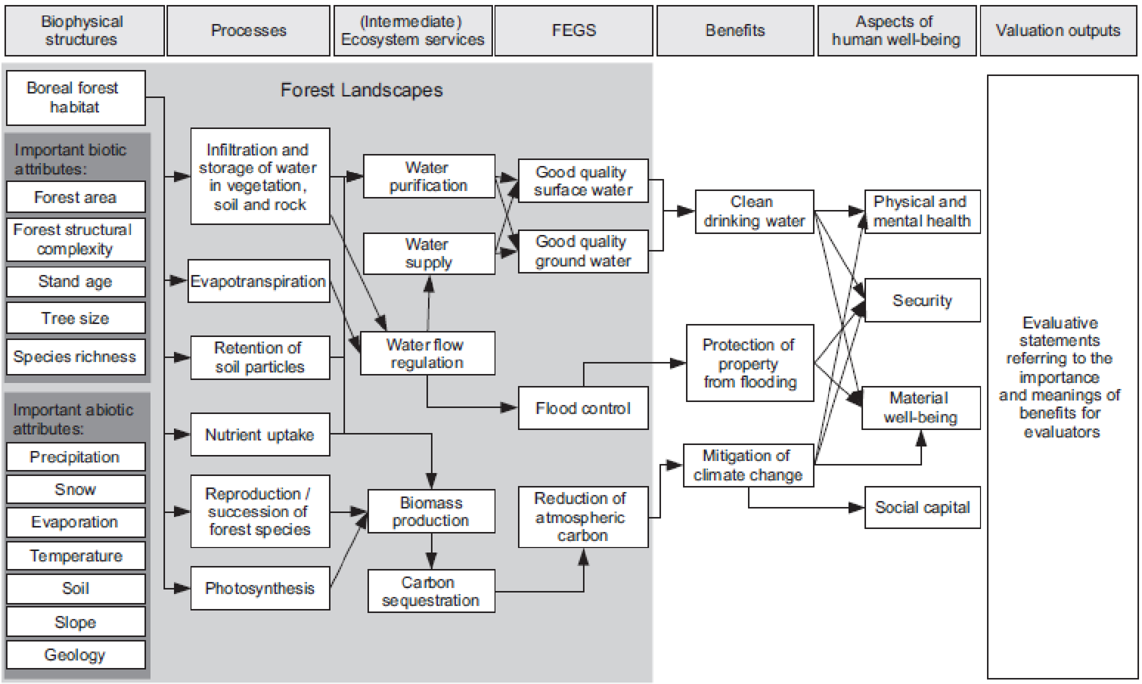
(a)



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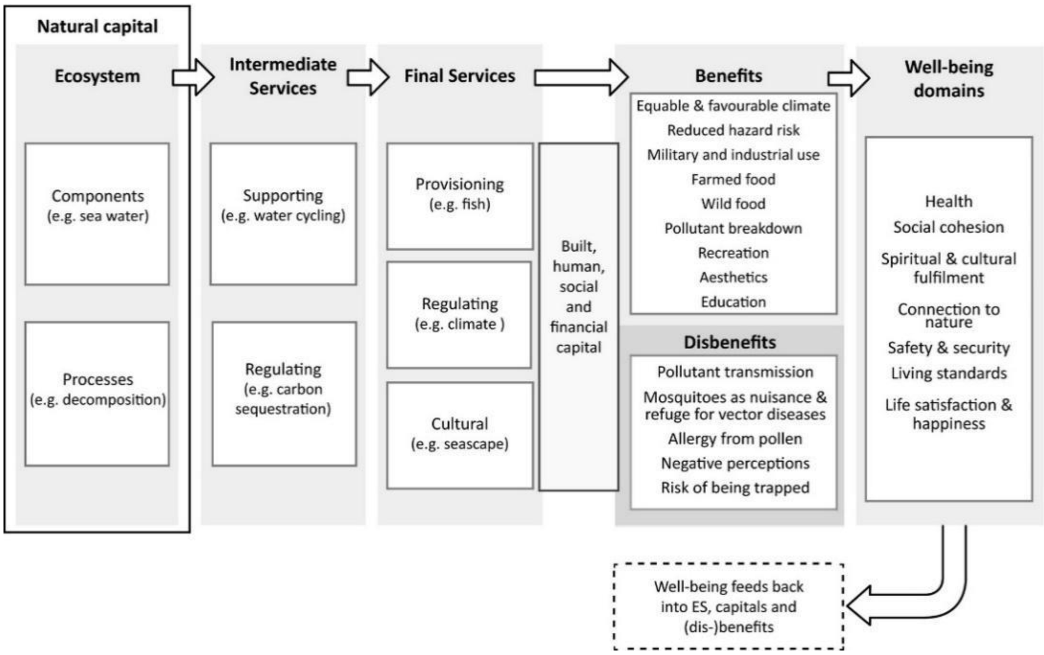

Figure 2.5: Extensions of the ES cascade framework: (a) Saariskoski et al. (2015) who included intermediate and final ES - this application of the framework is for the services of good quality surface and ground water, flood control and reduction of atmospheric carbon; and (b) Rendon et al. (2019) who incorporated dis-benefits and classified well-being into seven domains: health, social cohesion, spiritual and cultural fulfilment, connection to nature, safety and security, living standards, life satisfaction and happiness.

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2.5. The TEEB conceptual framework

The Economics and Ecology of Biodiversity (TEEB 2010) based its conceptual framework on the ES cascade framework (Figure 2.6). TEEB extended the framework by adding a feedback from human wellbeing to institutional and individual value perceptions that influence the use of ES and how this informs the management and/or restoration of ecosystems and biodiversity.

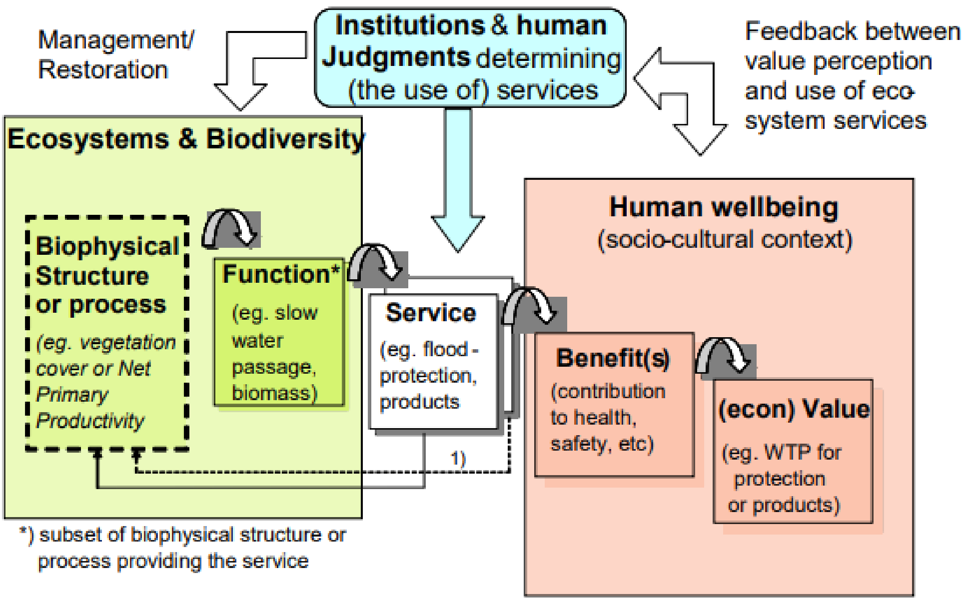

Figure 2.6: Conceptual framework from TEEB (2010).

2.6. GEO BON Ecosystem Service Working Group conceptual framework

Tallis et al. (2012) present a conceptual framework (Figure 2.7) from the GEO BON Ecosystem Services Working Group that also has similar elements to the ES cascade framework. It was designed to integrate national statistics, numerical models, remote sensing and in situ measurements to track changes in ES across the globe. This conceptual framework distinguishes among the structure and function of ecological systems relevant to a service (the supply), the service actually used or enjoyed by people (the service), and the change in people's well-being that results (the benefit). A key aspect of this framework is that the service comes about through both supply and benefit, and is not strictly linear; an important distinction that also arises in other more recent frameworks.

The metrics of supply indicate the biophysical potential of a system to produce a given benefit. Service metrics add information on the location and activities of human beneficiaries and indicate the amount of service actually delivered to people. Benefit metrics add information on society's preference for a given level of benefit and indicate how important a given amount of service is in economic or non-economic terms.

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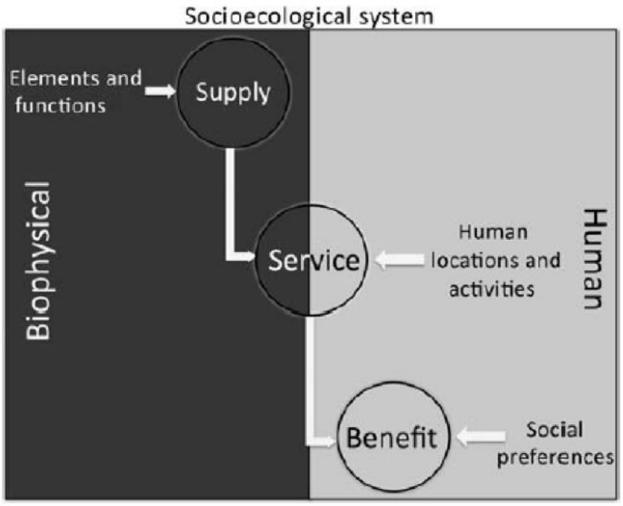

Figure 2.7: Conceptual framework of the GEO BON Ecosystem Service Working Group (Tallis et al. 2012).

2.7. Framework for Final Ecosystem Goods and Services

The Framework for Final Ecosystem Goods and Services (FEGS) was developed by the US Environmental Protection Agency Office of Research and Development (Landers and Nahlik, 2013). The concept of FEGS was adopted as a foundation for defining, classifying and measuring ES. The term "final" is used to emphasise the ultimate (i.e., last) biophysical entity in nature used by individuals to acquire a [human] benefit. As La Notte (2017) states 'while all ecosystem services are derived from ecological processes (or socio-ecological processes) not all processes produce ecosystem services'.

FEGS are principally derived from nature, with the ecological production function distinguished from the overall total economic value, which includes an economic production function (Landers and Nahlik 2013; Boyd and Bhanzaf 2007). Reasons for using FEGS include avoiding ambiguity and double counting, focusing on beneficiaries, and linking natural and social capital.

2.8. IPBES Conceptual Framework

The conceptual framework of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Figure 2.8) includes six interlinked elements constituting a social-ecological system that operates at various scales in time and space: nature; nature's benefits to people (similar to ES); anthropogenic assets (built, human, social and financial capitals); institutions and governance systems and other indirect drivers of change (socio-political, economic, technological and cultural); direct drivers of change (climate change, habitat conversion and exploitation, pollution, alien invasive species); and good quality of life (similar to human wellbeing, defined in terms of food/water/energy/livelihood security, good health, social relationships, equity, spirituality and cultural identity) (Díaz et al. 2015).

