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Bridging soil biodiversity and human well-being: an actionable framework to measure links between the natural capital and plural value of soils

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Abstract: Human activities contribute to soil degradation globally, endangering life belowground and services like food production and climate regulation. To reverse this situation, an actionable framework to connect soil health and soil biodiversity status with human well-being, integrating the biophysical, economic and social domains, is urgently needed. Here, learning from previous generalist and soil-specific frameworks, we introduce the Soil Biodiversity and Well-being Framework, which creates the conceptual architecture to quantifiably link soil natural capital with human beneficiaries, soil management, environmental pressures, and societal responses. Furthermore, we outline the requirements for its operationalization, based on a flexible set of measurable indicators for soil natural capital assets, plural valuation of soil-mediated nature's contributions to people, and human well-being. Implementation of the framework by multiple stakeholders (e.g., scientists, farmers or policymakers) can generate the multidimensional and quantitative evidence to support action towards transformative change for sustainable soil management and soil biodiversity conservation.

Soils, the foundation of life belowground, are under severe threat[1]. Soil biodiversity represents almost 60% of planetary species[2] and supports essential functions and services such as nutrient cycling, food production and climate regulation. However, unsustainable soil management practices and other anthropogenic impacts, such as human-induced climate change and land degradation (e.g., chemical pollution and deforestation), pose a serious menace to soil biodiversity and soil-mediated nature's contributions to people (NCP) - the contributions of living nature to people's quality of life[3,4]. Loss of soil biodiversity threatens soil functions, endangering the sustainability of human societies[5]. Despite its significance, assessing the consequences of human actions on global soil environments for human well-being remains challenging, primarily due to a persistent disassociation between soil natural capital data (e.g., soil physiochemistry and soil biodiversity) and socioeconomic indicators across spatial and temporal scales. This gap restricts the development and implementation of effective long-term biodiversity-based solutions for soil ecosystems, as required by the plan of action 2020-2030 for the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity[6]. While recent policy efforts – such as the proposed EU Soil Monitoring Law – aim to establish harmonized soil health monitoring frameworks[7], and initiatives like Land Use and Coverage Area frame Survey (LUCAS) and Soil Biodiversity Observation Network (Soil BON)[8,9] are beginning to provide standardized data on soil properties and biodiversity; however, these efforts are not designed to capture the socio-economic consequences of shifts in soil health. Bridging this gap is essential for empowering stakeholders—from landowners to policymakers—to make informed decisions that support the sustainable use and conservation of soil resources[10].

The Kunming-Montreal Global Biodiversity Framework[11] points in this direction, aiming to sustainably manage biodiversity and to value, maintain, enhance, and restore NCP across key ecosystems. Yet, despite soils being the foundation for many of the positive effects of nature protection, most of the conceptual frameworks aimed at guiding conservation and management, usually disconnect soil biodiversity and related ecosystem functions from mainstream nature conservation. Soils are framed almost exclusively as a driver of food production, rather than recognizing their broader contributions to ecosystem resilience and human well-being[12]. Hence, the focus of the Kunming-Montreal Global Biodiversity Framework on NCP demands a conceptual framework tailored specifically to soil ecosystems but that also incorporates measurable indicators which integrate the biophysical, economic, and social dimensions. In particular, a harmonized, soil-specific framework that is both conceptual (i.e., capturing the complex links between soil natural capital and soil-mediated NCP through plural valuation approaches) and actionable (i.e., including environmental, economic and social measurable indicators and metrics) is currently lacking.

To address this need, we introduce the Soil Biodiversity and Well-being Framework (SBWF), a conceptual and practical tool to structure the evidence on the links between soil management, soil natural capital, soil multifunctionality, soil-mediated NCP and human well-being. It links the Kunming-Montreal Global Biodiversity Framework targets with soil environments, making clearer our understanding of the plural values that individuals and communities hold about soils, and the connections with human well-being. It therefore supports efforts to overcome systemic barriers and drive transformative change toward mainstreaming sustainable soil management and restoring soil health and biodiversity in natural, managed and degraded soils[13,14].

The SBWF builds on relevant conceptual frameworks and participative methods to identify and agree the main components to be represented in the SBWF, and the links between them. The conceptual component of the framework incorporates the central role of soil biodiversity, a key component of soil natural capital, for the provision of soil-mediated NCP, considering beneficiaries and their preferences in determining the value of each NCP. It also includes the influence of external forces and drivers on both soil attributes, soil-mediated NCP, and beneficiaries' preferences. The actionable component of the SBWF outlines specific metrics and measurable indicators for each conceptual category of the framework.

The SBWF was developed to address the following research questions: i) How soil biodiversity, in combination with other soil natural capital assets, underpins NCP and human well-being, ii) How human-derived actions impact soil biodiversity, soil-mediated NCP and human well-being, iii) What land and soil management practices enhance soil health and soil biodiversity and the delivery of human well-being from NCP, and iv) What responses (behavioral and institutional) improve the sustainable use of soil biodiversity, protect soil multifunctionality and increase economic, social and environmental well-being. Therefore, the SBWF holds the potential to become a standard for future global soil assessments by international initiatives, such as the FAO's Global Soil Partnership.

The challenge of linking soil capital and well-being

Several existing conceptual frameworks were reviewed and matched to our research questions in terms of i) the role of (soil) biodiversity as crucial structure of the natural capital for the delivery of NCP and ii) proper valuation of soil-mediated NCP. In parallel, the elements worth incorporating into the SBWF were also identified. The review was limited to studies that had developed i) general conceptual frameworks focusing on the links among biodiversity and/or natural capital, ecosystem services (ES) and/or nature's contributions to people (NCP) and human well-being (i.e., not targeting any ecosystem in particular), and ii) conceptual frameworks including soils and soil biodiversity to some extent (Figure 1).

Biodiversity in ES/NCP general conceptual frameworks. Many of the general ES/NCP conceptual frameworks include characteristics of the ecological system and of the socio-economic system. However, the role of biodiversity within an ES framework has historically caused controversy[15,16]. The controversy primarily concerns whether biodiversity can only be considered as an underpinning component for all service delivery, or whether biodiversity or individual species can be a component of a final service (i.e., can be directly valued)[15,17].

The Millennium Ecosystem Assessment pioneered the conceptual interlinkage between indirect and direct biodiversity change, ES (provisioning, regulating, cultural and supporting services) and categories of human well-being[18]. Therefore, the Millennium Ecosystem Assessment puts biodiversity as central for the delivery of ES (Figure 1). After this, new conceptual frameworks emerged, with different views about the relation between biodiversity and ES[19,20]. The Economics and Ecology of Biodiversity defined "Biodiversity" as "the sum total of organisms including their genetic diversity and the way in which they fit together into communities and ecosystems". This central role of biodiversity is maintained in the more recent conceptual framework by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[21]. In addition, the "Biodiversity" described by The Economics and Ecology of Biodiversity also fits into the concept of natural capital stock, adopted by the Natural Capital Metrics framework[22]. Therefore, drawing a parallel with the limited stocks of physical and biological resources found on earth.

However, these frameworks have been rarely applied in real soil environments and when applied, even though soil biodiversity is crucial for the delivery of ES/NCP in these ecosystems, it has been unassessed. For example, in studies applying the The Economics and Ecology of Biodiversity for agricultural landscapes in Africa and Europe, biodiversity was solely represented by vegetation and birds[23,24]. This underestimates the importance of soil biodiversity in the delivery of ES/NCP in terrestrial ecosystems, and its relationship with other soil natural capital assets. Thus, strongly highlighting the need for soil-specific ES/NCP conceptual and actionable frameworks, with clear and precise indicators to monitor soil natural capital, including soil biodiversity.

Drivers of ES/NCP in general conceptual frameworks. The Millennium Ecosystem Assessment also defined external forces as direct and indirect drivers of change in socio-ecological systems. Later, other conceptual frameworks better explained the feedback relations among drivers of change, biodiversity, ES and human well-being[25-31]. However, these frameworks have been rarely applied to assess the impacts of drivers and/or pressures in real soil environments. For example, in one of the only studies found that applied the IPBES framework in real soil environments, it used published data to identify the driving factors and consequences associated with changes in deltaic soils[32]. Although the IPBES framework was useful to detect how changes could impact different NCP, the work concluded that not all NCP were equally covered in the literature and that most studies lacked assessment of quality of life. Furthermore, there was no mention of soil biodiversity. This example highlights the limits of generalist ES/NCP frameworks to increase our knowledge on the impacts of drivers on soil biodiversity and the potential cascading effects on the delivery of NCP and human well-being.

The role of people in conceptual frameworks. The Framework for Ecosystem Service Provision includes the vision that ES and human well-being happen within social-ecological systems, an idea not included in the precedent conceptual frameworks[25] (Figure 1). It included the role and attributes of ES beneficiaries as relevant actors to ES supply. It also incorporates mechanisms of either mitigation or adaptation to environmental change through the effect of response strategies (management). In the same direction, The Natural Capital Framework for sustainably efficient and equitable decision making recognized the importance of considering decision-led changes (e.g., policy) over a defined period of time on the natural capital status[26]. The GEO BON conceptual framework[27] defined that services come about through both supply and benefit, and are not strictly linear.

These concepts are merged in the Natural Capital Metrics framework[22], focused on evidencing the linkages between sustainable management of natural capital assets and the people who benefit from them, and emphasises the multi-directional interrelationships between (i) the natural world (assets); (ii) the aspects of the natural world that impact on human' well-being (ES and disservices); (iii) the humans who receive these impacts (beneficiaries); (iv) internal pressures; and (v) external drivers within a socio-ecological system. Next-generation frameworks started questioning the instrumental vs. intrinsic value of the ES dichotomy, fueling the development of diverse/plural valuation of ES/NCP.

The interaction between people and the environment being a fundamental requirement of ES/NCP delivery has been clearly articulated in several studies[33], but the principle has rarely been tested. A notable attempt to model these relationships was based on public responses on the aesthetics of planted urban wildflower meadows[34]. The retrospective analysis concluded that typically there is a failure to measure suitable variables, particularly those relating to human elements of the system, and that guiding frameworks are necessary to inform appropriate data collection.

ES/NCP value in general conceptual frameworks. An early criticism of the Millennium Ecosystem Assessment was that the typologies of ES did not reliably differentiate between services, functions, or benefits, thereby hampering valuation approaches[35]. The first ES cascade framework distinguished more clearly between biophysical structures or processes (e.g., net primary production), functions (e.g., biomass), services (e.g., harvestable products) and benefits in terms of value (e.g., willingness to pay for harvestable products), linking ecological processes with elements of human well-being following a pattern like a production chain[19].

