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Natural Capital, Ecological Infrastructure, and Ecosystem Services in Agroecosystems

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Glossary

Agroecosystem Ecosystem arbitrarily defined as a spatially and functionally coherent unit of agricultural activity, and includes the living and nonliving components involved in that unit as well as their interactions. The basic unit of study for an agroecologist.
Ecological infrastructure The way natural capital stocks are organized to produce ecosystem goods and services.
Ecosystem services The direct and indirect contributions of ecosystems to human well-being.
Natural capital The stocks of natural assets (e.g., soils, forests, and water bodies) that yield a flow of valuable ecosystem goods or services now and into the future.
Natural resource management The management of natural resources, including soils, land, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.
Soil (1) The unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (2) The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics.

Introduction

Population growth and the need to obtain energy and food from the planet's finite resources are intensifying pressures on natural ecosystems that are required for life support. This increasingly raises questions about the sustainability and viability of agricultural systems into the future, and one's ability to mitigate the impacts of ongoing production gains on the environment. Much of the current economic growth strategy is based on the false assumption that natural resources, such as land and water, are inexhaustible, which they are not, raising the question of the long-term viability of the current economic model (Munda *et al.*, 1994). A recent report to the United Nations "Building a Sustainable and Desirable Economy-in-Society-in-Nature" (Costanza *et al.*, 2012) stated that new economic models and agricultural systems are needed, "that respect planetary boundaries and recognize that the ultimate goal is sustainable human well-being and not growth of material consumption" (Rockström *et al.*, 2009).

In his latest book Brown (2012) argued that "food is the new oil and land is the new gold." He identifies major pressures on agroecosystems, which threaten food security globally. These include increasing soil erosion, desertification, salinity, and the expansion of urban areas over the best and most versatile soils. Despite the fact that land is continually being lost to urbanization, the total area under cultivation continues to rise, with new arable and pasture lands being created, often at the expense of forests. Demand for agricultural land continues to increase in line with population growth. This has resulted in the clearing of marginal land that is more susceptible to degradation.

The Millennium Ecosystem Assessment (MEA, 2005) was a wakeup call for the society, because it highlighted the link between ecosystems and human well-being (**Figure 1**), and elucidated the rapidity with which ecosystems are being degraded, as well as the associated social and economic impacts of environmental degradation. The MEA generated sufficient concern about the health of the natural ecosystems to lead many governments and international agencies to seek out a less destructive and more sustainable way forward. There is widespread agreement that if ecologically sustainable development is to be achieved, one must both protect some

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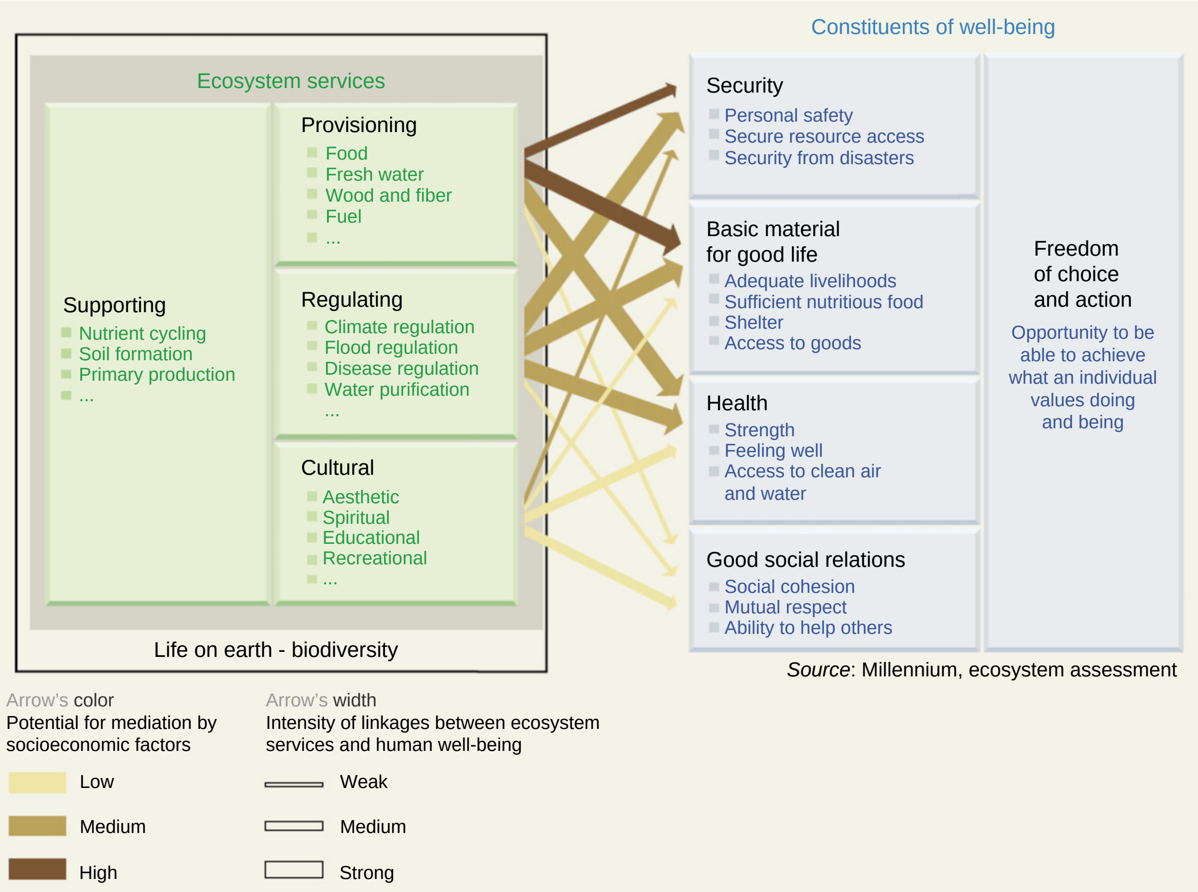

Figure 1 Millennium ecosystem assessment framework for ecosystem services. Reproduced from MEA, 2005. Millennium Ecosystem Assessment: Ecosystems and Human Well-being: Synthesis. Washington, DC: Island Press.

ecosystems from development, and find better ways of managing those one uses for production. The 'ecosystems approach' to natural resource management (NRM) focuses on how to better manage the natural resources (Convention on Biological Diversity (CBD) principles of the ecosystem approach). It accomplishes this by recognizing the wide range of benefits that one obtains from the harvested goods and ecosystem services they deliver through better representing the value of ecosystem services in decision-making frameworks and indicators of progress (Robinson *et al.*, 2013).

The major challenge for agroecosystems is to shift from management of a single function, namely production, to management that meets multifunctional goals of production and land stewardship. This challenge is becoming more widely recognized, for example, in the European Union Common Agricultural Policy (CAP), where reforms are slowly transitioning away from a focus on production only to a broader land stewardship and ecosystem service delivery approach to provide additional services, including clean water or increased biodiversity. Intensive use of agricultural land for food production can result in soil degradation and declining biodiversity, thus limiting the provision of ecosystem services. The challenge for future agricultural production is to limit and mitigate degradation processes, while maintaining and even increasing yields. The economies of nations worldwide rely on the sustainability of agroecosystems. As history has shown, entire civilizations can be lost if agroecosystems collapse (Diamond, 2005; Hillel, 1991; Montgomery, 2007).

To create more multifunctional agroecosystems, new frameworks and tools are needed to enable resource managers and policy makers to more holistically quantify the ecological value of natural resources, and thus enable more informed decisions on trade-offs. Research in agronomy, soil science, and the hydrological and environmental fields also needs to adapt to the changing policy landscape that the ecosystem services approach to sustainable development brings (Bouma, 2005; Daily, 1997; Robinson *et al.*, 2013).

The ecosystem services approach and associated discipline of Ecological Economics bring a new set of terminology to agriculture and agricultural systems, giving it a more economic feel. Ecosystems are conceptualized as 'natural capital,' as distinct from manufactured and human capital, and the functions of ecosystems that benefit society are termed 'ecosystem services.' These concepts have gained considerable traction in NRM research and policy making over the past decade. Resource management frameworks based on ecosystem services approaches are being adopted and promoted by many international organizations including: the Conference of the Parties to the CBD, the Food and Agriculture Organization of the United Nations, The Organization for Economic Cooperation and Development, the United Nations Environment Programe (UNEP), and the United Nations Development Program (Robinson *et al.*, 2013). The concept of ecosystem services is the foundation for international initiatives, such as the Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010) initiative, and the Intergovernmental Panel on Biodiversity and Ecosystem Services (Marris, 2010).

This article examines the concepts of natural capital, ecological infrastructure, and ecosystem services in the context of agroecosystems, with a focus on soil. The article provides a brief history of the origin of the concepts, their modern use, and how they are being adapted to agroecosystems. It then discusses some major challenges associated with the further development of these concepts for future research and use in NRM.