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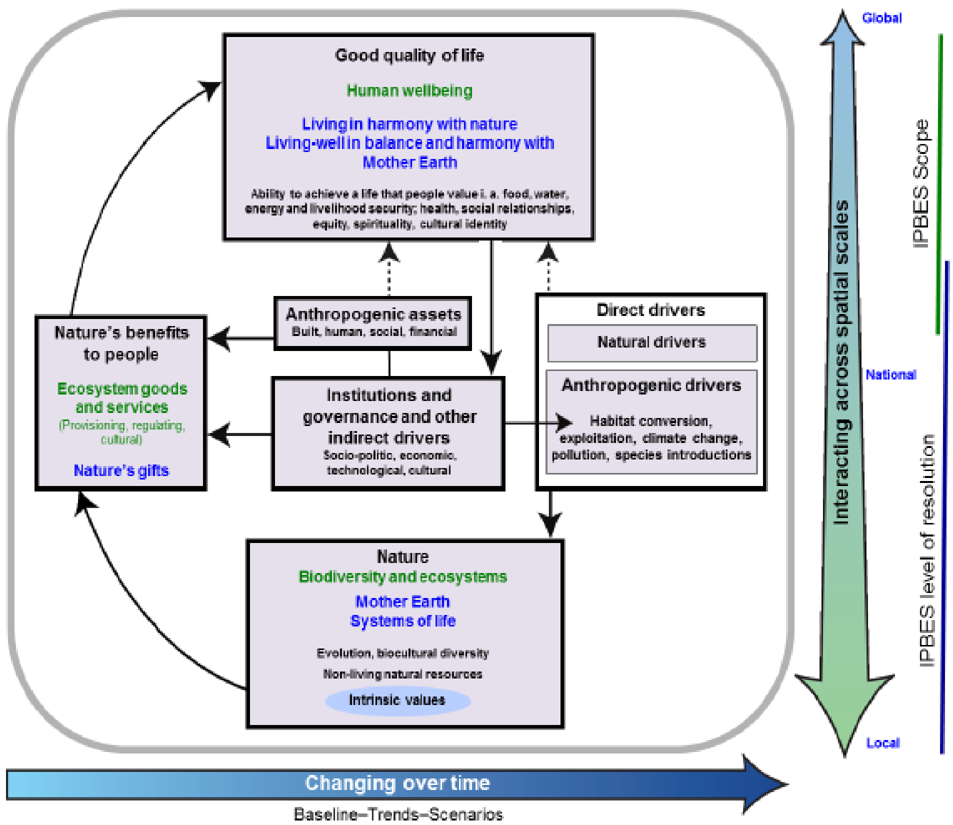

Figure 2.8: IPBES conceptual framework (Díaz et al. 2015).

2.9. Jones et al. (2016) Conceptual Framework

Jones et al. (2016) developed a conceptual framework for combining stocks and flows of natural and human-derived capitals in ES assessments. They applied a systems approach to identify critical natural capital and critical human-derived capital to guide sustainable management of the stocks and flows of all forms of capital which underpin provision of multiple ES (Figure 2.9a). The framework emphasises the multiple roles that humans perform in an ES assessment, e.g. as co-producers of ES, as beneficiaries of those services, and through the addition of capital to realise those services.

This conceptual framework has been updated to better emphasise the role of users/beneficiaries and their characteristics (defined as social, cultural and human capital) in determining how services are delivered (Figure 2.9b) (Jones et al. 2021). This approach helps in particular with cultural services, but the framework is transferable to all types of service.

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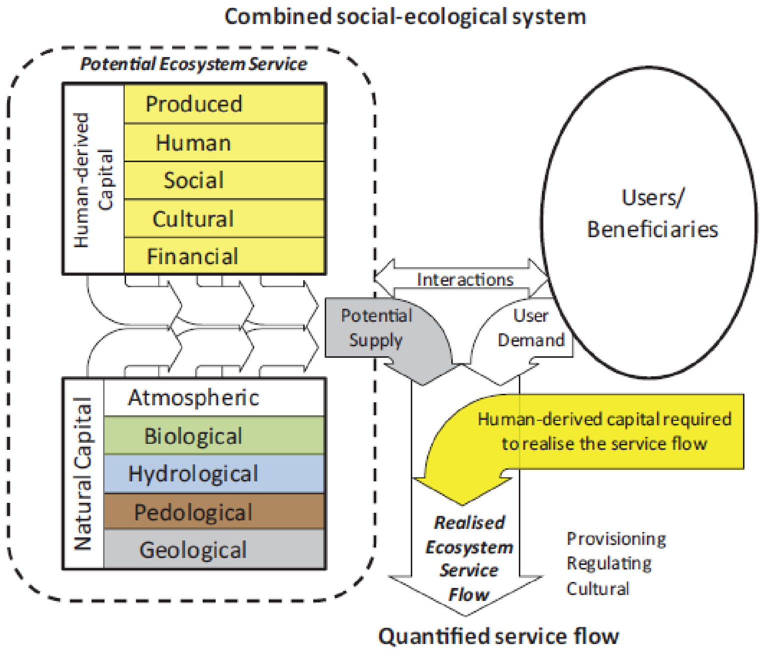
(a)



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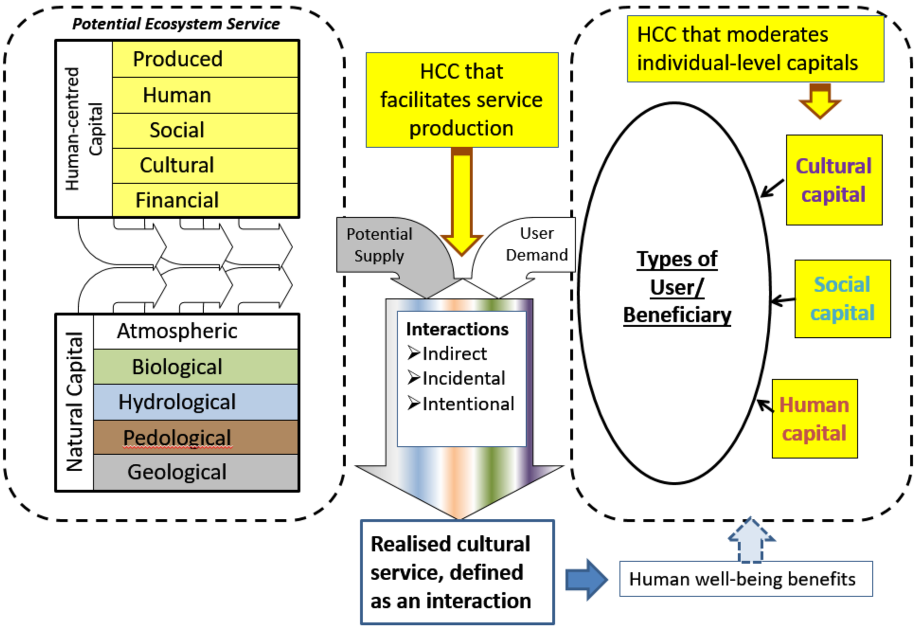

Figure 2.9: Conceptual framework showing how different forms of human-derived capital and natural capital co-produce potential ES, which in combination with demand from users/beneficiaries then produce a flow of realised ES: (a) original version based on Jones et al. (2016); and (b) updated version based on Jones et al. (2021) (Note: HCC – Human Centred Capital).

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2.10. UKCEH Natural Capital Metrics conceptual framework

The Natural Capital Metrics project undertaken by the UK Centre for Ecology & Hydrology focused on evidencing the linkages between natural capital assets and people who benefit from them (Figure 2.10) (Harrison et al. 2017). It combines elements of the ES cascade framework of Potschin and Haines Young (2011) with elements from the Framework for Ecosystem Service Provision (FESP) of Rounsevell et al. (2010) and the conceptual framework of Jones et al. (2016) to show the multi-directional interrelationships between (i) the natural world (Natural Capital Assets); (ii) the aspects of the natural world that impact on humans wellbeing (Ecosystem Services and Disservices); (iii) the humans who receive these impacts (Beneficiaries); (iv) internal Pressures; and (v) external Drivers within a socio-ecological system.

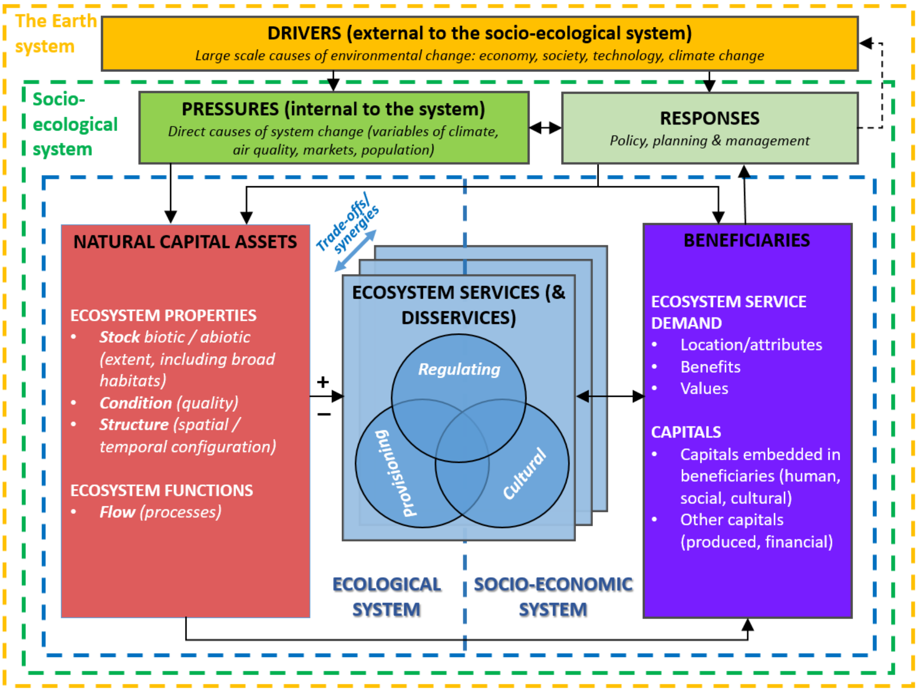

Figure 2.10: Conceptual framework of Natural Capital Metrics project (Harrison et al. 2017).

2.11. Representation of soil and soil biodiversity in ES conceptual frameworks

The first mention of soils in the context of 'natural capital' can be traced back to the UK Parliamentary records. In a letter to the Canadian Legislative Council from William Badgley Esq of Montreal, dated January 27th 1836 (Badgley 1837), he refers to "the climate, the soil, the natural advantages, or if I may be allowed the expression, the Natural Capital or wealth of the country." Recent consideration of soil and the services it supplies came to prominence with Daily et al (1997). A range of articles that highlighted and explored the contribution of biota to ES followed (Wall et al. 2004; Bell et al. 2005; Lavelle et al. 2006; de Bello et al. 2010; Gianinazzi et al. 2010; Guimares et al. 2010; Smukler et al. 2010; Hedlund & Harris 2012; Keith and Robinson 2012; Wall et al. 2012).

Barrios (2007) offered a conceptual framework focused on the link between soil biota, ES and land productivity. The framework considered soil biota and the direct and indirect impacts that soil

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processes (C and N cycling, food web interactions, soil structure modification) have on soil-based ES (Figure 2.11).

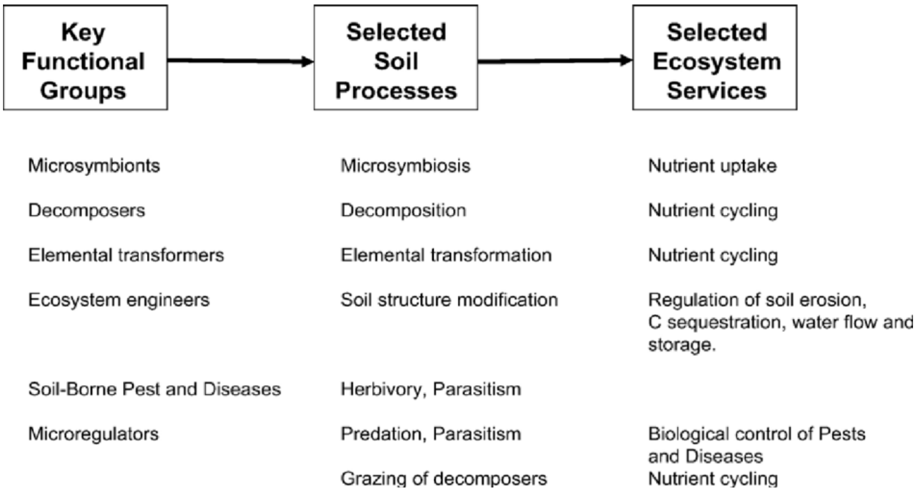

Figure 2.11: Links between key functional groups of soil biota, soil processes and ES as proposed by Barrios (2007).

