ISO/TS 18718

English Title:

Assessment of ecological soil functions and related-ecosystem services: definitions, descriptions and conceptual framework

French title

Evaluation des fonctions des sols et les services écosystémiques rendus : définitions, descriptions et cadre conceptuel

Scope

This standard provides definitions, descriptions and a framework for the assessment of ecological soil functions and of related-ecosystem services, based on a review of existing documents. It describes the main characteristics of key ecological soil functions and how they relate to soil characteristics and to ecosystem services.

This standard does not cover non-ecological soil functions.

Foreword

Introduction

Ecosystem services can be seen as the various ways Nature provides a service to Mankind. Since they are quite easily understandable and communicable policy makers and citizens have asked for valuations of ecosystem services provided by land (not just soil). Several international, EU, national or local assessments have been conducted leading to a great number of publications, the most famous one being the Millennium Ecosystem Assessment [1]. These valuations have proposed their own frameworks (linking soil functions with ecosystem services) and definitions leading to a wide diversity of results. Furthermore, terminology and definitions are different between natural sciences dealing with soil functions, and socio- and environmental economics sciences pushing the 'ecosystem services' concepts. Within these disciplines there are also different definitions across countries or policy areas, and even within countries, the understanding of definitions used in science can be different from policy. Having an international common way to describe, assess soil functions and related ecosystem services is crucial to further compare valuations made in different countries, soil types and land uses for management or remediation purposes. For communication purposes, transparency and consistency, common and shared definitions and conceptual frameworks are needed. For the effectiveness of policies and management it is important that methods are appropriate in relation to the policy's objective.

1 Scope definition

This document presents the conceptual links between ecological soil functions and ecosystem services provided by soils (Figure 1.). It includes the description of main biotic and abiotic processes underlying soil functioning and connexions with several ecosystem services. The document also defines all terms and concepts needed to support the developed framework for the assessment of soil functions and related ecosystem services.

This document is to be read in conjunction with ISO/TS 18721 that presents the soil characteristics and indicators needed to assess ecological soil functions (see Figure 1).