The first framework to explore the concepts of plural values was The Economics and Ecology of Biodiversity, which acknowledged the distinction between ecological, socio-cultural, and economic benefits and values. As a result, the conceptual framework of the IPBES, due to its inclusive nature, required the consideration of multiple value systems[21], termed plural values. A major distinction adopted in the IPBES framework was between intrinsic values and anthropocentric values, including instrumental and relational values, needing multidimensional valuation approaches, not only focused on economic terms (Figure 1). The IPBES framework kept biodiversity and drivers of change as key players in the delivery of NCP. The NCP concept embraces, but goes beyond the ES approach, emphasizing that culture is central to all the links between people and nature[36]. However, application of the IPBES framework with respect to soil environments is still infrequent. When it is applied, studies using exclusively economic or socio-cultural valuation methods are the most common[37,38,39], thus underestimating the plural value of NCP. Furthermore, a large heterogeneity of valuation methods for each NCP exists, hampering comparability and stressing the need for a harmonized framework.

Limits of ES/NCP general conceptual frameworks for soil

In the literature, although the Millennium Ecosystem Assessment, The Economics and Ecology of Biodiversity, IPBES and other conceptual frameworks, offer a foundational guide, their broad approach lacks specificity for soil ecosystems, especially in the context of international initiatives such as the Global Soil Partnership. Therefore, there remains a strong need for conceptual clarity around soil aspects and the links between them. This conceptual clarity can only be defined through specific ES/NCP conceptual frameworks for soils, with the capacity to measure their plural value. This is crucial because the outcomes of transformative actions, in terms of improvements in soil protection and health, will depend on how society perceives the benefits obtained from soils.

Moving beyond conceptual clarity, there is a need to track the performance of new policies and transformative interventions, such as the European Union Soil Monitoring Law. Therefore, we need to define and harmonize measurable indicators. This allows us to quantify the status of soil natural capital (including soil biodiversity), plurally value the impacts of human actions on soil-mediated NCP and link it to categories of human well-being. This detail requires a soil-focused framework since natural capital assets are very ecosystem-specific, as well as the type of benefit that is delivered to society.

Specific conceptual frameworks linking soil and ES/NCP. As a consequence of the limitations of generalist frameworks to tackle soil ecosystems and the specific benefits that society obtains from them, soil-specific ES/NCP conceptual frameworks have been developed since the beginning of the 21st century (Figure 1). However, an increased consideration of soil, its biodiversity, and the services it supplies came to prominence in the late 20th century[40]. Multiple articles that explored the links between soil biodiversity and ES followed[41-50], contributing to the development of conceptual frameworks focusing on soil and soil biodiversity and its links to ES[51-52]. The first attempt was a simple framework linking soil biota, soil processes and soil-mediated ES, but omitted the impacts of drivers of change on soil biodiversity and other soil natural capital stocks, and effects on human well-being[51] (Figure 1).

Later, the Natural Capital and ES framework went beyond this first attempt by connecting five main components: (i) soil natural capital (physical, chemical and biological soil properties); (ii) the processes behind soil natural capital formation, maintenance and degradation; (iii) anthropogenic and natural drivers of soil processes (e.g., management and erosion); (iv) provisioning, regulating and cultural soil-mediated ES, as products of multiple processes; and (v) human needs fulfilled by soil-mediated ES[52] (Figure 1). However, the Natural Capital and ES framework did not include specific indicators for soil biodiversity or harmonizable methodologies to assess other soil-related natural capital assets, and did not describe valuation methods for the multidimensional benefits of soil-mediated ES/NCP for human well-being. Thus, these omissions limited the creation of the required evidence to link these soil-related categories to promote soil protection and transformative change.

To partially solve this methodological gap, frameworks were developed with the aim of understanding the economic value of soil biodiversity and soil-mediated ES[53-54]. Although these frameworks represented a step forward in the conceptualization of the relationship between soil biodiversity and human societies, the studies using them underestimated the non-economic value of soils and soil biodiversity[55,56] (Figure 1).

As a conclusion to this section, we found three major challenges in relation to conceptual frameworks connecting soil natural capital and human well-being. Firstly, many current soil-specific frameworks only consider how soils underpin NCP and human well-being from an economic standpoint. This limited conceptualization underestimates the role of different types of values in determining the status of human well-being. Therefore, new frameworks considering plural valuation of soil-mediated NCP are required to correctly depict the real socio-ecological relationships between soils and human societies, and synergies and trade-offs between the ecological, economic and social spheres. Secondly, the more generalist frameworks are a useful tool to understand the plural valuation of NCP in socio-ecological systems. Unfortunately, they lack the required specificity to accurately define and quantify the links between soil natural capital properties and functions to deliver soil-mediated NCP, including the role of soil biodiversity within those processes. Finally, none of the frameworks shown in this section included specific and measurable indicators that were sufficiently specific for soil. Thus, strongly limiting our capacity to track progress of the impact of societal responses on soil and soil biodiversity status and the multidimensional delivery of NCP.

The Soil Biodiversity and Well-being Framework

The SBWF directly responds to the three major challenges found in conceptual frameworks linking soils and benefits for human societies. It builds on previous generalist and specific frameworks to create a unique framework with the potential to accurately connect soil natural capital with the plural values of soil-mediated NCP, including measurable indicators for each conceptual category. Thus, it provides a comprehensive approach for structuring and integrating evidence for use by international initiatives and other relevant actors, thereby promoting the incorporation of soil biodiversity into conservation policy actions (Figure 2). This conceptual and actionable framework identifies, defines and describes the elements, processes and attributes related with soil management, soil natural capital, soil multifunctionality, NCP and well-being, and the linkages between them, assigning specific and measurable indicators.

The SBWF, co-created through participative methods, facilitates quantification of the environmental, economic, and social costs of maintaining unsustainable soil management strategies in natural and managed soils, amid escalating climate change and land (soil) degradation.

The co-creation process was initiated by a participatory online workshop. This was attended by stakeholders from 25 institutions chosen to represent a variety of organizational types covering academia (universities and research centers), global initiatives, enterprises, and farmer and nature associations, and to encompass a range of expertise (e.g., ecology, soil science, economics, sociology, agronomy, climatology, communication and engagement). The workshop served as an introduction to the preliminary components of the SBWF, their definitions and interactions. It included interactive sessions to further develop the conceptual and actionable framework, including indicators and methodologies to assess them. Several cycles of iteration were carried out with these core stakeholders, who constitute the co-authors of this manuscript, to define and agree the final version of the SBWF (Figure 2). This was supplemented by group or bilateral consultations with other stakeholders from academia, biodiversity networks, farmers, landowners, the agricultural sector, policy-makers, community leaders, national laboratories for soil science, relevant government agencies, and Intergovernmental Organizations, such as the Global Soil Partnership and the Global Soil Biodiversity Initiative. This helped to increase the potential of the SBWF to become the future global standard for assessing soil biodiversity and its importance for planetary and human wellbeing.

The SBWF builds strongly on the Natural Capital Metrics conceptual framework. Adaptations have been made to make the framework specific for soil ecosystems, and to better reflect the key contributions of soil biodiversity and soil management to sustainability, resilience and well-being. The SBWF follows the Millennium Ecosystem Assessment and The Economics and Ecology of Biodiversity in considering soil biodiversity as central for the delivery of ecosystem functions, although it recognizes that biodiversity has a greater or lesser role depending on the soil processes. The SBWF additionally considers soil properties and processes as the building blocks of functioning soils, and emphasized that the interactions between structure and processes may be physical (e.g. water infiltration), chemical (e.g. redox processes) or biological (e.g. mineralisation). For example, redox processes are crucial to explain the leaching behavior of chemical pollutants present in soils[57].

The SBWF defines a single specific socio-ecological system (blue dashed line; Figure 2). It is divided into an ecological system, comprising natural capital assets, and a socio-economic system, which consists of the beneficiaries of soil-mediated NCP. Soil-mediated NCP are provided at the intersection of the ecological and socio-economic system. This is a sub-component of the entire social-ecological system (purple dashed line; Figure 2).

The SBWF uses the conceptual framework of NCP proposed by the IPBES to acknowledge the diversity of nature’s values. It recognizes variation in soil biodiversity and its ability to deliver NCP and well-being, across the social-ecological system. Its distinctive feature is adaptability, allowing customization to the specifics of each social-ecological context. NCP result from the dynamic interplay between the ecological part of the socio-ecological system and the socio-economic and socio-cultural dimensions (beneficiaries and their demands). The SBWF's capability to navigate these complexities makes it a distinct asset for promoting effective soil conservation.

In relation to the external forces affecting the socio-ecological system, and building on The Framework for Ecosystem Service Provision, the SBWF has adapted a drivers/pressures box to contain drivers of change at the global/national level (e.g., climate change and land degradation). It also contains a new land management box, to reflect the importance of sustainable soil and land management interventions, represented as external forces, at a field/landscape level. In addition, the responses box includes measures from the socio-ecological system to counteract the negative impacts of external forces. The content of Figure 2, all the boxes of the SBWF diagram, will be comprehensively explained, as follows:

Natural capital assets. Natural capital assets (Figure 2) encompass attributes of soils and ecosystems for delivering NCP (Table 1), categorized into Properties (incorporating Extent, Stock, and Condition) and Functions (which define Processes): *i)* 'Extent' quantifies area of habitat or soil type; *ii)* 'Stock' measures quantity of matter and is subdivided into abiotic and biodiversity stocks (e.g. soil organic matter and total soil microbial biomass, respectively); *iii)* 'Condition' describes stock quality and structure and is both context-dependent and function/NCP-specific. For example, a given level of an attribute, such as soil pH, may constitute high quality for one function but low quality for another, or the level of degradation of soil quality due to chemical pollution will be dependent on the type of pollutant (e.g., organic vs inorganic pollution); and *iv)* 'Functions' are expressed as fluxes or rates, covering vital soil processes, such as decomposition or nitrogen mineralization. Thus, the natural capital component of the SBWF comprehensively integrates soil material stocks and binding ecological processes, both crucial for the delivery of nature's contributions to people.

Nature's contributions to people. The SBWF underscores the central role of natural capital assets in the delivery of soil-mediated NCP. It illustrates this broad contribution through arrows, representing multiple soil functions (soil multifunctionality), connecting natural capital assets to NCP. The SBWF emphasizes the importance of soil multifunctionality to support both positive and negative impacts on NCP provision ("+" and "-" symbols on arrows), creating cascading effects and trade-offs in complex soil ecosystems[58]. This highlights that the same soil process may lead to benefits for one NCP, but to disbenefits for another NCP, for example high respiration from soil biodiversity, which can be considered a benefit for 'habitat creation and maintenance', maintaining an active decomposer community, but would be likely a disbenefit for 'regulation of climate', since it implies rapid levels of carbon turnover[59] (Table 1).

