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Soil-derived Nature's Contributions to People and their contribution to the UN Sustainable Development Goals

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This special issue provides an assessment of the contribution of soils to Nature's Contributions to People (NCP). Here, we combine this assessment and previously published relationships between NCP and delivery on the UN Sustainable Development Goals (SDGs) to infer contributions of soils to the SDGs. We show that in addition to contributing positively to the delivery of all NCP, soils also have a role in underpinning all SDGs. While highlighting the great potential of soils to contribute to sustainable development, it is recognized that poorly managed, degraded or polluted soils may contribute negatively to both NCP and SDGs. The positive contribution, however, cannot be taken for granted, and soils must be managed carefully to keep them healthy and capable of playing this vital role. A priority for soil management must include: (i) for healthy soils in natural ecosystems, *protect* them from conversion and degradation; (ii) for managed soils, *manage* in a way to protect and enhance soil biodiversity, health and sustainability and to prevent degradation; and (iii) for degraded soils, restore to full soil health. We have enough knowledge now to move forward with the implementation of best management practices to maintain and improve soil health. This analysis shows that this is not just

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desirable, it is essential if we are to meet the SDG targets by 2030 and achieve sustainable development more broadly in the decades to come.

This article is part of the theme issue 'The role of soils in delivering Nature's Contributions to People'.

1. Introduction

Previous studies have examined the role of soils in contributing to ecosystem services, showing that soils have a decisive and positive contribution to many [1–5]. Other papers in this special issue [6–20] have considered each ecosystem service in turn, classified according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Nature's Contributions to People (NCP, [21,22]), thus providing the most comprehensive treatment to date of the role of soils in delivering NCP. Other studies have examined the role of soils in contributing to the UN Sustainable Development Goals (SDGs, [23–26]), arguing that soils also play a vital role in delivering the SDGs. In a Forum paper, Keesstra *et al*. [27] explored the role of soils in delivering the SDGs through a series of short essays focusing on the SDGs related to food security, water scarcity, climate change, biodiversity loss and health threats. They used an approach which mapped the functions provided by soils (table 1) to these five SDGs.

Using a similar approach, Smith *et al*. [29] examined how soil carbon sequestration as a climate mitigation strategy provides co-benefits and trade-offs to the delivery of all SDGs. Like Keesstra *et al*. [27], Smith *et al*. [29] first considered the functions provided by the soils and mapped these to NCP, with the delivery of these NCP then mapped on to the delivery of the SDGs. We use a similar approach here, drawing on the extensive analysis presented in the other papers presented in this issue [6–20], to examine the role of soils in contributing, positively or negatively, to the UN SDGs.

2. The impact of Nature's Contributions to People on the UN Sustainable Development Goals

The IPBES Global Assessment [22] defined 18 NCP as 'all the contributions, both positive and negative, of living nature (i.e. diversity of organisms, ecosystems and their associated ecological and evolutionary processes) to the quality of life of people' [21]. NCP and ecosystem services are related, but not precisely parallel concepts [30]. The IPBES authors stressed that NCP is a way to think of ecosystem services, rather than a replacement for the term. As noted by McElwee *et al*. [31], NCP was proposed to be a broader umbrella to engage a wider range of disciplines, particularly from the social sciences and humanities, and a larger range of values around ecosystems [32]. Unlike ecosystem services described in the earlier Millennium Ecosystem Assessment (MA, [33]), supporting services were no longer considered as separate entities, but many NCP can be mapped onto the MA ecosystem services. Table 2 shows NCP as proposed by IPBES, with the corresponding ecosystem services, as described in the Millennium Ecosystem Assessment, to which they are related.

The UN SDGs were developed under an initiative by the UN aiming to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere by 2030. The 17 goals were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development which set out a 15-year plan to achieve the goals [34]. Table 3 summarizes the SDGs.

Table 1. The seven soil functions as defined by the European Commission [28].