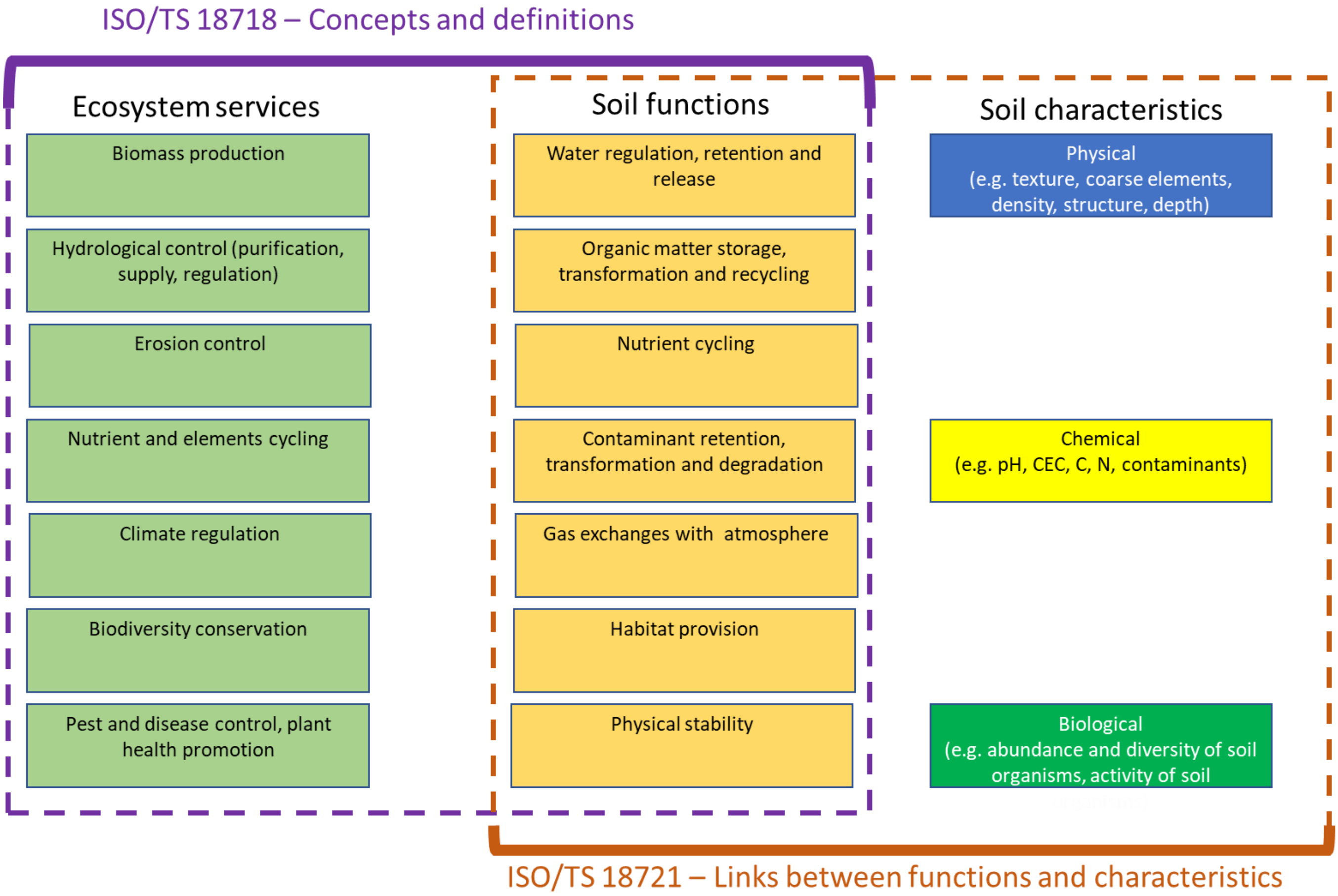

Figure 1. Links between ISO/TS 18718 and 18721 on the assessment of soil functions and related-ecosystem services

2 Normative references

There are no normative references in this document

3 Terms and definitions

Proposal for general text to terms and definitions:

For the purposes of this document, the terms and definitions given in ISO 11074 and the following apply.
ISO and IEC maintain terminological databases for use in standardization at the following addresses:
— ISO Online browsing platform: available at https: //www .iso .org/obp
— IEC Electropedia: available at: http: //www.electropedia .org

3.1
soil

Upper layer of the Earth's crust transformed by weathering and physical/chemical and biological processes and composed of mineral particles, organic matter, water, air, and living organisms organized in soil horizons

Note 1 to entry: In a broader horizon civil engineering sense, soil includes topsoil and sub-soil; deposits such as clays, silts, sands, gravel, cobbles, boulders, and organic matter and deposits such as peat.

3.2
topsoil
Upper layer(s) of a natural soil that is generally dark colored and has a higher content of organic matter and nutrients when compared to the (mineral) horizons below, excluding the humus layer

Note 1 to entry: For arable land, topsoil refers to the ploughed soil depth, while for grassland; it is the soil layer with high root content.

3.3

Indicator

Quantitative, qualitative or binary variable that can be measured, estimated, calculated or described, representing the status of conditions and the impact of operations and management.

adapted from [SOURCE: ISO 14050:2020]

Note 1 to entry: An indicator is generally backed up by an interpretation framework.

3.4

Soil processes

The interactions (physical, chemical or biological) among soil components underlying soil formation, soil functions and ecosystem services and which can be used for their quantification.

3.5

Soil functions

Roles performed by soil that support ecosystems, the biosphere, the water environment and human activities" (ISO 11074)

Note 1 to entry: Soil functions are the result of one or a combination of soil processes that drive the dynamics of the ecosystem structure or composition

3.6

Soil health

Capacity of a type of soil, at a given time, within natural or managed ecosystem boundaries, to function and provide ecosystem services

3.7

Soil quality

Capability of a type of soil, within natural or managed ecosystem boundaries, to function and provide ecosystem services

3.8
Ecosystem services

Benefits people obtain from one or several ecosystems

Note 1 to entry: These are generally distinguished into provisioning, regulating, supporting and cultural services.

Note 2 to entry: Ecosystem services are sometimes called "environmental services" or "ecological services".