NCP represent various dimensions, including material NCP (e.g., food and feed), regulating NCP (e.g., climate regulation or soil erosion prevention), and non-material NCP (e.g., biodiversity education or tourism) (Table 1), and spatio-temporal scales. The spatial scale of NCP supply depends on the NCP type: field scale (especially for material NCP such as crop production), landscape scale (especially for non-material NCP such as relaxing experiences of nature), or multi-scale (e.g., for Regulation of hazards and extreme events, where infiltration is governed by soil structure at sub-field level, but which integrate at landscape scale to determine flooding hazard).

Beneficiaries. The realization of potential NCP relies on the demand articulated by the beneficiaries of these services and the capacity of ecosystems to deliver such NCP. The Beneficiaries box is subdivided into 'attributes' and 'outcomes' (Table 1). Beneficiaries shape service supply through attributes such as geographical location, socio-economic status and different types of capital, which in turn shape the Outcomes. This is further nuanced by the plural valuation of the outcomes obtained by the beneficiaries from the delivery of NCP, such as an increase in quality of life or the obtention of desired benefits (Table 1). For instance, benefits such as nutrition from food or access to clean water (facilitated by a water regulation service), contribute to enhanced well-being, encompassing physical and mental health, security, and material prosperity.

External forces. Every facet in the social-ecological system is influenced by external forces, operating across scales. The SBWF considers three types of external forces: drivers and pressures (national / global scale), land management (field and landscape scale) and responses (across scales). Drivers and pressures operate at large scales, from regional or continental, such as the EU Common Agricultural Policy, to global, such as climate change and consequent land degradation impacts, political and economic dynamics, or societal and technological influences (Table 1). These pressures can directly impact natural capital or shape beneficiary behavior and might extend their impact via land management (Table 1), thereby directly altering ecosystem properties and functions[60]. The SBWF highlights sustainability challenges from soil management actions potentially causing synergies or trade-offs between NCP - e.g., chemical inputs used in crop management can increase production of food and materials, but can also cause habitat loss, a dysregulation of freshwater quality and impaired regulation of processes for decontamination of soils and sediments. In this sense, the Land Management box is subdivided into 'type of management' and 'interventions/practices' (Table 1). On the other hand, the Responses reveal measures, within the social-ecological system, to counteract negative impacts on beneficiaries and/or nature and are categorized by scale (i.e., international, national, regional *vs* local) and type (i.e., societal, political and management; Table 1). These responses, enacted through changes in management or policy at different scales, have the potential to safeguard or enhance natural capital assets, adjust other capital inputs, or shape beneficiary demand for NCP (Table 1).

The SBWF multidimensional indicators. Complementary to the conceptual component of the SBWF, the actionable component provides a structured set of specific and measurable indicators (and the methodologies for assessing them) for natural capital assets and soil functions (Table S1), NCP values (Table S2) and human well-being (Table S3). Indicators for the natural capital assets, are organized by type of asset (i.e., extent, stock, condition and function) and for each indicator a specific methodology has been defined (Table S1). The indicators have been selected based on criteria of measurement feasibility and harmonization, where possible. For example, for soil biodiversity, to incorporate the abundance and taxonomic and functional diversity of soil organisms (such as viruses, bacteria, archaea, fungi, protists, nematodes, arthropods, annelids, plants and vertebrates), we aimed to align with methodologies by the international initiatives. These include LUCAS and Soil BON. In terms of soil features (like soil total N and P), the methodological alignment has been searched with The International Network on Soil Biodiversity of the FAO's Global Soil Partnership (Table S1). Soil biodiversity attributes (extent, stock, condition, and processes) align with the 'Essential Biodiversity Variables' outlined by Soil BON, and to the System of Environmental and Economic Accounting.

Beyond the 'Essential Biodiversity Variables', the SBWF broadens its scope by linking these attributes to NCP, values, and well-being. The linkage of soil biodiversity, soil multifunctionality and soil-mediated NCP data through tailored statistical models facilitates precise quantification of the role of soil organisms in the delivery of each measured soil function and NCP. For example, the role of soil biodiversity, and other drivers (i.e., climate, soil features and management), in the delivery of soil multifunctionality and soil-mediated NCP can be quantified using regression and structural equation models[61,62]. This expansion towards linking soil natural capital and NCP involves specific valuation methods, employing biophysical, economic and socio-cultural indicators capturing relevant plural values—instrumental and relational— for each NCP (Table S2). More in-depth, for each material, regulating or non-material NCP, we defined a more detailed biophysical and monetary indicator, and/or a socio-cultural indicator, and the associated valuation methodology (Table S2). This approach recognizes that nature's values, spanning instrumental, relational, and intrinsic dimensions, are shaped by diverse worldviews and knowledge systems. Finally, to link natural capital and soil-mediated NCP with human well-being in social-ecological systems, a set of multidimensional indicators for good quality of life have been selected based on the European Union statistical methodology on income and living conditions.

The SBWF as an open framework for a diversity of users

The SBWF is built as an open and dynamic framework and so, depending on the question of interest, it can be utilised from different starting points. For example, for a user interested in how soil biodiversity and other soil natural capital assets combine to underpin NCP and human well-being, they may start from the natural capital assets box. For the user, the outcome would quantify the role of soil natural capital in the synergistic delivery of NCP. Alternatively, another user may want to explore land and soil management practices that enhance soil health and/or soil biodiversity and the delivery of human well-being from NCP; if so, they may start from the external forces or the responses box. In the latter case, the user could compare the qualitative and quantitative performance of soil management practices in relation to soil health, soil-mediated NCP and human well-being. This comparison would be based on measurable multidimensional indicators, which to our knowledge, is not possible with other frameworks.

Users can also select indicators most suited to their purpose. The framework also allows the development of multi-scalar spatial studies through scaling modelling strategies, if required[63]. Thus, the SBWF can potentially be used by a wide range of stakeholders, from landowners to policymakers, with different questions and interests in relation to soils. Furthermore, the definition of a multidimensional set of measurable indicators allows the SBWF to go beyond consultation and/or communication tools; it can be used when i) defining strategic plans for multidimensional monitoring of soil health dynamics and their impacts for human societies, and ii) obtaining recommendation of soil management practices based on available information. A limitation that the SBWF would face is that not all indicators are easily measurable. For example, the feasibility and ease of measuring soil moisture through gravimetric methods is not comparable to the feasibility and ease of quantifying total soil microbial biomass or performing economic cost-based methods. This, in addition to data accessibility, should be carefully considered before operationalizing the framework and is the main reason why the framework was built in an open and dynamic manner.

Operationalizing the SBWF

The SBWF is aligned with the need to increase science-society dialogue and the engagement of multiple soil-related stakeholders to bridge the gap between knowledge holders and decision makers. Therefore, the operationalization of the framework by stakeholders would produce new soil-related data and allow the development of statistical or AI models to link nodes (such as drivers, soil natural capital assets, NCP or categories of human well-being) through causal pathways and study their dynamics and synergies and trade-offs through[64] through new software (Figure 3). As such, the main aim of the SBWF is to be a useful and appropriate operational tool for different stakeholders that include: i) soil managers and advisors – to effectively implement region-specific sustainable soil management practices, ii) policymakers from different administrative scales - to better understand the multidimensional value of sustainable soil management, soil health and soil biodiversity, iii) scientists from different disciplines - to select harmonized and comparable indicators and methodologies when designing experiments or monitoring programmes, and iv) global initiatives such as the Global Soil Partnership or the International Union for the Conservation of Nature (IUCN) - to create new evidence of the links between soil management, soil natural capital, highlighting soil biodiversity, and the delivery of NCP and quality of life, (Figure 3).

More specifically, for example, a soil manager could use a software (or platform), based on the SBWF, to define which categories of natural capital assets to select, and which indicators to measure, depending on interest and budget, prior to a transition towards more sustainable soil management practices. As shown in Figure 3, this type of user could obtain, through soil analysis and economic assessment, quantified data - soil properties (e.g., soil organic carbon and microbial biomass), soil multifunctionality (e.g., yield) and economic data (e.g., yield value) – that can be introduced in the software. This software, through models connected to decision support systems, can provide the user with an assessment of the provision of multiple NCP, under current soil management practices, along with recommendations for practices to maximize their synergistic provision, considering regional context (e.g., climate) (Figure 3). The sum of data in such a software or platform (with open repositories), can be used by other stakeholders with other purposes. A national ministry or an international institution could use it, for example, to study the ratio of organic agriculture that can be desired, in a particular landscape or region, to maximize the synergistic delivery of soil-mediated nature's contributions to people at a policy-relevant scale.

As an example of how global initiatives might adopt the SBWF, the conceptual and actionable components of the SBWF could be used as to develop an assessment tool focused on sustainable soil management practices. The purpose of this tool would be to increase the specificity of the IUCN Global Standard of Nature-based Solution (NbS) for soil ecosystems and i) position soil biodiversity as an NbS, ii) better align sustainable soil management with the IUCN Global Standard for NbS, and iii) provide policy recommendations (at different scales) to enhance adoption of sustainable soil management practices that protect, conserve and restore soil natural capital assets, such as soil biodiversity, and enhance the delivery of soil-mediated NCP. This is aligned with the Criterion 1 of the IUCN Global Standard for NbS, which emphasizes the importance of identifying the societal challenge that the NbS will address (in this case, sustainable soil use and conservation) to ensure deliberate and purposeful design aimed at meeting needs for human well-being.

Considering that the generalist and strategic approach of the Global Standard of NbS may be one of the main barriers to its use[65], linking it to the SBWF would help develop a more accessible, condensed, clear and practical tool that facilitates specific and practical soil management guidance. Furthermore, considering the potential benefit of a more operational approach for NbS[66-67] this exercise may be a specific example of operationalization of the NbS framework for soil biodiversity and sustainable soil management using the SBWF.

Such a tool would follow all the aspects covered in the IUCN Global Standard of NbS, but using the elements, processes, attributes and connections detailed in the SBWF. For example, Criterion 3 of the IUCN Global Standard of NbS is "NbS result in a net gain to biodiversity and ecosystem integrity" and could be transformed into "sustainable soil management practices have a positive impact on soil biodiversity and ecosystem integrity and the impact is periodically assessed". The merging of the SBWF with the IUCN Global Standard of NbS at a conceptual and analytical level would improve monitoring of the impacts of soil management on soil natural capital assets (e.g. soil biodiversity and soil functions) and soil-mediated NCP. Following the rationale of the IUCN Global Standard for NbS, sustainable soil management must address specific challenges while simultaneously providing human well-being and biodiversity benefits. It should preserve and enhance soil biodiversity and increase the flow of NCP through activities that promote job creation, empowering women and vulnerable groups or ensuring yields to meet the needs of the population. This assessment tool would also be used to identify barriers and recommendations for better integration of these practices and interventions for the conservation of soil biodiversity and soil ecosystem functions and the delivery of NCP and human well-being.

