Enhancing the ecological infrastructure of soils

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Abstract
The recent financial crisis has led to massively increased investments in built infrastructure as a means of rapidly stabilising and reinvigorating economies around the globe. However, just as built infrastructure delivers a range of socio-economic services that underpin modern societies, there is also an ecological infrastructure that maintains the provision of the ecosystem services that support a wide range of ecological as well as socio-economic benefits. Given the worsening water and food crises and increasing population pressures, one wonders why larger investments are not being made to ensure that our ecological infrastructure has the capacity to continue to produce sufficient flows of ecosystem services to satisfy the world's future needs. A large part of the answer to this question is, despite its importance, that the concept of ecological infrastructure is not yet widely recognised and understood. This paper highlights the importance of investing in the ecological infrastructure of soils. We begin by developing the concept of ecological infrastructure through a comparison of the key elements, systems and services that constitute built infrastructure and ecological infrastructure. We then highlight the role of soils as a fundamental element of ecological infrastructure. We highlight the importance of pore connectivity and soil water flow and transport as essential features of a robust and resilient soil ecological infrastructure that can be invested in, and enhanced, through carbon investment strategies.

Key Words
Ecological infrastructure, ecosystem services, soil, macropores, water and food crises.

Comparing built and ecological infrastructure
Water scarcity, projected climate change impacts, the worsening global food crisis and the global financial crisis are powerful drivers for major investments in water and other built infrastructure. Many people now have direct and regular access to a variety of socio-economic services that this type of infrastructure provides. Water, energy, transport and communications infrastructure (Table 1) is used by so many of us so often that we consider them to be essential (Australian Government Treasury 2004)

Table 1. Built infrastructure, associated systems, and the services and benefits they provide.

Infrastructure*	Systems	Services	Benefits
Water	Dams, channels, treatment plants	Water for urban, agricultural, industrial use	Sufficient quality water; Flood mitigation
Energy	Power stations, power lines	Generation, storage, transmission of energy	Energy for construction, maintenance & equipment operation
Transport	Road, rail, terminals ports	Despatch, delivery, receipt of goods & services	Access to goods, services and travel
Communication	Transmitters, cables, receivers, satellites	Information storage, transport and delivery	Connecting individuals, organizations across space and time

* Also includes health, education, industry, defence and other built infrastructure

Investing in built infrastructure provides increased capacity for the delivery of various services required by growing populations. In addition, built infrastructure investments are used to stimulate rapid economic growth, and billions of dollars are now being invested by a number of countries in a wide range of public and private infrastructure developments as part of their response to the global financial crisis.
As with built infrastructure, we note that rivers, soils, aquifers, wetlands and other landscape elements are key components of an 'ecological infrastructure' that supports the continuing delivery of ecosystem services required by natural systems for their survival, and mankind for human well-being (Table 2).

Table 2. Ecological infrastructure, ecosystems, and the services and benefits they provide.

Ecological Infrastructure*	Ecosystems	Ecosystem Services	Ecosystem Benefits
Rivers	River ecosystems	Water delivery within and between elements (and ecosystems)	Provides water, sediment, nutrients to floodplains, wetlands, aquifers, estuaries; and habitat
Aquifers	Aquifer ecosystems	Water capture, storage, purification, dilution (underground)	Soil moisture, stream flow, wetlands (base flows) in dry seasons
Wetlands	Wetland ecosystems	Water storage, filtration and purification	Inception & dilution of non beneficial organic & inorganic materials; habitat
Soils	***Soil ecosystems***	***Support medium, storage and supply of water & nutrient for plants; waste treatment/removal***	***Maintain (& increase) soil biological and vegetation productivity & biodiversity)***

* Also includes catchments, forests, rangelands, vegetation, floodplains, estuaries etc

Ecological infrastructure consists of landscape elements, ecosystems, ecosystem services and the interconnections within and between them (Figure 1).