1	biomass production, including agriculture and forestry
2	storing, filtering and transforming nutrients, substances and water
3	biodiversity pool, such as habitats, species and genes
4	physical and cultural environment for humans and human activities
5	source of raw material
6	acting as carbon pool
7	archive of geological and archaeological heritage

There have been a number of studies that have mapped the relationship between NCP (or other categorizations of ecosystem services) onto the SDGs. Wood *et al*. [35], for example, assessed the contribution of ecosystem services to the SDGs and specific SDG targets using the 'The Economics of Ecosystems and Biodiversity' definitions [36]. Yang *et al*. [37] used an expert elicitation exercise to assess the contribution of ecosystem services to the SDGs and Anderson *et al*. [38] used a similar approach to assess the contribution of NCP to the SDGs. Johnson *et al*. [39] described a modelling toolkit to link ecosystem services described in the InVEST suite of models to delivery of the SDGs. For soils specifically, Keesstra *et al*. [27] and Smith *et al*. [29] used ecosystem services and NCP framings, respectively, to examine the role of soils, or soil carbon sequestration specifically in the case of Smith *et al*. [29], in contributing to the delivery on the SDGs.

Of the studies described above, the matrix of NCP and SDGs is based on Anderson *et al*. [38] since they specifically focused on the NCP categorization on ecosystem services. Table 4 shows a matrix of NCP and SDGs, with an associated relationship indicated if over 50% of expert respondents in Anderson *et al*. [38] identified a relationship. We use the relationships identified by Anderson *et al*. [38], supplemented with other well-defined relationships, to map soil-derived NCP onto the SDGs.

3. Soil-derived Nature's Contributions to People and their contribution to the UN Sustainable Development Goals

Each paper in this issue [6–20] has presented evidence for the contribution of soils to NCP. Table 5 summarizes the potential positive, negative and context-specific contributions of soils to NCP arising from these papers.

In table 6, we map the soil contributions to NCP onto the relevant SDGs using the relationships between NCP and the SDGs outlined in §2.

As seen from tables 5 and 6, soils have the capacity to contribute positively to all NCP and SDGs, but if poorly managed, degraded or polluted, may contribute negatively.

Table 2. IPBES NCP, with the corresponding Millennium Ecosystem Assessment (MA) ecosystem services and categories shown.

NCP category	NCP	MA category	MA ecosystem service
		supporting service	soil formation
		supporting service	nutrient cycling
		supporting service	primary production
material NCP	food and feed	provisioning service	food
	materials and assistance	provisioning service	fibre
	energy	provisioning service	energy
	medicinal, biochemical and genetic resources	provisioning service	medicinal products, biotechnical approaches and genetic biodiversity
non-material NCP	learning and inspiration	cultural service	aesthetic values
	supporting identities	cultural service	spiritual and religious values
	physical and psychological experiences	cultural service	recreation and ecotourism
regulating NCP	regulation of climate	regulating service	climate regulation
	regulation of freshwater quantity, flow and timing	provisioning service	water
	regulation of freshwater and coastal water quality	regulating service	water purification and waste treatment
	regulation of hazards and extreme events	regulating service	natural hazard regulation
	habitat creation and maintenance	regulating service	
	regulation of air quality	regulating service	air quality regulation
	regulation of organisms detrimental to humans	regulating service	pest regulation and disease regulation
	pollination and dispersal of seeds and other propagules	regulating service	pollination
	regulation of ocean acidification	regulating service	water regulation
	formation, protection and decontamination of soils and sediments	regulating service	erosion regulation
cross-cutting NCP	maintenance of options		

This highlights (i) the great potential of soils to underpin the NCP and SDGs, and (ii) the importance of managing soils well and maintaining them in a healthy, unpolluted condition.

4. Conclusion

Figure 1 summarizes the contributions of soils to delivering the SDGs by showing (i) the functions provided by soils, (ii) the NCP provided by soils underpinned by these functions and (iii) impacts on the SDGs through the NCP supported by soils.

As shown in the papers in this special issue and summarized here (table 5), soils contribute positively to the delivery of all NCP and have a role in underpinning all SDGs (table 6). While highlighting the great potential of soils to contribute to sustainable development, the recognition that poorly managed, degraded or polluted soils may contribute negatively to both NCP and SDGs shows that this positive contribution cannot be taken for granted. Soils must be managed carefully to keep them healthy and capable of playing this vital role [23–27].

The importance of maintaining healthy soils needs to be viewed against a backdrop of widespread and increasing rates of soil degradation globally [43]. There are around 11 million km^2 of degraded land globally [44] and around 120 thousand km^2 of land is lost to degradation every year, with over 3.2 billion people adversely impacted by global land degradation [45]. Therefore, soil management is not only required to keep soils healthy; there is also an enormous task to restore millions of km^2 of degraded lands to health. In the light of this, a few priorities emerge to allow soils to contribute optimally to the SDGs, as follows:

Table 3. The UN SDGs [34].

