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Elaborations on the use of the ecosystem services concept for application in ecological risk assessment for soils

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ABSTRACT

This paper describes scientific developments that have raised awareness that changes in ecological risk assessment (ERA) methods are necessary. These changes have also been triggered by developments in environmental policies. This is illustrated by examples for The Netherlands and Europe. The ecosystem services concept seems to gain a central role in developments of new ERA methods. Main reasons for this are the integrative character of the concept, making it possible to integrate over environmental compartments or over environmental assessment methods, the concept's strength as communication tool and the possibility to value ecosystem services in economic terms. A method using ecosystem services in ERA is presented here in more detail, as an example. In this method assessment endpoints are derived from structures and processes in the ecosystem that are considered indispensable for the provision of particular ecosystem services. The approach facilitates fine-tuning ERA to specific land use demands.

1. Ecological risk assessment

Traditionally ecological risk assessment (ERA) focuses on assessing the risk of chemical contamination. Often, the species sensitivity distribution (SSD) model (Posthuma et al., 2002) is used to determine safe levels and intervention values for contaminants, based on the available ecotoxicological data for effects of a single contaminant on growth, reproduction or survival of single species, or processes performed by microorganisms. SSD results have been used as a first step in ecological risk assessment of contaminated sites, and the method has been refined to assess risks of chemical mixtures (Baas et al., 2009; Boekhold, 2008; Posthuma et al., 2008). Also, safety factors are being applied on SSD results to take into account – amongst others – the presence of multiple chemicals in the environment (Van Straalen and Van Leeuwen, 2002).

It has been acknowledged that the sole use of SSDs is not sufficient to assess ecological risks. Solomon and Takacs (2002) mention the need for other lines of evidence, such as observations from mesocosms and field tests, as well as ecological knowledge on the role and function of sensitive species in the environment. For this reason a Triad approach is often recommended, in which chemical, toxicological and ecological data for a contaminated site are assessed along converting lines of evidence (Chapman, 1986; Jensen and Mesman, 2006). The Netherlands Standards Institute has recently published a guideline for the process of performing a Triad for soil risk assessment (NEN, 2010), recognising the need for different lines of evidence. Specific endpoints have not been identified in this procedural protocol.

At a strategic level concern has been expressed about the (lack of) impact of ERA on decision-making. Some of these concerns date far back and generally address the relevance of ERA results for decision makers. Power and McCarty (1997) pointed at the need for an integrative approach to ecosystem study that considers multiple stressors and the interactions amongst these stressors. "The interpretation of relevance of controlled experiments requires insight into the functioning of ecological systems as a whole." Calow and Forbes (2003) identified areas for improvement of ERA in order to make it more informative for decision makers. Their concern addresses all extrapolation steps used in ERA, ranging from individuals through populations to communities, and finally the relationship between community composition and ecosystem processes and services. At the same time they stressed the importance of the balance between pragmatism and ecological relevance. Suter and Cormier (2008) stated that while the scientific community is good at performing environmental assessments, these have been of little influence in decision-making. They mentioned that "decision makers have not been appropriately concerned with ecological endpoints." One of the reasons would be that risk assessors have not been enough "concerned about the ultimate goal of preserving and protecting the environment by providing scientific input to good environmental management decisions". Looking in the direction of solutions, Apitz (2008) observed an increasing number of papers, workshops, web pages, etc. in the ERA arena, using terms such as 'ecosystem based', 'sustainable management', 'resistance', 'resilience', 'ecosystem services', and 'ecosystem health'. She concludes: "While all these concepts have

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value, clear definitions are rare. It is critical as we cross discipline and adapt tools designed for different purposes that we are explicit about how these terms are defined and how we link what we measure with what we are trying to achieve".

In conclusion, it seems that there is a growing need to develop methods for a more integrated assessment of environmental risks, mainly to provide decision makers and the general public with a better insight in the necessity and urgency to protect the environment against certain risks or to restore damage caused by stressors in the environment.