Origin of the Concepts

In the second half of the twentieth century, some environmentally aware economists (Schumacher, 1973) and ecologists (Westman, 1977) began to highlight the societal and economic benefits one obtains from ecosystems. The economists started to analyze environmental problems in economic terms in order to point out the dependence of human societies on natural ecosystems (de Groot, 1987, 1992). They stressed that the undervaluation of the contributions of ecosystems to public welfare and economic growth was due in part to the fact that many ecosystem services are public-owned and consequently not adequately quantified in terms comparable with economic indicators (Braat and de Groot, 2012; Costanza *et al.*, 1997). To ensure sustainability, they argue that the critical nonmarketed contributions of ecosystems underpinning human economies need to be explicitly incorporated in economic decision making.

An emerging discipline, ecological economics (Costanza, 1991; Costanza *et al.*, 2012), sees global economies as a subsystem of the larger finite global ecosystem. Economies exchange energy, materials, and waste flows with the social and ecological systems with which they coevolve (Braat and de Groot, 2012; Martinez-Alier, 2001). Ecological economists question the sustainability of the existing economy, because environmental impacts are not internalized and raw material and energy are not seen as finite resources (Martinez-Alier, 2001). One of the main focuses of ecological economics is to develop biophysical indicators and indices of sustainability (Costanza, 1991) and include the environment in macroeconomic accounting. Following the trend set by environmental economics, ecological economics uses concepts from conventional neoclassical, or welfare economics, and expands them to include environmental impacts, ecological limits, finite natural resources, and issues of equity and scale as necessary requirements for increasing the sustainability of human activities (Martinez-Alier, 2002). Ecological economics acknowledges the reality of entropy, and emphasizes the dependence of economic systems on social systems, and of social systems on ecological systems. Foundational concepts include natural capital, ecosystem services, and ecological infrastructure (see Sections Natural Capital, Ecological Infrastructure, and Ecosystem Services).

Natural Capital

Natural capital refers to the extension of the economic idea of manufactured capital to include environmental goods and services. The first documented usage of the term in this context can be traced back to at least as early as 1837 (Robinson *et al.*, 2012). In the twentieth century, William Vogt pioneered the idea of natural capital in his book, 'Road to Survival' (Vogt, 1948). In it he wrote, "By using up our real capital of natural resources, especially soil, we reduce the possibility of ever paying off the debt" (Mooney and Ehrlich, 1997, p. 44). Costanza and Daly (1992) went on to define natural capital as "stocks of natural assets (e.g., soils, forests, and water bodies) that yield a flow of valuable ecosystem goods or services into the future". This concept was brought into prominence by the landmark paper by Costanza *et al.* (1997) who defined it as 'the stock of materials or information contained within an ecosystem.' Natural capital, like all other forms of capital, is a stock as opposed to a flow, but the idea of information, connection, and organization of stocks (Robinson *et al.*, 2009) is being increasingly associated with the concept. Natural capital stocks can move around the earth-system and can be equated, for example, with the goods one harvests from nature, termed by Costanza *et al.* (2012) as 'stock-flows.' The interaction between stocks forms the basis of the flow of emergent ecosystem services that Costanza *et al.* (2012) termed 'fund-services,' because they arise from the fund of stocks. A major difference between neoclassical and ecological economists is that neoclassical environmental economists mostly embrace what is termed a 'weak sustainability' approach, which assumes substitutability between natural and manufactured capital, for example, substituting soil nutrients from mineral weathering with fertilizer, whereas ecological economists generally advocate the 'strong sustainability' approach, which maintains that natural capital and manufactured capital are complementary rather than substitutable (Costanza and Daly, 1992).

Ecological Infrastructure

Ecological systems are complex and interconnected. Interactions between organisms and their environment take place at multiple and nested scales. Amplifying feedbacks and counterbalancing loops occur within and between scales, and thresholds and tipping points separate alternative stable states of systems (Walker *et al.*, 2006). These many and varied interactions can be simply referred to as 'connectivity.' Connectivity in the ecological sense includes both quantity (number) and quality (strength, direction, and duration) of connections. This notion is recognized by some authors (Costanza *et al.*, 1997; Costanza *et al.*, 2012; Dominati *et al.*, 2010a,b; Robinson *et al.*, 2009) using the natural capital concept, but its importance cannot be overstated. A holistic conception of nature links natural capital and ecosystem services within a framework that explicitly accounts for ecological connectivity. It must go beyond simple 'stocks and flows' and depict a supply chain that ultimately delivers ecosystem services required for human well-being.

The concept of 'infrastructure,' which is defined as 'the underlying foundation, or framework, of a system' (American Heritage Dictionary, 2009), is robustly applicable to both ecological and socioeconomic systems. The term 'ecological infrastructure' was introduced and elaborated in government policy reports in 1977 and 1981 in the Netherlands (Van Selm, 1988b). In this earliest usage, ecological infrastructure was related to the design of structures that would enable many species to move between the 'islands' of natural environments that were left remaining among the 'oceans' of agricultural land (Van Selm, 1988a). The term ecological infrastructure has continued to be used as a design concept for the incorporation of ecological features, such as 'corridors' and 'networks' into human infrastructure design (Morrish, 1995; Xuesong and Hui, 2008). However, some authors are now suggesting that ecological infrastructure can also be used to depict an underlying framework that supports the terrestrial and aquatic ecosystems producing clean air, clean water, and biodiversity that is critical to the resilience and regenerative capacity of natural and human systems alike (Quinn and Tyler, 2007; Postel, 2008).

The essential feature of the underlying framework of ecological infrastructure is connectivity (Arthington *et al.*, 2006; Soule *et al.*, 2004; Ward and Stanford, 1995). Maintaining ecological connectivity is the key to ecosystem health and integrity, and a certain level of ecological integrity is required for the continued production of ecosystem services that are essential for human well-being. The relationship between natural capital, ecological infrastructure, and ecosystem services can be conceptualized as 'Ecological infrastructure is how natural capital stocks are organized to produce ecosystem goods and services' (Bristow *et al.*, 2010; **Figure 2**). Being the source of ecosystem services, ecological infrastructure also provides the 'sink' for the wastes produced by socioeconomic systems (**Figure 2**).

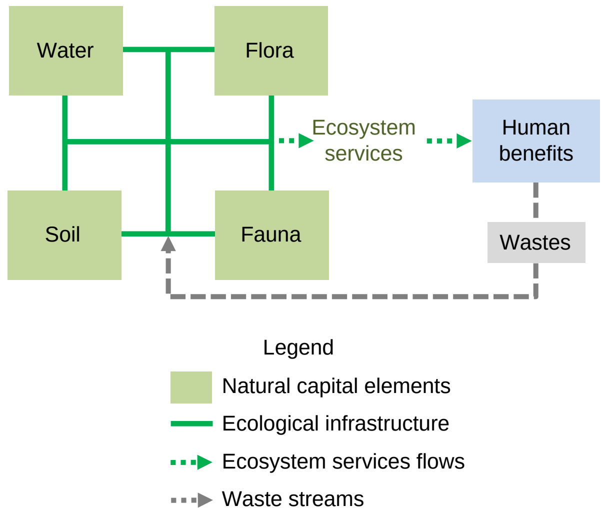

Figure 2 The relationship between natural capital, ecological infrastructure, and ecosystem services.

Ecosystem Services

The origin of the concept of ecosystem services is to be found within work from the 1970s (Braat and de Groot, 2012; Gomez-Baggethun *et al.*, 2010). Mooney and Ehrlich (1997) trace the first usage of 'Nature's services' to a report from 1970 entitled, 'Study of Critical Environmental Problems,' but the paper by Westman (1977) is strongly associated with the development of modern-day ecosystem service concepts. Proponents of the modern-day ecosystem services approach argue that the functions of ecosystems beneficial to society must be accounted for in economic decision making to increase the sustainability of human activities (Braat and de Groot, 2012). References to ecosystem services in the professional literature have grown exponentially since 1990 (Costanza and Daly, 1992; Daily, 1997; de Groot, 1992). In the late 1990s, much of the focus was on methods to estimate the economic value of ecosystem services (Costanza *et al.*, 1997; Hanley and Spash, 1993; Patterson, 1998).

The definition of ecosystem services continues to evolve from:

- The conditions and processes through which natural ecosystems, and the species that make them up, sustain, and fulfill human life (Daily, 1997).
- The benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza *et al.*, 1997).
- The benefits people obtain from ecosystems (MEA, 2005).
- Components of nature, directly enjoyed, consumed, or used to yield human well-being (Boyd and Banzhaf, 2007).
- The aspects of ecosystems utilized (actively or passively) to produce human well-being (Fisher *et al.*, 2009).
- The direct and indirect contributions of ecosystems to human well-being (TEEB, 2010).
- To the final contributions that ecosystems make to human well-being – Common International Classification of Ecosystem Services (CICES, 2013).

The definition by the MEA (2005) is regarded by many as a simple and appropriate working definition of the concept. The increasing acceptance of the importance of ecosystem services in policy-making circles over the past two decades has resulted in the development of general typologies and classification systems, which characterize the diversity of roles played by ecosystems. De Groot's classification system (1992) was one of the first. It defined ecosystem functions as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" and grouped these functions into four primary categories:

- Regulation functions to regulate essential ecological processes and life support systems and the maintenance of ecosystem health,
- Habitat functions to provide refuge and reproduction habitat to wild plants and animals,

- Production functions for processes creating living biomass used for human consumption (food, raw materials, energy resources, and genetic material),
- Information functions to provide opportunities for reflection, spiritual enrichment, cognitive development, recreation, and esthetic experience.