SDG	goal
	end poverty in all its forms everywhere
	end hunger, achieve food security and improved nutrition, and promote sustainable agriculture
	ensure healthy lives and promote well-being for all at all ages
	ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
	achieve gender equality and empower all women and girls
	ensure availability and sustainable management of water and sanitation for all
	ensure access to affordable, reliable, sustainable, and modern energy for all
	promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all
	build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
	reduce inequality within and among countries
	make cities and human settlements inclusive, safe, resilient, and sustainable
	ensure sustainable consumption and production patterns
	take urgent action to combat climate change and its impacts
	conserve and sustainably use the oceans, seas, and marine resources for sustainable development
	protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
	promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels
	strengthen the means of implementation and revitalize the global partnership for sustainable development

Table 4. Relationship between NCP and SDGs. A relationship is shown (in blue) only to those interactions indicated by over 50% of expert respondents in Anderson *et al*. [38]. Note: impacts where a relationship was not identified by Anderson *et al*. [38], but where the relationship is well-documented elsewhere are shown (in green). These are the impact of habitat creation and maintenance [40], and the impact of regulation of air quality [41] on SDG3, the impact of regulation of ocean acidification on SDG13 through enhanced mineral weathering [42] and the impact of regulation of organisms detrimental to humans on SDGs 2, 12 and 15 [14].

NCP		SDG																
		1 NO POVERTY	2 ZERO HUNGER	3 GOOD HEALTH AND WELL-BEING	4 QUALITY EDUCATION	5 GENDER EQUALITY	6 CLEAN WATER AND SANITATION	7 AFFORDABLE AND CLEAN ENERGY	8 DECENT WORK AND ECONOMIC GROWTH	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	10 REDUCED INEQUALITIES	11 SUSTAINABLE CITIES AND COMMUNITIES	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	13 CLIMATE ACTION	14 LIFE BELOW WATER	15 LIFE ON LAND	16 PEACE, JUSTICE AND STRONG INSTITUTIONS	17 PARTNERSHIPS FOR THE GOALS
material NCP	food and feed																	
	materials and assistance																	
	energy																	
	medicinal, biochemical and genetic resources																	
non-material NCP	learning and inspiration																	
	supporting identities																	
	physical and psychological experiences																	
regulating NCP	regulation of climate																	
	regulation of freshwater quantity, flow and timing																	
	regulation of freshwater and coastal water quality																	
	regulation of hazards and extreme events																	
	habitat creation and maintenance																	
	regulation of air quality																	
	regulation of organisms detrimental to humans																	
	pollination and dispersal of seeds and other propagules																	
	regulation of ocean acidification																	
	formation, protection and decontamination of soils and sediments																	
cross-cutting NCP	maintenance of options																	

Table 5. Summary of the potential positive, negative and context-specific contributions of soils to NCP arising from papers in this issue. Note, these impacts are illustrative rather than comprehensive. SOC, soil organic carbon.

NCP	positive impacts provided by soils	negative impacts provided by soils	mixed impacts provided by soils
1) food and feed (material NCP; [20])	nutrients to sustain life, physical environment to support plant growth, supports biota that contribute to plant growth	insufficient nutrient concentrations to sustain life, toxic elements and compounds, physical environment inhibits plant growth or supports pests and pathogens that inhibit plant success; inequitable distribution of nutrients through trade	chemical stoichiometries and physical conditions that favour some plants over others
2) materials and assistance (material NCP [16])	cheap construction materials; healthy indoor air quality in earthen architecture; low-carbon construction materials; construction materials fulfilling the circular economy (no waste); reduced energy in use for well-designed earthen architecture	may lead to a shortage of soil for agriculture in some places; if extracted from a quarry –> related environmental impacts	depending on the architecture some of the positive impacts may be withdrawn, e.g. if stabilized with cement, may not any longer be a low-carbon construction material
3) energy (material NCP; [15])	soils (peats) can be burnt to provide energy; soils contribute nutrients and water to grow energy crops	burning of peats releases large stores of carbon so soils increase greenhouse gas emissions; energy crops may occupy areas that could otherwise be used for food production, so soils provide less food; energy crops encourage disturbance of permanent land use, which results in loss of soil carbon, so soils release carbon; use of organic wastes for energy reduces carbon inputs to soils, which results in reduced carbon storage in soils (soils increase greenhouse gas emissions); if wind turbines or hydro schemes are located on deep peats, changes to the hydrological regime can result in large emissions of soil carbon to the atmosphere (so soils increase greenhouse gas emissions)	
4) medicinal, biochemical and genetic resources (material NCP; [18])	soils with their ecosystem services are indispensable for intact ecosystems, clean water, healthy food in general as well as the provision of substances, enzymes and organisms for medicinal and technical purposes	soil dust, nutrient depletion and contamination may have direct or indirect adverse effects on human health	the genetic and biochemical resources of soil are still largely unexplored
5) learning and inspiration (non-material NCP; [17])	soils provide an opportunity for formal and informal study; inspiration leading to art and literature, and sources of biomimicry and design; indigenous knowledge around soils is rich and widespread, contributing to better management around fertility and erosion in particular	none	none