Increasingly the soil community has picked up and considered soils in the context of ES beyond biota, for example in the context of soil hydrology (Clothier et al. 2008). Concurrently there has been a growing discussion of the role of soils as natural capital (Knowler 2004). Palm et al. (2007) began linking classical soil science with natural capital and ES concepts, acknowledging the link to soil vulnerability and resilience to degradation. Several conceptual frameworks have emerged from these discussions, including Robinson et al. (2009) who suggest a typology for soil natural capital that builds on the approach of Barrios (2007) (Robinson et al. 2013, Figure 2.12).

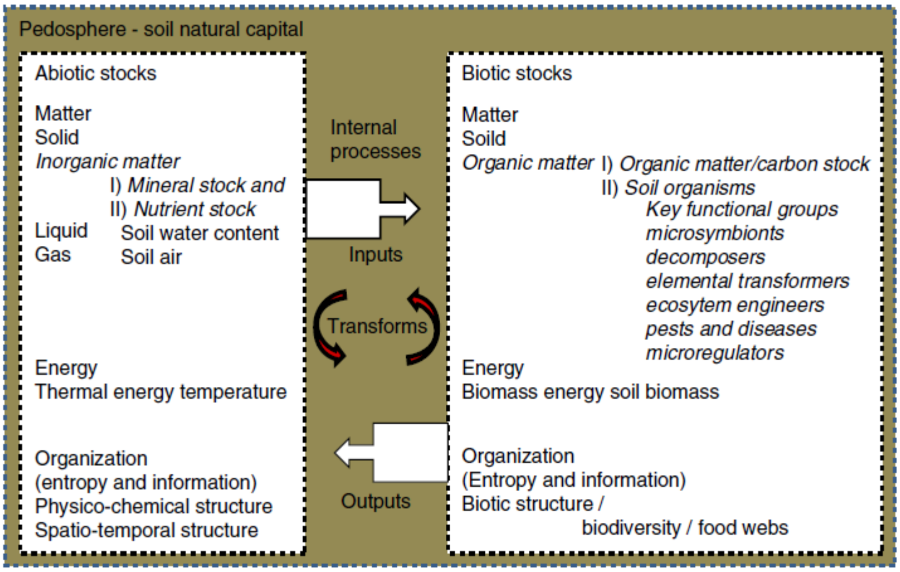

Figure 2.12: Soil natural capital stocks using a matter, energy and organisation framework (Robinson et al. 2009) divided between abiotic and biotic components (Robinson et al. 2012). Reproduced from Robinson et al. (2013).

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Dominati et al. (2010) recognised that soils had been underrepresented in the ES approach and developed a framework to classify and quantify soil natural capital and ES, synthesising the different aspects. The framework consists of five main interconnected components: (i) soil natural capital, characterised by standard soil properties; (ii) the processes behind soil natural capital formation, maintenance and degradation; (iii) drivers (anthropogenic and natural) of soil processes; (iv) provisioning, regulating and cultural ES; and (v) human needs fulfilled by soil ES (Figure 2.13).

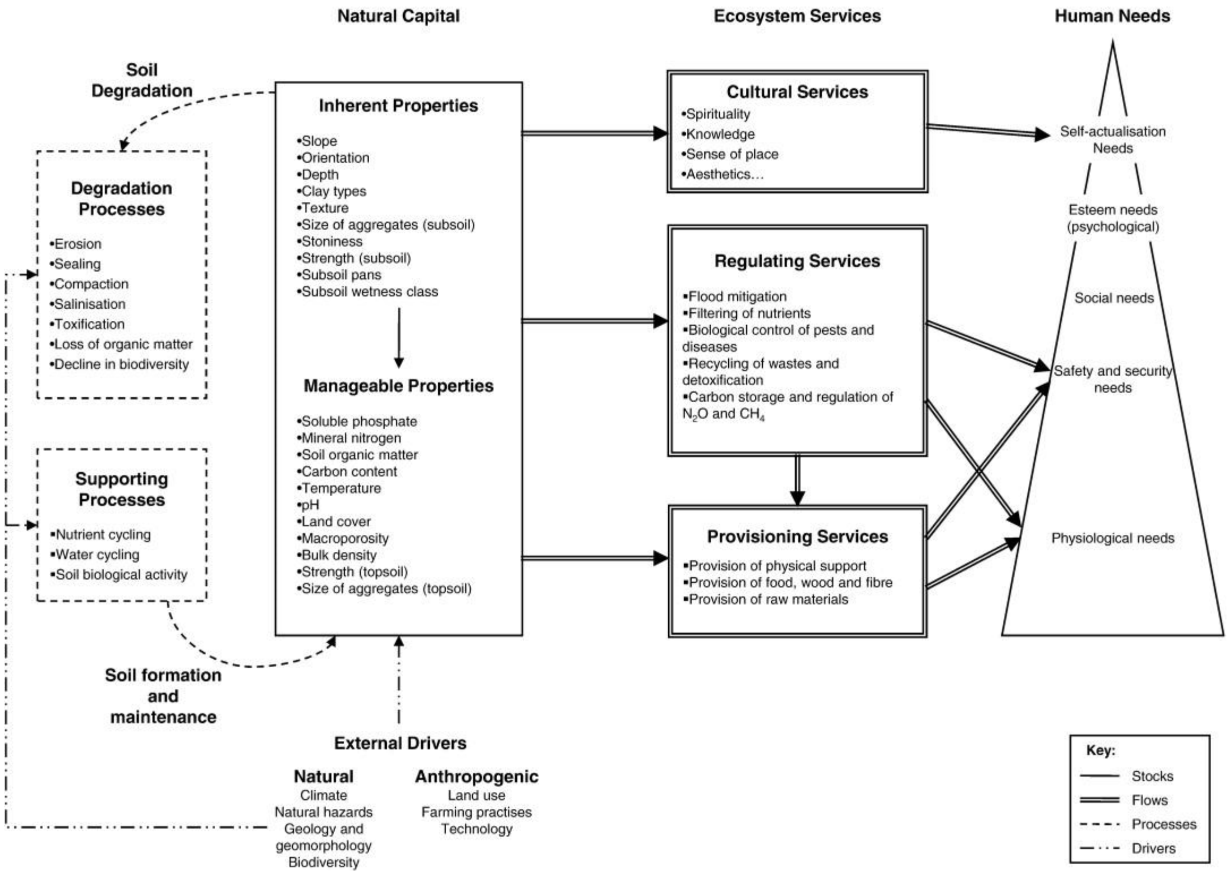

Figure 2.13: Conceptual framework linking soil natural capital and ES (Dominati et al. 2010).

Soil properties used to characterise soil natural capital are the measurable physical (e.g. porosity, texture), chemical (e.g. pH, readily available phosphate), and biological (e.g. microbial biomass) characteristics of a soil. They also describe a number of supporting processes: nutrient cycling, water cycling and soil biological activity. Each soil service is the product of multiple properties and processes. Dominati et al. (2010) also suggest that it is useful to distinguish between inherent soil properties that derive from soil formation and those that can be influenced by active management. These could also be classified by timescales, e.g. long-term fixed inherent properties, such as geology/slope, and variable factors, such as climate (medium-term) and management (short-term). They describe a number of degradation processes that also need to be accounted for: erosion, sealing, compaction, loss of organic matter and biodiversity, salinisation and toxification.

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Dominati et al. (2014) went on to consider how these frameworks fit within the wider context of the Earth system. They considered the idea of ecological infrastructure supporting the ES supply chain (Figure 2.14).

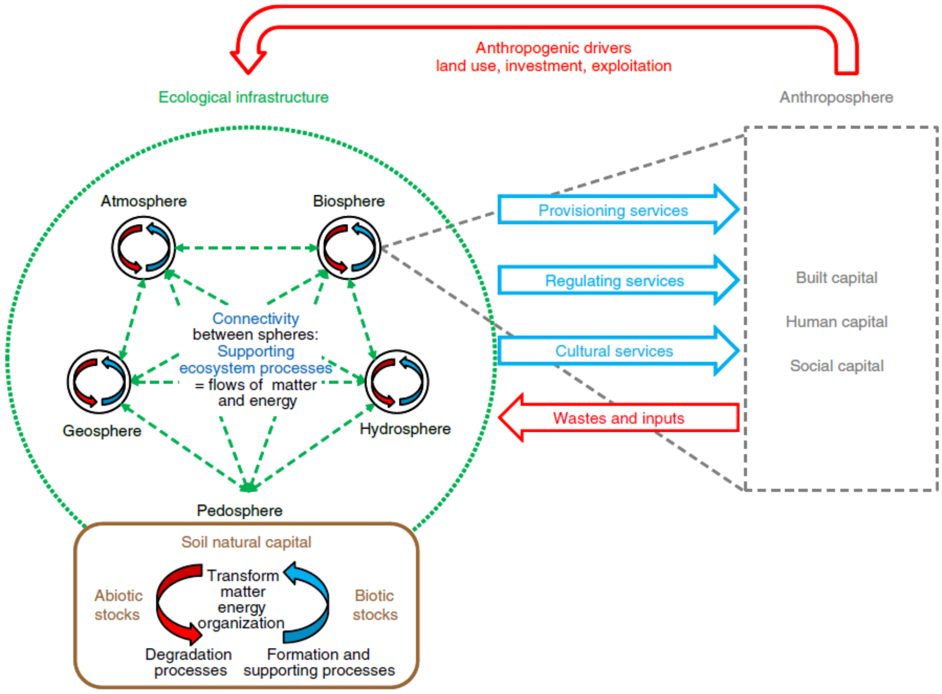

Figure 2.14: Combined framework for natural capital, ecological infrastructure and ES (Dominati et al. 2014).

Concurrent activities such as the UN System of Environmental and Economic Accounting (UN SEEA, 2014) recognised the importance of soils, highlighting soils as one of the seven natural assets within the SEEA. Obst (2015) pointed out that whilst soils were part of the SEEA, they remained one of the least developed parts. The SEEA was incorporated into the EU Inca project (production of ecosystem accounts) in 2015[1].

The SEEA identifies seven principal assets (Mineral & energy resources, Timber, Aquatic, Other biological, Water resources, Land cover, and Soil), that complement the UN accounts for goods and services from which we derive Gross Domestic Product (GDP). The SEEA are satellite accounts and there are a range of accounts within it that describe the flows of environmental goods and services. The latest version of the SEEA[1] contains condition accounts. These are broadly divided into abiotic condition (physical or chemical characteristics), and biotic condition, which are subdivided by composition (e.g. invertebrates), structure (food webs) and function (n fixers or decomposers). Moreover, they promote the use of what are termed logic chains to identify the flows of ES. Each logic chain for a given ES has a number of components: (i) the ecosystem service; (ii) the common ecosystem types (ES are supplied either by individual ecosystems or in combination); (iii) factors determining supply (ecological and societal); (iv) factors determining use; (v) potential physical metrics; (vi) the associated benefit/s; and (vii) the main users and beneficiaries.

[1] https://ec.europa.eu/environment/nature/capital_accounting/index_en.htm

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Attempts have been made to demonstrate how a SEEA based framework could be applied to soils (Robinson et al. 2017). This work demonstrates the clear need for data demonstrating change in the amount or condition of the asset. It is worth noting that the basic reporting unit of SEEA is by ecosystem type, and that components of ecosystems have not been extensively explored within the SEEA framework currently. Therefore, many aspects of soil ES are still relatively poorly specified from a SEEA perspective.

2.12. Summary

Many of the existing conceptual frameworks include characteristics of the biophysical or ecological system and of the human or socio-economic system, with ES joining the two. The more recent frameworks see the ES as occurring from an interaction between social/human systems and natural systems, rather than a linear progression of benefits which people receive from nature.