The paper by Costanza *et al.* (1997) on the total value of global ecosystem services was a milestone in the mainstreaming of ecosystem services (Braat and de Groot, 2012). It detailed seventeen goods and services, including most of de Groot's (1992) functions. The monetary figures presented had a profound impact on both science and policy communities. The paper generated strong support as well as fervent criticism (Toman, 1998), and it marked the start of a notable increase in the development and use of monetary valuation concepts for NRM in parallel with the ongoing development of ecosystem services quantification.

Daily (1997) produced an ecosystem services framework including five services:

- Production of goods: Food, pharmaceuticals, durable materials, energy, industrial products, and genetic resources;
- Regeneration processes: Cycling and filtration processes and translocation processes;
- Stabilizing processes: Regulation of hydrological cycle, stabilization of climate, and coastal and river channel stability;
- Life-fulfilling functions: Esthetic beauty, cultural, intellectual, and spiritual inspiration;
- Preservation of options: Maintenance of the ecological components and systems needed for future.

De Groot *et al.* (2002) identified 23 functions in the four primary categories established in earlier work (de Groot, 1992) and detailed the corresponding processes and services, noting that "ecosystem processes and services do not always show a one-to-one correspondence" (de Groot *et al.*, 2002, p. 397). To the four categories, they later introduced a fifth, a carrier function and specified that the "regulation functions provide the necessary preconditions for all other functions" (de Groot, 2006, p. 177). Ekins *et al.* (2003) used a similar classification to argue that the principles of environmental sustainability must be based on the maintenance of the important life-support 'functions of nature' that form the basis on which the 'functions for people' are fundamentally dependent.

The novel idea that de Groot *et al.* (2002) and Ekins *et al.* (2003) advanced in their frameworks was that some ecosystem functions – or processes – support others. The Millennium Ecosystem Assessment (MEA, 2005) took up this idea in a 'framework of ecosystem services' (**Figure 1**). The MEA was conducted under the umbrella of the UNEP. It studied the state and relevance of ecological systems for society, and introduced the concept of ecosystem services to a global audience. The MEA assessed the consequences of ecosystem change for human well-being, and defined ecosystem services as "the benefits people obtain from ecosystems" (MEA, 2005, p. 40). The MEA framework classified ecosystem services into four categories:

- Provisioning services, the products obtained from ecosystems;
- Regulating services, the regulation of ecosystem processes;
- Cultural services, obtained from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and esthetic experiences;
- Supporting services, those that are necessary for the production of all other ecosystem services.

The first three categories of services directly affect people, whereas the supporting services maintain the other services and life support. The approach set out in the MEA has since been adopted and used widely (Barrios, 2007; Lavelle *et al.*, 2006; Sandhu *et al.*, 2008; Swinton *et al.*, 2007; Zhang *et al.*, 2007).

The MEA was followed by The Economics of Ecosystems and Biodiversity study (TEEB, 2010), which was also carried out under the UNEP umbrella. The TEEB study aimed at providing more comprehensive data and understanding of the economic significance of the loss of ecosystem services and the consequences of policy inaction. The TEEB study took a clear economic approach to facilitate the adoption of an ecosystem services approach in policy making. This was brought about by increasing research on the monetized value of ecosystem services, and the associated increasing interest of policy makers in designing market-based instruments (e.g., payments for ecosystem services and economic incentives for conservation) to affect change (Braat and de Groot, 2012). In the TEEB framework, an extension of the so-called cascade model (Haines-Young and Potschin, 2009) was presented (**Figure 3**). Here ecosystem services are placed between the natural and human systems. This framework also separates services from human benefits and their economic values. A benefit is not a service. It is the advantage one receives from a good or service.

A further refinement that has emerged from the development and discussion of these typologies is the differentiation between 'intermediate' processes (analogous to the MEA supporting services) and 'final' services (Boyd and Banzhaf, 2007; Fisher *et al.*, 2009). This refinement stems from the need to differentiate between intermediate products and final products in welfare economics accounting to avoid double counting. The United Kingdom's national ecosystem assessment (Watson and Albon, 2011) adopts this differentiation, focusing on the delivery of final services. Ecosystem services are undoubtedly becoming an increasingly influential tool, but adoption of the concept is constrained by the confusion surrounding the definition of terms and the limited number of practical examples of application. The quantitative relationships between ecosystem components and ecosystem processes, functions, and service delivery are still poorly understood in many areas, and conceptual frameworks continue to be refined.

An Ecosystem Approach for the Management of Agroecosystems

The CBD laid down 12 principles to guide an ecosystems approach (**Table 1**). These principles are highly anthropocentric, as they focus on management and decision making. The strong emphasis on management is of particular relevance to agroecosystems, as is the recognition of the need to manage

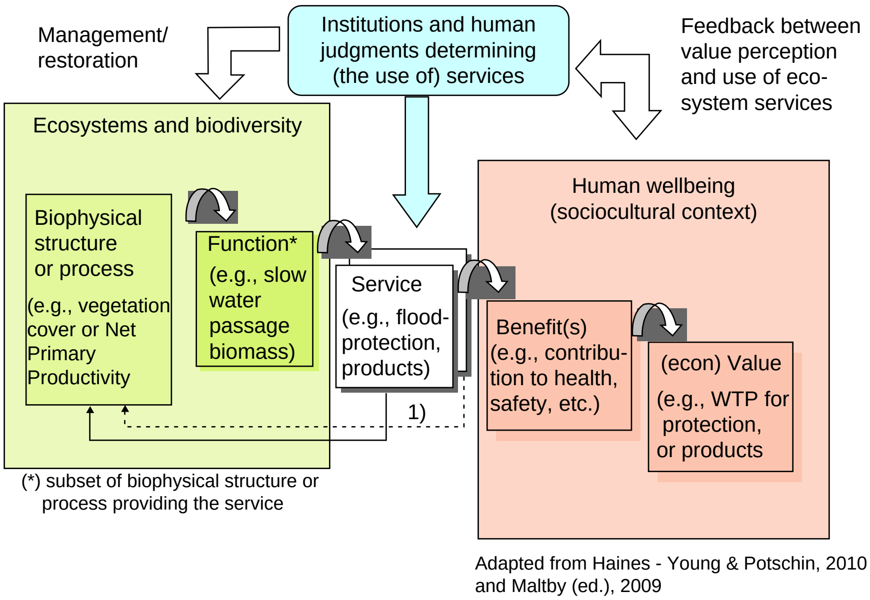

Figure 3 The Economics of Ecosystems and Biodiversity framework for ecosystem services: The pathway from ecosystem structure and processes to human well-being. WTP, Willingness to pay. Reproduced from Figure 1.4 in TEEB, 2010. The economics of ecosystems and biodiversity: Mainstreaming the economics of nature: A synthesis of the approach, conclusions and recommendations of TEEB. Available at: www.teebweb.org (accessed June 2013).

Table 1 Convention on biological diversity: Twelve principles of the ecosystem approach

Principle 1	The objectives of management of land, water, and living resources are a matter of societal choices
Principle 2	Management should be decentralized to the lowest appropriate level
Principle 3	Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems
Principle 4	Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management program should: a. Reduce those market distortions that adversely affect biological diversity b. Align incentives to promote biodiversity conservation and sustainable use c. Internalize costs and benefits in the given ecosystem to the extent feasible
Principle 5	Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach
Principle 6	Ecosystems must be managed within the limits of their functioning
Principle 7	The ecosystem approach should be undertaken at the appropriate spatial and temporal scales
Principle 8	Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term
Principle 9	Management must recognize that change is inevitable
Principle 10	The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity
Principle 11	The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations, and practices
Principle 12	The ecosystem approach should involve all relevant sectors of society and scientific disciplines

Source: Reproduced from Convention on Biological Diversity: 12 Principles of the Ecosystems Approach. Available at: http://www.cbd.int/ecosystem/principles.shtml (accessed June 2013).

ecosystems in a socioeconomic context to maintain ecosystem services provision, via balancing the conservation of resources with their use (Robinson *et al.*, 2013). The power to choose the outcomes of ecosystem management, but not necessarily the means, rests with society. In addition, it is recognized that change is inevitable, which is a growing area of interest within Soil Science, with respect to understanding how human activity is causing soil change on anthropogenic time scales (Richter *et al.*, 2011).