[SOURCE: ISO 14050:2020 3.2.4 note 1 and 2 added]

3.9

Soil ecosystem services

Soil-related subset of ecosystem services directly and quantifiably controlled or provided by soils and their chemical, physical and biological characteristics, processes and functions.

3.10

Characteristic

Property or attribute of a material that is measured, compared, or observed (ISO DIS 11074:2023 Vocabulary)

3.11

Contaminant

Substance or agent present in an environmental medium as a result of human activity

Note 1 to entry: There is no assumption in this definition that harms result from the presence of the contaminant. [SOURCE: ISO 21365:2019]

3.12

Decomposition

Breakdown of complex organic substances into simpler molecules or ions by physical, chemical, and/or biological processes (source: ISO DIS 11074:2023 Vocabulary)

3.13

Degradation

Physical, chemical and biological breakdown of the substances (source: ISO DIS 11074:2023 Vocabulary)

3.14

Soil erosion

Removal of soil by the physical forces of water and wind (Source: ISO 14055-1:2017)

3.15

Percolation

Transport of infiltration water through a layer of soil (source: ISO 18772:2008)

3.16

Macropores

Large pores (up to 50 or 75 µm) created by both physical processes (e.g., swell-shrink, freeze-thaw) and biological agents (e.g., plant roots and soil fauna)

4 General consideration

This document aims to describe the various biotic and abiotic processes that contribute to the ecological soil functions, which in turn support ecosystem services. The following chapters offer definitions of main soil functions and their links with ecosystem services supported by soils. Finally, a conceptual framework linking processes to functions and services is proposed, it also integrates natural drivers, soil management and the demands of society.

5 Description of ecological soil functions

5.1 General

Soil functions are one or a combination of soil processes that drive the dynamics of the ecosystem structure or composition (see table 1). Each function may be divided into different sub-functions [1]. Soil processes are the interactions among physical, chemical and biological soil components underlying soil functions.

Table 1 illustrates how soil functions and sub-functions are influenced and connected to biological and/or physico-chemical processes.

5.2 Water regulation, retention and release

Water regulation, retention and release is the capacity of the soil to receive, store and conduct water for subsequent use (e.g. by plants) and to prevent drought, flooding and soil erosion. It is supported by the following sub-functions:

- Biological retention by plants: the ability of plants (mainly) through roots to retain and absorb water,
- Water retention: the capacity of soil to store water mainly depending on its thickness, texture, amount of gravel/stones, organic matter content and structure, the latter being influenced by e.g. climate, biological activities, and soil management practices,

- Infiltration and percolation depend on soil texture and are maintained through a continuum of bio-physical processes, supported by the soil biota considered as ecosystem engineers (as earthworms, enchytraeids, ants, fungal hyphae, plant roots, etc) that develop e.g. macropores, which provide a conduit for water within the soil matrix. Physical and chemical impact, like compaction, crust formation, soil frost, hydrophobicity etc. are also of importance for infiltration and percolation.

5.3 Organic matter storage, transformation and recycling

This function includes soil processes that contribute to the incorporation of organic matter in the soil and its decomposition. The function can be defined by three main groups of processes which take place in the soil:

- Decomposition includes the biological processes controlling the breakdown of organic matter which results in the production of CO_2 and CH_4. Almost all soil organisms play a role in the decomposition of organic matter.
- Resource reallocation are processes that make resources available, unavailable or that replace them. This includes mixing and moving soil through leaching, bioturbation, occlusion of organic matter by aggregation, allocation of assimilated C and N from plants and microbes into the soil by exudation, and the uptake of C and N by the food web.
- Biochemical transformation are processes involved in the conversions of molecules. That includes transformations of inorganic molecules that lead to the production of N2O (nitrification and denitrification), as well as the consumption of CH_4 (methanotrophy). Biochemical transformations are mainly performed by soil micro-organisms.