2. Co-developments in environmental policies

The recent developments in ecological risk assessment also reflect changes in policy arenas. This is illustrated by examples taken from Dutch and European soil policies. Traditionally, soil policies focused strongly on the chemical quality of soils, thereby ignoring non-chemical stressors, the specific demands of land use and the naturally supporting role of the soil ecosystem. In the preparation of the Dutch soil policy letter (VROM, 2003), the Ministry of Environment expressed the need for an approach that would enable more systematic attention for different forms of land use and the role of ecological processes therein (VROM, 2000). It was proposed to explain the significance of the soil ecosystem for a land user on the basis of 'ecological services' (TCB, 2003). The idea behind this was that land use depends on the performance of ecological functions, and that therefore land users would be motivated to protect these functions. As a consequence, the soil policy letter also stated that soil quality is not only dependent on chemical characteristics; soil biological and physical quality should also be taken into account, meaning that stressors of non-chemical nature are to be taken into account as well. This notion has been taken further in the European Soil Strategy (EC, 2006), where soil threats were specified that refer to the chemical, biological and physical aspects of soil: loss of organic matter, loss of biodiversity, compaction, sealing, salinisation, erosion, flooding and land slides, and contamination. The European Soil Strategy stressed the importance of soil functions by explicitly listing these functions as protections goals (EC, 2006). The 'soil functions' in the Soil Strategy also largely comply with the definition of ecosystem services.

These developments in soil policies do not stand by themselves. Policies to protect and enhance biodiversity, and a 'good ecological status' as required by the Water Framework Directive call for better integrated approaches. The above changes in soil policies demand for subsequent changes in ERA, with emphasis on the functioning of the ecosystem, and with focus on non-chemical stressors as well where appropriate.

3. Ecosystem services in ERA

The call for changes in ERA has been heard by a large number of scientists. Different directions are being investigated to develop more integrative approaches for ERA, such as using the vulnerability concept in ERA (De Lange et al., 2010), using population modelling in ERA (Baveco and De Roos, 1996; Forbes et al., 2010; Klok and De Roos, 1996), and using ecosystem services as endpoints in ERA as e.g. discussed at a recent meeting of 'A Community on Ecosystem Services' (ACES, 2010). In this paper we focus on the use of ecosystem services as endpoints in ERA for soils. We expect our approach to be applicable as well in aquatic ERA and decision-making, but given our background the examples in this paper refer to the terrestrial environment.

Different arguments have been brought forward to advocate the use of the ecosystem services concept in ERA.

Communicative strength is mentioned by Chapman (2008), who advocates using ecosystem services as assessment endpoints because environmental policies are focusing on ecosystem services in the expectation to better explain the value of ecosystems for mankind. In an assessment of effects of sealing – the permanent covering with impermeable materials – on soil functions, the Dutch Soil Protection Technical Committee (TCB) adopted the ecosystem services concept for communication purposes mainly, to explain the importance of good quality open soils in urban areas rather than discussing the impact of sealing (TCB, 2009, 2010). Also the European Food Safety Authority (EFSA) gives the ecosystem services concept a central role in defining specific protection goal options, amongst other reasons because of communicative strength (Nienstedt et al., this issue).

The *overarching* or *integrative aspects* of the ecosystem services concept are mentioned by Munns et al. (2009), who discussed the possibilities to link data needs and assessment processes for ERA with the USA National Resource Damage Assessment process. They argued that both processes would benefit if assessment endpoints were focused on ecosystem services. This idea shows the usefulness of the ecosystem services concept in combining different environmental assessment approaches. In a review of the methods used in the Netherland for setting standards for contamination and assessing ecological risks – which are tightly linked to each other – TCB recommended to include ecosystem services in ecological risk assessment by developing soil quality indicators for ecosystem services. TCB considered ecosystem services as a suitable overarching concept to be assimilated in a soil policy that centres on the different uses of soil by society (TCB, 2008). In the EFSA scientific opinion on the development of specific protection goal options for risk assessment of pesticides the ecosystem services concept has a central role because it may be applied to all ecosystems (and all environmental compartments) at a range of spatial and temporal scales. Relevant ecosystem services are identified, dependent on possible exposure to pesticides and specific landscape elements. In general, for these ecosystem services key species or groups of species are identified, and respective protection goals may then be formulated (Nienstedt et al., this issue).

The possibility to *value* ecosystem services, in monetary terms or otherwise, is another aspect that makes the concept attractive for decision makers. Valuation may make it easier for decision makers to weigh for instance the benefits of risk reduction measures or restoration of contaminated soils for the society, as applied in Net Environmental Benefit Analysis. Net environmental benefits reflect the gain in value of environmental services or other ecological properties attained by remediation or ecological restoration minus the value of adverse environmental effects caused by these actions (Efroymson et al., 2004). Methods for valuation of ecosystem services are available (e.g. Chee, 2004), though still under discussion, as are the implications for policy making (Fisher et al., 2008; Daily et al., 2009).