International initiatives, such as The Economics of Ecosystems and Biodiversity, (TEEB, 2010) and the United Nations initiative 'The Economics of Land Degradation' (September 2011) have embraced an ecosystems approach, using the concepts of natural capital and ecosystem services as their framework for addressing sustainable land management. The ecosystems approach is also reflected in the European Union's strategy for land management in the CAP. In 2007, the European Commission published the Thematic Strategy for

Soil Protection, which identified a specific policy need to address the threats to soils, including the protection of the essential soil functions and ecosystem services that they provide. A number of international projects are now working on strategies to embed ecosystem services into decision making and policy frameworks for land and soil management (Soil Service, SoilTrEC, and EcoFinders). Defra in the UK has also adopted an ecosystem services approach to inform resource management: the 'ecosystem-based approach' (Beddington, 2010; Defra, 2007, 2013). The UK also released the 'UK National Ecosystem Assessment' (Watson and Albon, 2011), which advertizes new ways of estimating national wealth (Watson and Albon, 2011) and now has a Natural Capital Committee to advise Treasury. In Wales, the new Natural Resources Wales organization incorporates the Environment Agency, Forestry Commission, and Countryside Council for Wales into a single body, to be organized using an ecosystems approach. Thus both policy and the government bodies that monitor and manage the environment are being influenced by the ecosystem services approach.

In this section, recent developments in soil natural capital frameworks that are relevant for agroecosystems are reviewed. The linkages between these frameworks and soils information and soil change are also explored, along with recent progress in ecosystem services frameworks that attempt to synthesize these concepts. Finally, valuation approaches are examined to provide an insight into the different contextual settings where valuation of ecosystem services can be useful.

Agroecosystems and Soil Natural Capital

Soil natural capital is perhaps a more intuitive concept for soil science and agronomy because it focuses on soil stocks, which are routinely measured and inventoried in soil surveys. Soil stocks are the building blocks of the soil infrastructure, so maintaining and developing these stocks is key to delivering ecosystem services. Definitions of soil natural capital and what it includes have developed in recent years. Palm *et al.* (2007) defined soil natural capital as texture, mineralogy, and soil organic matter. Robinson *et al.* (2009) added 'matter, energy, and organization,' recognizing the importance of connections and organization as a stock. Dominati *et al.* (2010a,b) (**Figure 4**) took a more generic approach following Costanza and Daly (1992), defining it as a stock of natural assets yielding a flow of either natural resources or ecosystem services. Dominati *et al.* (2010a,b) (**Figure 4**) differentiated between inherent and manageable soil properties similar to the inherent and dynamic properties used by Robinson *et al.* (2009) (**Figure 5**). These concepts attempt to differentiate between stocks that change through pedological processes and

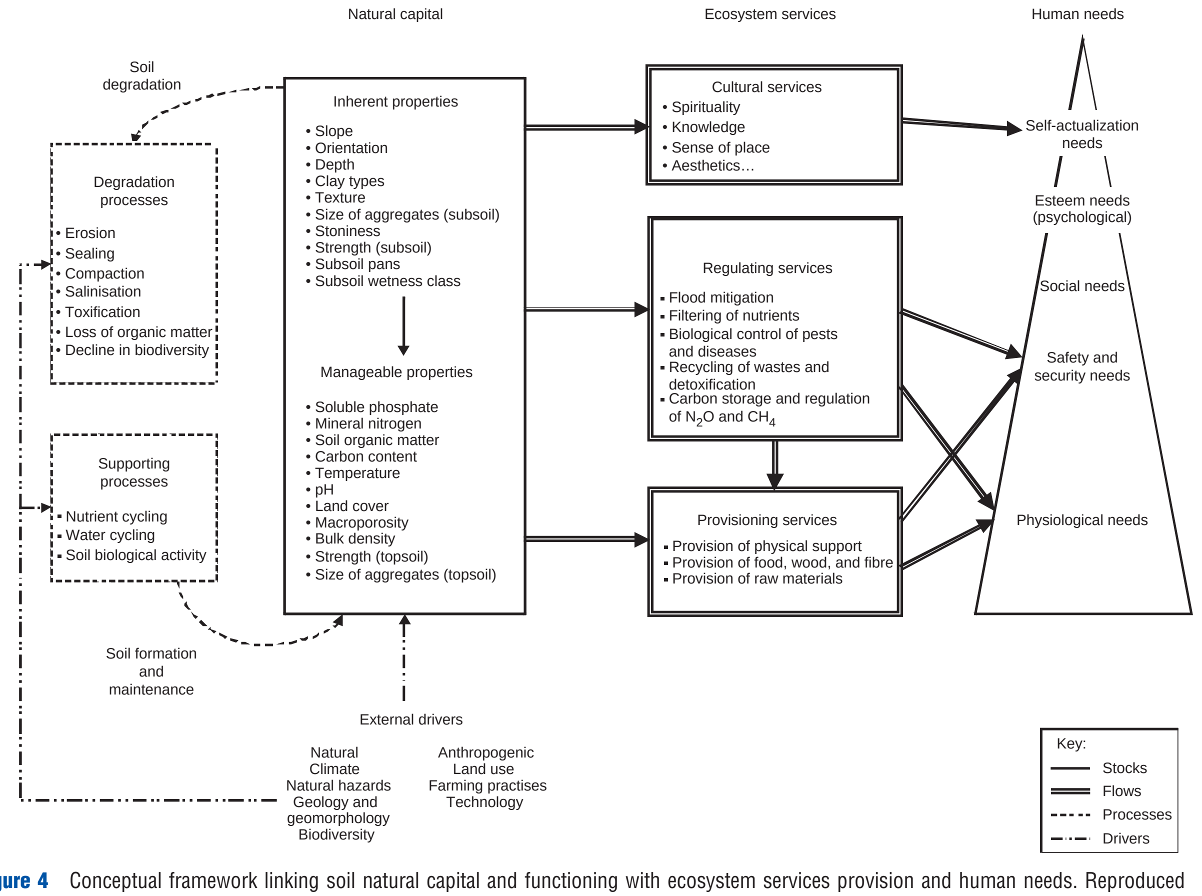

Figure 4 Conceptual framework linking soil natural capital and functioning with ecosystem services provision and human needs. Reproduced from Dominati, E.J., Patterson, M.G., Mackay, A.D., 2010a. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics 69, 1858–1868.

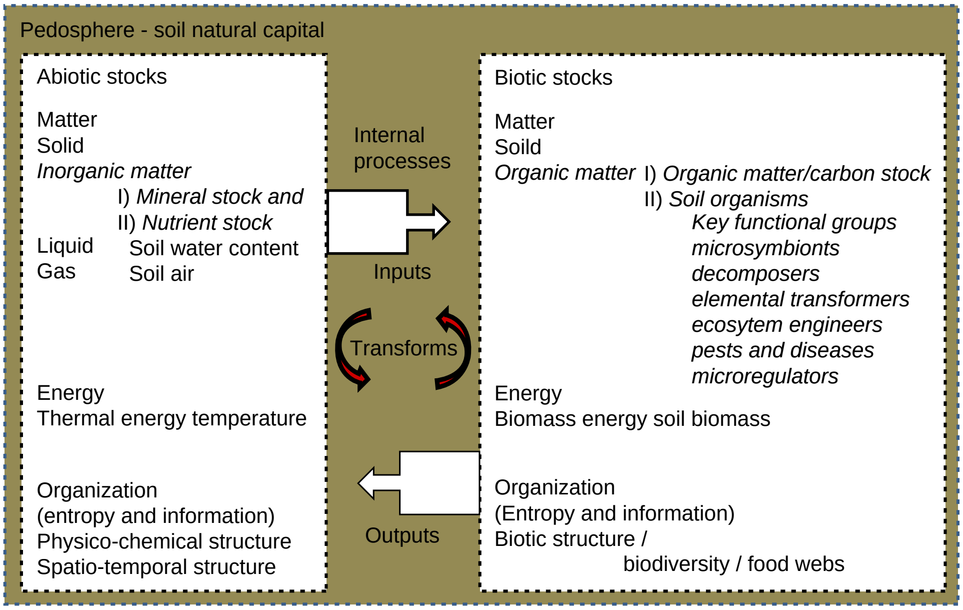

Figure 5 Soil natural capital stocks using a matter, energy, and organization framework (Robinson *et al.*, 2009) divided between abiotic and biotic components (Robinson *et al.*, 2012). Reproduced from Robinson, D.A., Hockley, N., Cooper, D., *et al.*, 2013. Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation. Soil Biology and Biochemistry 57, 1023–1033.

those that can be changed by management. For example, inherent soil properties would typically include soil depth, texture, and mineralogy. They cannot readily be changed without significant modification of the soil or its environment (Dominati *et al.*, 2010a,b) (**Figure 4**). Manageable or dynamic soil properties typically include nutrients, organic matter, and soil moisture and structure, all of which can be influenced by land use. Robinson *et al.* (2013) synthesized these concepts, with some of the work done on soil biology (Barrios, 2007) by splitting the capital stocks into abiotic and biotic components (**Figure 5**), in order to recognize that there are constant fluxes and transformations of materials between the biotic and abiotic pools. It is these processes that contribute to soil formation, development or supporting processes in Dominati *et al.* (2010a,b) framework (**Figure 4**). The biological component of soil acts as a biogeochemical cycling engine. Key functional groups rather than particular species are of greatest interest in the delivery of ecosystem services (**Figure 4**).