5.4 Nutrient cycling

This function is defined as the capacity of a soil to release, take up and recycle nutrients from different inputs (e.g., plant residues, litter, roots exudates, manure, composts) and to support the uptake of nutrients from soil minerals and organic matter, water and air by plants and the soil community. It is supported by the following sub-functions:

- Nutrient transformation refers to a range of soil biological processes which lead to changes in the chemical or physical status of nutrient resources (excluding assimilation). These processes are: mineral weathering, mineralisation, N transformations, S transformations and fragmentation of organic matter.
- Nutrient reallocation refers to a change in location of and access to nutrient resources and encompasses two main processes: bioturbation and aggregation. Nutrient reallocation influences the other sub-functions by controlling the availability and accessibility of resources needed for the biological processes in nutrient transformation and assimilation.
- Nutrient assimilation describes the processes controlling nutrient acquisition from the soil and incorporation into biomass by soil biota (food web assimilation), by plants directly (root foraging) or indirectly by plant mutualists: mycorrhizal acquisition and N-fixation. Nutrients that are assimilated by soil biota can be mineralized again and cycle through other processes in the Nutrient transformation sub-function; in turn, Nutrient transformations can enhance or reduce the availability of nutrients for assimilation by soil biota and plants.

5.5 Contaminant retention, transformation and degradation

As for nutrients, soils are a storage reservoir for contaminants. As a consequence, soils act as a filter for water and air pollutants and as a transformation medium for chemicals. Water quality is particularly dependent on this soil function, because chemical inputs to soil may cause severe water pollution if they are not captured and/or transformed by the soil [3]. This function can be divided into 3 sub-functions:

- The retention function depends on the soil characteristics (e.g., soil depth, acidity, redox potential, clay and organic matter contents), on contaminant physicochemical characteristics (e.g., polarity, water solubility) as well as on environmental factors (soil moisture, temperature) and biological processes of sorption and assimilation [4, 5].
- As for the retention function, the transformation function also depends on the soil, contaminant and environmental conditions, for physicochemical reactions but will also be controlled by the activity of soil organisms such as bacteria or fungi. Such biological transformations change the structure/nature of the contaminants.
- Transformation may be complete leading to the full degradation of contaminants.

5.6 Gas exchanges with atmosphere

Soil is a place of intensive production, transformations, and consumption of a number of gases, which are transported to and from the atmosphere [6]. Soil can either take up (captation) or release (emission) gases such as oxygen (O_2), carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2) and nitrous oxide (N_2O). Those exchanges are governed by soil conditions as e.g. porosity, temperature, humidity, pH, redox, organic matter and nutrients content but also by soil biological activities. All soil organisms require oxygen for their metabolism, and, among other gases, they all produce carbon dioxide. Soil microbes are also the main divers involved in the captation and/or release of greenhouse gases such as methane (CH4) and nitrous oxide (N2). Note that some communities are also involved in the emission of volatile contaminants as methylmercury [7].

5.7 Habitat provision

The habitat function of soils represents the capacity of a soil and its features to provide the necessary resources and conditions allowing the survival and reproduction of a large number of species [8]. Such function may be divided into two sub-functions that are the habitat quality (i.e. physical, chemical, and biological characteristics of the soil environment that enable the establishment and maintenance of diverse communities) and the harboring biodiversity (i.e. the maintenance of biodiversity and gene pools by supporting populations and their interactions [9].

Soils provide habitat for a majority of all living species on Earth and the largest part is yet unknown, especially for microorganisms [10, 11]. Thus, soil is identified as a source of unique biological materials [12] as itt supports the provision of genetic resources. Soil organisms play an important role in the release and/or retention of nutrients and in controlling diseases and regulating pests. These organisms affect soil fertility and food production and, therefore, serve the grand societal challenge of food security [12].

5.8 Physical stability

The physical stability of a soil depends on its inherent stability linked to soil characteristics as its texture (coarse or fine), aggregate size and structure, porosity, stone and organic matter content, pH and the evolution of its stability linked to climate (e.g. freeze-thawing) and biological activity.

Soil erodibility by water or wind is influenced by soil texture and aggregate stability. Soils with low infiltration rates accelerate erosion because of high runoff rates.