Properties included in the biophysical system varied, but encompassed ecosystem properties, natural resources or natural capital assets in general or specific ecosystem structures, as well as ecological processes and functions. Some frameworks differentiated intermediate and final ecosystem services, others differentiated between ecosystem stocks (extent and condition) and ecosystem service flows, whilst others linked natural capital assets to major land use types.

Properties included in the human system also varied, but encompassed beneficiaries (and their preferences or demand for services, and the characteristics of users which shape that demand), benefit, value and aspects of human well-being. A few also highlighted other types of capital that may be required to realise an ecosystem service flow. In terms of ES, most frameworks include them in general (i.e. as a single entity), with a few breaking them down into provisioning, regulating, cultural and supporting services.

The role of biodiversity in the ES approach and hence its position within an ES framework has caused some discussion (Silvertown 2015; Mace et al. 2012). The ES approach is anthropocentric and some have been concerned that biodiversity, particularly where it cannot be easily monetised or where its role may be incompletely understood, may not be sufficiently accounted for (Silvertown 2015; Jax & Heink 2015). Biodiversity is thought to contribute to ES in multiple ways. It contributes to the fundamental underpinning processes (and regulating services) that produce final ES, it may also provide resilience against environmental change if there is sufficient redundancy within the system (Mace et al. 2012). In CICES, biodiversity is recognised as important in maintaining nursery populations and habitats (including gene pool protection) that are needed for sustainable populations, although Liquete et al. (2016) suggests that nursery populations should be related to benefit and ecological integrity analysed separately. Species and genetic diversity can contribute directly to ES, e.g. genetic diversity of wild crop relatives is a natural asset which can be used to improve crop breeding. Biodiversity contributes to cultural services through physical and experiential interactions such as aesthetic appreciation, education as well as non-use values, characteristics or features of living systems that have an existence value that lead to moral well-being and good mental health (CICES). Jax & Heink (2015) considers that motivation for the inclusion of biodiversity in the ES approach should be considered, i.e. conservation, resource protection or moral (existential value). In SOILGUARD, we focus on soil biodiversity which is even less well understood in relation to processes and functions and unlikely to be well recognised by many people from a cultural perspective. An understanding of how soil biodiversity relates to ecosystem function and other elements of natural capital, including biodiversity of other organisms, is critical.

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3. The Soil Biodiversity and Wellbeing conceptual framework (SBWF)

The scoping review of existing, relevant conceptual frameworks was used to identify the core elements that it would be useful to include in the Soil Biodiversity and Wellbeing Framework (SBWF). A draft framework was developed and iterated around the SOILGUARD Network of Knowledge during several events (the kick-off meeting in June 2021, the WP1 workshop in July 2021) and through online exchanges for comment. The final conceptual framework is shown in Figure 3.1.

The SBWF builds strongly on the conceptual framework from the Natural Capital Metrics project (Harrison et al., 2017), but adaptations have been made to make the framework better reflect the important role that soil biodiversity and land management play in SOILGUARD. The framework is broadly structured around the Drivers-Pressures-State-Impact-Response (DPSIR) (European Environment Agency, 1999) approach which emphasises the role of humans-in-nature (Berkes and Folke 1998; Rounsevell et al. 2010), similar to the concept of socio-ecological systems (Gallopin, 1991). However, we have deliberately not strictly followed this approach as it can be overly restricting. Rather, we have used parts of the DPSIR framing where it adds value and clarity to the SOILGUARD conceptual framework, such as for the drivers and responses boxes. We have adapted the pressures box to be more specifically focused on land management, reflecting the importance of sustainable soil and land management in SOILGUARD. We have also integrated further detail into what would be the state-impact box (blue dotted line in Figure 3.1) on the different interacting components of the ecological and socio-economic systems drawing on the experience of other frameworks. We recognise that there are a number of frameworks adopted or used by the EU, including SEEA, CICES and DPSIR. Thus we have endeavored to maintain some consistency of approach and terminology with these frameworks. For example, the SEEA report[2] describes how DPSIR can be used as a framework to present the policy relevance of the natural capital accounting approach.

It is important to note that the framework can be utilised from different starting points depending on the question of interest. For example, if a user were interested in understanding how ES demand interacts with ES supply they may start from the Beneficiaries box. Alternatively, a user may start with the Land Management box if they were interested in understanding how different aspects of soil biodiversity are affected by different types of soil and land management and how this interacts with other attributes of natural capital to affect ES delivery.

The blue dashed line in Figure 3.1 defines a single specific socio-ecological system, which in SOILGUARD can be considered to represent one of the seven NUTS2 case study regions. It is divided into an ecological system, which consists of natural capital assets, and a socio-economic system, which consists of the beneficiaries who demand different ES. Ecosystem services and disservices are provided at the intersection of the ecological and socio-economic system.

[2] https://unstats.un.org/unsd/statcom/52nd-session/documents/BG-3f-SEEA-EA_Final_draft-E.pdf (Section 14.4.5).

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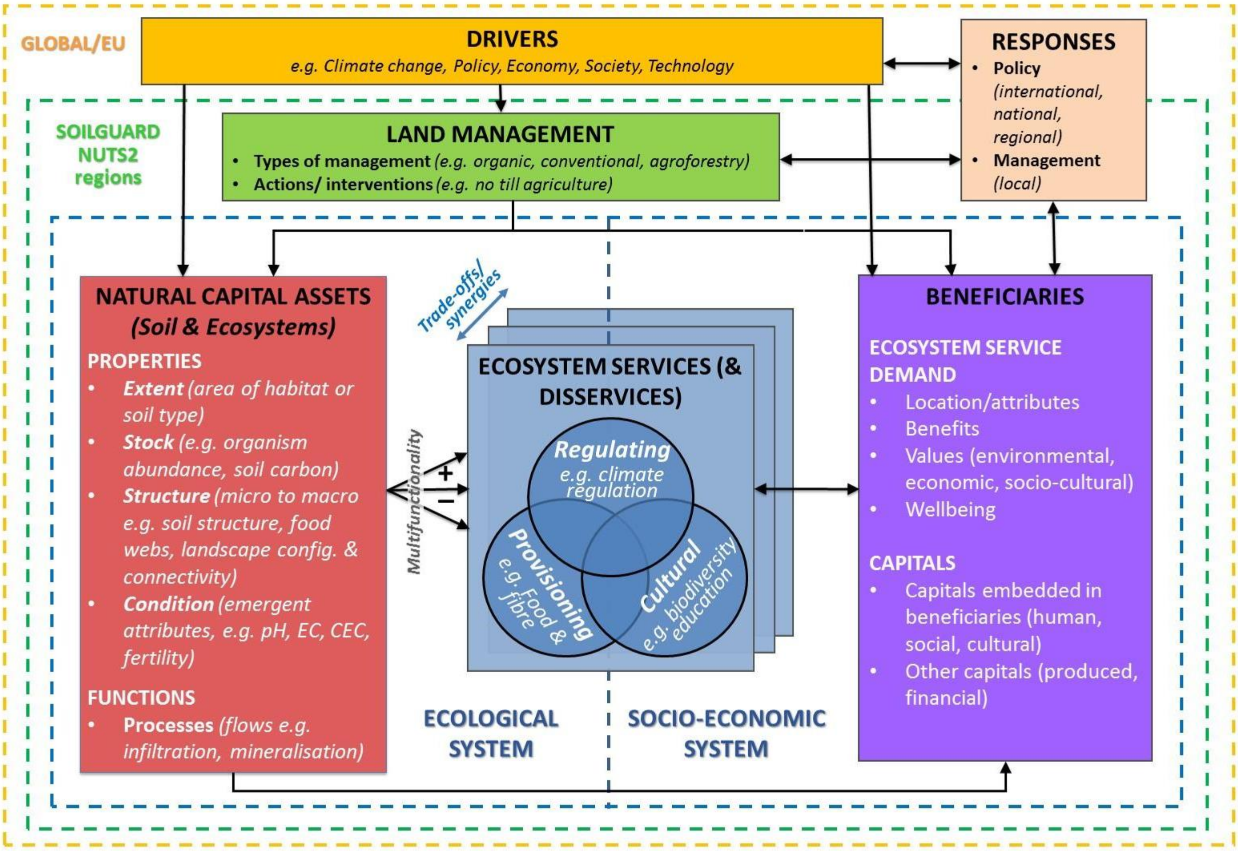

Figure 3.1: Conceptualisation of the Soil Biodiversity and Wellbeing Framework.

The **Natural Capital Assets** box covers the attributes of soils and ecosystems that are important for delivering ES. These are divided in to four **properties**:

- First is **extent,** which is defined as the area of a particular habitat or soil type or geology. Whether habitat area or soil type area is most important will depend on what is being investigated, but it could also be broken down in different ways, for example, by starting with habitats and then sub-sectioning by soil type or vice-versa.
- Second is **stock**, which is defined as the quantity of something that is directly measured and can be matter, liquid or gas. For example, the abundance of a soil organism, quantity (as mass or volume) e.g. of soil carbon, or the amount of topsoil or subsoil. Some stocks can be seen as composite, and can be further broken down, e.g. the stock of soil can be subdivided into sand, clay, peat, air filled space, soil-water components.
- Third is **structure**, which is related to extent and stock, but describes the connectiveness of these properties. This can be on a micro scale through soil structure, for example, how carbon and mineral material combine in space to form aggregates, or structural measures such as porosity. Or it can be at a macro scale in terms of the spatial configuration and connectivity of habitats, landscapes and soils.
- Fourth is **condition**, which is a measure of the quality of the stock. Condition measures will differ, depending on the type of stock, examples include the diversity of soil organisms, chemical measures such as pH, Electronic Conductivity or Cation Exchange Capacity. It should

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be noted that condition is both context dependent (often related to a benchmark), and service dependent. Good condition of a soil can mean different things in different contexts or habitats. For example, a pH7 soil may be considered in good or bad condition depending on the ecosystem or habitat type. A high level of water table or soil saturation may be good for one service (long-term carbon sequestration in peat) but bad for other services (agricultural production).

Finally, in the natural capital assets box we identify **functions**. These are defined as the range of functions or processes that occur within soils, broadly analogous to supporting services in some frameworks. Some of these will directly produce flows of ES for beneficiaries, others are internal processes which are an integral part of the natural capital of soils. Functions (or processes) are expressed in terms of fluxes or rates (quantity per unit of time). Examples includes mineralisation, infiltration and decomposition. Thus, the natural capital component explicitly includes both stocks of soil material and the ecological processes that link them.

There are obviously many interactions and linkages between the different natural capital attributes, which are not represented in the SBWF as the purpose of the conceptual framework is to present the higher level, holistic interlinkages between the different elements of SOILGUARD. The evidence chains in WP5 will build on the SBWF and provide this more detailed breakdown of natural capital asset relationships drawing on the work of WPs 2 and 3. The SBWF does, however, highlight that the natural capital assets in their totality provide a wide range of functions and ES through the multiple arrows linking the natural capital asset box with the ecosystem services and disservices boxes. The SBWF also highlights the importance of multifunctionality in this linkage. The "+" and "-" symbols on the arrows indicate that the various natural capital properties and functions can have a positive or negative effect on ES provision.

The **Ecosystem Services (& Disservices)** box encompasses a range of potential ecosystem services and disservices that can be supplied by the natural capital assets covering **provisioning** services, such as food & fibre, **regulating** services, such as climate regulation or soil erosion prevention, and **cultural** services, such as biodiversity education or tourism. Natural capital can also lead to disservices, e.g. increasing greenhouse gas emissions due to earthworm activity (Lubbers et al. 2013). The same process may lead to benefits for one service, but through another suite of interactions may also lead to disservices. Thus the framework captures the complexity of natural systems, and highlights the challenges of management decisions which involve possible trade-offs and/or synergies between services. The spatial scale over which an ES can be potentially supplied depends on the ES in question: field level (particularly for provisioning services) or landscape level (particularly for cultural services).