Farmers understand and appreciate the value of their soil natural capital and continually explore ways to supplement stocks or compensate for a lack of it in different ways. Most commonly, the natural capital is supplemented with added capital or built capital, which is associated with technologies employed to replenish and lift the productive capacity of soils. As an example, fertilizers or animal wastes are used to substitute depleted nutrients and irrigation is used to overcome limited water supplies or water-holding capacity. Artificial drains can be used to improve soil drainage and compensate for a lack of macropores. Identifying where soil natural capital stocks are restricting and how they can be improved using added or built capital is critical for monitoring and the assessment of the sustainability of land uses (Dominati, 2011; Mackay, 2008). An important benefit of using an ecosystem approach with monetized valuation is that changes in stocks can be assessed and interventions valued, allowing the grower the opportunity to consider different options using a comparable value, for example, an economic value.

Agroecosystems and the Provision of Ecosystem Services

The literature addressing the provision of ecosystem services from agroecosystems has focused on two areas: the general provision of ecosystem services from agroecosystems, or more specifically the provision of services from soils. Most of the work done on ecosystem services from agroecosystems uses the MEA (2005) framework (Porter *et al.*, 2009; Sandhu *et al.*, 2010; Swinton *et al.*, 2007; Zhang *et al.*, 2007). The main ecosystem services addressed in relation to agroecosystems are generally the provision of food, feed, fuel, and fiber, the filtering of nutrients and contaminants, carbon storage, greenhouse gases regulation, and pollination and cultural services, including recreation and esthetics. Many of the other ecosystem services provided by agroecosystems (**Table 2**) have not been studied.

General ecosystem service frameworks tend to consign the soil system to 'supporting services' based on the MEA (2005). Although supporting services are vital for the provision of all other services, this classification can result in the role played by soils in the provision of other services being overlooked. For example, the TEEB initiative (TEEB, 2010) has removed supporting services from their framework, as they do not directly benefit society, and now refers to them as 'biophysical structure, processes, and functions' (**Figure 3**). As a consequence one may fail to recognize the large differences that exist between soils in their ability to provide services. For instance, the

Table 2 Goods and ecosystem services provided by agroecosystems and their soils

Service	*Definition*
Provisioning services	
Provision of food, feed, fuel, and fiber	Agroecosystems, first purpose is to produce food and grow crops for a diversity of purposes. Soils physically support plants and supply them with nutrients and water
Provision of raw materials	Soils and vegetation can be a source of raw materials, for example, topsoil, peat, turf, sand, clay minerals, biomedical and medicinal resources, genetic resources, and ornamental resources. However, the renewability of these stocks is sometimes questionable
Provision of support for human infrastructures and animals	Soils represent the physical base on which human infrastructures and animals (e.g., livestock) stand
Regulating services	
Flow regulation	Soils have the capacity to absorb and store water, thereby regulating water flows (fresh water levels) and mitigating flooding
Filtering of nutrients and contaminants	Soils can absorb and retain nutrients (N, P) and contaminants (*Escherichia coli*, pesticides) and avoid their release in water bodies
Carbon storage and greenhouse gases regulation	Soils have the ability to store C and regulate the production of greenhouse gases, such as nitrous oxide and methane
Detoxification and the recycling of wastes	Soils can absorb (physically) or destroy harmful compounds. Soil biota degrades and decomposes dead organic matter thereby recycling wastes
Regulation of pests and diseases populations	By providing habitat to beneficial species, soils and vegetation of agroecosystems can control the proliferation of pests (crops, animals, or humans) and harmful disease vectors (viruses and bacteria) and provide biological control
Pollination	Agroecosystems provided habitat for the regulation of beneficial insect populations, ensuring key biological processes, such as pollination of crops
Cultural services	
Recreation/ecotourism	Natural and managed landscapes can be used for pleasure and relaxation (walking, angling, and mountain biking)
Esthetics	Appreciation of the beauty of natural and managed landscapes (wildlife viewing and scenic driving)
Heritage values	Memories in the landscape from past cultural ties (landscape associated with an important event of regional or national significance)
Spiritual values	Sacred places
Cultural identity/inspiration	Natural and cultivated landscapes provide a sense of cultural identity. This establishes a strong cultural linkage between humans and their environment

Source: Adapted from Dominati, E.J., Patterson, M.G., Mackay, A.D., 2010a. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics 69, 1858–1868; Dominati, E.J., Patterson, M.G., Mackay, A.D., 2010b. Response to Robinson and Lebron – Learning from complementary approaches to soil natural capital and ecosystem services. Ecological Economics 70, 139–140; MEA, 2005. Millennium Ecosystem Assessment: Ecosystems and Human Well-Being: Synthesis. Washington, DC: Island Press; TEEB, 2010. The economics of ecosystems and biodiversity: Mainstreaming the economics of nature: A synthesis of the approach, conclusions and recommendations of TEEB. Available at: www.teebweb.org (accessed June 2013); and CICES, 2013. Common International Classification of Ecosystem Services (CICES). Available at: http://www.cices.eu/ (accessed June 2013).

MEA mentions 'soil formation' as a supporting service and recognizes that 'many provisioning services depend on soil fertility' (MEA, 2005, p. 40). Further, the role of soils in the provision of regulating services like flood mitigation, filtering of nutrients, and waste treatment is mentioned, but the part played by soils in the provision of these services and more generally in the provision of services from above-ground ecosystems is not explicitly identified. General ecosystem services frameworks need to be extended to explicitly detail the relationships between soil stocks, soil processes, and soil services, as they contribute to the ecosystem service supply chain.

A major emphasis of ecosystem service frameworks is provisioning services, which include food, feed, fuel, and fiber. The current valuation of agricultural land is primarily based on its productive capacity. This is referred to as Ricardian land value (value in agricultural production) (Daly and Farley, 2010). Other components of land value, such as value for development (location, distance from urban centers, iconic coastal, and lake side, distance to services, such as roads and power lines), land value as a speculative investment, or as a hedge against risk are usually small, but can become significant.

However, soils provide other important functions that support ecosystem services delivery. This was articulated, for example, by Daily (1997), Andrews *et al.* (2004), and Wall *et al.* (2004), who described in detail the services soils provide to human society, from being a substrate for plant growth to buffering floods to recycling wastes. Daily (1997) noted that soils are a valuable asset that 'takes hundreds to hundreds of thousands of years to build and very few to be wasted away' (Daily, 1997, p. 113). Given the important role of soil biology in the functioning of soils, there has been an increasing interest in the contribution of the below-ground biota and microbial communities in supporting processes and thereby providing services (Barrios, 2007; Bell *et al.*, 2005; de Bello *et al.*, 2010; Gianinazzi *et al.*, 2010; Guimarães *et al.*, 2010; Hedlund and Harris, 2012; Keith and Robinson, 2012; Smukler *et al.*, 2010; van Eekeren *et al.*, 2010; Wall *et al.*, 2004; Wall, 2012). Dominati *et al.* (2010a,b) recognized that a