Table 1 – Soil functions and underling processes

Soil Functions	Sub-function	Biological processes (examples)	Physico-chemical processes (examples)
Water regulation, retention and release	Biological retention by plants	Root foraging, absorption by plants (evapotranspiration)	
	Water retention	Bioturbation, aggregation, fragmentation	Water retention by soil texture and organic matter (adsorption, retention)
	Infiltration and percolation	Macropore formation, root foraging, bioturbation, aggregation	Diffusion
Organic matter storage, transformation and recycling	Decomposition	Biotic fragmentation, microbial grazing, microbial respiration, methanogenesis	Fragmentation linked to climate conditions
	Resource reallocation	Aggregation, bioturbation, exudation, foodweb assimilation	Leaching, adsorption
	Biochemical transformation	Methanotrophy, nitrification, denitrification	Leaching, adsorption
Nutrient cycling	Nutrient transformation	Fragmentation of litter, mineralization, nitrogen transformations, sulfur transformation, biochemical weathering	Fragmentation of rocks (e.g. frost/thraw), physical and chemical weathering of rocks, precipitation, dissolution
	Nutrient reallocation	Aggregation, bioturbation	Adsorption/desorption, atmospheric deposition, Precipitation/dissolution, erosion/run-off, leaching, N volatilization
	Nutrient assimilation	Foodweb assimilation, mycorrhizal acquisition, nitrogen fixation, root uptake	
Contaminant retention, transformation and degradation	Retention	Biosorption, bioassimilation, bioaccumulation	Sorption, complexation, …

	Transformation	Biotransformation	Photodegradation, oxido-reduction
	Degradation	Biodegradation, mineralization	Photodegradation, oxido-reduction
Gas exchanges with atmosphere	Emission	Bacterial activity (e.g. respiration, nitrous oxide and methane production)	Diffusion, exchange
	Captation	Bacterial activity (e.g. nitrogen fixation, methane consumption)	Diffusion, exchange
Habitat provision	Habitat quality	Biotic foraging (e.g. plants, earthworms)	Abiotic conditions (e.g. moisture and temperature, pH, organic matter, porosity…)
	Harboring biodiversity	Abundance, diversity and activity of soil biota Interactions/networks as antibiosis, competition and invasive alien species, predation, parasitism, microbial grazing Resistance and defense, plant metabolism enhancement	
Physical Stability	Inherent soil stability	Aggregation linked to biological activity	Abiotic aggregation (texture, stone and OM content, pH), erosion (water and wind), lixiviation
	Stability evolution	Macropore formation, bioturbation, roots	Freeze-thaw alternation

Note: Some terms for processes mentioned in Table 1 also have a meaning as indicators. For indicators, see ISO 18721.

6 Description of ecosystem services related to soils

6.1 Biomass production

Biomass production is a provisioning service defined as the capacity of a soil to support humans with food, feed, fiber and fuel.

This particular service is sustained by several soil functions needed for plant growth as physical stability, water storage, cycling of nutrients, organic matter storage and transformation and habitat for organisms (e.g. plant symbionts).

6.2 Hydrological control (purification, supply, regulation)

Hydrological control is a regulation service defined as the capacity of a soil to regulate the flow of water and to control its quality by removing pollutants. It refers to the capacity of a soil to infiltrate rainfalls, store water and release it for plants, feed groundwaters as well as purify it through the capacity of the soil to retain, degrade, transform contaminants.

6.3 Erosion control

Erosion control is a regulation service defined as the capacity of a soil to prevent or limit soil erosion by water, wind or other forms. Controlling erosion rates is the reduction in the loss of material by virtue of the stabilizing effects of the presence of plants and organisms that mitigate or prevent potential damage to human use of the environment or human health and safety. Erosion control can be achieved by managing runoff and providing protection to the soil surface. Limiting run-off is supported by a better infiltration of water in soil, i.e. maintaining and improving soil structure and porosity. Concerning the protection of soil surface, vegetation is generally the most effective form of erosion control because it both vegetation cover reduces the impact of raindrops (splash effect) and absorbs water.

6.4 Nutrient and elements cycling

Nutrients and elements cycling in soils is a regulation service that results from chemical weathering of rocks, biological fixation of atmospheric nitrogen, decomposition of organic matter and deposition from the atmosphere in rain, wind-blown particles or as gases. Soil stores, moderates the release, and cycles these nutrients and other elements. During these biogeochemical processes, nutrients and elements can be transformed into plant available forms, held in the soil, or lost to air or water. Activity of soil organisms is at the center of the transformation and cycling of nutrients in the environment.