These potential ES are only realised if there is a demand for them from **Beneficiaries** of the services. Beneficiaries influence service supply through their preferences or **demands**, and these in turn may be influenced by their **location** or **attributes** such as their social or economic status, the **benefits** that are supplied and how they are **valued**, for example in terms of environmental, economic or socio-cultural values. Benefits, such as nutrition from food or clean water from a water regulation service in turn leads to improved wellbeing, which can be physical and mental health, security or material **wellbeing**, for example. Other **capitals** may be required to realise an ecosystem service flow; some of these are embedded in beneficiaries such as human, social and cultural capital, whilst others are external such as financial capital or produced capital, for example, farm machinery or irrigation infrastructure.

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All the elements within the blue dashed box (which indicates a specific socio-ecological system) may be influenced by external **Drivers**[3]. Drivers are defined as being external to the local socio-ecological system, for example, the Common Agricultural Policy at the EU level or climate change at the global level. These drivers can directly affect the natural capital or can influence beneficiary behaviour. In addition to climate change, external drivers include broader **political**, **economic**, **societal** or **technological** influences on the socio-ecological system.

These drivers also affect **Land Management,** which is defined as being internal to the socio-ecological system where it directly influences natural capital assets (through changing ecosystem properties and functions) and beneficiaries (through changing the capitals used by beneficiaries to realise an ES, such as footpaths for accessing recreation services). Important aspects of land management being considered in SOILGUARD are the **types of management** included in the cross-biome network of sites, for example, conventional vs organic, and specific **actions or interventions** being undertaken on a farm (or in a forest), such as no till agriculture.

The **Responses** box adds a temporal dimension to the framework in that negative outcomes within the socio-ecological system may trigger responses that can be through changes in **management** or **policy** at different scales or levels. These changes in management or policy aim to maintain or enhance natural capital assets (influencing the supply of ES), modify other capital inputs or beneficiary demand for ES.

3.1 The role of soil biodiversity in the SBWF

Soil biodiversity (e.g. abundance, biomass and diversity of soil organisms) is principally represented in the SBWF in the Natural Capital Assets box through the stock and condition properties. However, it is important to understand how biodiversity relates to function and this is a critical part of SOILGUARD. Only an increase in our understanding of the links between soil biodiversity and soil-mediated ES (and their simultaneous provision through soil multifunctionality) will enable the quantification of the environmental, economic and social costs of maintaining current unsustainable agricultural and forestry practices, under the increasing severity of climate change. Barrios et al. (2007) propose pooling species into functional groups, identifying “keystone species” and “redundant species” to try to better understand the complexity of soil biota interactions with function and process. Table 3.1 has been adapted from Barrios (2007) to classify soil biodiversity into functional groups. This may be a useful way to incorporate soil biodiversity into the analytical part of the SBWF and will be further discussed across the SOILGUARD consortium as the fieldwork in WPs 2 and 3 is defined and implemented.

[3] In this framework we combine Drivers and Pressures into one component, but separate those which are external to the system and those which are internal to the social-ecological system.

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Table 3.1: Linking soil organisms to function and service (adapted from Barrios 2007). Note many of these linkages are currently undefined or not well established. This table represents a proposed framework that SOILGUARD could extend and update based on the evidence from WPs 2 and 3. The current content of the table should be viewed as possible examples. Note: microbes will be measured in bulk soil, rhizosphere and endosphere (plant-microbiome interactions).

Potential soil organisms of interest	Functional groups	Processes	Ecosystem Services
Mycorrhizal fungi	Microsymbionts	Decomposition, Plant nutrient uptake	Nutrient cycling, Crop productivity
Bacteria, Saprotrophic fungi, Mites (Oribatida), Woodlice (Isopoda), Millipedes (Diplopoda)	Decomposers	Decomposition, Soil structure modification	Nutrient cycling, C sequestration, Water flow and storage, Crop productivity
Ammonia oxidizing microbes, Free living N2 fixing bacteria & AMF (N fixation), Denitrifiers (regulation of GHG)	Inorganic elemental transformers (C,H,O, N,P, S)	Elemental transformation	Nutrient cycling, C sequestration, Water flow and storage, Crop productivity
Earthworms, Enchytraeids, Dipteran larvae, Ectomycorrhizal fungi	Ecosystem engineers	Soil structure modification	Regulation of soil erosion, C sequestration, Water flow and storage, Crop productivity
Nematodes, plant and human pathogenic microbes, Nematophagous fungi, Plant growth promoting rhizobacteria (PGPR), Viruses, Bacterial sources of antimicrobial resistance genes	Interactors (soil borne pests and disease causing pathogens; plant growth promoting organisms)	Herbivory, Parasitism, Predation, Facilitation	Biological regulation of pests and diseases, Crop productivity
Archaea	Pathogens	Predation, Parasitism	Biological control of pests and diseases, Crop productivity

The soil biodiversity attributes of extent, stock and condition in the SBWF can also be related to the 'Essential Biodiversity Variables' (EBVs). Criteria for EBVs have been defined by GEO BON to support monitoring initiatives in reporting changes in status and trends in elements of biodiversity linked to assessing progress towards the 2020 Targets of the Convention on Biological Diversity (CBD). A suite of soil ecological indicators based on the EBVs has been recently suggested by Guerra et al. (2021) that directly link to current global targets such as the CBD, the Sustainable Development Goals (SDGs), and the Paris Agreement. These EBVs encompass four complementary dimensions of soil systems (soil physics, soil chemistry, soil biodiversity, and soil ecosystem functions) and relate to specific ecological indicators that consider the multiple facets of soil ecology between biodiversity and key ecosystem functions. Guerra et al. (2021) aim to provide a holistic overview of soil systems that addresses specific societal needs (e.g. soil health, nutrient cycling and fertility, or plant pathogens), but also extends the use of soil ecological data to other policy realms besides nature conservation, such as climate action and land degradation neutrality. The Soil Biodiversity Observation Network (SOILBON) propose to use

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these soil EBVs to underpin a global soil biodiversity and ecosystem function monitoring framework (Figure 3.2).

The proposed indicators for soil EBVs (in the outer ring of Figure 3.2) by Guerra et al. (2021) can be mapped to the properties and functions in the SBWF Natural Capital Asset box (i.e. extent, stock, structure, condition and function). For example, the EBV of habitat extent falls into the SBWF category of extent, population abundance falls into stock, soil aggregation falls into structure, taxonomic diversity falls into condition, and nutrient cycling falls into function. We will further explore links between the soil EBV's and SOILGUARD indicators and metrics as the analytical part of the SBWF is developed. This will include links to the final design and measurements of the fieldwork in WPs 2 and 3, and how they might translate to the evidence chains work in WP5.

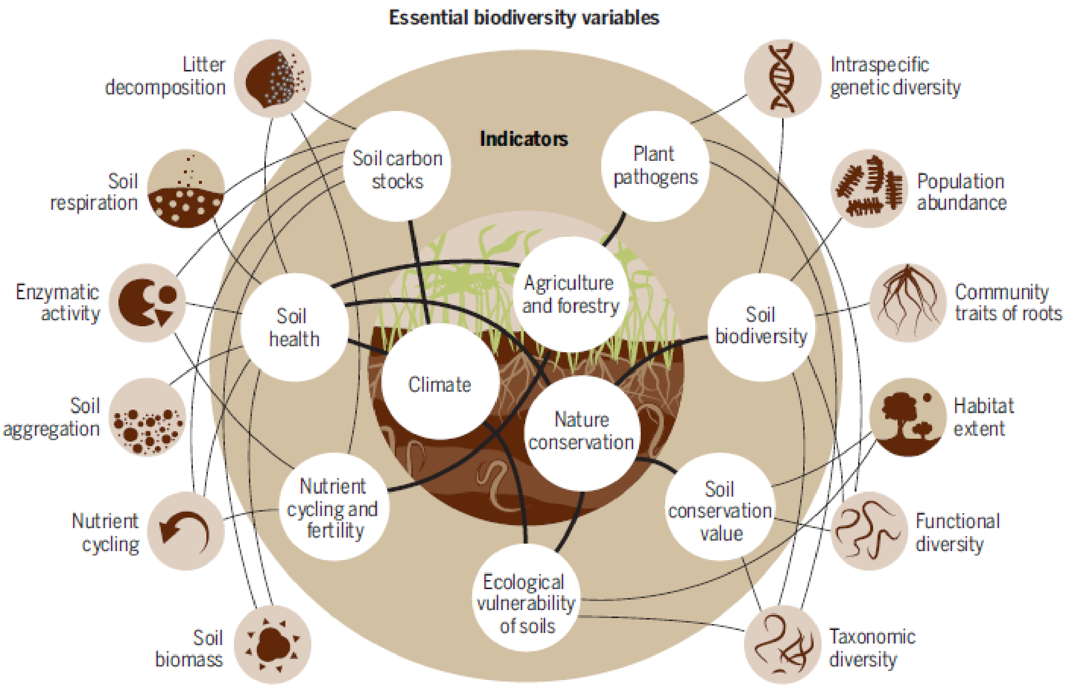

Figure 3.2: Guerra et al. (2021) framework for linking soil biodiversity to policy. Links between global soil essential biodiversity variables (EBVs) (outer ring) are prioritised by the Soil Biodiversity Observation Network (SoilBON) and policy sectors (centre) through the use of soil ecological indicators (inner ring). Thin lines correspond to links between EBVs and soil indicators; thicker lines refer to links between each soil indicator and specific policy sectors. The EBVs for soil systems are proposed as a holistic system approach, where soil organisms are intertwined with relevant soil chemical, physical, and functional properties, contributing to overall societal well-being.

3.2 The role of wellbeing in the SBWF

Wellbeing is principally represented in the SBWF in the beneficiary box, but it is also an outcome of the overall interlinkages/relationships in the SBWF. The review of existing conceptual frameworks shows the conceptualization and terminology around wellbeing tends to be varied and inconsistent in the literature with most studies relating wellbeing to improvements in benefit and value (Table 3.2).

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However, major gaps remain in articulating the impacts of changing ES supply on human wellbeing (Johnson et al. 2019). Definitions have evolved from relatively simple wellbeing measures, such as economic, health and shared (social) values (Mace and Bateman, 2011), to an increased number of domains (Rendon et al. 2019) including spiritual and cultural fulfilment, connection to nature, and life satisfaction and happiness. Johnson et al. (2019) used the United Nations Sustainable Development Goals (e.g., reduced hunger, improved human health) to assess progress on wellbeing. More recently, the IPBES conceptual framework has drawn on advances in valuation research, through the conceptualisation of nature's contributions to people, the integration of diverse values and indigenous and local knowledge systems, to show the multiple ways nature contributes to human wellbeing (Gomez-Baggethun and Martin-Lopez 2015). IPBES define human wellbeing in terms of the ability to achieve good quality of life; a life that people value with food, water energy and livelihood security, health, social relationships, equity, spirituality and cultural identity (Diaz et al. 2015).

Table 3.2: Comparison of wellbeing categorisations used in existing conceptual frameworks. Note this table represents options for that SOILGUARD could extend and update based on the evidence from WP4. The current content of the table should be viewed as possible examples.

MEA	**UKNEA**	**Saariskoski et al. (2015)**	**Rendon et al. (2019)**	**IPBES**
Basic material for a good life	Economic value	Material wellbeing	Living standards	Livelihood security
Health	Health value	Physical and mental health	Health	Physical, mental and emotional health
Good social relations	Shared (social) value	Social capital	Social cohesion	Social relationships
Security		Security	Safety and security	Food, energy and water security
Freedom of choice and action				Equity
			Spiritual and cultural fulfilment	Spirituality
			Life satisfactions and happiness	Cultural identity
			Connection to nature	

In SOILGUARD, WP4 are implementing an integrated valuation approach that mainly focuses on the socio-economic system and will be used to expand the Beneficiaries box of SBWF (see Section 5). This approach builds upon the IPBES values assessment (Anderson et al., 2022), in which nature's contributions to people contribute to human well-being by providing instrumental, intrinsic and relational values to society. These values are being assessed in WP4 using different methodologies, estimating monetary and socio-cultural indicators (see Table 5.3b). We will further explore links between indicators associated with benefits, values and wellbeing as the work in WP4 progresses and is integrated into the analytical part of the SBWF.