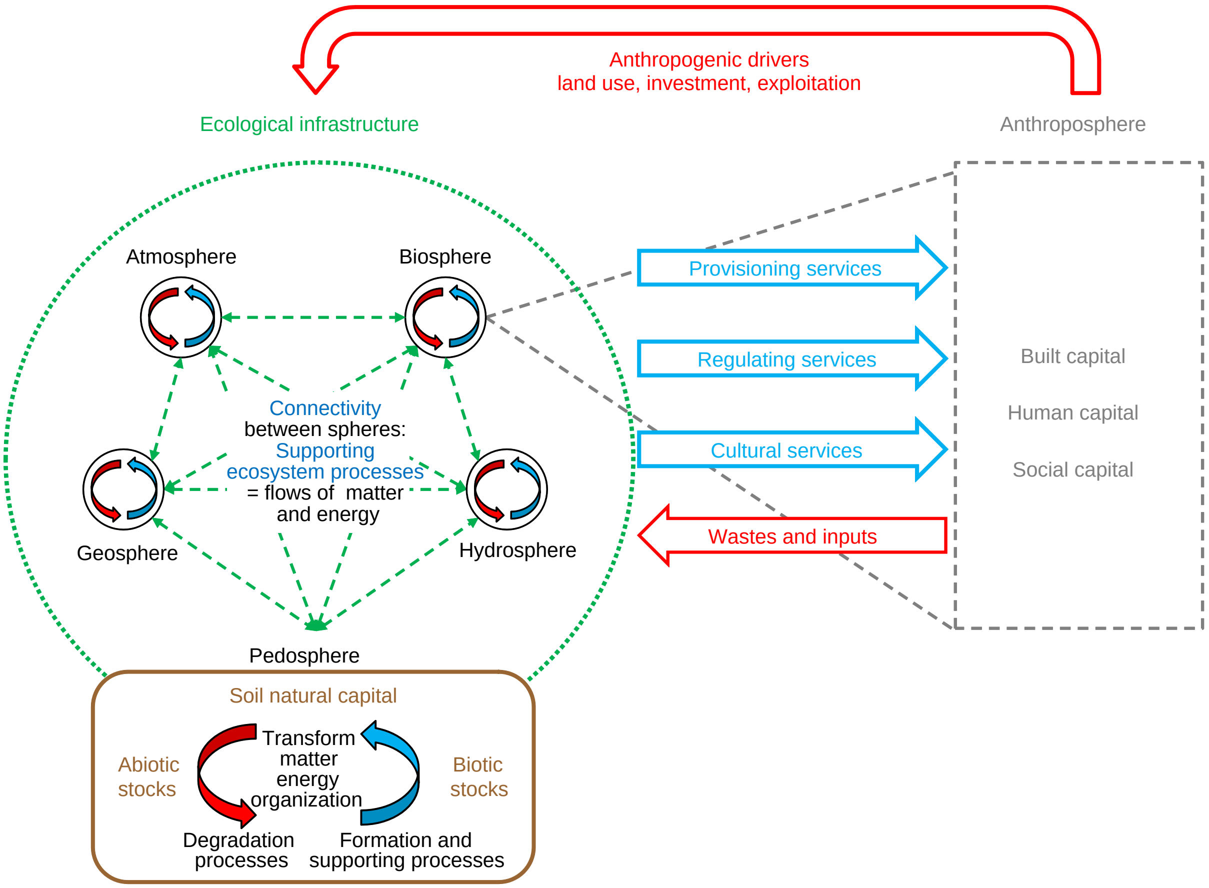

Figure 6 Combined framework for natural capital, ecological infrastructure, and ecosystem services.

combined natural capital and ecosystem service approach is needed for soils (Figure 5). They detailed each of the ecosystem services provided by soils and studied the properties and processes behind them (Dominati, 2011). Robinson *et al.* (2012) also proposed a holistic framework detailing goods and services from soils. **Table 2** provides a summary of goods and ecosystem services provided by agroecosystems and their soils based on the latest literature.

Ecological Infrastructure and the Ecosystem Service Supply Chain

No matter how modified they may be, agroecosystems are inseparable from the ecological infrastructure that forms the basis for the provision of ecosystem services. This is because all living organisms require material, energy, and information inputs and produce waste and other outputs.

Recent work has recognized the importance of understanding the continuum along the ecosystem service supply chain (Mooney, 2010; Robinson *et al.*, 2012). Dominati *et al.* (2010a,b) were the first to bring all these concepts together in an overarching framework (**Figure 5**). In that framework, the ecological infrastructure component is identified on the left side and constitutes the soil natural capital, including the processes acting on and within soils. When put to use, these stocks contribute, along with built capital, toward the delivery of ecosystem services that fulfill human needs. Robinson *et al.* (2012) synthesized these ideas to fit within the stock-flow, fund-service framework used in ecological economics (Daly and Farley, 2010; Farley and Costanza, 2010; Georgescu-Roegen, 1971).

Figure 6 incorporates the concepts developed by Bristow *et al.* (2010), Dominati *et al.* (2010a,b), and Robinson *et al.* (2012) into a framework that goes beyond the pedosphere and considers the bio-, geo-, atmo-, hydro-, and anthropospheres and is applicable to agroecosystems.

On the left-hand side, the earth-system approach (**Figure 6**) recognizes all the Earth's resources. The major compartments, or 'spheres,' are the atmosphere; hydrosphere, including oceans, surface and ground water, and lakes; the biosphere with its plants and animals, including humans; the pedosphere, the thin skin of soil around the earth; and the geosphere, containing rocks and minerals. The pedosphere is expanded to give an example of the biotic and abiotic stocks that each compartment contains, in this case the soil natural capital stocks (**Figure 6**). Stocks and their condition within each sphere are tangible materials that can be stock piled and are relatively easy to quantify. The arrows within each sphere represent the processes that build up or degrade stocks. These processes result in the cycling and flow of materials and their transformation. Supporting and degradation processes are influenced by external drivers, embodied by flows coming from and going to the other spheres. The connectivity among and within spheres, that is the flows of matter, energy, and information, maintain the integrity of the ecological infrastructure, and can also be referred to as supporting processes (Dominati *et al.*, 2010a,b; MEA, 2005; TEEB, 2010).

On the right-hand side of the framework is the anthroposphere. The anthroposphere is contained within the biosphere and includes various types of anthropocentric capital: built capital (transport, communications, water, energy, housing, and other infrastructure), human capital (health, education, and security capital), and social capital (equity, agency, leadership, institutions, and social networks) (**Figure 6**). Ecosystem services, classified here according to the Millennium Ecosystem Assessment typology (MEA, 2005), are the flows coming from the ecological infrastructure, directly useful to humans. Many of these services are intangible, so they cannot be stockpiled and in general can be measured as units per unit time. The processing of goods directly harvested from the various spheres, as well as the use of natural stocks, built capital and ecosystem services, results in wastes, or impacts on each of the earth system spheres. Anthropogenic drivers, such as land use and management, determine the levels of natural resource exploitation, changes to natural capital stocks and the provision of ecosystem services, and the nature, and quantity of wastes produced.

A sustained flow of ecosystem services depends on the integrity, and thus connectivity, of the ecological infrastructure. This means that the entire supply chain needs to be considered when identifying and determining the impacts of land management on agroecosystems. At present, the value of an agroecosystem is generally limited to its immediate economic productivity capacity, but agroecosystems provide a wide range of services, and are also valuable for maintaining the integrity of ecological infrastructure.

The ecosystem services approach has been very useful in highlighting the lack of consideration for the holistic and long-term value of agroecosystems. An important challenge is how best to deal with recognizing the value of the ecological infrastructure, along with the ecosystem services, beyond provisioning. Given the global level of environmental degradation, food security for growing populations can only be achieved via agroecosystems that serve a dual purpose. Along with producing socioeconomic goods, such as food, feed, fuel, and fiber, the farming enterprises must also contribute toward the integrity of the ecological infrastructure that underpins the continued provision of essential ecosystem services (Gliessman, 2007).

Approaches to Valuation

The economic value of commodities produced by agroecosystems is well understood. Agricultural products are gradually transformed as they progress along the ‘production chain,’ where economic value is often added at a number of stages. Agroecosystems are also closely linked to the economic value of land. The value of agricultural land is currently defined mostly by its productive capacity. The productive capacity of the land, plus its location, plus the value of the built infrastructure on the land determine the land's economic value. There are very few valuation systems that recognize or capture the other contributions land makes to the well-being beyond its economic contribution. To achieve land use sustainability, one needs to value the multifunctionality of this scarce resource and include it in decision making.

To convince financial institutes, economists, and others in society regarding the value of soils, the current approach to valuing land and agroecosystems needs to be extended to include all the ecosystem services provided. Approaches that have the capacity to quantify and value the ecosystem services supplied by agroecosystems would be a significant advance on the current method. Such approaches would provide a holistic representation of the sustainability of current land use, and the pivotal role the pedosphere plays in human well-being.

It has been widely argued that the undervaluation of the contributions of ecosystems to human welfare, including agroecosystems, can be partly explained by the fact that they are not adequately quantified in terms comparable with economic services and built capital (Braat and de Groot, 2012; Costanza *et al.*, 1997). In response, since the 1990s, an increasing number of studies have focused on the economic valuation of ecosystem services (Costanza *et al.*, 1997) including services from agroecosystems (Breure *et al.*, 2012; Porter *et al.*, 2009; Sandhu *et al.*, 2008). This is because framing ecological concern in economic terms has great appeal to decision makers (NZIER, 2013; Braat and de Groot, 2012; Robinson *et al.*, 2012).

There is an enormous scope to improve the provision of ecosystem services from agroecosystems, but first a more holistic value of land is needed to inform a number of contexts. Economic valuation of ecosystem services from agroecosystems can assist in (Defra, 2007; OECD, 2002):

- revising national accounting: fully accounting for the environmental impacts of economic activities in decision making, use indicators of change in natural capital stocks, contribution of agriculture to GDP/exports,
- land use decision making: priority setting, cost effectiveness of policy, comparing infrastructure developments/land uses/policy options using cost–benefit analysis including ecosystem services provision and costs of degradation,
- creating new insights for policy development,
- designing incentives, setting charges/taxes, creating markets for ecosystem services (policy around payments for ecosystem services), and
- communicating with the public and land managers about the value (e.g., moral, esthetic, economic, and ecological) of the environment and agroecosystems.

Value is often solely associated with price. Although price is a type of value (monetary value), the two are not synonymous, and any kind of commodity, including ecosystem services, can have many values associated with it. Valuation is about using a common measure to bring things into a frame of comparability (Robertson, 2012), and the common measure might or might not be of economic value.