Further considering its wider adoption, the SBWF has potential to implement a unified methodology for the Action Plan of the International Network on Soil Biodiversity (NETSOB) from the FAO-Global Soil Partnership, concerning the 2020-2030 Plan of Action for the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity. Where possible, the SBWF actionable framework has been harmonized with the methodologies selected by Working Groups 1 and 2 of the NETSOB (*see* section The SBWF multidimensional indicators and Table S1). Harmonized methodologies are a critical step when assessing the cumulative impacts of multiple sectors on the status of soil biodiversity and on its multidimensional value for human well-being[68]. The SBWF would also allow one to define the type of interventions (at different scales) that would enhance soil biodiversity and the delivery of NCP. Finally, the SBWF multidimensional valuation of soil-mediated NCP could also be potentially adopted or harmonized by the NETSOB Working Group 3, obtaining an approach, which includes measurable indicators, towards identifying the relationship between soil biodiversity and human well-being for future global soil biodiversity assessments.

Future outlook

The SBWF has been developed from a transdisciplinary perspective, firmly understanding that the involvement of academic and non-academic actors is imperative for more holistic and creative solutions to the global degradation of soil natural capital. However, powerful barriers still exist in the research/society/policy spheres to action transformative change. This includes: the lack of habit of academics to collaborate with other social actors or non-academic groups[69]; the lack of trust of soil managers in traditional 'experts', particularly agricultural researchers from academic and government institutions[70], and; the lack of political will to further develop new environmental laws or even apply and fund them after approval[71].

To overcome these barriers, all societal actors must realize the value of soil-mediated services provided both to society and to the daily life of individuals, and that soil is a scarce and finite commodity. This type of cultural transition takes time and no single action can trigger it. However, the operationalization of the SBWF in future global soil assessments would improve the plural valuation of soil and soil biodiversity into political, economic, and day-to-day decision-making. At the same time, the SBWF can help co-create the required evidence to raise awareness and inspire transdisciplinary action and transformative change towards a just and sustainable use of soils and soil biodiversity[72]. This would facilitate the prioritization of sustainable soil management and soil biodiversity as a fundamental cornerstone for steering the world towards a sustainable, healthy and resilient future.

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AUTHORS CONTRIBUTIONS

S.L., L.M., L.J. and P.A.H. conceptualized the main goals and aim, developed the methodology, contributed, and supervised the development of the framework and wrote the original draft. C.Y. conceptualized the main goals and aim, developed the methodology, contributed, and supervised the development of the framework and reviewed and edited the original draft. P.S.C., M.B., L.P., M.H., T.G.C., R.G., G.B., E.M., F.T.V., S.S., A.S., M.G., A.D., K.S., T.V.S., H.H., I.A., F.G.O., J.M.S., L.O.M., Z.T., T.P., F.B., J.A.F., X.S., M.P.B., J.N., R.T., N.S., M.Z., P.Z., P.V., J.S., M.M., A.M., R.G. and D.R. contributed to the development of the framework through their different expertise, from soil ecology to soil science, economics, sociology and environmental policy, and edited and reviewed the original draft and further iterations.

DECLARATION OF INTERESTS

The authors declare no competing interests

SUPPLEMENTAL INFORMATION

Document S1. Tables S1-S3

FIGURE LEGENDS

Figure 1. Timeline of the most relevant conceptual frameworks contributing to the Soil Biodiversity and Well-being Framework. At the top (**generalist**; green color boxes) and bottom (**soil-specific**; brown color boxes) of the figure are the chronologically appearances of the most important and common ideas to different conceptual frameworks (orange color boxes), and how they lead to the most important knowledge gaps today (pink color boxes).

Figure 2. The Soil Biodiversity and Well-being Framework. The whole social-ecological system is represented at different scales, with the purple dashed line representing largely external **drivers and pressures** (mustard yellow box), the green dashed line representing the field to landscape scale at which management decisions tend to be made. The blue dashed line incorporates the intrinsically linked ecological system of **natural capital assets** (brown box), and the socio-economic system, which includes the **beneficiaries** (purple box) who shape the demand for services. Together the natural components and beneficiaries define the services and benefits to people (**Nature's Contributions to People**, blue box). **Responses** (light brown box) represent direct and indirect adjustments within the social-ecological system which may influence any part of the system including, at an operational scale, **land management** (green box).

Figure 3. Roadmap to operationalize the Soil Biodiversity and Well-being Framework. From a network of stakeholders (green boxes in the upper part of the figure) implementing the Soil Biodiversity and Well-being Framework, soil properties, soil multifunctionality and Nature's Contributions to People plural values data may be obtained. The data obtained can be operationalized through modelling (central part of the figure). First, the data (and optional metadata) could feed data platforms and/or be stored in data repositories. Then, the same data might be used to create models which can be executed through execution engines. The more data is produced by the network of stakeholders, the more robust the models could be, through proper reconfiguration. Finally, all these data and models might feed, for example, decision support systems to synthesize data and model outputs to provide early warnings, insights and recommendations depending on the type of stakeholder. The models might also produce useful information even without feeding into decision support systems. Both options could reach the user through user-friendly interfaces and/or forums. The impact of operationalizing the Soil Biodiversity and Well-being Framework, through actionable models or apps is shown in the purple boxes (lower part of the figure) by type of stakeholder.

TABLES

Table 1. Main features included in the Soil Biodiversity and Well-being Framework. ***Natural Capital Assets*****:** These include: **extent-**the area of a particular habitat, soil type or geology, **stock-** the quantity of something that is directly measured, **condition**- a context-dependent measure of the quality of the stock, **functions**- functions or processes that occur within soils**.** Columns are lists (i.e., do not read across). ***Soil-mediated nature's contributions to people*****:** Columns are lists (i.e., do not read across). ***Aspects of beneficiaries*****:** Attributes describe features of beneficiaries and outcomes the benefits obtained from nature's contributions to people. Columns are lists (i.e., do not read across). ***External forces: Aspects of global and continental drivers affecting natural capital assets, NCP, and beneficiaries*****:** Drivers and/or pressures are categorized into environmental, economic, societal, technological and political. Columns represent lists (i.e., do not read across rows). ***Aspects of land management affecting natural capital assets, NCP, and beneficiaries*****:** For each type of ecosystem or landscape unit, types of management and options / practices eligible by landowners or managers are described. ***Aspects of responses by beneficiaries to changes in NCP delivery, global drivers and/or land management actions*****:** Responses are categorized into international, national and/or regional and local. Management responses (local) are categorized into i) strategic and guidance and ii) actions and measures.

NATURAL CAPITAL ASSETS

Extent	Stock	Condition	Function (process)
• Area of ecosystem / habitat type (e.g., cropland, grassland and/or forest) • Extent of soil type	*ABIOTIC STOCKS* • Soil nutrients available • Soil organic matter *BIODIVERSITY STOCKS* • Total soil microbial biomass • Abundance of bacteria, archaea, fungi, protists, nematodes, collembola, microarthropods, mites, earthworms in the bulk soil • Abundance of functional genes (e.g., nutrient cycling, pathogenesis, antibiotic resistance genes and/or resources for biotechnology)	*QUALITY* • Soil type • Soil texture; % sand, silt, clay • Soil moisture • Soil organic matter content (appropriate or relative to the potential SOM content of the habitat or land use) • Soil pH • Water retention capacity • Soil chemical pollution *STRUCTURE* • Soil aggregate stability • Bulk density • Air-filled pore space • Landscape composition and configuration *BIODIVERSITY STRUCTURE* • 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 functional genes (e.g., nutrient cycling, pathogenesis, antibiotic resistance genes and/or resources for biotechnology)	• Plant biomass production • Soil potential respiration • Carbon (C) sequestration • Methanogenesis • Potential N mineralization • Denitrification • Litter decomposition • Soil enzymatic activities (associated with C, N, P cycling) • Leaching of nutrients (NO_3/PO_3) • Leaf, stem, or root damage (insect and fungal pathogen) • Reduction in efficacy of antibiotics • Soil erosion / soil loss • Infiltration • Red/ox

NATURE'S CONTRIBUTIONS TO PEOPLE

Material	Regulating	Non-material
• Food and feed production • Energy production • Production of materials • Production of medicinal resources	• Habitat creation and maintenance • Pollination and dispersal of seeds and other propagules • Regulation of air quality • Regulation of climate • Regulation of freshwater quantity, location and timing • Regulation of freshwater and coastal water quality • Formation, protection and decontamination of soils and sediments • Regulation of hazards and extreme events • Regulation of detrimental organisms and biological processes	• Learning and inspiration • Physical and psychological experiences • Supporting identities • Maintenance of options

BENEFICIARIES

Attributes	Outcomes

• Location of beneficiary (relative to NCP) • Human capital (e.g., education level, health) • Social capital (e.g., farmer networks) • Cultural capital (e.g., societal perception of farming activities, personal value systems and viewpoints of individuals) • Produced capital (e.g., farm machinery, irrigation infrastructure) • Financial capital (e.g., household or farm business economic assets and income) • Socio-economic status of beneficiary	• Desired benefits • Good quality of life (human well-being and living in harmony with nature) • Plural values (intrinsic, relational, instrumental)

EXTERNAL FORCES				
GLOBAL AND CONTINENTAL DRIVERS/PRESSURES				
Environmental	**Economic**	**Societal**	**Technological**	**Political**
• Climate change: changes in temperature and rainfall regime and acute phenomena (e.g., heatwaves and drought) • Land degradation: land in a state that results from persistent decline or loss of biodiversity and functions	• Global crop prices • Incomes for farmers / soil managers • Fertilizer / fuel prices • Subsidies affecting market prices (e.g., EU Common Agricultural Policy) • Land prices • Carbon price	• Demography (age of land managers) • Availability of methods and expertise • Voluntary quality assurance schemes • Global product demand • Protein demand for food/feed • Dietary choice	• Soil informatics • Precision farming	• International / national policies and initiatives • Sustainable Development Goals (SDGs) • Trading agreements • EU Green deal (e.g., Farm to Fork Strategy, Biodiversity Strategy and Circular Economy Strategy)

LAND MANAGEMENT		
Ecosystem or landscape unit	**Type of management**	**Interventions / practices**
Cropland	Conventional	• Chemical inputs: level of intensity • Type of tillage (e.g., reduced tillage or no tillage) • Crop variety • Cover cropping • Intercropping • Others
	Organic	
	Others (e.g., agroecology or regenerative)	
Grassland	Conventional	• Chemical inputs: level of intensity • Diversity (e.g., low diversity or mixed species swards)
	Organic	
	Others (e.g., rotational grazing)	
Forest	Clear-cut	• Diversity (e.g., low diversity or mixed species) • Native / non-native species • Drainage
	Continuous cover	
Landscape	Landscape management	• Landscape diversity and configuration • Semi-natural components (field margins, hedgerows, streamside, flower strips or remaining natural vegetation)