To summarise, main reasons for using the ecosystem services concept in ERA are the integrative character of the concept, making it possible to integrate over environmental compartments and over environmental assessment methods, the concept's strength as communication tool, providing a common language for natural scientists, socio-economists, decision makers, risk managers and stakeholders and the public, and the possibility to put a value to ecosystem services, thus facilitating decision-making.

4. Use of ecosystem services concept in ERA for contaminated soils

Within the context of ecological risk assessment new approaches are needed to facilitate the assessment of soil health and the capacity of soils to provide ecosystem services. Such new approaches should be applicable in site-specific risk assessment as well as for derivation of environmental quality objectives, in order to maintain linkage between the two areas of ERA. We believe that consistent adoption of the ecosystem services concept may just provide the innovative breakthrough to boost ERA forward in decision-making. How? Simply by using assessment endpoints and indicators that are clearly linked to and representative for specific ecosystem services. Not so much by changing the way assessment studies are usually conducted, but rather by shifting the focal point of assessment away from biodiversity and ecosystem health towards ecosystem services and associated benefits for society. Suggestions for such an approach have been made before (Chapman, 2008; Faber, 2006; Faber et al., 2006a,b). In the following we elaborate on this approach by providing more detailed examples while addressing both environmental quality standard setting and site-specific risk assessment, in the context of land use.

In most EU Member States the protection of soils traditionally has been focused on the overall protection of species and soil processes ('multifunctionality'). In the area of remediation of contaminated land, land use-specific soil remediation targets have been developed ('suitability for use'), aiming at increased cost-efficiency. Additionally, biological references for soil quality were developed (Rutgers et al., 2005), acknowledging that soil communities are a strong reflection of land use. Sustainable land use implies proper soil management to enhance and preserve the soil community that is thought representative for a particular type of land use.

In remediation of soils, the land use perspective and the concept of 'suitability for use' are playing increasingly important roles. The choice for references in risk assessment is critical, in which we have to accept that soil communities change as a result of land use. ERA thus requires a good knowledge of current-time land-use specific references, rather than e.g. a pre-agro-industrial reference in an assessment for agricultural land use. Obviously, in conservation areas ERA would require more pristine references. Given the particular land use in any particular case, we would argue for a reference based on sustainable management under circumstances whereby functional soil biodiversity is favoured, and thus the provision of ES is enhanced.

While soil ecosystems are infinitely complex, the question is basically: "What to protect?" (Van de Leemkule, 2001). Soils need protection against chemicals and other stressors, obviously, but in order to determine the *level* of protection the next question would be: "Which factors determine or modulate the risk to the soil ecosystem from pollution and other stressors?" The analysis of this question subsequently helps in the identification of scenarios and criteria. An approach has been proposed that is based on ecotoxicological sensitivity of specific, vulnerable 'indicators' that are associated with soil ecosystem services (Thomsen et al., in press, 2006). This approach was aimed to tailor risk assessment in lieu with land use and concurring demands for soil quality. The assessment is focused on characteristics and vulnerability of the biological community and soil ecosystem functioning. Appropriate indicators are derived by systematic breakdown of soil ecosystem structures and processes that underlay soil ecosystem services in a conditional sense, i.e. 'ecosystem service providers', ESPs (Kremen, 2005). Thus, ecosystem services are first broken down into ecological requirements, defined as the actual structures or processes of the ecosystem that underlie ecosystem services as a *conditio sine qua non*: ecosystem services provision is dependent on these requirements. In other words, ecological requirements need some minimum qualitative or quantitative level in order for the ecosystem to function properly for the provision of a particular ecosystem service. This is elaborated in Table 1.

In order to assess the state of ecological requirements, indicators may be denominated as potential means; indicators may include soil biota, soil processes, or ecological states and conditions. Numerous indicators may thus be conceived, as illustrated by way of example in Table 2.

Ecosystem services, their ecological requirements, and indicators can be ranked or weighed by either societal or ecological importance with respect to a specific type of land use (Faber et al., 2006a). This may affect the weighing of assessment results, and thus the outcome of decision-making. From a societal viewpoint, stakeholders may attach different values to ES and their indicators (as perceived culturally or from economic perspective, given the land use). While such societal weighing is part of the decision-making and risk management process, the ecological weighing (if done at all) is part of ERA. Within ERA, indicators may be ranked according to increasing ecological relevancy as they differ in relevancy for a single or series of ecosystem services. As an exercise of mind this is elaborated in an ecological context for clusters of soil ecosystem services under five types of land use (Table 3); for a ranking of indicators, see elsewhere (Faber et al., 2006b, p. 202). Various methods for ranking may subsequently be used to process data, befitting the purpose of a particular risk assessment, either to reduce ignorance and uncertainty (cf. Thomsen et al., 2006), or to make use of data in a balanced multi-criteria framework (Linkov et al., 2004). But that is beyond the scope of this paper.