Environmental management is, as a rule, associated with qualitative information in valuation problems. Thus, there is a clear need for methods that are able to take into account qualitative information, or information of a ‘mixed’ type (both qualitative and quantitative) (Munda *et al.*, 1994). Martinez-Alier *et al.* (1998) argued that incommensurability (the

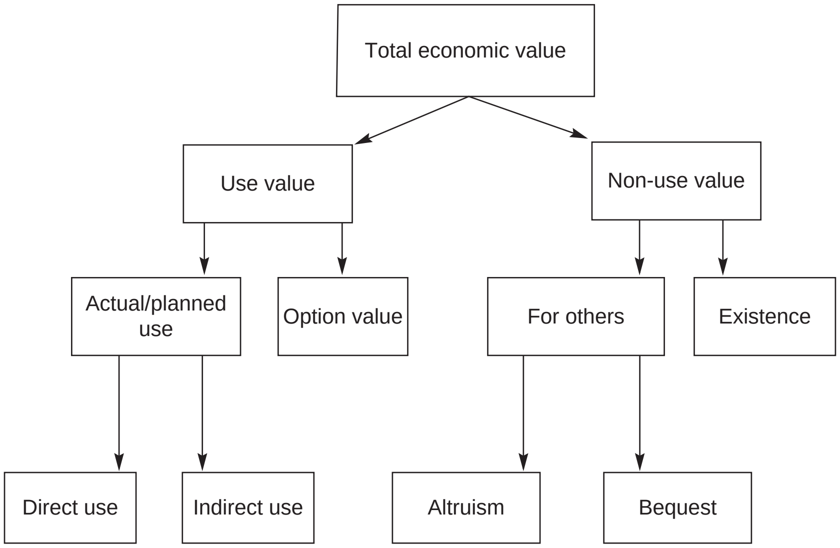

Figure 7 Total economic value. Adapted from Defra, 2007. An Introductory Guide to Valuing Ecosystem Services. London: Department for Environment, Food and Rural Affairs.

absence of a common unit of measurement across plural values) is the 'foundation stone for ecological economics' (Martinez-Alier *et al.*, 1998, p. 279), and that instead of complying with any type of physical reductionism (monetary, energy, or other), valuation should push toward multicriteria analysis and the use of weak comparability (comparing options without recourse to a single type of value) and which does not imply a hierarchy of values. Ecological economics investigates a range of theories of value including the neoclassical economic theory of value. These include:

- The embodied energy theory of value (EMERGY) (Hannon *et al.*, 1986; Patterson, 1998): EMERGY considers energy as the fundamental driver of ecological systems and thereby the economy.
- Ecological value: Ecological value is defined as the value of direct and indirect interactions of a component of an ecosystem, an ecological entity (species), or compartment, with the other components of the same ecosystem (Cordell *et al.*, 2005).
- Contributory value: Natural ecosystems make contributions to the value of final economic goods and services (Norton, 1986; Ulanowicz, 1991). Contributory value assigns value to environmental resources not due to their direct value to humans, but according to their indirect role in maintaining and accentuating the ecosystem processes that support these direct benefits (Costanza *et al.*, 1989, p. 338).

Even though a range of value theories exist, economic value is still getting the most traction in resource management. The rationale of neoclassical economic valuation of ecosystem services lies in the need to ensure that all the services are taken into account in decision making on the same basis as the conventional costs and benefit of conventional economic activity (Pearce and Barbier, 2000).

Neoclassical economics uses the concept of total economic value (TEV). TEV can be broken down into several components, which can then be used to describe the value of ecosystems (**Figure 7**). TEV can be broken down into use and nonuse values (Defra, 2007; Patterson, 1999; Pearce, 1995). Use values include direct and indirect use, and option values:

- Direct-use value: The value of all goods and services derived from the direct or planned use of ecosystems, consumptive use of resources (e.g., food, timber, and parks), or nonconsumptive use of services (e.g., recreation and landscape amenity). They are generally attributed to provisioning and cultural services.
- Indirect-use value: They are derived from the functioning of ecosystems underlying direct-use activities (Defra, 2007; Pearce, 1995). Indirect-use values correspond to supporting processes and regulating services.
- Option value: The value that people place on having the option to use, directly or indirectly, a resource or service in the future, even if not currently in use (Costanza *et al.*, 1989; Defra, 2007).

Nonuse value, also referred to as 'passive value,' is not related to the actual use of ecosystem goods and services, but is derived from the knowledge that ecosystems are maintained (Defra, 2007). They concern all types of services. Nonuse value can be further subdivided into three main components (**Figure 7**):

- Existence value: It relates to the existence of ecosystem goods and services even if an individual has no actual or planned use for it (Costanza *et al.*, 1989). Many people are willing to pay for the preservation of species (whales and rainforest insects) even if they know they might actually never be in contact with them.
- Altruistic value: The value individuals attach to the availability of the ecosystem resources or services to others in the current generation.
- Bequest value: The value that people place on knowing that ecosystem goods and services will be available for future

generations. Bequest value is sometimes regarded as part of existence value.

Some authors (e.g., Pearce, 1995) debate the merit, and hence application of this classification to neoclassical economic valuation, but the TEV framework is a useful tool to identify what type of value is being measured, based on the type of good or service concerned, thereby assisting the selection of an appropriate valuation method (Defra, 2007).

Neoclassical economic valuation is used to measure public and individual preferences for changes in ecosystem services provision. **Table 3** presents a number of valuation techniques currently used for the valuation of ecosystem services. Valuation techniques for valuing ecosystem services can be distinguished by the type of preferences they elicit: (1) revealed or (2) stated.

1. Revealed preference techniques obtain values by looking at individuals' preferences and willingness to pay (WTP) for a marketable good with environmental attributes. These techniques rely on conventional markets, actual markets in which the environmental goods and services are already traded (e.g., timber market or CO_2 market). Revealed preference techniques can also value nontradable goods and services indirectly through marketed goods and services that embody their values (e.g., air pollution affects the price of houses) (**Table 3**).
2. Stated preference techniques elicit individuals' preferences for a given change in a natural resource or service through structured questionnaires (Defra, 2007; Pearce and Barbier, 2000). Stated preference techniques use hypothetical markets, which are simulated markets, where individuals can express their WTP for a nontraded environmental good or service (Pearce and Turner, 1990; Pearce and Barbier, 2000). These techniques, including contingent valuation, choice modeling, and the more modern deliberative group valuation, are the only ones that can estimate nonuse values for some natural resources. In some cases, these nonuse values can be a significant component of the overall TEV (Defra, 2007, **Table 3**).

Valuing environmental goods and services provides additional information that can potentially be used in a benefit–cost analysis (BCA), if appropriate. BCA quantifies, in monetary terms, as many of the costs and benefits of a proposal as is feasible (Defra, 2007). It has been, and still is, extensively used for resource management and decision making. Failure to include ecosystem services in benefit–cost calculations implicitly assigns them a value of zero. To date this has been the norm, and it has contributed to the major depletion of natural capital stocks and increasing environmental issues (MEA, 2005). Valuing ecosystem goods and services for inclusion in BCA is one of the tools available to advance sustainable development by ensuring that policies completely account for the costs and benefits of development proposals on the natural environment (Defra, 2007). For policy making in the context of agroecosystems and resource management, the more relevant application of economic valuation is to compare management options, or assess an investment in either built (e.g., irrigation) or ecological (e.g., soil conservation) infrastructure.

A number of problems have been raised regarding the use and effectiveness of neoclassical economic valuation in assessing the value of ecosystem goods and services that, as yet, lack markets, and in taking these values into account in decision making. These include:

1. Imperfect knowledge or information: Some neoclassical valuation techniques that try to elicit individual's WTP for a nonmarket good are confronted by anomalies based on human beings having imperfect knowledge of ecological processes and functions (Patterson, 1998). This is particularly important when valuing ecosystem services as they are often abstract and the result of complex biophysical processes unknown to nonexperts. Even when using revealed preference methods, challenges arise from the complexity of the biophysical processes. Imperfect information about processes and the provision of ecosystem services is transferred to the quantification of the service and then the economic valuation. Data availability is also always a challenge because a great deal of information, both biophysical and economic, is needed for the quantification and valuation of ecosystem services.
2. Discounting: Another argument against neoclassical economic valuation is its nonequitable aspect when it comes to the intergenerational assignment of benefits and costs. Discounting is an important, but very controversial part of BCA. It is used to compare present and future costs/benefits (Gasparatos *et al.*, 2008). The greater the discount rate adopted, the greater the devaluation of future costs/benefits. Therefore, in projects with a long time horizon, for example, encompassing several generations, future impacts can count for little, or even nothing. This is contrary to the interests of future generations, because it amounts to a nonequitable distribution of costs and benefits. It has been suggested that low discount rates should be adopted for projects that will greatly affect future generations, since small discount rates capture long-term net benefits, whereas higher discount rates put more weight on short-term benefits.
3. Market failure: The exchange of some economic goods and services takes place in markets. However, markets can, and often do, fail. One of the most common areas of market failure is in the provision of public goods, such as ecosystem services. Either ecosystem services are lacking markets, or if markets exist, they can fail to reflect the entire value of the service. For example, there is a market for carbon. The multifunctional value associated with soil carbon includes not only carbon storage, but also the importance of organic matter for soil structure cohesion, and nutrient retention. These values are always very significant for soil functioning, whereas carbon prices fluctuate quickly and frequently. The use of stated-preference methods to determine the value of ecosystem services offers solutions to deal with market failure.
4. Validity of techniques: Whatever the technique used, there are always uncertainties associated with it. For example, where cost-based approaches are used to value services, sometimes the valuation is limited to the scale covered by the technique or the infrastructure element considered, for example, dam, road, or building, whereas the extent of the