(*Continued*.)

Table 5. (*Continued.*)

NCP	positive impacts provided by soils	negative impacts provided by soils	mixed impacts provided by soils
6) supporting identities (non-material NCP; [17])	soil has been metaphorically and linguistically linked to human identities in major world languages and religions; concepts of a 'land ethic' shape farmer and other identities, as well as gendered experiences of soil; cultural identities often expressed through the use of soil in housing and food	metaphorical concepts of 'native soil' and 'blood and soil' have been used to justify exclusion/violence against others	access to the benefits of soils for identities can be limited by environmental injustices or unfair blame for the degradation
7) physical and psychological experiences (non-material NCP; [17])	green spaces and gardening allow for physical and mental benefits of being in nature; recreation, tourism and sport all depend on, and can bring financial benefits to, good soil management	recreation and tourism can be bad for soils; compaction and damage reported in some tourist sites	none
8) regulation of dimate (regulating NCP; [19])	restoration of soil functionality and enhancement of SOC concentration in the root zone has numerous environmental and economic co-benefits; in addition to creating climate-resilient soil and agriculture, through adaptation and mitigation of climate change, restoration of soil health through sequestration of SOC is also pertinent to improving soil and environmental quality	soils of agricultural and other managed ecosystems contain lower carbon stocks than natural vegetation because of the long-term land use and degradation (i.e. erosion) induced depletion of SOC stock; soils are also a major contributor to greenhouse gases like CH_4 and N_2O that has an important role in climate change feedback and elemental cycling	adoption of restorative management practices, which conserve soil and water and strengthen elemental cycling, can create a positive soil/ecosystem carbon budget and sequester atmospheric carbon; understanding and predicting the impact of climate change on soil microbiomes is a grand challenge for our planet
9) regulation of freshwater quantity, flow and timing (regulating NCP; 10])	healthy soils have high infiltration capacity that increases green water (for crop production and nature) and regulates blue water (less floods and droughts); soils also function as a filter for pollutants	unhealthy soils can form crusts and increase the risk of floods and droughts; soil may be eroded and clog up waterways, reservoirs and infrastructure downstream	high infiltration rates may also cause a lack of water in the riverine system in (semi) arid system; plants will make use of this water on the hillslopes in summer, but as a consequence, rivers run dry
10) regulation of freshwater and coastal water quality (regulating NCP; [11])	natural soils and constructed wetlands provide water purification by absorbing pollutants	water pollution caused by non-point source pollution in farmland with overused chemicals	positive and negative water quality impacts depend on soil environmental capacity
11) regulation of hazards and extreme events (regulating NCP; [13])	healthy soils attenuate floods by storing and slowly releasing stormwater, and this ability to store water in the soil profile during wet periods is also important to mitigate droughts, which is used by plants during drought periods; healthy soils can sustain vegetation with a root system that directly reduces erosion potential, landslide risk, and negative impacts associated with windstorms	degraded soils or those with poor drainage or under intensive irrigation are prone to water logging conditions that increase risks for flood, severe erosion, and landslides; soils that do not support healthy vegetative cover result in reduced infiltration, increased evaporation and reinforcement of drought conditions and soil loss via windstorms	while soils with commercial crops can have some beneficial effects on hazards, agricultural management practices must be carefully chosen to balance productivity with hazard protection

(*Continued.*)

Table 5. (*Continued.*)