RESPONSES		
International, national and/or regional		**Local**
Societal	**Political/Policy**	**Management**

• Soil awareness programs • Knowledge exchange • Change in diets	• Soil Strategy • Policy compromises • Protection of soil biodiversity • Land use planning • Carbon conservation policies • Land sharing vs. land sparing approaches • Conservation, protection, and restoration policies	STRATEGIC & GUIDANCE • Building common strategies with soil managers • Guidance on maintaining soil quality ACTIONS & MEASURES • Landscape scale management • Selection of crop species and rotation • Practices to address soil degradation Conservation measures

Figure 1

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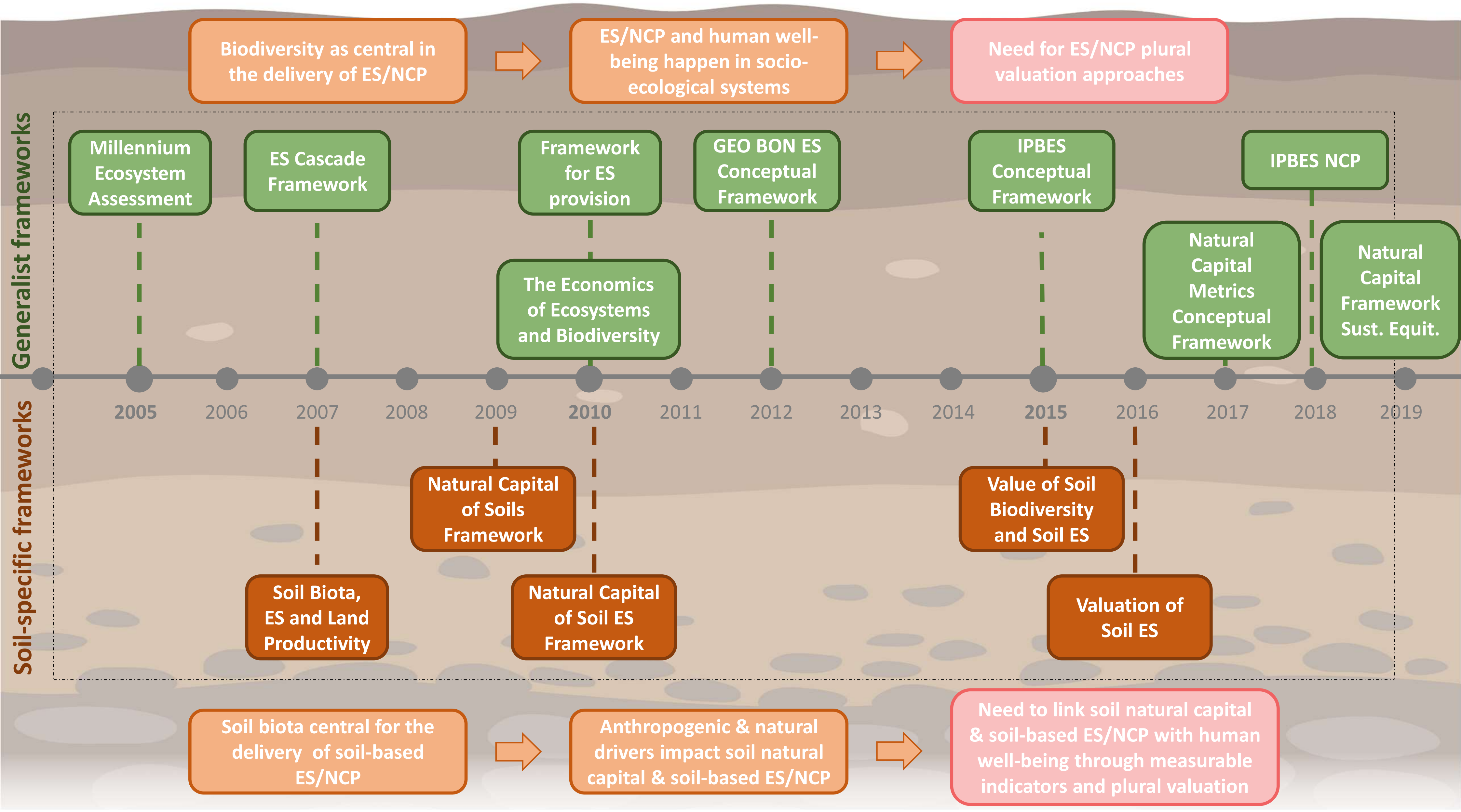

Figure 2

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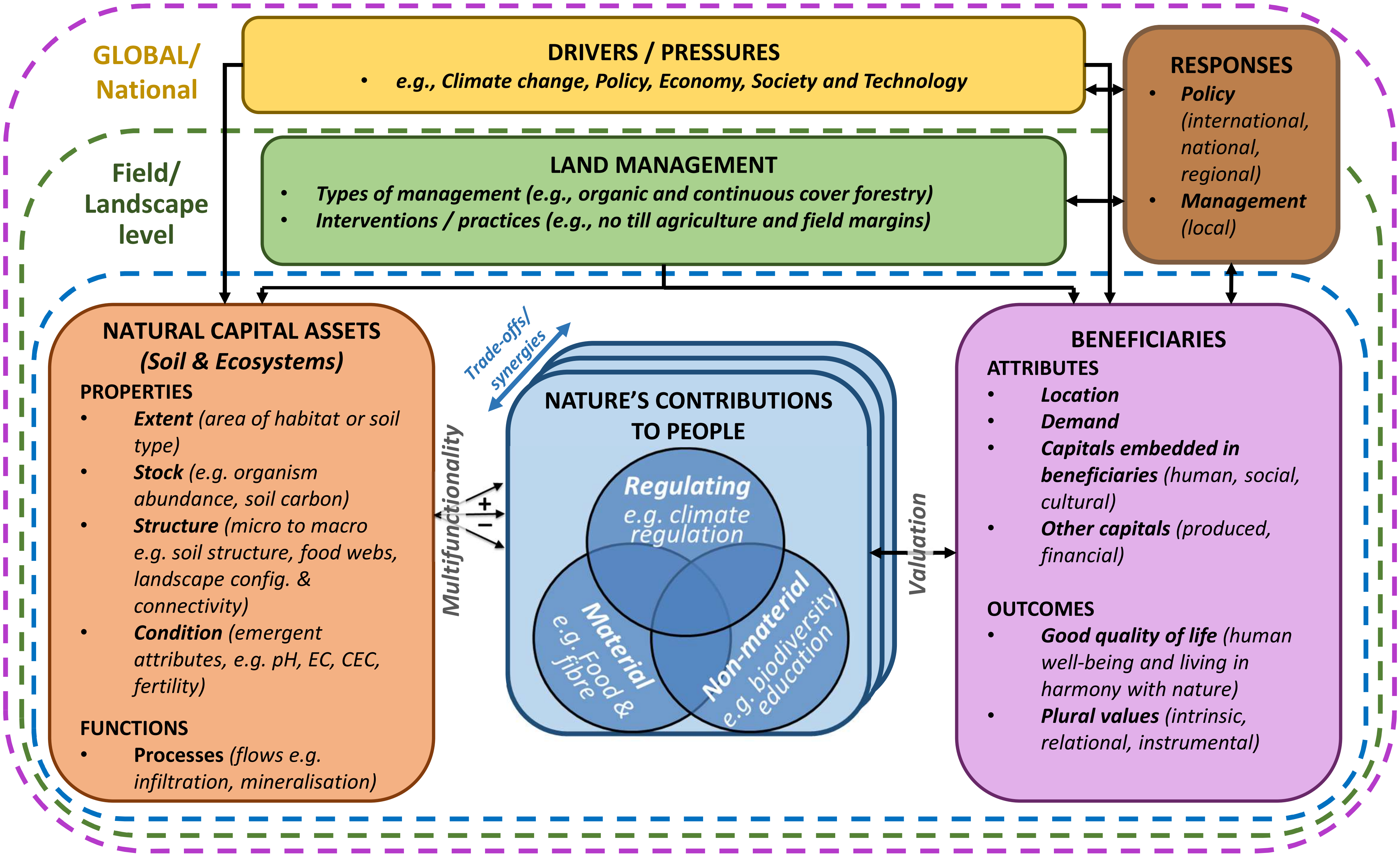

Figure 3 Click here to access/download;Figure;Figure 3.pdf

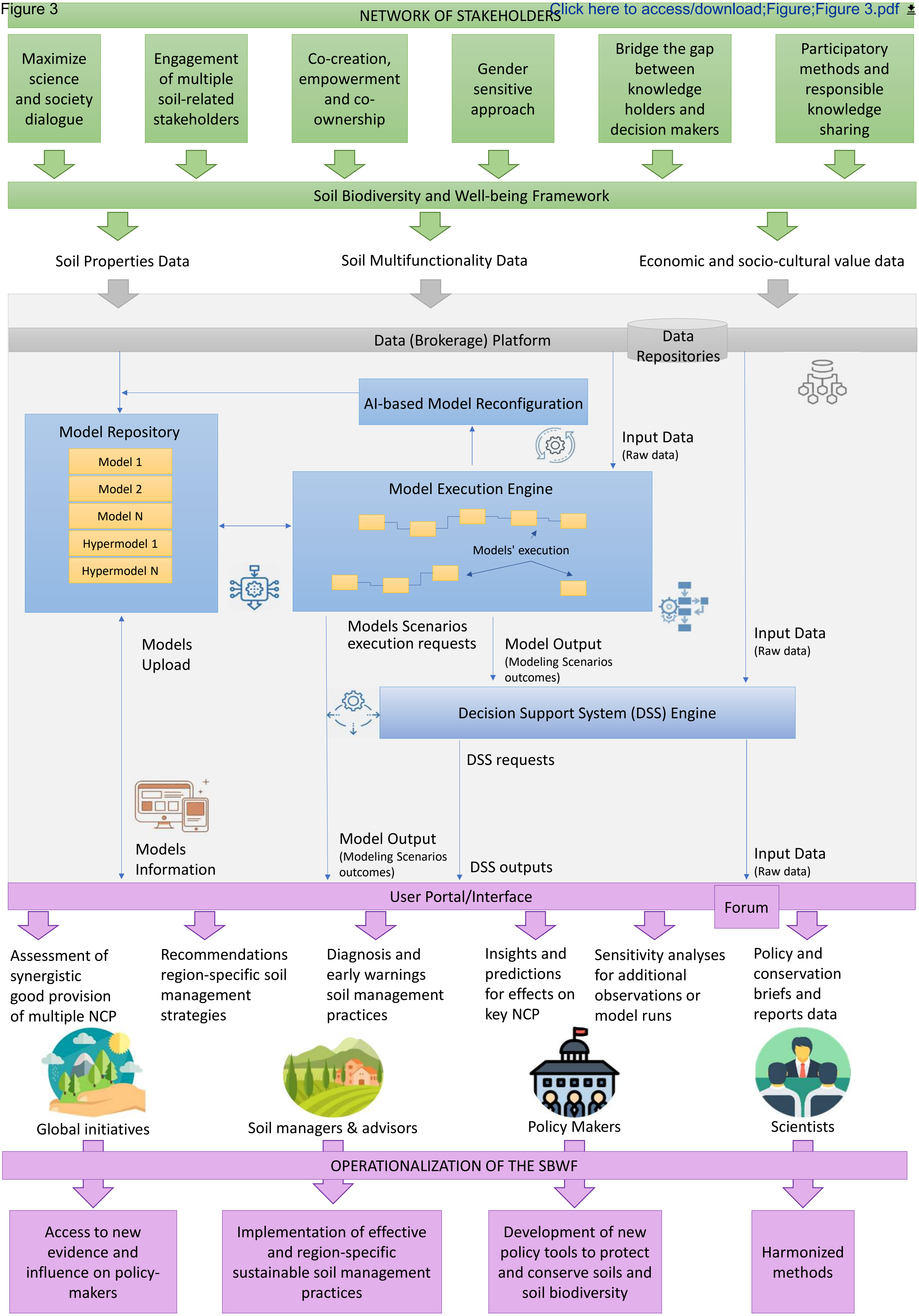

Table S1: Indicators and methodologies to assess soil natural capital assets. Indicators and methodologies are selected based on criteria of measurement feasibility and harmonization, where possible.