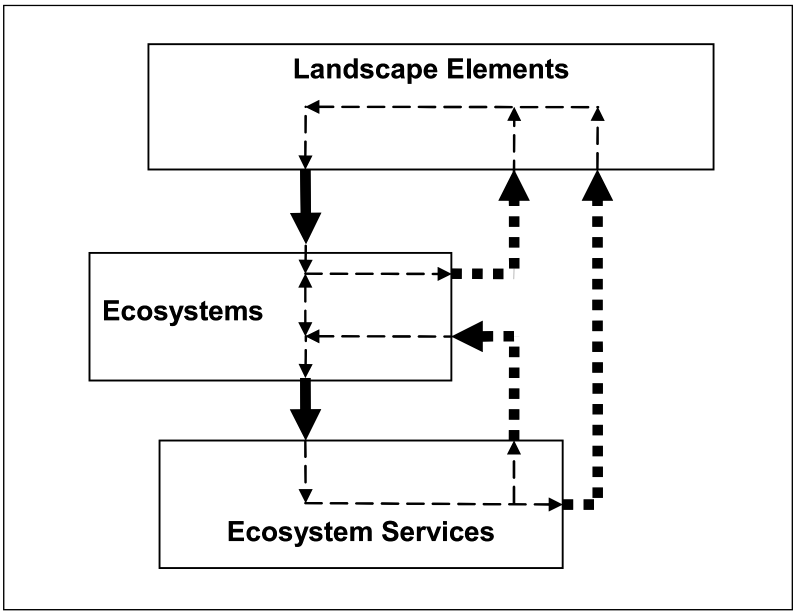

Figure 1. Ecological infrastructure consists of landscape elements, ecosystems, ecosystem services and the interconnections within and between them.

We argue that growing populations will require an increase in the capacity of existing ecological infrastructure if it is to continue to produce the range of ecosystem services necessary for our present living standards to be maintained and improved. Even though the importance of maintaining the flow of ecosystem goods and services is now well-established in the literature (Costanza *et al.* 1997), the role and importance of the ecological infrastructure that sustains the ecosystems that provides the goods and services is barely recognised (Postel 2008).

While our investments in built infrastructure have been ever-increasing, we have not been investing sufficiently in our ecological infrastructure. Inadequate investment in ecological infrastructure has led to a worsening environmental crisis, in which critical ecosystem services have been and are being lost in many regions across the globe. For example 60% of ecosystem services examined by the Millennium Ecosystem Assessment in 2005 were found to be degraded (http://www.millenniumassessment.org/en/Index.aspx). Some world famous examples of the kind of environmental degradation resulting from a failure to understand and invest in ecological infrastructure include Lake Chad, the Aral Sea and Easter Island.

In practical terms, investing in ecological infrastructure should include objectives, actions and outcomes aimed at identifying those areas that are most suitable for development, with a primary focus on the regenerative capacity of natural systems to continue to support human socio-economic requirements. Sufficient investment in ecological infrastructure will therefore involve strategic and targeted investments aimed at:

- gaining a better knowledge of the structure, function and processes of ecological infrastructure
- the restoration of degraded or degrading ecological infrastructure, and
- maintaining the resilience and regenerative capacity of 'undisturbed' ecological infrastructure[1] in the case of future developments.

We may also need to find a way of enhancing the capacity of ecological infrastructure if we continue to place ever-increasing demands upon it.

Enhancing ecological infrastructure: Understanding and investing in soils

Soil is a primary 'filter' of the world's water and through this plays a critical and valuable role in determining the quality and quantity of groundwater and surface water (Clothier *et al.* 2008). It is the size and shape of soil pores and their connectivity that either enhances or curtails the capacity of soil to buffer and filter, so understanding and investing in soils to ensure beneficial soil structure is critical. Clothier *et al.* (2008) demonstrated the importance of this and suggested that macropores which support preferential flow and transport underpin 12 of 17 ecosystem services provided by soils. Jarvis (2007) provided an extensive review of the principles and controls on preferential flow and transport in soil. Clothier *et al.* (2008) then estimated the global value of the ecosystem services provided by the soil's macroporous infrastructure to be some US$304 billion per year.