6.5 Climate regulation

Global climate regulation is defined as the capacity of a soil to regulate greenhouse gases (i.e., carbon dioxide, nitrous oxide and methane) as well as water and heat fluxes. It includes carbon sequestration defined as the process of transferring CO_2 from the atmosphere into the soil, through plants, plant residues and other organic inputs which are stored or retained in the soil as part of the soil organic matter. Activity of soil organisms and soil moisture are at the center of this regulating service.

Soil also influences regional water cycles (e.g. by infiltration and evapotranspiration) and heat fluxes, thereby having an impact on local climate conditions. Such local climate regulation helps to reduce the urban heat island phenomenon (higher temperatures in urban areas).

6.6 Biodiversity conservation

Soil, through its habitat function can support an incredible diversity of organisms and their interactions, which in turn are responsible for a myriad of ecological functions and processes which sustain all biotic ecosystem services. Biodiversity also encompasses the range and diversity of habitats that soils provide from microhabitats to landscapes [8]. Biodiversity conservation is thus the critical pillar allowing the maintenance and resilience of all biotic ecosystem services in soil. Soil is a hotspot of biodiversity and genetic resources, forming the basis for providing biochemical resources and medicinal services and goods [11].

6.7 Pest, disease control, plant health promotion

Soil biodiversity promotes pest control [12, 13], either by acting directly on belowground pests, or by acting indirectly on aboveground pests. An efficient natural pest control avoids having to use chemical control methods such as pesticides. Ecosystems presenting a high diversity of soil organisms typically present a higher natural control potential, since they have a higher probability of hosting a natural enemy of the pest.

Soil biodiversity also promotes plant health where the interactions between soil organisms (pest or harmless biota) and plants. can trigger, induced resistance and defense mechanisms and enhance plant metabolism allowing them to resist and cope with pests or pathogens [14].

Loss of soil biodiversity will likely cause loss of biodiversity in entire natural ecosystems.

6.8 Contaminant-related ecosystem services

Contaminant-related ecosystem services refer to the benefits that ecosystems provide by helping to reduce or regulate contamination levels in the environment. These services can include a variety of functions that help to transform, filter or absorb contaminating substances, as well as preventing or mitigating the negative impacts of contamination on living beings, including humans

6.9 Air quality regulation

Air quality regulation is defined as the contribution of soils and plants, with their high exchange surfaces, contribute to the fixation of pollutants (heavy metals, PAHs, NOx and SOx) emitted by human activities;

7 Conceptual framework of ecosystems services provided by soils

Several conceptual frameworks were developed in the literature [13 -17, 20] to connect soil characteristics, functions and ecosystem services. Most of them focus on agricultural landscapes and land management (e.g. agricultural management practices). They mainly account for soil physical, chemical, or biological characteristics. The consideration of soil contamination linked to trace elements or persistent organic pollutants are less present in such frameworks and need also to be included when dedicated to urban or industrial soils [18, 19].

The conceptual framework presented in figure 2 depicts two sections: on the left ecosystem functioning as determined with chemical, physical and biological characteristics and on the right the socio-economic system which has to manage the societal demands related to the delivery of ecosystem services with many win-wins, and with no unacceptable trade-offs [20].

Ecosystem services provision is typically represented as the flow of ecosystem services into benefits for people. Specific demands in society may feed back into the management of ecosystems through socio-economic market mechanisms, and policy and governance regulation and incentives (payment for ecosystem services, e.g., carbon credits). These societal demands affect the ecosystem as a whole as well as soil characteristics, as measured with chemical, physical and biological indicators. There should be a sustainable balance between the supply and the demand to maintain soil functioning and avoid soil degradation.

Climate, invasive species and pests all influence the ecosystem as natural drivers driving requirement of additional inputs as well as mitigating or adaptive measures (e.g., cultivars, irrigation, pesticides, mowing periods). The reverse arrow from ecosystems to natural drivers acknowledges the feedback/responsibility that management (e.g. farming) may have on the occurrence of pests and invasive species. A bidirectional relation exists between natural and anthropogenic drivers, acknowledging both a human influence (by society at large) on natural drivers as well as vice versa responsive behaviour of humans to the natural drivers.

