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Abstract

Can soil be considered as just a component of terrestrial ecosystems and agroecosystems or is it an ecosystem in itself? The present piece of opinion suggests that we should refer to the original definition of the ecosystem given by Tansley and apply it to the soil viewed as a multi-scale assemblage of ecological systems.

Introduction

The concept of ecosystem services generated an overabundant literature over the last 20 years. In more than a thousand publications (1,560) indexed by ISI Web of Science™ (last update November 29, 2014) soil was considered as the main provider of ecosystem services. Agricultural and forest production, protection against erosion and flooding, water stocking, fixation of atmospheric carbon and nitrogen are among the most often cited ecosystem services provided by soil. If soil renders so many services to mankind this questions the manner we consider it from a scientific, conservational or economical point of view. Can soil be considered as just a component of terrestrial ecosystems and agro-ecosystems or is it an ecosystem in itself? Published articles using the expression "soil ecosystem" showed a two-fold increase in the last three years. This census also revealed that the concept of ecosystem applied to the soil was not novel and was even familiar to the scientific community: the earliest paper (Auerbach 1958) was published in the prestigious journal "Ecology", the official organ of the Ecological Society of America. Let us examine the problem in the light of present-day knowledge on soils and ecosystems.

The ecosystem concept, from Tansley to now

The word "ecosystem" appears for the first time in a seminal paper by Tansley (1935) who defines it as a system (in physicist sense) including "the whole complex of organisms inhabiting a given region" but also, and this was the novelty, "the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense." Tansley indicates explicitly that no limit of size or nature can be attributed to ecosystems, even if the examples cited in his paper concern mainly vegetation, his best known subject. With this paper, Tansley introduced an epistemological break in ecological science, still based at that time on Clements' thought (Clements 1916), who considered the "plant society" as a "complex organism", not considering the physical environment. In that frame, the soil was only the physical support of vegetation. Thereafter, the ecosystem concept remained relatively poorly used by ecologists, as was the case for European (continental) plant ecologists, who preferred to turn to phytosociology, building and describing units

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(associations, alliances, etc.), copied on the Linnean classification of living organisms (species, genera, families, etc.).

Odum (1953) replaced the ecosystem concept in the frame of bioenergetics, applying principles of thermodynamics in an endeavour to assess transfers of matter and energy on a quantitative base. He defined the ecosystem as a ‘‘natural unit that includes living and non-living parts interacting to produce a stable system in which the exchange of materials between the living and non-living parts follows circular paths”. Stability became an important attribute because it allowed for the first time the ecosystems to be discerned, modelled and mapped by a larger scientific community. Odum’ views were largely popularized in Europe by Duvigneaud (1974, 1980) and were seminal to the development of the International Biological Programme (IBP). According to Odum, the ecosystem is the basic unit of Nature, quasi self-sufficient because it only needs energy sources (lastly solar energy) to maintain its equilibrium. This means a neat restriction from Tansley’s definition, since independence (even though relative) from the immediate environment is a prerequisite. This vision of the ecosystem became rapidly successful, because it allowed to compute mass and energy balance, by making inventories of organisms living at the inside of a well-determined envelope, and measuring respiration, nutrient uptake, productivity and other ecosystem’s attributes. Such basic units can also be used as quantifiable monitoring units, hence the successful development of methods and concepts for “ecosystem management.” According to Odum’ views, putting limits to ecosystems (not on the paper but on the field) is a delicate work, because one has to accept or reject some frontier visible on the field (forest edge, river, pond shore, cliff, etc.) as determining the “independence” of the ecosystem. According to this concept, which was dominant for a long time in ecology, soil cannot be considered as an ecosystem, because it relies entirely on vegetation for organic matter inputs, the “fuel” of its inhabitants.

Since IBP studies, which stimulated a large array of inventories and balance sheets of the living world, from Equator to Poles, from the deep ocean to the highest mountains, the ecosystem concept became popular and well suited to the media, in the same manner and for the same reasons as the concept of biodiversity, notably after the Rio World conference (1992). Ecological research came in hand with this media coverage of concepts previously handled with caution by the scientific community. Most spectacular developments concerned the recognition of the non-independence of the units acknowledged as basic units by Odum and followers. The thorough study of terrestrial environments allowed ascertaining the interdependence and the permanent renewal of “motifs” composing forests, watersheds, landscapes and, above all, the enormous share of stochasticity issuing from dispersal, immigration and extinction of living organisms. The ecosystem cannot be considered in isolation, each organism ensuring the functions for which it has been “programmed”, but rather becomes an entity largely open to the outside and eminently changing (Tilman 1999). The realization of changes taking place at the global scale, in particular the greenhouse effect and its spectacular and still unresolved ecological consequences, contributed to open the “Pandora’s box” of the Odum’ ecosystem. This urged some scientists to reject the ecosystem concept and propose new paradigms taking into account stability, disturbance and spatial scale. O’Neill (2001) speaks of “ecological systems” which are “composed of a range of spatial scales, from the local system to the potential dispersal range of all the species within the local system.”