Type of asset	Indicator (units)	Methodology
Extent	Area of ecosystems (ha or km^2)	Measure the location and size of different ecosystem types in a spatially explicit manner (e.g. in ha or km2) through earth observation data sets such as the Copernicus programme in the EU[1].
Extent	Extent of soil type (ha or km^2)	Measure the location and size of different ecosystem types in a spatially explicit manner (e.g. in ha or km2) through GIS connected to soil attributes data bases[2].
Stock (Abiotic)	Soil total N (mg / g dry soil)	Soil total N is quantified using the Kjeldahl method[3].
Stock (Abiotic)	Soil available P (mg / kg dry soil)	Soil available P is quantified using the Olsen method[4].
Stock (Abiotic)	Soil organic C (% or tonnes / ha)	Soil organic carbon is quantified using the Walkley & Black chromic acid wet oxidation method[5].
Stock (Biodiversity)	Total soil bacterial biomass (µmol of PLFA biomarker / g of dry soil)	Phospholipid fatty acid analyses (PLFA) is performed suspending 5 g of dried soil in a methanol/chloroform/water mix. Samples are first extracted and the total lipid extract is then divided into fractions of different polarity using SPE columns. The chloroform fraction contains non-polar lipids NLFA while the methanol fraction contains the polar lipids PLFA. The fatty acids are liberated from the polar lipids and derivatized to form fatty acid methyl esters (FAME) which are then analyzed using a GC-MS. PLFA concentrations are determined by GC-FID and stable carbon isotope ratios of individual compounds by GC-IRMS. Identification of PLFA is performed by comparison of retention time data on two different analytical columns and by GC-MS. The internal standard methyl nonadecanoate fatty acid (19:0) is used for calculating concentrations. Identification of the compounds will be based on a BAME mix (Supelco 47080-u) and a FAME mix (Supelco 18919-1AMP). Biomarkers to quantify bacterial biomass are C16:1ω7(t), cy17:0, C18:1ω9t and cy19:0 for gram negative bacteria and i14:0, i15:0, ai15:0, i16:0, i17:0 and ai17:0 for gram positive bacteria, Sulphate reducing bacteria and actinomycetes can be quantified using marker 10Me16:0, 10Me17:0 and 10Me18:0[6].
Stock (Biodiversity)	Total soil fungal biomass (µmol of PLFA biomarker / g of dry soil)	From the PLFA fraction (above), the biomarker used to quantify saprotrophic fungi is the C18:2ω6c. From the NLFA fraction (above), the biomarker used to quantify AMF is the C16:1ω5(+t) marker[7].
Stock (Biodiversity)	Total soil protistan biomass (µmol of PLFA biomarker / g of dry soil)	From the PLFA fraction (above), the biomarker used to quantify protists is the C20:4ω6. Due to the broad taxonomy of protist this marker will mainly target ciliates and flagellates[8].
Stock (Biodiversity)	Abundance of soil bacteria and fungi through eDNA (gene counts / g of dry soil)	DNA extraction is performed from 0.25 g of entirely homogenized dried (and sieved) soil by use of the DNeasy PowerSoil Pro Kit (Qiagen Inc., Valencia, CA, USA). The abundance of total bacteria and fungi are quantified using qPCR targeting the 16S rRNA and ITS as molecular markers, using 1108f and 1132r primers for bacteria[9] and ITS1/qITS2* primers for fungi[10].
Stock (Biodiversity)	Abundance of soil nematodes	Free living terrestrial nematodes are extracted from 100 g fresh soil by using an Oostenbrink elutriator (600 ml/min up-current[11]) followed by sieving (4 sieves with a mesh of 45 µm), and Baermann extraction (cotton wool filters; 24 hours extraction time). Light textured soils are extracted without pre-processing, but

	(nematodes / 100 g of fresh soil)	heavy textured soil (clay) will be pre-soaked before entering the elutriator. Total numbers are counted in duple in a subsample of about 10% of the total sample and expressed in numbers per 100 g soil.
Stock (Biodiversity)	Abundance of soil microarthropods (arthropods / 100 g of fresh soil)	For the micro-arthropod (Acari and Collembola) research, per plot 2 undisturbed soil samples (5 cm diameter, 0-10 cm soil depth) are collected. The samples are subdivided into a 0-5 and 5-10 cm sub-sample, kept in a cool box during transported and storage (stored as intact soil columns) until enumeration and identification. Microarthropods are extracted from each of the 4 sub-samples per plot separately using Tullgren extraction (increase of temperature from room temperature to 35 degrees Celsius during at least 5 days)[12]. After extraction, the 4 microarthropod samples are lumped to create two laboratory samples which are stored in 70% alcohol. Total numbers will be counted and expressed in numbers per 100 g soil.
Stock (Biodiversity)	Abundance of N-cycle genes (gene counts / g of dry soil)	DNA extraction is performed from 0.25 g of entirely homogenized dried (and sieved) soil by use of the DNeasy PowerSoil Pro Kit (Qiagen Inc., Valencia, CA, USA). The abundance of microbial guilds involved in N-cycling are determined by real-time qPCR, using the genes encoding the different catalytic enzymes as molecular markers. Specifically, bacterial and archaeal ammonia oxidizers are quantified through the *amoA* gene, denitrifiers through the *nirS* and *nirK* genes, N_2O reducing bacteria through the *nosZI* and *nosZII* genes, and nitrogen fixers through the *nifH* genes[13].
Condition (Quality)	Soil texture (% of clay, silt and sand)	Soil texture is defined using the method described in *Kettler et al., 2001*[14].
Condition (Quality)	Soil moisture (kg of water / kg of soil)	Soil moisture is quantified using a gravimetric method[15].
Condition (Quality)	Soil Organic Matter (% or tonnes / ha)	About 58% of the mass of organic matter exists as carbon. We can estimate the percentage of SOM from the SOC% (above) using the conversion factor 1.72. This conversion factor can vary in different soils, but 1.72 provides a reasonable estimate of SOM for most purposes.
Condition (Quality)	Soil pH and conductivity	Both soil pH and electrical conductivity are measured from a 1:2.5 (soil:water) dissolution using lab pH-meter and from a 1:5 (soil:water) dissolution using a lab conductivity-meter (soil previously dried and sieved)[16,17].
Condition (Quality)	Water retention capacity (%)	Soil water retention is quantified following the ISO 11274:2019.
Condition (Structure)	Soil aggregate stability	The slake test is used to qualitatively evaluate differences in soil aggregate stability. Briefly, three intact soil aggregates per soil sample are taken and submerged into distilled water in a Petri dish, recording the time each aggregate takes to fall apart, and how much of the aggregate remains. Based upon these two characteristics, each soil aggregate will be scored from 1 (least stable, 100% falls apart in less than 5 seconds) to 4 (most stable, less than 10% of the aggregate falls apart after 5 minutes submerged in water).
Condition (Structure)	Bulk density (g / cm^3)	Soil bulk density is measured through the cylinder method[18].
Condition (Structure)	Soil air porosity (%)	Soil air porosity is measured through the method described by McKeague[19]. *Soil Porosity = (1 - (Bulk Density ÷ Particle Density)) x 100.*
Condition (Structure)	Landscape composition and configuration	Landscape metrics are algorithms that quantify the spatial structure of patterns – primarily composition and configuration - within a geographic area. The term "landscape metrics" has historically referred to indices for categorical land cover maps, but with emerging datasets, tools, and software programs, the field is growing to include other types of landscape pattern analyses such as graph-based metrics, surface metrics, and three-dimensional metrics. The choice of which