Ecological risk assessment may be conducted on the basis of the indicators for ecosystem services. As stated before, this may concern either the derivation of soil quality objectives or site-specific ERA (scenarios A resp. B in Fig. 1), as explained in the following sections.

Soil quality objectives (scenario A) may be specified for different types of land use if related ecosystem services and associated

Table 1
Regulatory functions and other aspects of the ecosystem as ecological requirements underlying ecosystem services.
After Faber et al., 2006a.

Ecological requirement	Ecosystem service (clustered)					
	Soil fertility	Adaptability, resilience	Buffer and reaction function	Biodiversity and habitat provision	Disease suppression and pest resistance	Physical structure
Functional biodiversity	X	X	X	X	X	
Structural biodiversity, species richness	X	X	X	X	X	
Ecosystem productivity	X	X		X	X	
Organic matter fragmentation, mineralisation	X		X	X		
Soil properties (pH, CEC, aggregates, pore space, WHC, etc.)	X		X	X		X
Nutrient cycling (supply, availability, assimilation, immobilisation)	X		X	X		
Autonomic development (nature)	X	X		X		
Soil organic matter build-up and maintenance	X		X		X	X
Carbon sequestration	X		X	X		
Greenhouse gases	X		X	X		
Groundwater supply and quality	X		X	X		X
Genetic variation and storage of genes		X	X	X	X	
Natural attenuation		X	X	X		
Adaptability, flexibility for use		X				
Air quality amelioration			X			
Water transport and storage			X	X		X
Landscape diversity				X		X
Soil archive (archaeological, geological)						X

Table 2
Examples of relevant indicators for ecological requirements underlying ecosystem services (after Faber et al., 2006a).

Ecosystem service (clustered)	Ecological requirement (examples)	Indicator (examples)
Soil fertility	Nutrient cycling	Litter mass loss rate
	• mineralisation nutrient	Potential nitrification
	• retention	Available phosphate
		K exchangeable
		Microbial biomass and activity
		Soil respiration rate
		N loss to sub-root soil
	Functional biodiversity	Nitrifying bacteria diversity, activity
	• presence of key groups	Carbon sources utilisation capacity
	• diversity within group	Nucleic acids microbial population characterization
		Nematode community composition
		Earthworms community structure
		Key stone species
	Soil organic matter build-up and maintenance	Labile SOM fractionation
		Fulvic/humic acids, polyphenols
		Soil aggregates size distribution
	Physicochemical soil properties	pH
	• rooting permeability	Soil bulk density
	• resistance to water logging	CEC
		Water holding capacity
		Texture; silt and lutum fractions
Adaptability and resilience	Functional biodiversity	Nematode community structure
• flexibility for land use and management changes		Earthworms community structure
• resistance to stressors		Fungi:bacteria ratio
		Nitrifying bacteria
	Genetic variation	Nitrifying bacteria
		Nucleic acids microbial population characterization
	Species richness	Diversity indices
	• connectivity	Key stone species
Buffer and reaction function	Soil organic matter build-up and maintenance	Anecic and epigeic earthworms
• natural attenuation	• litter incorporation in soil	Root turnover
• capacity for ageing		Labile SOM fractionation
	Physicochemical soil characteristics	CEC
		Soil aggregate stability
	Soil structure and bioturbation	Earthworm density
Biodiversity and habitat provision	Functional biodiversity	Key stone species
• above-ground biodiversity regulation	• nutrient immobilisation	Soil food web biomass distribution
• humus type regulation	• herbivory	Root herbivore nematodes
	Structural biodiversity	Diversity indices
	Genetic biodiversity	Iso-enzymes
		Nucleic acids characterization
Disease suppression and pest resistance	Functional biodiversity	Soil-borne predators of pests
		Specific suppressive taxa
Physical structure	Soil organic matter build-up	Anecic and epigeic earthworms
	Soil structure	Soil aggregate stability
	• carrying capacity for heavy weights	Soil compaction

indicators are selected. In the derivation process for chemical soil quality objectives obviously those indicators will be selected that are sensitive and have been used in toxicity testing. The toxicity data may be compiled from literature to make up datasets that can be used

Table 3
Rating of the degree by which local land use is considered dependent on clusters of soil ecosystem services (after TCB, 2003). Legend: +, highly dependent; −, not dependent, +/−, moderately dependent or variable with stakeholder.