The socio-economic system leads to anthropogenic drivers of change that impact the ecosystem. This framework differentiates between direct anthropogenic drivers (usually positive), such as conservation and regeneration policies and payments for ES, and indirect anthropogenic drivers and pressures, soil threats and land use policies. Finally, land use policies can affect ecosystems both negatively as positively.

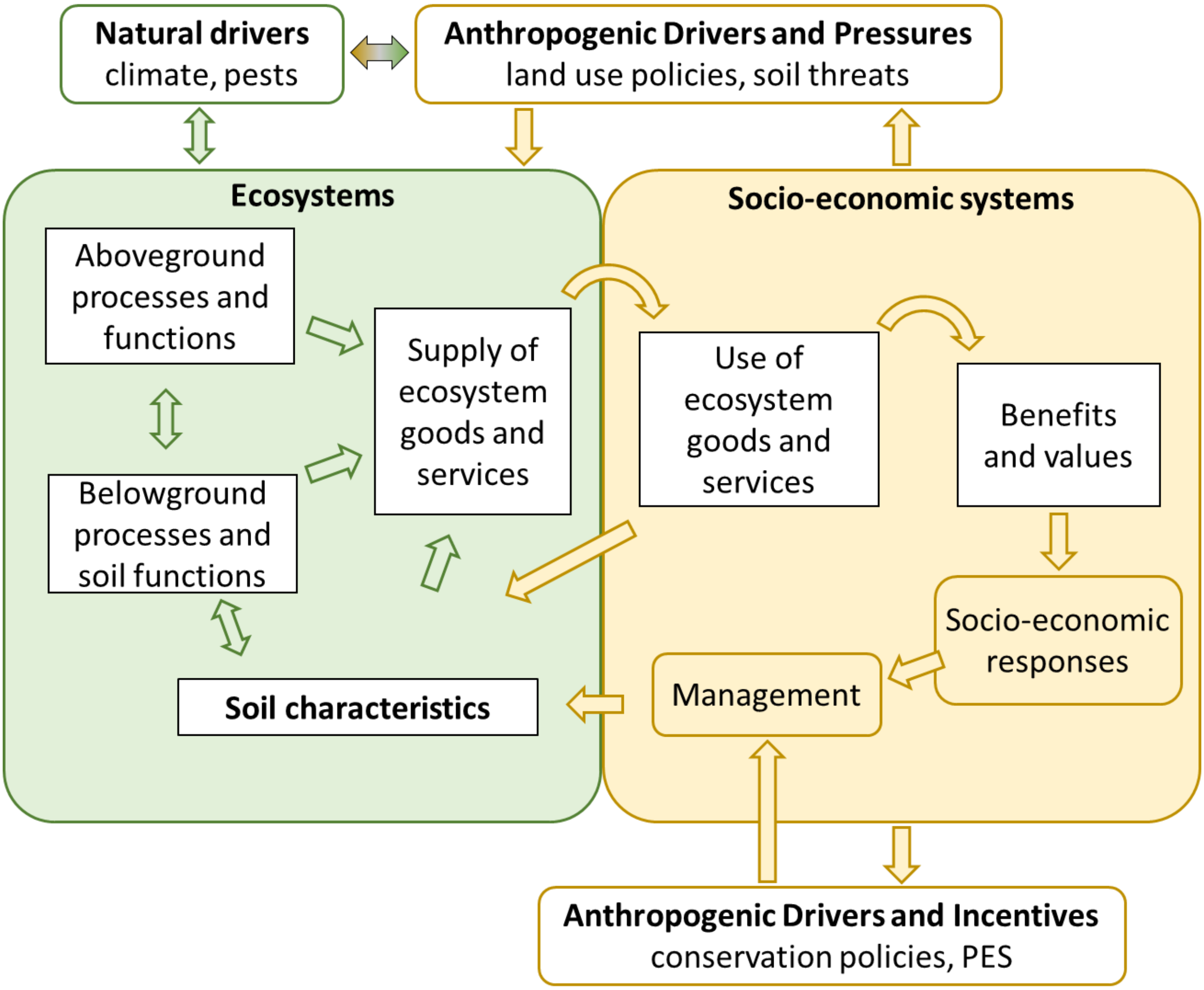

Figure 2. Conceptual framework of ecosystems services provided by soils (adapted from [20])

Annexe A (informative)

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