		metrics to use requires careful consideration by the analyst, taking into account the data and application[20].
Condition (Biodiversity structure)	Phage diversity (each OTU/ASV relative abundance is expressed in %)	For viromics, viral size fractionation is achieved by resuspending 50 g of dried soil in 70 ml amended potassium citrate prime (AKC') buffer, followed by filtration through a 0.22 µm membrane. The filtrate is then ultracentrifugated to concentrate purified virus-like particles. The concentrate is treated with DNase to remove free DNA prior to virion lysis and DNA extraction with the DNeasy PowerSoil Pro Kit (Qiagen Inc., Valencia, CA, USA). Quality check and quantification of DNA is performed fluorimetrically using the Invitrogen Qubit. The results are used for deciding DNA re-extraction and re-measurement of DNA quantity. DNA extracts are used for library construction and further Illumina high-throughput sequencing[21].
Condition (Biodiversity structure)	Bacterial/Archaea diversity (each OTU/ASV relative abundance is expressed in %)	Bacterial and archaeal diversity is assessed using a metabarcoding approach targeting the 16S rRNA gene. Total nucleic acids will be extracted from 0.25 g of dried soil, using the DNeasy PowerSoil Pro Kit (Qiagen Inc., Valencia, CA, USA). Quality check and quantification of DNA is performed fluorimetrically using the Invitrogen Qubit. The results are used for deciding DNA re-extraction. PCR amplification of the bacterial and archaeal 16S rRNA gene (V3-V4 region) is conducted using primers 341F (5'–CCTAYGGGDBGCWSCAG-3') and 806R (5'-GGACTACNVGGGTHTCTAAT-3')[22]. PCR products are pooled and used for library preparation and sequencing. Sequencing will be conducted using the v3 chemistry (PE300) on the MiSeq or NextSeq platforms (Illumina).
Condition (Biodiversity structure)	Fungal diversity (each OTU/ASV relative abundance is expressed in %)	Fungal diversity is assessed using a metabarcoding approach targeting the internal transcribed spacer region (ITS2) of the ribosomal operon. The protocol closely follows the procedures outlined for the bacterial/archaeal assessment (including same DNA extracts) but use primers ITS3ngs (5'-CANCGATGAAGAACGYRG-3') and ITS4ngs (5'-CCTSCSCTTANTDATATGC-3')[23].
Condition (Biodiversity structure)	Non-fungal eukaryotic diversity (each OTU/ASV relative abundance is expressed in %)	Non-fungal eukaryotic diversity is assessed using a metabarcoding approach targeting the 18S rRNA geneV4 variable region (310-330 bp). The protocol closely follows the procedures outlined for the bacterial/archaeal assessment (including same DNA extracts) but use primers Euk575Fngs; 5'-ASCYGYGGTAAYWCCAGC-3') and (Euk895Rngs; 5'-TCHNHGNATTTCACCNCT-3')[24].
Condition (Biodiversity structure)	Protistan diversity (each OTU/ASV relative abundance is expressed in %)	Protistan diversity is assessed using a metabarcoding approach targeting a 516bp region of the 18S rRNA gene (V4-V5 regions). The protocol will closely follow the procedures outlined for the bacterial/archaeal assessment (including same DNA extracts) but use primers 616*f (5'-TTAAARVGYTCGTAGTYG-3') and 1132r (5'-CCGTCAATTHCTTYAART-3')[25].
Condition (Biodiversity structure)	Nematode diversity (classic method)	This protocol is a continuation of the Nematode abundance quantification (above). After counting, the nematodes are killed and fixed in hot and cold 4% formaldehyde, respectively. At least 100 randomly selected nematodes are identified to family or whenever possible to genus. Nematodes are assigned to trophic groups and colonizer-persister groups using the online tool NINJA[26].
Condition (Biodiversity structure)	Nematode diversity (eDNA; each OTU/ASV relative abundance is expressed in %)	Nematode diversity is assessed using a metabarcoding approach targeting a 523bp region of the 18S rRNA gene (V6-V8 regions). The protocol will closely follow the procedures outlined for the bacterial/archaeal assessment (including same DNA extracts) but use primers Nemf (5′-GGGGAAGTATGGTTGCAAA-3′) and 18Sr2b (5′-TACAAAGGGCAGGGACGTAAT-3′)[27].
Condition (Biodiversity structure)	Microarthropod diversity (classic method)	For the micro-arthropod (Acari and Collembola) research, per plot 2 undisturbed soil samples (5 cm diameter, 0-10 cm soil depth) are collected. The samples are subdivided into a 0-5 and 5-10 cm sub-sample, kept in a cool box during transported and storage (stored as intact soil columns) until enumeration and identification. Microarthropods are extracted from each of the 4 sub-samples per plot separately using Tullgren extraction (increase of temperature from room temperature to 35 degrees Celsius during at least 5 days). After extraction, the 4

		microarthropod samples are lumped to create two laboratory samples which are stored in 70% alcohol. The dry weight of the soil sample will be determined after the extraction is finished. The laboratory sample is used to identify the microarthropods to species (most adults), genus (most juveniles) or higher taxa. Microarthropods are afterwards assigned to functional guilds.
Condition (Biodiversity structure)	Microarthropod diversity (eDNA; (each OTU/ASV relative abundance is expressed in %)	Arthropod diversity is assessed using a metabarcoding approach using two sets of primers targeting the COI gene (5′->3′): the F230R_modN marker with the forward primer LCO1490 (5'-GGTCAACAAATCATAAAGATATTGG-3') and the reverse primer 230R_modN (5'-CTTATRTTRTTTATNCGNGGRAANGC-3') and the BE marker with the B forward primer (5'-CCIGAYATRGCITTYCCICG-3') and the E reverse primer (5'-GTRATIGCICCIGCIARIAC-3')[28].
Condition (Biodiversity structure)	Annelid diversity (eDNA; (each OTU/ASV relative abundance is expressed in %))	Earthworm diversity will be assessed using a metabarcoding approach targeting a short region (70bp) of the mitochondrial 16S rRNA gene. The protocol will closely follow the procedures outlined for the bacterial/archaeal assessment (including same DNA extracts) but use primers ewD (5-ATTCGGTTGGGGCGACC′-3′) and ewE (5′-CTGTTATCCCTAAGGTAGCTT-3′).
Condition (Biodiversity structure)	Diversity of functional genes	The soil genetic potential is determined using a shotgun metagenome sequencing approach based in the same DNA extracts used for the assessment of bacterial, archaeal, fungal, protistan, nematode, arthropod and annelid diversity. The DNA extracts will be pooled and used for library preparation and metagenome sequencing using the TruSeq Nano library preparation kit and sequencing on an Illumina NovaSeq with PE150[29].
Function (Provision of food)	Biomass production (tonnes / ha/ year)	The indicator "biomass production, for the soil function "provision of food", can be assessed through quantifying the production of biomass per unit of land surface and time. This data can be obtained through surveys filled by the landowners, under all the data protection measures required.
Function (Energy production)	Fuel wood and charcoal production (tonnes / ha / year and MWh / ha / year)	The indicator "fuel wood and charcoal production", for the soil function "energy production" can be assessed through quantifying the production of fuel wood and charcoal per unit of land surface and time. These units can be converted into energy units. This data can be obtained through surveys filled by the landowners, under all the data protection measures required.
Function (Production of materials)	Timber production (tonnes / ha / year)	The indicator "timber production", for the soil function "production of materials" can be assessed through quantifying the production of timber per unit of land surface and time. This data can be obtained through surveys filled by the landowners, under all the data protection measures required.
Function (Production of medicinal resources)	Plants of medicinal interest (number of plants / ha)	The indicator "plants of medicinal interest", for the soil function "production of medicinal resources" can be assessed through direct counting of known plants for their medicinal interest per unit of land surface.
Function (Production of medicinal resources)	Genes related with medical biotechnology (number of genes / unit of soil)	The indicator "genes related with medical biotechnology", for the soil function "production of medicinal resources" can be assessed through soil eDNA metagenomics (*see above the indicator "diversity of functional genes"*) and specific assessment of genes known by its relation with the production of metabolites of potential interest for medical biotechnology.
Function (flood regulation)	Water holding capacity (changes in WHC%)	The indicator "water holding capacity", for the soil function "flood regulation", can be assessed through the quantification of changes on the soil water holding capacity (*see above the indicator "water holding capacity"*). An increase in WHC is a proxy to assess increased flood regulation.

Function (flood regulation)	Water infiltration (mm soil / hour)	The indicator “water infiltration”, for the soil function “flood regulation”, can be assessed through the standard test method for infiltration rate of soils in field using double-ring infiltrometer (ASTM D3385-18).
Function (regulation of detrimental organisms)	Leaf damage	The indicator “leaf damage” (insects and fungal pathogens), for the soil function “regulation of detrimental organisms” is assessed in 10 leaves, randomly chosen from at least 5 different plant individuals within each site. This is performed in fresh leaves, and for each of the dominant plant species (those accounting for >50% of the relative cover at each site). Leaf damage (occurrence, and percentage cover) is divided in 8 categories, (i-iv) insect herbivores, and v-viii) foliar pathogens): i) chewing, ii) sap-sucking or rasping, iii) leaf-mining, iv) galling, and v) rust fungi, vi) downy mildews, vii) powdery mildews and viii) leaf spots. Leaf damage will be assessed visually, using a magnifier lens when needed, and using the visual guidelines available at: https://bug-net.org/detailed-protocol-estimating-leaf-damage/.
Function (regulation of detrimental organisms)	Relative abundance of soil pathogens (OTU/ASV relative abundance in %)	The indicator “relative abundance of soil pathogens”, for the soil function “regulation of detrimental organisms” is assessed through eDNA surveys (*see above the indicators bacterial, fungal, protistan and nematode diversity*). The bioinformatic analysis will be focused on quantifying the relative abundance of those soil organisms previously described as potential pathogens.
Function (soil erosion prevention)	Soil Organic Matter (changes in SOM% or tonnes / ha / year)	The indicator “Soil Organic Matter”, for the soil function “soil erosion prevention”, can be assessed through the quantification of changes on the soil organic matter (*see above the indicator “Soil Organic Matter”*). An increase in SOM is a proxy to assess increased soil erosion prevention.
Function (nutrient cycling)	Potential N mineralization (mg N / kg soil / day)	The indicator “Potential N mineralization”, for the soil function “nutrient cycling”, is measured by determination of the available mineral N (NH_4^+-N and NO_3^--N) forms before and after a incubation of 10 g of soil in the laboratory, at 80% of water holding capacity (WHC) and 30°C for 14 days, and extracted with KCl 1M in a 1:5 ratio. The amount of N forms in the soils is calculated using a linear calibration curve with standards and expressed as mg N kg^{-1} soil and rates are expressed as mg N kg^{-1} soil day^{-1} [30].
Function (nutrient cycling)	Litter decomposition (relative mass remaining)	The indicator “litter decomposition”, for the soil function “nutrient cycling”, is assessed in situ using the Tea Bag Index (http://www.teatime4science.org/method/stepwise-protocol/). Briefly, five Lipton Green tea and five Rooibos tea bags are buried in the soil at each site in 8-cm deep holes, separated 15 cm from each other. Each individual bag is weighted and tagged before burying it in the field. After 60 days, all bags are collected, oven-dried at 70ºC for 48 hours and weighted after removing all dirt. The two types of tea (green tea vs rooibos) are used as representative of different litter qualities, as green tea is more labile and rooibos more recalcitrant. The difference in weight at t=0 and t=60 will be used to calculate a net litter decomposition rate (k) and a litter stabilization factor (S).
Function (nutrient cycling)	Soil enzymatic activities (nmol enzyme / g dried soil / hour)	The indicator “soil enzymatic activity”, for the soil function “nutrient cycling”, Quantification of potential enzymatic activity of acid phosphatase (EC 3.13.2), N-acetylglucosaminidase (EC 3.2.1.50), xylosidase (EC 3.2.1.37), cellobiohydrolase (EC 3.2.1.91), and β-glucosidase (EC 3.2.1.21) will be determined using 4-methylumbelliferone (MUB/MUF)-coupled substrates[31]. Briefly, 1 g of dried soil is suspended into 120 ml of distilled water. The soil suspension is added to respective MUB-couple substrates into a microplate well containing MUB pH 6 and incubated for 1h at 37ºC in the dark. Following incubation, 0.1M THAM pH 10 is added to terminate the reaction and increase fluorescence signal for its detection at 360nm excitation and 460 nm emission. MUB standards will be used to calculate enzyme activities as nmol h^{-1} g^{-1} dry soil.
Function (Climate regulation)	Carbon sequestration (tonnes / ha/ year)	The indicator “carbon sequestration”, for the soil function “climate regulation”, can be assessed through quantifying Soil Organic Carbon (*see above the indicator “Soil Organic Carbon”*)) per unit of land surface and time.