NCP	positive impacts provided by soils	negative impacts provided by soils	mixed impacts provided by soils
12) habitat creation and maintenance (regulating NCP; [6])	soils are a habitat for many species, including plants and species with aboveground life stages; soils store and provide nutrients, water and shelter; soils have a buffering capacity for perturbations, enabling resilience of ecosystems	soil loss proceeds faster than soil formation; specific interactions of soil biology, chemistry and physics required for adequate functioning which makes soil restoration difficult; opaqueness of soils precludes non-destructive *in situ* observations of soil life and its functioning	plant-soil feedbacks promote certain habitat conditions over others; this can be beneficial when desired ecosystem development is promoted or detrimental when an undesired state is promoted (e.g. increased expansion of invasive species); propagules stored in the soil can promote or counteract habitat creation depending on the identity and functioning of the species
13) regulation of air quality (regulating NCP; [8])	sink for airborne pollutants; biofiltration of gaseous pollutants; landfill covers	particulates and dust storms; NH_3 and NO_x from fertilizer use	positive and negative air quality impacts from plant growth
14) regulation of organisms detrimental to humans (regulating NCP; 14])	suppression of pathogens by indigenous microbial communities; inactivation of detrimental organisms by abiotic factors	reservoir for pathogens; reduced capacity to regulate detrimental organisms when soil health is poor	practices that promote soil suppression of pathogens may reduce agricultural productivity
15) pollination and dispersal of seeds and other propagules (regulating NCP; [7])	healthy, non-polluted soils provide nesting substrate for a vast number of pollinators and seed dispersers, as well as support for alternative (to crops) floral resources; clay from soils is used to counteract toxicity associated with fruit secondary metabolites	unhealthy, polluted soils (enriched with nitrogen or other nutrients, pesticides) will change floral resource availability and quality (nutrient and sugar content, odour, size and shape), leading to changes in foraging behaviour and reducing fitness; tilled soils will reduce nesting opportunities	while nutrient enrichment can improve crop productivity, when in excess it can lead to loss of pollination services, leading to a null (or negative) net effect
16) regulation of ocean acidification (regulating NCP; [9])	facilitates weathering which removes CO_2 from the atmosphere; reduces the impact of ocean acidification; improves ocean CO_2 buffering capacity	cation exchange and secondary minerals could reduce weathering contribution	element release during weathering could impact wider ecosystems
17) formation, protection and decontamination of soils and sediments (regulating NCP; [12])	physico-chemical interactions of contaminants with mineral and organic soil components, and biochemical transformations facilitated by soil microorganisms confer contaminants 'cleaning' action of soil	inorganic contaminants including heavy metal(loid)s are derived from geogenic origin through weathering of parent materials, while both organic/inorganic contaminants are derived from anthropogenic origin in soil	soil plays a critical role in the transformation of contaminants and their subsequent transfer to groundwater, surface water, ocean, and atmosphere, and controls the mobility, bioavailability and toxicity of contaminants
18) maintenance of options (cross-cutting NCP)	healthy, well-managed soils allow multiple options to be considered now and in the future	unhealthy, poorly managed soils can lead to ecosystem degradation and desertification, with knock on effects for the reduction in other NCP	

Table 6. The contribution of soils to the SDGs, with contributions derived from relationships between NCP and the SDGs outlined in §2. Dependencies enabling positive SDG effects are shown in blue, those leading to negative SDG effects are shown in red.

NCP	potential impacts on SDGs by soil-based NCP	dependency on the sign of the likely impact
1) food and feed		if healthy and well managed, soils provide nutrients and a physical environment to sustain life and support plant growth; poorly managed/polluted soils may lack nutrients, contain toxic compounds or pests and pathogens that inhibit plant growth
2) materials and assistance		soils provide cheap, low-carbon construction materials with low levels of waste, and can reduce energy use in well-designed earthen architecture; overuse of soils for construction could threaten soils to produce food and mining can have negative impacts
3) energy		peat soils can be burnt to provide energy and soils contribute nutrients and water to grow energy crops; the burning of peats is bad for climate change and biodiversity; if sited on peats, wind turbines can damage biodiversity and cause loss of carbon
4) medicinal, biochemical and genetic resources		soils provide ecosystem services that are essential for intact ecosystems, clean water, healthy food, medicinal products and human well-being; soil dust, nutrient depletion and contamination may have adverse effects on human health
5) learning and inspiration		soils provide an opportunity for study, inspiration leading to art and literature and sources of biomimicry and design. Indigenous knowledge around soils is rich and widespread, contributing to better management around fertility and erosion, in particular
6) supporting identities		soil has been linked to human identities; concepts of a 'land ethic' shape farmer and other identities, as well as gendered experiences and cultural identities through the use of soil; concepts of e.g. 'blood and soil' have been used to justify exclusion/violence against others
7) physical and psychological experiences		green spaces and gardening allow for physical and mental benefits of being in nature; recreation, tourism and sport all depend on, and can bring financial benefits to, good soil management; recreation and tourism can be bad for soils through compaction and damage
8) regulation of climate		restoration of soil health and increasing soil organic matter contribute to adaptation and mitigation of climate change; poorly managed soils can lose carbon to the atmosphere and be a source of CH_4 and N_2O emissions