The ecosystem concept has been also at the heart of the controversy between “reductionism” and “holism” in ecology or, in more fashioned terms, between “community” and “ecosystem” ecology, as exemplified in the excellent book of Golley (1996) on the subject, to which the reader is referred. Far from settling the debate in this piece of opinion it is just worth to recall that Tansley was justly reluctant of both the reductionism of Gleason (1926) and the holism of Clements (1916), basing his arguments on the fact that the part and the whole had the same importance if we want to fully understand how properties emerge in the universe (see Ponge 2005 for a review). This "merry-go-round" overview should not be closed without paying homage to the Russian scientist and philosopher Vladimir Ivanovitch Vernadsky, who was the first to give a scientific basis to the unity of living and non-living matter (Lapo 2001).

The soil as an embedded and embedding ecosystem

The philosopher and physicist Sir Arthur Koestler described the concept of the "holon", corresponding to embedded functional units, allowing us to understand how an organism functions in a self-regulated manner (Koestler 1969). Above organisms (the subject he had to present in the course of a biological congress held in Alpbach, Austria, 1968), Koestler described the universe as a series of environments infinitely embedded in a hierarchical manner. His hierarchical concept was highly successful in biology, filling a gap in the knowledge of self-regulating systems, and even though he remained better known for his philosophic work, landscape ecology was largely inspired from Koestler's "holon" concept. This vision adds to our view of the universe a dimension which could be named "vertical", mimicking the fractal dimension popularized by Mandelbrot (1983). It offers the advantage of allowing travel through the scales of perception that the scientist discover when dissecting a system which he(she) is studying or acting on. Koestler's concept implies that one cannot consider a level of perception without taking into account the level immediately above it. This was shown in an elegant manner to apply to the soil in a paper by Coleman et al. (1992), to which E.P. Odum himself participated. The hierarchically nested structure of detrital food-webs was a focus topic of Andrei Pokarzhevskii's soil science, a concept this author applied fruitfully to the bio-indication of soil pollution (Pokarzhevskii 1996).

However, the hierarchical concept of the soil ignores the existence of constant back and forth streams through the embedded scales thus defined. In particular, the "holon" concept does not take into account the reversibility and instability of embedding, as soon as "ecosystems" are considered, which are far from machines made of clearly discernible elements. As an example, take a look to North American Douglas fir forests of the Pacific Coast, where our most common European earthworm, *Lumbricus terrestris*, unknown in New World until European colonization, now proliferates at the end of a two-century "Conquest of the West" (Cameron et al. 2012). In its original environment, the western coniferous forest, Douglas fir is a keystone species, imposing a millenary cycle to the forest ecosystem, renewal being mainly ensured by fire. Douglas fir accumulates a huge amount of hard-to-decay litter, impeding any natural regeneration despite an enormous stock of nitrogen and other favourable nutrients, available only through the mycorrhizal network of the adult (to which seedlings are still not or cannot be connected). Only fire is able to make these nutrients available to seedlings, in the absence of burrowing earthworm species. The arrival of *Lumbricus terrestris*, a soil engineer burrowing and feeding activities of which are known to favour a rapid turnover of main nutrients in forests (Ponge 2003, 2013), will change the environmental conditions prevailing in the soil of western coniferous forests. In line with the abovementioned mechanism it can be postulated that woody landscapes of the western US will evolve to a large extent in the next decades. If we follow the views taken true by Koestler and followers, what is embedded in what in Douglas fir forests? Previously dependent on the arboreal cover, the soil becomes, at least during the time of seedling establishment, the master chief of the ecosystem, upsetting equilibria rather than relying on them.

What is the place of the soil in a non-hierarchic concept of embedded ecosystems? By the diversity of its biotic (plant roots included) and non-biotic components, its gaseous and water compartments, the functions it ensures through its various interactions (e.g. trophic networks, mineral weathering, decomposition, humification) and its visible upper and lower limits (from surface litter to parent rock), the soil is indeed an ecosystem, belonging to the universal category of open systems (Ashby 1956). By its living character, well established by Gobat et al. (2010), and the services it renders to the Planet (Lavelle et al. 2006), the soil is indeed an ecosystem in the sense given to this term by Tansley in 1935. Soils are naturally embedded in Odum' terrestrial ecosystems (forests, meadows, etc.), from which they are essential parts, functionally speaking, and their "memory" (Schaefer 2011). During forest renewal (before and during the start of a new cohort of trees), soil acquires even a dominant role (Ponge et al. 1998). Although physically embedded in the ecosystem sensu Odum, the soil can, at least at key moments of its development, be embedding it functionally.