Ecosystem service cluster	Land use				
	Nature	Agriculture	Public open space	Allotment gardens	Gardens
Soil fertility	+	+	+/−	+	+/−
Adaptability, resilience	+/−	+	+/−	−	−
Buffer and reaction function	+	+	+	−	−
Biodiversity and habitat provision	+	−	+	−	+
Disease suppression and pest resistance	−	+	+/−	+/−	−
Physical structure	+	+	+	+/−	−

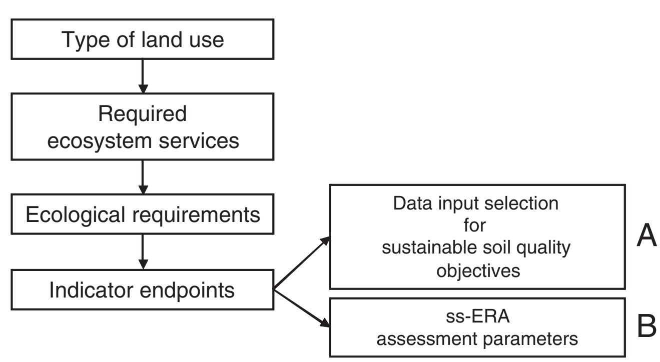

Fig. 1. Application of relevant indicators for evaluation of ecosystem service provision in risk assessment, derived through ecological requirements that are conditional for sustainable land use of specific type. (A) Literature toxicity data for relevant indicators may be used for derivation of soil quality criteria for sustainable land use. (B) In site-specific ecological risk assessment the indicator status may be assessed through bioassays or field inventories, if vulnerable to the particular stressor in case.

in the traditional ways of deriving soil quality objectives. Such a compilation was used by Thomsen et al. (in press) to draw attention to soil ecosystem health as determinant for future availability of biologically productive land.

Alternatively, site-specific ERA (scenario B) may use the status of ecosystem services indicators to assess suitability for use of the soil. Given the desired type of land use and specific aims of local stakeholders, vulnerable indicators are selected to be used in bioassays or to be assessed through field inventory and monitoring in a Triad approach. Notably, indicators should be selected as relevant as can be in view of the intended land use and management practises in question, e.g. relevant for the type of agricultural use in terms of cropping and soil management. Recently, the approach has been standardised as a process protocol for Triad-based ecological risk assessment for soils in The Netherlands (NEN, 2010).

5. Discussion

A prime cause for frequent miscommunication between land using stakeholders and scientific risk assessors and a subsequent lack of acceptance of results of ecological risk assessment may be associated with the question “What to protect?” This question is not answered optimally if the relation between intended land use and assessment indicator is not logical and meaningful (“So what?”). Our approach works both ways: the land-manager gains insight in what soil ecosystem services are beneficial and desirable, and subsequently need management, while the risk assessor is focused what tools (indicators) to apply. The concept of ecosystem services speaks both ways.

The above approach is largely focused on requirements and indicators for ecosystem services that are typically and primary associated with soils, i.e. supporting services. With respect to some stakeholder groups it might be expedient for risk assessors to focus on ecosystem services indirectly related to soil, i.e. the provisioning, regulating, and cultural services. This will require more knowledge of ecosystem functioning to assess indirect effects on these services, e.g. of soil contamination. Preferably, risk assessment should simultaneously address all ecosystem services needed for the envisaged land use objectives as well as those required by non-local stakeholders (e.g. C-sequestration and water regulation).

A second factor to convince stakeholders and decision makers is the possibility for valuation of ecosystem services, in a monetary sense or otherwise. The subsequent implicit valuation of relevant ecological indicators may enhance the support for ERA. Economic valuation will also facilitate to use of the outcome from site-specific risk assessment in cost-benefit analysis.

The concept of ecosystem services allows for the simultaneous assessment of different stressors affecting the suitability for use. To this extent, we expect that indicators that are vulnerable to the various stressors involved will be useful. Thus, the concept and the aforementioned approach for selection of assessment endpoints will befit the requirements put forward by developments in soil policy, e.g. the EU Soil Strategy.

In conclusion: communication can be improved and the question what to protect can be answered more satisfactory. We pose that the use of indicators related to specific ecosystem services which are linked to land use objectives (stakeholder demands) will enhance the societal relevance of risk assessment, therefore increase acceptance of results and the potential for actual use in decision-making. The considerate breakdown of ecosystem services into quantifiable indicators, as advocated in this paper, thus sustains both societal and scientific demands to further ERA.

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