(*Continued*.)

Table 6. (*Continued.*)

NCP	potential impacts on SDGs by soil-based NCP	dependency on the sign of the likely impact
9) regulation of freshwater quantity, flow and timing		healthy soils have high infiltration capacity that increases green water and regulates blue water, and function as a filter for pollutants; unhealthy soils increase the risk of floods and droughts. Eroded soil can clog up waterways, reservoirs and infrastructure
10) regulation of freshwater and coastal water quality		natural soils and constructed wetlands provide water purification by absorbing pollutants; water pollution can result from non-point source pollution in farmland with overused chemicals
11) regulation of hazards and extreme events		by storing water, healthy soils attenuate floods, mitigate droughts, and sustain vegetation root systems that reduce erosion and landslide risk and effects of windstorms; degraded soils exacerbate the above risks
12) habitat creation and maintenance		soils are a habitat for many species and provide nutrients, water and shelter and enabling the resilience of ecosystems through buffering; soil loss proceeds faster than soil formation and soil restoration is difficult
13) regulation of air quality		soils are a sink for airborne pollutants, act as a biofilter for gaseous pollutants and are used as landfill covers, all helping to improve air quality; soils contribute particulates and dust storms and NH_3 and NO_x from fertilizer use
14) regulation of organisms detrimental to humans		suppression of pathogens by indigenous microbial communities. Inactivation of detrimental organisms by abiotic factors; soils are also a reservoir for pathogens, and poor soil health leads to reduced capacity to regulate detrimental organisms
15) pollination and dispersal of seeds and other propagules		healthy, non-polluted soils provide nesting substrate for a vast number of pollinators and seed dispersers and support alternative floral resources; unhealthy, polluted soils change floral resource availability and quality leading to changes in foraging behaviour
16) regulation of ocean acidification		soils facilitate weathering which removes CO_2 from the atmosphere, reduces the impact of ocean acidification and improves ocean CO_2 buffering capacity; cation exchange and secondary minerals could reduce weathering contribution
17) formation, protection and decontamination of soils and sediments		physico-chemical interactions of contaminants with soil and biochemical transformations facilitated by soil microorganisms confer the cleaning of contaminants by soils; organic and inorganic contaminants are of anthropogenic and geogenic origin
18) maintenance of options		healthy, well-managed soils allow multiple options to be considered now and in the future; unhealthy, poorly managed soils can lead to ecosystem degradation and desertification, with knock on effects for other NCP