Function (Climate regulation)	Soil potential respiration (nmol of CO_2 / g of dried soil / day)	The indicator "soil potential respiration", for the soil function "climate regulation" is estimated using the NaOH trap method. 5 g of dried soil are incubated at 60% of their field capacity in a sealed jar for one week in a growth chamber under 20 ºC and dark conditions. Inside each jar, a small Erlenmeyer flask with 3 ml of NaOH 0.1 M is placed, in order to capture the CO_2 released during the week. After the incubation period, the excess NaOH (inversely proportional to the soil respiration) will be quantified with HCl 0.1 N after stabilization with $BaCl_2$ 1M.
Function (Climate regulation)	Soil respiration, methanogenesis and denitrification (nmol of CO_2, CH_4, and NO_2 / g of dried soil / day)	The indicator "soil respiration, methanogenesis and denitrification", for the soil function "climate regulation" is estimated in the laboratory (microcosms), following the procedures described in[32].
Function (regulation of freshwater quality)	Nutrient leaching (g of nutrient / g of soil / hour or kg nutrient / ha / year)	The indicator "nutrient leaching", for the soil function "regulation of freshwater quality" is estimated using soil columns (100 g of 2-mm sieved and previously air-dried soil sample). In each of these columns, the capacity of the soil to retain nutrients is estimated in a two-step procedure: i) measuring available N and P in the leachates obtained after watering with 200 ml of distilled water the soil column (natural capacity of soil to retain current nutrient levels), and ii) measuring available N and P in the leachates obtained after adding 0.5 g of standard NPK inorganic fertilizer and watering with 200 ml of distilled water the soil column (natural capacity of soil to retain fertilization nutrient levels).
Function (regulation of hazards)	Antibiotic resistance genes (number of genes / unit of soil)	The indicator "antibiotic resistance genes", for the soil function "regulation of hazards" is estimated through soil eDNA metagenomics (*see above the indicator "diversity of functional genes"*) and specific assessment of genes known by its relation to antibiotic resistance.
Function (physical and psychological experience)	Abundance / diversity of plants with conservation interest	The indicator "abundance / diversity of plants with conservation interest", for the soil function "physical and psychological experience" is assessed by counting plants of conservation interest in 10 m x 10 m soil plots. These species are classified according to their conservation interest using international standards (IUCN red list) and local expert knowledge.

Table S2. Indicators and methodologies to assess the plural value of soil-mediated nature's contributions to people. Indicators and methodologies are selected based on criteria of measurement feasibility and harmonization, where possible. The color of cells indicates the NCP category: green for Material NCP, blue for Regulating NCP and orange for non-Material NCP.

Nature's Contribution to People		**Beneficiary**	**NCP valuation (nature-based, statement-based, behaviour-based or integrated valuation)**			
			Biophysical & Monetary indicators (examples)	**Valuation methods for biophysical and monetary indicators (examples)**	**Socio-cultural indicators (examples)**	**Valuation methods for socio-cultural indicators (examples)**
Food and feed production	Material	Farmers, public	Crop yield (ton / [ha x yr]) to market prices ($ / ton)[33]	Market price method	Perception of importance by stakeholders (n of mentions)	Preference assessment[34]
Energy production	Material	public	Energy production (MWh / [ha x yr]) to market prices ($ / MWh)	Market price method	Perception of importance by stakeholders (rating score)	Preference assessment[35]
Production of materials	Material	Farmers, public	Biomass production ((ton /	Market price method	Perception of importance by	Content analysis[36]

Nature's Contribution to People		Beneficiary	NCP valuation (nature-based, statement-based, behaviour-based or integrated valuation)			
			Biophysical & Monetary indicators (examples)	Valuation methods for biophysical and monetary indicators (examples)	Socio-cultural indicators (examples)	Valuation methods for socio-cultural indicators (examples)
			[ha x yr]), market prices ($ / ton)[33]		stakeholders (n of mentions)	
Production of medicinal resources	Material	public	Aromatic/medicinal crop yield (ton / [ha x yr]) to market prices ($ / ton)[37]	Market prices method	Perception of importance by stakeholders (rating score)	Preference assessment[38]
Regulation of freshwater quantity (Flood regulation)	Regulating	public	Costs of alternative measures for provide the same service (e.g. water storage) ($ / m^3)[39]; WTP for a reduction in flooding risk or an increase in water storage capacity ($ / person x yr)[40]	Cost-based methods, stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (score)	Cognitive mapping[41]
Regulation of detrimental organisms (Biological control)	Regulating	Farmers	(Avoided) costs of pesticide application ($ / ha)[39]	Cost-based methods	Perception of importance by stakeholders (n of mentions) Preferences by stakeholders (rating score)	Content analysis[42] Preference assessment[43]
Soil formation and protection (Soil erosion prevention)	Regulating	public	Costs of soil erosion prevention ($ / metric tons soil); WTP for increased soil stability ($ / person x yr)[44]	Cost-based methods, stated-preference methods (e.g. discrete choice experiment)	Preferences by stakeholders (n of respondents)	Preference assessment[45]
Soil formation and protection (Nutrient cycling)	Regulating	public	Available N and P (mg / kg soil) to market prices of fertilizer ($ / kg)[54]; WTP for changes in nutrient load ($ / person x yr)[40]	Market prices, cost-based methods (e.g., replacement costs), stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (rating score,)	Preference assessment[46]
Climate regulation	Regulating	public	Carbon sequestration (CO2eq in ton / ha x yr) to social costs of carbon ($ / ton)[39]; WTP for carbon sequestration ($ / person x yr)[40]	Cost-based methods (e.g. damage costs), stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (rank/ placement)	Deliberative method / pebble distribution method[47]
Habitat creation	Regulating	public	WTP to preserve habitat provision ($ / person x yr)	Stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (n of mentions)	Preference assessment[41]
Pollination	Regulating	public	Costs of alternative measures provide the same service (e.g., honeybee stocking) ($ / ha)[48]; WTP for	Cost-based methods, stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (rating score,)	Preference assessment[49]

Nature's Contribution to People		Beneficiary	NCP valuation (nature-based, statement-based, behaviour-based or integrated valuation)			
			Biophysical & Monetary indicators (examples)	Valuation methods for biophysical and monetary indicators (examples)	Socio-cultural indicators (examples)	Valuation methods for socio-cultural indicators (examples)
			pollination ($ / person x yr)			
Regulation of air quality	Regulating	public	WTP to preserve air quality ($ / person x yr)	Market prices, cost-based methods, contingent valuation (e.g. discrete choice experiment)	Perception of importance by stakeholders (n of mentions)	Preference assessment[42]
Regulation of freshwater quality	Regulating	public	Costs of decontamination of nutrient loads ($ / kg N/ P)[48]	Cost-based methods, stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (spatial map/score)	PPGIS[50]
Regulation of hazards and extreme events	Regulating	public	Costs for avoided damages	Cost-based methods, stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (rating score)	Preference assessment / deliberative methods[51]
Physical and psychological experience (Tourism)	Non-Material	Public, tourists		Revealed-preference methods; Stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (rating score)	Preference assessment[52]
Physical and psychological experience (Aesthetic landscapes)	Non-Material	Public, tourists	WTP for increased heterogeneity of landscapes ($ / person x yr)	Stated-preference methods (e.g. discrete choice experiment)	Preferences by stakeholders (rating score of landscape features)	Preference assessment[53]
Learning and inspiration (Biodivers ity education)	Non-Material	public	WTP for an increased provision of learning and inspiration ($ / person x yr)	Stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (n of respondents)	Narratives[54]
Supporting identities	Non-Material	public		Stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (n of mentions)	Preference assessment / Focus groups[55]
Maintenance of options	Non-Material	public		Stated-preference methods (e.g. discrete choice experiment)	Perception of importance by stakeholders (rating score)	Preference assessment[56]

Table S3. Quality of life dimensions included in the SBWF and indicators. Indicators data available at: https://ec.europa.eu/eurostat/web/quality-of-life/database.

Quality of life dimension[57]	Indicators*
Access to food, energy, water and economic security	Income Material deprivation Housing conditions Quantity/quality of employment Physical safety Wealth/Debt Police-recorded offences / Crime rate Trust in institutions Discrimination /equal opportunities Pollution /Noise from neighbours
Physical, mental and emotional health, education, leisure and social interactions	Life expectancy Self-perceived health status Quantity/quality of/access to leisure Relations to people Social support Social cohesion Tertiary educational attainment Satisfaction with time use Help from others
Cultural heritage, identity and stewardship	Satisfaction with landscape and built environment Life satisfaction Frequency of being happy in the last 4 weeks

*Material living standards are measured on the basis of three sub-dimensions: income, consumption and material conditions. Indicators selected for these sub-dimensions are based on the EU-SILC. Productive or main activity dimension is measured through three sub-dimensions: quantity of employment, quality of employment and other main activity (inactive population and unpaid work). Indicators selected for these sub-dimensions are based on the EU-LFS. Health dimension is mainly measured through three sub-dimensions: health outcome indicators such as life expectancy, the number of healthy life years and subjective assessments of own health, chronic diseases and limitations in activity. Indicators selected are based on the EU-SILC and the EHIS. The educational dimension is measured by currently available indicators grouped in four sub dimensions: population's educational attainment (including the number of early school leavers); self-assessed and assessed skills; participation in life-long learning and opportunities for education (rate of enrolment of pupils in pre-primary education). Indicators selected for these subdimensions are mainly based on the EU-LFS. The leisure and social interactions dimension is measured through two sub-dimensions: leisure activities (quantity and quality) and social interactions. Indicators are based on the EU-SILC Ad-hoc modules on Social and Cultural Participation and Subjective Well Being. The economic and physical safety dimension is measured in terms of two sub-dimensions: physical safety and economic safety. Indicators are based on the EU-SILC. There are 3 sub-dimensions covered in the governance and basic rights dimension: trust in institutions and public services; discrimination and equal opportunities and active citizenship. Indicators are based on the EU-SILC Ad-hoc modules, the EU-SES and the EU-LFS. The natural and living environment dimension is measured through subjective indicators based on the EU-SILC. Overall experience of life is measured using three sub-dimensions: life satisfaction (cognitive appreciation), affect (a person's feelings or emotional states, both positive and negative, typically measured with reference to a particular point in time) and eudaemonics (a sense of having meaning and purpose in one's life, or good psychological functioning.). This is in line with the OECD guidelines on Measuring Subjective Well-Being. Indicators are based on the 2013 EU-SILC Ad-Hoc Module.

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