Given the significant value of these services provided by macropores, it is critical that we increase both our understanding of, and the investment needed for initiating and sustaining soil macropores. A prime way of achieving this is through carbon investment in soil. Potentially this is a win/win situation: improved ecological infrastructure and carbon capture and storage. Robinson *et al.* (2009) have highlighted the need to improve understanding and definition of soils' 'natural capital'. Their definition recognises the quantity, quality and dynamic behaviour of the various components making up the soils' natural capital, but appears to differ somewhat from our definition of ecological infrastructure in that it does not highlight issues of 'connectivity' as a key component of natural capital. Nevertheless, it is a major step forward in highlighting the need for more work on understanding those aspects of soils – their ecological infrastructure – that supports the delivery of ecosystem services. Figure 2 shows X-ray tomographs of two identical soils from neighbouring orchards (genoforms). Different carbon-investment strategies used in these different orchards have changed the ecological infrastructure (phenoforms) of the soils. Consequently, the two formerly identical soils now perform quite different ecosystem services due to the altered macroporous infrastructures and connectivity within them.

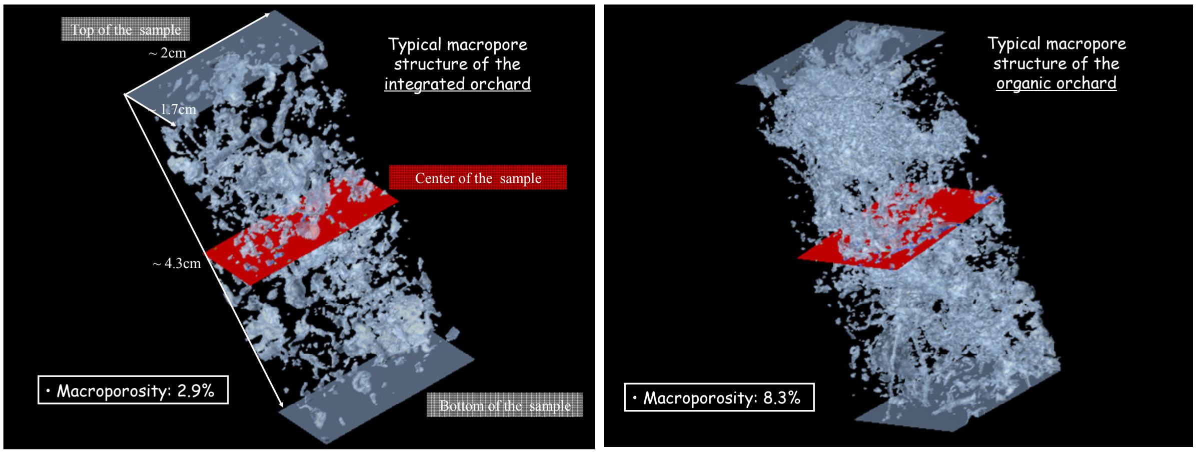

Figure 2. The X-ray tomographic images of two identical soils that have undergone different carbon-investment strategies, resulting in a different ecological infrastructure with relation to macroporosity

[1] All ecological infrastructure has now been disturbed, at least to some degree, by human activities, for example global climate change

The results of these different carbon investment strategies show that investing in ecological infrastructure can increase the ecosystem-services and hence the benefits provided by soils. This research is focused only on a particular component of soil infrastructure, but the findings highlight the potential benefits of improving our understanding of the structure and function of ecological infrastructure and investing in it.

Conclusions

Ecological infrastructure underpins the delivery of ecosystems services required by natural systems for their survival, and mankind for human well-being. We have argued that growing populations will require an increase in the capacity of existing ecological infrastructure if present living standards are to be maintained and improved. But while investments in built infrastructure have been ever-increasing, we have not been investing sufficiently in our ecological infrastructure.

Soil is a critical component of ecological infrastructure and this paper reveals how soils' production of ecosystem services can be enhanced through carbon investment strategies. The next challenge is to

- further develop our understanding of the soil's infrastructure and particularly connectivity, and
- use that understanding to implement appropriate investment strategies in ecological infrastructure to ensure delivery of the range of ecosystem goods and services humans depend upon, many of which are currently taken for granted.

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