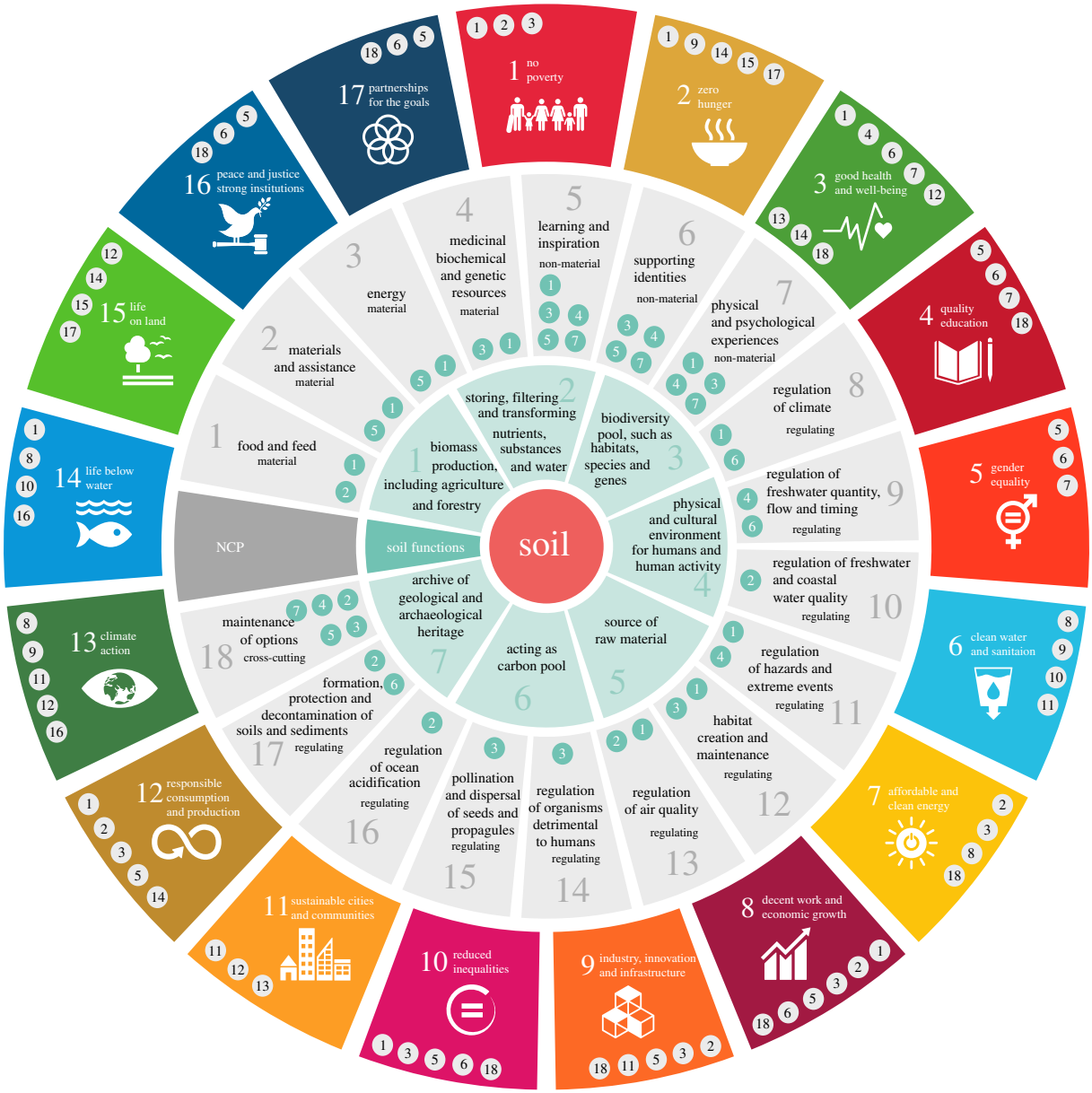

Figure 1. Functions provided by soils (inner ring), the NCP provided by soils underpinned by these functions (middle ring) and impacts on the SDGs through the NCP supported by soils (outer ring). Light blue numbered circles in the middle ring show the corresponding soil functions that contribute to the NCP. Grey numbered circles in the outer ring show the corresponding NCP that contribute to the SDGs.

— For healthy soils in natural ecosystems, *protect* them from conversion and degradation
— For managed soils, *manage* in a way to protect and enhance soil biodiversity, health and sustainability and to prevent degradation
— For degraded soils, restore to full soil health

These priorities map well onto the categories *protect*, *manage* and *restore*, outlined for nature-based solutions [46]. Options to restore degraded soils include revegetation, reduction of grazing pressure where soils are degraded by overgrazing, bioremediation with appropriate vegetation and restoring or maintaining soil organic matter levels by returning organic matter to the soil [43,47]. Options to better manage soils in managed systems include maintaining ground cover, reducing disturbance (e.g. by reducing the intensity of tillage), maintaining soil organic matter levels by returning organic matter to the soil, increasing soil biomass and diversity by providing carbon and reducing disturbance, preventing erosion, minimizing chemical inputs and preventing overgrazing of grasslands [48].

There is still a wealth of work to be done to better understand the processes linking soil functions to delivery of NCP, and wider work to better understand how NCP contribute to the SDGs. But we have enough knowledge now to move forward with the implementation of best management practices to maintain and improve soil health. This analysis shows that this is not just desirable, but it is essential if we are to meet the SDG targets by 2030, and sustainable development more broadly in the decades to come.

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