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4. Ecosystem service categorisations

There have been differences in interpreting the meaning of the different components in the ES framework, e.g. biophysical components, ecological functions, intermediate services and final services (La Notte 2017). Common terminology and a systematic classification of concepts is important. Issues that arise in existing classifications include:

- Ambiguity on the distinction between final, intermediate and supporting services that can lead to double-counting, although it can be difficult to have fixed definitions as classification to a final service depends on context (Potschin-Young et al. 2016).
- Conflicting descriptions of functions, processes and services.
- Confusion between classifications of services, goods and benefits.

The initial comprehensive classification of ES terminology and approach was the Millennium Ecosystem assessment (MA 2005), which included the categories of provisioning, regulating, cultural and supporting services. Other classifications have built upon the Millennium Ecosystem assessment, with TEEB adding a new 'habitat services' group, including 'maintenance of life cycles' and 'maintenance of genetic diversity'.

The Common International Classification of Ecosystem Services (CICES)[4] has been designed to help measure, account for, and assess ES. It is based on the cascade approach (Potschin and Haines-Young 2016) to enable understanding of the relationships between biophysical components and societal well-being. CICES is a comprehensive classification with a hierarchical structure including detailed differentiation between abiotic and biotic elements. Service definitions are composed of a clause describing the biophysical output and another clause defining how it contributes to benefits (Haines-Young and Potschin 2018). CICES has been used widely in ES research for designing indicators, mapping and valuation. CICES does not include the MA (2005) 'supporting services', but merges the TEEB (2010) 'habitat services' with regulating services, in a category called 'regulating and maintenance services' (La Notte 2017). CICES also proposes that elements that determine the capacity of the ecosystem to deliver particular services can be represented by concepts other than that of a service, e.g. measures of ecosystem condition. However, La Notte et al. (2017) suggests that some of the regulatory services described in CICES are really biotic structures and processes and care needs to be taken that these are not mislabeled as services. They also state that as services should be processes, that provisioning services in CICES are really benefits which could cause double-counting, and existence and bequest values are listed as services but these could also be part of the valuation process.

In Final Ecosystem Goods and Services (FEGS), processes and supporting services are labelled as intermediate goods and services, with the final ecosystem good or service being the point of hand-over from ecological production function to economic production function. FEGS places emphasis on the benefits, beneficiaries and the socio-economic system, but has a clear internally consistent approach to defining the final ecosystem good/service. Meanwhile CICES places greater emphasis on the ecological system.

[4] CICES v5.1 https://cices.eu/

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IPBES (Diaz et al. 2019 and IPBES 2019) suggests that previous approaches based on stock and flow of assets and services did not engage perspectives from the social sciences and some practitioners, e.g. indigenous people. IPBES uses the terminology of nature, nature's contributions to people (NCP) and a good quality of life to broaden the scope of the widely-used ES framework to extensively consider diverse worldviews on human-nature interactions (see Diaz et al. 2019 for further information; Figure 4.1). NCP and ES are considered as nested terms (rather than near-synonyms as proposed by some authors (de Groot et al. 2018), with NCP embracing and broadening the ES concept (Peterson et al. 2018, Diaz et al. 2019; Kadykalo et al. 2019), embedded into the legitimate and mandated policy context of IPBES (Harrison et al. 2019).

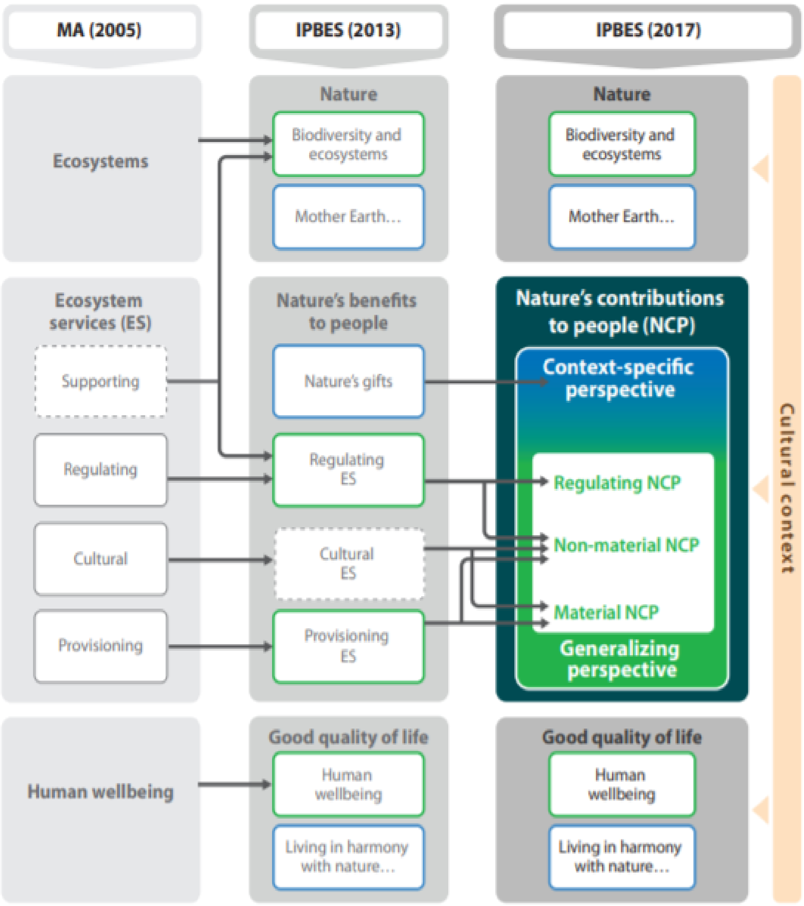

Figure 4.1: Evolution of nature's contributions to people (NCP) and other major categories in the IPBES conceptual framework with respect to the concepts of ecosystem services and human wellbeing as defined in the Millennium Ecosystem Assessment (Diaz et al. 2019).

There are 18 categories for reporting NCP organised in three partially overlapping groups: regulating, material and non-material NCP (Figure 4.2). Beneficial NCP include, for example, food provision, water purification and artistic inspiration, whereas detrimental contributions include disease transmission and predation that damage people or their assets (Diaz et al. 2018). The IPBES global assessment states that while internally consistent, the categories are context-specific and usually not intended to be

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universally applicable. Figure 4.2 also shows how the NCP relate to wellbeing (or quality of life in IPBES terminology) based on instrumental and relational values.

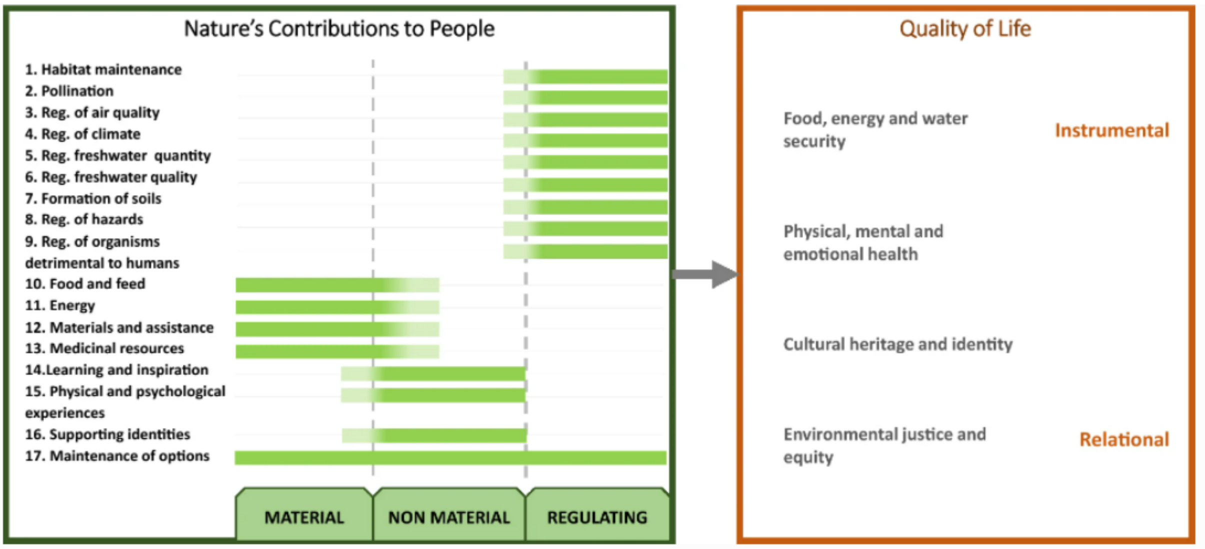

Figure 4.2: Mapping of the 18 NCP reporting categories used in IPBES assessments onto three broad groups of material, non-material and regulating NCP and their relationship with quality of life (Christie et al. 2019; adapted from Diaz et al. 2019).

4.1 Summary

It is important that SOILGUARD adopts a common ES classification across all WPs so that we are using consistent terminology and concepts and avoid ambiguities. A number of issues are worth considering in selecting a common ES classification to use in SOILGUARD:

- The classification is well recognised and ideally signed-off/accepted by multiple users, including governments and the European Union.
- It avoids conflicting descriptions of functions, processes and services. We would recommend that the best approach is to incorporate functions and processes in the attributes of natural capital or as regulating services where appropriate (this is reflected in the IPBES classification). CICES regulation and maintenance class has been criticised as some of the regulating services are better described as processes or functions of natural capital.
- It avoids confusion between classifications of services, goods and benefits.
- It has a clear distinction between final, intermediate and supporting services to avoid double-counting.
- It ensures that contributions from social perspectives and indigenous practitioners are captured, e.g. IPBES Nature's Contributions to People.

Taking these considerations into account, SOILGUARD has decided to use the IPBES NCP classification as a common starting point for all WPs, recognising that we may need to adapt the classification as the project progresses. The IPBES framework is a relatively recent classification that has been accepted by many different stakeholders, including 138 governments and the EU. The need to adapt the classification to better represent soil-mediated NCP will be considered as the SBWF is applied and

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tested across WPs within SOILGUARD. The SBWF, as shown in Figure 3.1, has been adapted to better reflect IPBES terminology in Figure 4.3.