Other ecosystems exist and are in turn embedded in the soil. We can cite the root tip, or the organo-mineral aggregates. For instance, growing root tips are the seat of numerous interactions (the microbial loop) between plants (exuding organic compounds), microbes (deriving energy and carbon from the plant, mineralizing humus and weathering mineral matter), and animals (feeding on microbes and mineralizing the microbial biomass), allowing the plant to take up and assimilate nutrients very efficiently (Bonkowski 2004). Soil aggregates, originating from faunal, root and microbial activity, are seats of carbon sequestration and render the soil and as a consequence crop production able to sustain global changes (Six et al. 2004). Numerous other examples exist, gathered and detailed in Gobat et al. (2010), which establish the existence of numerous ecosystems at the inside of the soil ecosystem, even if the term "ecosystem" has rarely if any been used for designating them.

The ecosystem concept can be fruitfully applied to the soil, making it a matter of study in itself for ecosystem as well as community ecologists. Moreover, considering the soil as an ecosystem can be important for future land management strategies. It is common view that soil is a substrate for crops, but also for roads and buildings, without addressing it as the place where most organisms live and die. This urges the diversity and integrity of soil biological functions to be protected worldwide as a necessary condition of mankind survival.

References

Ashby WR (1956) An introduction to cybernetics. Chapman and Hall, London

Auerbach SI (1958) The soil ecosystem and radioactive-waste disposal to the ground. Ecology 39:522−529

Bonkowski M (2004) Protozoa and plant growth: the microbial loop in soil revisited. New Phytol 162:617−631

Cameron EK, Zabrodski MW, Karst J, Bayne EM (2012) Non-native earthworm influences on ectomycorrhizal colonization and growth of white spruce. Écoscience 19:29−37

Clements FE (1916) Plant succession: an analysis of the development of vegetation. Carnegie Institution of Washington, Washington

Coleman DC, Odum EP, Crossley DA Jr (1992) Soil biology, soil ecology, and global change. Biol Fert Soils 14:104−111

Duvigneaud P (1974) La synthèse écologique: populations, communautés, écosystèmes, biosphère, noosphére. Doin, Paris

Duvigneaud P (1980) La synthèse écologique: populations, communautés, écosystèmes, biosphère, noosphére, 2nd ed. Doin, Paris

Gleason HA (1926) The individualistic concept of the plant association. Bull Torrey Bot Club 53:7−26

Gobat JM. Aragno M, Matthey W (2010) The living soil: fundamentals of soil science and soil biology. Science Publishing Corporation, Bremen

Golley FB (1996) A history of the ecosystem concept in ecology: more than the sum of the parts. Yale University Press, New Haven

Koestler A (1969) Beyond atomism and holism: the concept of the holon. In: Koestler A, Smythies JR (Eds) Beyond reductionism: new perspectives in the life sciences. Hutchinson, London, pp 192−231

Lapo AV (2001) Vladimir I. Vernadsky (1863–1945), founder of the biosphere concept. Int Microbiol 4:47–49

Lavelle P, Decaëns T, Aubert M, Barot S, Blouin M, Bureau F, Margerie P, Mora P, Rossi JP (2006) Soil invertebrates and ecosystem services. Eur J Soil Biol 42:S3−S15

Mandelbrot B (1983) The fractal geometry of Nature. Freeman, San Francisco

Odum EP (1953) Fundamentals of ecology. Saunders, Philadelphia

O'Neill RV (2001) Is it time to bury the ecosystem concept? (with full military honors, of course!). Ecology 82:3275−3284

Pokarzhevskii AD (1996) The problem of scale in bioindication of soil contamination. In: Van Straalen NM, Krivolutskii DA (Eds) Bioindicator systems for soil pollution. Kluwer, Dordrecht, pp 111−121

Ponge JF (2003) Humus forms in terrestrial ecosystems: a framework to biodiversity. Soil Biol Biochem 35:935−945

Ponge JF (2005) Emergent properties from organisms to ecosystems: towards a realistic approach. Biol Rev 80:403−411

Ponge JF (2013) Plant-soil feedbacks mediated by humus forms: a review. Soil Biol Biochem 57:1048−1060

Ponge JF, André J, Zackrisson O, Bernier N, Nilsson MC, Gallet C (1998) The forest regeneration puzzle. BioScience 48:523−530

Schaefer VH (2011) Remembering our roots: a possible connection between loss of ecological memory, alien invasions and ecological restoration. Urban Ecosyst 14:35−44

Six J, Bossuyt H, Degryze S, Denef K (2004) A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Res 79:7−31

Tansley AG (1935) The use and abuse of vegetational concepts and terms. Ecology 16:284−307

Tilman D (1999) The ecological consequences of changes in biodiversity: a search for general principles. Ecology 80:1455−1474