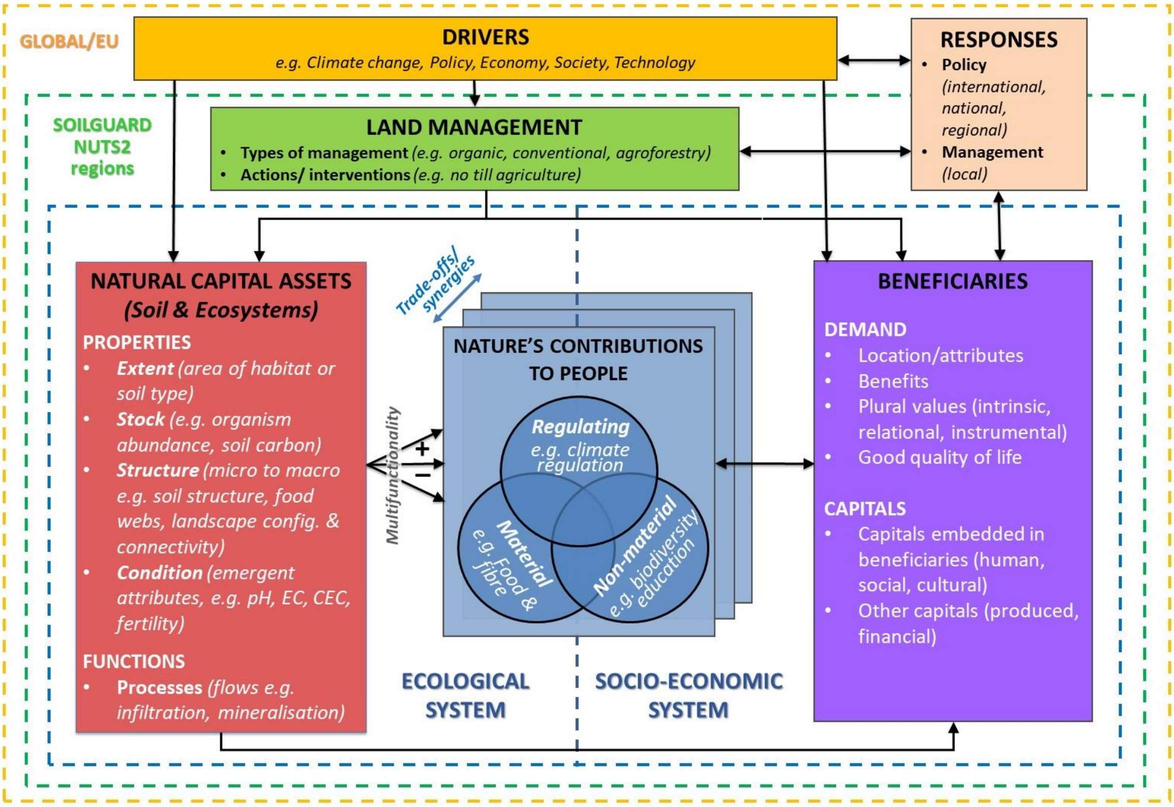

Figure 4.3: The SOILGUARD Soil Biodiversity and Wellbeing Framework revised to match the IPBES NCP classification and terminology.

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5. Mapping SOILGUARD tasks to the SBWF

The different elements (WPs) of SOILGUARD are mapped onto the SBWF in this section to inform the integration of the different disciplinary aspects of the project. This mapping is preliminary and will be updated as the analytical part of the framework and each WP progresses. This initial mapping is based on the WP1 workshop held in July 2021, where participants were asked to map their tasks in SOILGUARD onto the different boxes of the SBWF, and further iteration via email and shared documents to refine this input across WPs. The outcomes from this iterative process are presented in the Tables 5.1 to 5.6.

WP2 will assess the status of soil biodiversity in the 234 selected sites, across eight biogeographical regions and three biomes (cropland, grassland, and forest) and relate these measurements to indicators of soil multifunctionality and soil-mediated NCP. Table 5.1 shows the different indicators of extent, stock, condition and function that are expected to be measured.

Table 5.1: Aspects of natural capital assets being considered in SOILGUARD. Columns are lists (i.e. do not read across). These indicators will be predominately measured at the site/field scale.

NATURAL CAPITAL ASSETS BOX			
Extent	**Stock**	**Condition**	**Function (process)**
• Habitat (e.g. arable, grassland, forest) area • Extent of soil type	ABIOTIC STOCKS • Soil nutrient chemistry – available N, P • Soil organic matter • Soil thickness/ quantity (bulk density/ soil depth) BIOTIC STOCKS • Total soil microbial biomass • Relative abundance of phages, bacteria, archaea, fungi, protists, nematodes, collembola, microarthropods, mites, earthworms • Relative abundance of bacteria, archaea and fungi in the rhizosphere • Relative abundance of functional genes (nutrient cycling, pathogenesis, AMR, resources for biotech, etc.)	QUALITY • Soil type • Soil texture; sand, silt, clay • Soil organic matter content (appropriate or relative to the typical SOM content of the habitat or land use) • Soil pH • Water retention capacity STRUCTURE • Soil aggregate stability • Landscape diversity and configuration BIOTIC STRUCTURE • Diversity of N cycle genes • Level of antibiotic resistance • Soil food webs/ networks metrics, e.g. biomass of fungal and bacterial energy channels • Diversity of soil bacteria, archaea, fungi, protists, nematodes, collembola, mites, earthworms, virus • Diversity of bacteria, archaea and fungi in the rhizosphere	• Biomass production • Soil potential respiration • C sequestration • Potential N mineralization • Litter decomposition • Soil enzymatic activities (C, N, P cycling) • Leaching of nutrients (NO_3/PO_3) • Leaf (insect and fungal pathogen) damages • Reduction in efficiency of antibiotics • Soil erosion/Soil loss • Infiltration

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All WPs will contribute measurements on a selected set of NCP as shown in Table 5.2. WP2 focuses on the linkages between natural capital and these NCP, including how they are affected by land degradation and sustainable soil management; WP3 focuses on the linkages between drivers (specifically climate change), natural capital and NCP; whilst WP4 focuses on the linkages between the NCP and their value/benefit for a good quality of life. WP5 brings together the evidence on the different interlinkages through the development and operationalisation of evidence chains.

Table 5.2: Aspects of nature's contributions to people being considered in SOILGUARD. The spatial scale of the NCP varies from field level (typical for material services) to landscape level (typical for non-material services). WP5 will develop methods for scaling-up the site-based field measurements to the landscape scale for linking between the indicators of natural capital attributes, NCP and benefits/values.

NATURE'S CONTRIBUTIONS TO PEOPLE			
	Material	**Regulating**	**Non-material**
Positive contributions	• Food production • Timber provision	• Biological control • Soil erosion prevention • Nutrient cycling • Climate regulation • Flood regulation • Water quality regulation	• Biodiversity conservation • Tourism/number of visitors • Aesthetic value • Biodiversity education • Abundance and diversity of weeds of conservation interest
Negative contributions		• Greenhouse gas emissions (CO_2, N_20,CH_4)	

WP4 is reviewing indicators and methodologies that can be used to value soil-mediated NCP. It will focus on those indicators, which: (i) are related to instrumental and relational values of soil-mediated NCP according to the literature review; and (ii) can be estimated with monetary and non-monetary valuation methods. This will depend on the perception and preferences of stakeholders in the SOILGUARD regions, data availability and the NCP assessment in physical units by WPs 2 and 3 (Tables 5.3a and 5.3b).

Table 5.3a: Aspects of beneficiaries being considered in SOILGUARD. WP4 will not estimate the different capital aspects directly, but will describe the relationship between the values of sustainable soil management (to be estimated in monetary and non-monetary terms) and the capitals.

BENEFICIARIES BOX	
Beneficiary attributes	**Capitals**
• Location of beneficiary (relative to NCP) • Benefits (Food, Timber) • Socio-economic status of beneficiary • Socio-economic values (see Table 5.3b) • Good quality of life (contribution of NCP to human wellbeing and quality of life)	• Human capital (e.g. education, health) • Social capital (e.g. farmer networks) • Cultural capital (e.g. improvement of societal perception of farming activities) • Produced capital (e.g. farm machinery, irrigation infrastructure) • Financial capital (e.g. household or farm business income)

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WP4 aims to pursue a pluralistic approach to valuation to increase the understanding of how sustainable soil management impacts soil biodiversity, soil-mediated NCPs and human wellbeing. Thus, different methodologies are being employed to assess socio-cultural values through a qualitative survey and a household survey. In these surveys, respondents are asked to rate the importance of NCP for their wellbeing and quality of life on a Likert scale and according to their perception. In addition, socio-cultural and economic valuation methods are being used to estimate the contribution of selected values to human wellbeing.

Table 5.3b: Links between NCP, beneficiaries, values and wellbeing/quality of life in SOILGUARD.

Nature's Contribution to People (in WP4)		Beneficiary	NCP valuation (estimation of socio-economic values according to land management changes)				Quality of Life (Wellbeing)
			Cost-based assessment	Socio-cultural valuation	Economic valuation	Preference assessment	
Food and feed	Material	Farmer	Market price method (crop yields)	Crop diversity (landscape)		Rating	Food, energy and water security
Energy production	Material	Society		Renewable energy (landscape)		Rating	
Production of materials	Material	Farmer				Rating	
Production of medicinal resources	Material	Society				Rating	
Regulation of freshwater quantity (Flood regulation)	Regulating	Society				Rating	
Regulation of detrimental organisms (Biological control)	Regulating	Farmer				Rating	
Soil formation and protection (Soil erosion prevention)	Regulating	Society			Soil health (soil fertility, earthworms)	Rating	
Soil formation and protection (Nutrient cycling)	Regulating	Society	Market prices/ Replacement cost method (nutrient leaching)			Rating	
Climate regulation	Regulating	Society		Carbon sequestration (landscape)	Climate regulation (carbon storage in soils)	Rating	
Habitat creation	Regulating	Society		Habitat diversity (landscape)	Habitat provision (hedgerows, flower strips etc.)	Rating	
Pollination	Regulating	Society				Rating	
Regulation of air quality	Regulating	Society				Rating	
Regulation of freshwater quality	Regulating	Society				Rating	
Physical and psychological experience (Tourism)	Non-Material	Society, Tourists			Recreational opportunities (access, walking paths)	Rating	Physical, mental and emotional health
Physical and psychological experience (Aesthetic landscapes)	Non-Material	Society, Tourists				Rating	

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Nature's Contribution to People (in WP4)		Beneficiary	NCP valuation (estimation of socio-economic values according to land management changes)				Quality of Life (Wellbeing)
			Cost-based assessment	Socio-cultural valuation	Economic valuation	Preference assessment	
Learning and inspiration (Biodiversity education)	Non-Material	Society				Rating	
Supporting identities	Non-Material	Society				Rating	Cultural heritage, identity and stewardship
Maintenance of options	Non-Material	Society				Rating	

Land degradation gradients are being used to select the sites for measuring indicators of soil biodiversity and natural capital in WP2. This will include sites that enable a comparison between conventional and sustainable land management, and a range of sustainable soil management interventions (Table 5.4).

Table 5.4: Aspects of land management being considered in SOILGUARD. These indicators will be predominately measured at the site/field scale.

LAND MANAGEMENT BOX		
Ecosystem/scale	**Type**	**Land management**
Cropland	Input/intensity	Organic vs. conventional (includes mineral/organic fertilizer and chemical vs. mechanical pest control)
	Sustainable Soil Management	Tillage vs. no tillage/reduced tillage
	Crop management	Cover crops
		Crop identity
Grassland	Inputs/intensity	Reduced inorganic fertilization vs. conventional
	Sward management	Low diversity vs. mixed species swards
Forestry		Clearcut vs. continuous cover
Landscape	Landscape management	Landscape diversity and configuration
		Semi-natural components (field margins, hedgerows, streamside, flower strips or remaining natural vegetation)

The main drivers being considered in SOILGUARD are land degradation (WP2) and climate change (WP3). However, other drivers will be important in providing context for the study (Table 5.5).

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Table 5.5: Aspects of drivers being considered in SOILGUARD. Those in grey will not be directly measured in SOILGUARD, but they could be considered indirectly in our analyses.

DRIVERS BOX				
Environmental	**Economic**	**Societal**	**Technological**	**Political**
• Land degradation/ Unsustainable soil management • Climate change (heatwaves, drought)	• Low incomes for farmers/soil managers • Fertilizer/fuel prices • EU subsidies affecting market prices • Land prices • Carbon price • World market	• Demography (lack of youth in farming) • Availability of methods and expertise • Voluntary quality assurance schemes • Global food demand • Protein demand for food/feed • Dietary choice	• Soil informatics • Precision farming	• New CAP • Green deal • Farm2Fork Strategy • Biodiversity strategy • Circular economy strategy • EU subsidies • SDGs • International/ national policies and initiatives

WP6 focuses on responses that promote the conservation of soil biodiversity, including through nature-based solutions and the integration of soil biodiversity into pan-European policies and international frameworks (Table 5.6).

Table 5.6: Aspects of responses being considered in SOILGUARD. Those in grey are likely to be outside the remit of this project.

RESPONSES BOX				
Management	**Economic**	**Societal**	**Technological**	**Political/Policy**
• Guidelines for soil quality indicators • Strategic planning for difference scenarios • Build common strategies with soil managers/farmers • Landscape scale management • Selection of crop species and rotation • Practices to address soil degradation • Conservation measures	• Profitability/ Sustainability	• Soil awareness • Knowledge exchange • Change in diets	• Develop indicators of soil diversity and function • Long-term data to show benefits to conservation/ economy • Harnessing soil biodiversity	• Soil Strategy • Policy compromises • Protection of soil biodiversity • Land use planning • Advice for farmers • Carbon conservation policies • Land sharing vs. land sparing approaches

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6. SOILGUARD glossary

A common understanding of key terms is essential for an interdisciplinary project such as SOILGUARD. The glossary detailed in this section is a first draft specifically focused on the SBWF. This initial version has focused on the identification of terms that need to be included in the glossary. We have also included common definitions from well recognised publications or initiatives, such as IPBES. These definitions are a starting point for the project and will be adapted as the project progresses if needed.

Term	Definition	Source
Beneficiaries	The interests of an individual (i.e. person, group and/or firm) that drive active or passive consumption and/or appreciation of ecosystem services resulting in an impact (positive or negative) on their welfare.	Landers and Nahlik (2013)
Benefits	Advantage that contributes to wellbeing from the fulfilment of needs and wants. In the context of nature's contributions to people, a benefit is a positive contribution. (There may also be negative contributions, dis-benefits, or costs from nature, such as diseases).	IPBES (2019)
Biodiversity	The variability among living organisms from all sources including, *interalia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems.	Mace et al. (2012), IPBES (2019)
Ecosystem condition	The physical, chemical and biological condition or quality of an ecosystem at a particular point in time.	Maes et al. (2020)
Conventional/ Unsustainable management	**Croplands:** Conventional management is characterised (with exceptions) by using chemical inputs, monoculture, and soil tilling. **Grasslands:** Grass monoculture with high inorganic N input is the dominant conventional grassland management practice in the EU Atlantic regions. **Forests:** Clearcutting is the most used forest management system in the EU Boreal regions and has been criticised due to its negative effects on biodiversity.	SOILGUARD proposal
Cultural capital	The broader factors that allow us to interact with each other and the environment, including values and beliefs, socially held knowledge as well as socio-political institutions.	Jones et al. (2016)
Disservice	Detrimental contributions from nature to people include disease transmission and predation that damages people or their assets. Many NCP may be perceived as benefits or detriments depending on the cultural, temporal or spatial context.	IPBES (2019)
Drivers (of change)	Drivers of change refer to all those external factors that affect nature, and, as a consequence, also affect the supply of nature's contributions to people. The IPBES conceptual framework includes drivers of change as two of its main	IPBES (2019)

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Term	Definition	Source
	elements: indirect drivers, which are all anthropogenic, and direct drivers, both natural and anthropogenic.	
Drivers (direct)	Drivers, both non human-induced and anthropogenic, that affect nature directly. Direct anthropogenic drivers are those that flow from human institutions and governance systems and other indirect drivers. They include positive and negative effects, such as habitat conversion, human-caused climate change, or species introductions. Direct non human-induced drivers can directly affect anthropogenic assets and quality of life (e.g., a volcanic eruption can destroy roads and cause human deaths).	IPBES (2019)
Drivers (indirect)	Human actions and decisions that affect nature diffusely by altering and influencing direct drivers as well as other indirect drivers. They do not physically impact nature or its contributions to people. Indirect drivers include economic, demographic, governance, technological and cultural ones, among others	IPBES (2019)
Economic value / Monetary value	Economists often use the concept of the 'Total Economic Value (TEV)' – as the sum of the values of all service flows that natural capital generates – to categorise values in terms of their use or non-use, each of which is associated with a selection of valuation methods. Use values can be both direct and indirect. Direct use values may be consumptive (e.g. drinking water) or non-consumptive (e.g. nature-based recreational activities). Indirect use values capture the ways that people benefit from something without necessarily seeking it out (e.g. flood protection). Non-use values are those that do not involve a direct or indirect use of the ecosystem service and can be estimated based on the preference for nature's existence derived from the knowledge that a good or service exists without the valuer using it: existence value, altruistic value, and bequest value. In SOILGUARD, we assess economic valuation to quantify instrumental values.	Pascual et al. (2017); Christie et al. 2019
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity, 1992).	IPBES (2019)
Ecosystem engineer	Organism that changes the abiotic environment by physically altering structure, which often have effects on other biota and their interactions, and on ecosystem processes (Gutiérrez & Jones 2008).	IPBES (2019)
Ecosystem function	Ecosystem functions are ecological processes related to the flow of energy between ecosystem components and nutrient transformation rates. It includes many processes such as biomass production, trophic transfer through plants and animals, nutrient cycling, water dynamics and heat transfer.	Adapted from IPBES (2019)
Ecosystem Services/Nature's contributions to people	Nature's contributions to people (NCP) are all the contributions, both positive and negative, of living nature (i.e. diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to the quality of life for people. Beneficial contributions from nature include such things as food provision, water purification, flood control, and	IPBES (2019)

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Term	Definition	Source
	artistic inspiration. SOILGUARD is working with soil-mediated NCP. If people derive a benefit from a soil function then that function is regarded as a NCP.	
Environmental or ecological values	Environmental or ecological values encompass the health state of a system, measured with ecological indicators such as diversity and integrity. In the ecosystem services literature, ecological values relate to the ecosystem functions, processes and components on which delivery of ecosystem services and benefits to humans depends.	Expanded from de de Groot et al. (2010)
Evidence chain	Graphs formalising the causal relationship between natural capital/biodiversity, ecosystem services, value and wellbeing.	Harrison et al. (2017)
Final Ecosystem Goods and Services (FEGS)	Components of nature, directly enjoyed, consumed or used to yield human well-being, are attributed to Boyd and Banzhaf (2007), who defined and initiated the theoretical development of the concept of Ecological Endpoints (Boyd 2007), which later came to be known as FEGS.	Landers and Nahlik (2013)
Financial capital	The money that facilitates the interaction of other forms of capital by funding the activities that might be required for the services to be realised, managed, or improved.	Jones et al. (2016)
Human capital	The productive capacity of human beings, encompassing the stock of capabilities held by individuals such as knowledge, education, training, skills as well as physical and mental characteristics like behavioural habits and physical and mental health.	Jones et al. (2016)
Impact	A measure of whether the changes in the state variables have a negative or positive effect on individuals, society and/or environmental resources.	Rounsevell et al. (2010)
Intermediate Goods and Services	Ecological processes, functions, structures, characteristics, and interactions that are essential to the existence of Final Ecosystem Goods and Services but are not directly enjoyed, used, or consumed by beneficiaries.	Landers and Nahlik (2013)
Land/Soil degradation	Land in a state that results from persistent decline or loss of biodiversity and ecosystem functions and services that cannot fully recover unaided within decadal timescales.	IPBES (2019)
Land degradation neutrality	State whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems.	Horizon Europe Soil Mission
Produced/ Manufactured capital	Manufactured assets or material goods, tools, machines, buildings and other forms of infrastructure that contribute to the production process but do not become embodied in its output.	Tinch et al. (2015)
Multifunctionality (ecosystem function)	An overall measurement of the levels at which different ecosystem functions are performing. High levels of multifunctionality mean that multiple ecosystem functions are performing at high levels simultaneously. Low levels can reflect strong trade-offs in the supply of different functions (one comes at a cost of another) or generally low performance across multiple functions. This index reflects the overall performance of the array of biological, geochemical and physical processes that occur within an ecosystem.	Manning et al. (2018)

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Term	Definition	Source
Multifunctionality (ecosystem service)	The co-supply of multiple ecosystem services relative to their human demand.	Manning et al. (2018)
Natural capital	That part of nature which directly or indirectly underpins value to people, including ecosystems, species, freshwater, soils, minerals, the air and oceans, as well as natural processes and functions. Natural capital underpins the other types of capital. In combination with other types of capital, natural capital forms part of our wealth; that is, our ability to produce actual or potential goods and services into the future to support our wellbeing (NCC glossary). Any stock or flow of energy and matter that yields valuable goods and services (Tinch et al. 2015).	NCC glossary, Tinch et al. (2015)
Nature-based solutions	Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.	IUCN (Cohen-Shacham et al. 2016)
Organic agriculture	Organic production is an overall system of farm management and food production that combines best environmental and climate action practices, a high level of biodiversity, the preservation of natural resources and the application of high animal welfare standards and high production standards in line with the demand of a growing number of consumers for products produced using natural substances and processes. Organic production thus plays a dual societal role, where, on the one hand, it provides for a specific market responding to consumer demand for organic products and, on the other hand, it delivers publicly available goods that contribute to the protection of the environment and animal welfare, as well as to rural development.	EC Regulation 2018/848
Pressures	Endogenous variables that quantify the effect of drivers within a system or region, e.g. temperature, precipitation, land cover, regional population, per capita water demand, crop prices.	Rounsevell et al. (2010)
Response	Response of society (e.g. policy response, such as the Kyoto protocol for reducing greenhouse gas emissions).	Rounsevell et al. (2010)
Social capital	The stock of contacts, trust, reciprocity and mutual understanding associated with social networks. It includes both 'bonding' social capital which consists of accumulated social relationships and bonds of trusts within a tight-knit, closed social group, and 'bridging' social capital which consists of relation- ships of trust in heterogeneous, open groups and between groups.	Jones et al. (2016)
Socio-cultural value / Non-monetary value	Value rooted in individuals and shaped by the social and cultural context. Socio-cultural values can refer to **principles**, i.e. core beliefs underpinning rules and moral judgements, **preferences**, i.e. the importance attributed to one entity relative to another, **importance**, i.e. the importance that something has subjectively based on experiences, objective needs or the intrinsic value of something, and values can be a **measure**, i.e. something that can be quantified. Within the context of SOILGUARD, we assess preferences and importance of nature's components for a good quality of life,	IPBES/6/INF/18; Scholte et al. (2015)

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Term	Definition	Source
	while acknowledging the role that principles play as determinants for those value types. We use socio-cultural valuation to assess instrumental and relational values (see value pluralism).	
Socio-economic valuation	Integrated assessment of monetary and non-monetary values to measure instrumental and relational values as applied in the SBWF. It comprises methods to assess market and non-market monetary values (see economic values) and non-monetary values (see socio-cultural values) to account for value pluralism.	
Soil	Soil is the result of the interactions between the atmosphere (as governed by climate), the biosphere (local vegetation, animal activities, including those of humans) and the geosphere (the rocks and sediments that form the upper few metres of the Earth's solid crust). Soil is any loose material on the surface of the Earth that is capable of supporting life.	Global Soil Biodiversity Atlas (2016)
Soil biodiversity	The variation in soil life, from genes to communities, and the ecological complexes of which they are part, that is from soil micro-habitats to landscapes.	FAO et al. (2020)
State	Definition and quantification of all those elements relevant to the supply of the ecosystem service variables that describe the whole of the social-ecological system	Rounsevell et al. (2010)
Sustainable Soil Management	Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern.	FAO (2017)
Quality of life	See "Wellbeing"	
Value pluralism	This "new school of valuation" explicitly applies a diversity of valuation methods to human nature issues and aims to account for different value domains. Value domains comprise non-anthropocentric, i.e. intrinsic, instrumental and relational values. **Instrumental value** refer to the value attributed to something as a means to achieving a particular end. **Relational values** are values that contribute to desirable relationships, e.g. among people/societies or people and nature. As **intrinsic values** (i.e. inherent values) are beyond the scope of anthropocentric valuation approaches, we consider only instrumental and relational values in SOILGUARD, that are assessed with socio-economic valuation.	Jacobs et al. 2016, Pascual et al., 2017, Christie et al. 2019
Wellbeing	A perspective on a good life that comprises access to basic resources, freedom and choice, health and physical, including psychological, well-being, good social relationships, security, equity, peace of mind and spiritual experience. Well-being is achieved when individuals and communities can act meaningfully to pursue their goals and can enjoy a good quality of life.	IPBES (2019)

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