Table 3 Economic valuation methods

Market type	*Method name*	*Method type*	*Type of value captured*	*Definition*	*Example*
Conventional market	Market price	Revealed preferences	Use values	Market prices can be used directly to capture the value of ecosystem goods and services already traded in markets	Market price of food, wood, or agricultural land
	Productivity change	Revealed preferences	Use values	Productivity change approach is not a valuation technique per se but can be used with diverse valuation techniques. It uses production functions to describe the relationship between a particular ecosystem service, the natural capital stocks behind it, and the production of a market good	Production function linking soil type, irrigation quantity, and air temperature to wheat yield (the traded commodity)
	Defensive expenditure	Revealed preferences	Use values	Defensive expenditure focuses on the price paid by individuals to mitigate against environmental impacts. The method uses the money spent by individuals to avoid exposure to degradation of the environment and a decrease in the provision of an ecosystem service as a proxy for the value of the service	The cost of mitigation techniques on farm to prevent nutrient and contaminant loss are used as a proxy for the value of the filtering of nutrients
	Replacement cost	Revealed preferences	Use values	The replacement cost approach uses the costs of replacing or restoring damaged ecosystem goods or services to their original state or productivity, using market goods, as a proxy for the value of the service	Cost of plowing to improve soil porosity as a proxy for the value of support, cost of drainage
	Provision cost	Revealed preferences	Use values	The provision cost approach is a variant of the replacement cost. It does not refer to the replacement or restoration of the ecosystem service *in situ*, but to actual costs of providing the damaged service through alternative means. This technique relies on the existence of human-made systems and techniques	Wetlands that provide flood protection may be valued through the cost of building human-made defences of equal function, e.g., dams or flood banks
	Hedonic pricing	Revealed preferences	Use values	Hedonic pricing seeks to find a relationship between environmental characteristics (view levels and air quality) and the price of properties (house and farm land). The value of the environmental component (good or service) can therefore be captured by modeling the impact of all possible factors influencing the price of the property	Influence of soil properties on farmland values
	Travel cost	Revealed preferences	Use values	The travel cost method is predominantly used in outdoor recreation modeling (fishing, hunting, boating, and forest visits). It is a survey-based technique that uses the cost of a trip taken by an individual to a recreation site (e.g., travel costs and entry fees) as a proxy for the value of the recreational service	Travel costs and entry fees are used as a proxy for the recreational value of, for example, a national park

(*Continued*)

Table 3 Continued

Market type	*Method name*	*Method type*	*Type of value captured*	*Definition*	*Example*
Hypothetical market	Contingent valuation	Stated preferences	Use and nonuse values	The contingent valuation method aims at obtaining an estimate of the economic value of a marginal change in the level of provision of an ecosystem good or service not traded in market by directly questioning a sample of the population concerned	Contingent valuation method uses questionnaires to obtain estimates of the social benefit from soil erosion reductions from programs to mitigate the off-site impacts of soil erosion for a watershed. Ask respondents their willingness to pay (WTP) for different scenarios to change erosion levels more than 20 years. Bids can be expressed as tax payments and used to suggest upper limits on per haectare payments for soil conservation programes (Colombo *et al.*, 2006)
	Choice modeling	Stated preferences	Use and nonuse values	Choice modeling is a family of survey-based methodologies for modeling preferences for goods, where goods are described in terms of their attributes and of the levels that these attributes take. Respondents are presented with several alternative descriptions of a good, differentiated by their attributes and levels, and are asked to rank the various alternatives, to rate them or to choose their most preferred. One of the attributes of the good is the price/cost, which is used to indirectly record people's WTP from their rankings, ratings, or choices	A lake may be described in terms of water quality, water clarity, number of fish species, catches per year, and entry fees. Participants are presented with different combinations of attributes and asked to choose their preferred combination or rank the alternative combinations. The results are then used to value an extra unit of, for example, water quality
	Group valuation	Stated preferences	Use values	Group valuation methods are based on principles of deliberative democracy and the assumption that decision making about public goods, such as ecosystem services, should not result from the aggregation of separately measured individual preferences, but from open public debate	Focus groups: aim to discover the positions of participants regarding an issue. In-depth groups: similar to focus groups, but less closely facilitated, and focus on how the group creates discourse on the topic. Citizens' juries: A sample of citizens considers evidence from experts and other stakeholders, hold group discussion on the issue, and give an informed opinion that is supposed to reflect public opinion. Deliberative forums: they spend time listening to the opinions of others (experts, stakeholders, or general public) with the aim of forming a collective view

service can be greater. In such a case, the price obtained will not be representative of the real value of the service. With stated preferences like contingent valuation or choice modeling, many biases, such as design bias, cognitive burden, strategic bias, or information bias are common when respondents state their WTP (Pearce *et al.*, 2006).
5. Sustainability concerns, such as rights, fairness, and intergenerational equity (Spash, 2007).

Because of the problems associated with economic valuation of ecosystem services, researchers are increasingly using several techniques simultaneously to compare results. Cost–benefit analysis is still frequently used because it is cheaper and quicker than other methods, and is well understood by decision makers. But methods, such as deliberative monetary valuation, a novel hybrid of economic and political processes to value environmental change, are now being used more often. This is because they are based on deliberative processes between stakeholder groups and therefore offer some answers concerning fairness and equity.

Application of the Concepts to Resource Management

Challenges of the Ecosystems Approach for Resource Management

Generally speaking, the ecosystems approach and the concepts of natural capital, ecological infrastructure, and ecosystem services are powerful tools for resource management as they contribute to a better understanding of the linkages between on-site changes and off-site impacts. With respect to agroecosystems and soil in particular, these concepts provide a holistic framework, which places agroecosystems within the greater ecological infrastructure.

A number of challenges must be overcome if the ecosystem services approach is to be used as an overarching framework for the management of agroecosystems. Robinson *et al.* (2012) identified four key research areas needing attention to further develop the soils' component of the ecosystems approach. Combining these specific research priorities for soils with general guidelines for application of the ecosystems approach (Braat and de Groot, 2012; Omuto *et al.*, 2012; TEEB, 2010) identifies the key challenges as:

- Framework development, to identify exactly how, where, and when soils and the other spheres are involved in the provision of ecosystem services.
- Quantifying changes to the natural capital stocks under the impact of natural and anthropogenic drivers. This can be achieved through monitoring and modeling of stocks, fluxes, and transformations, within and between spheres and identifying appropriate indicators that can be used in monitoring schemes. This requires enhancing the quantity and quality of information on the functioning of ecological infrastructure: data generation and collection, analysis, validation, reporting, monitoring, and integration with other disciplines.
- Better assessment of spatial and temporal dynamics of service provision, including threshold changes, alternative states, and irreversibilities, especially in relation to beneficiaries.
- Developing means to value ecosystem services and incorporating these values into decision making about alternative management options.
- Developing management strategies and decision-support tools including models and maps of natural resources.
- In the long-term harmonization of methods, measurements, and indicators for the sustainable management and protection of soil resources.

Investing in Ecological Infrastructure for Resource Management

The concept of ecological infrastructure provides a framework that locates ecosystem services within a holistic model of nature. Ecological infrastructure is also directly comparable to built infrastructure in terms of the need for public investment to maintain its integrity. In developing and developed countries alike, there are increasing demands for additional and improved public infrastructure. The global recognition of the need for built infrastructure investment can be used to exemplify and prioritize investment in ecological infrastructure.

Bristow *et al.* (2010) argued that although built infrastructure investment has been ever-increasing, one has not been investing sufficiently in the ecological infrastructure. Indeed, inadequate investment in ecological infrastructure has led to a worsening environmental crisis, in which critical ecosystem services have been and are being lost across the globe. For example, 60% of ecosystem services examined by the Millennium Ecosystem Assessment (MEA, 2005) was found to be degraded. This means that the underlying ecological infrastructure that provides these services is deteriorating, or has collapsed. When the current state of global ecological infrastructure is added to increasing population growth and resource consumption trends, the need for significant and ongoing investment in ecological infrastructure is undeniable.

Investing in ecological infrastructure involves three strategies that must be carried out concurrently:

1. Research and extension investment to improve and disseminate knowledge about ecological infrastructure and the ecosystem services it provides;
2. Restoration of degraded ecological infrastructure; and
3. Maintenance and enhancement of the capacity of relatively undisturbed ecological infrastructure to continue to produce ecosystem services.

Improving our knowledge about ecological infrastructure is necessary to ensure that 'returns' on ecological infrastructure investments are maximized. Although there are still many knowledge gaps, humans already possess a vast amount of information about how healthy catchments, forests, rivers, wetlands, soils, and coral reefs should look and function. The extent and depth of this knowledge is sufficient to begin investing in restoring, maintaining, and enhancing ecological infrastructure immediately (Karr, 1993; MEA, 2005). Sufficient investment in ecological infrastructure also obviates the various problems that arise from the use of neoclassical economic concepts to value ecosystem goods and services that are not amenable to market-based logics. Whether or not ecosystem

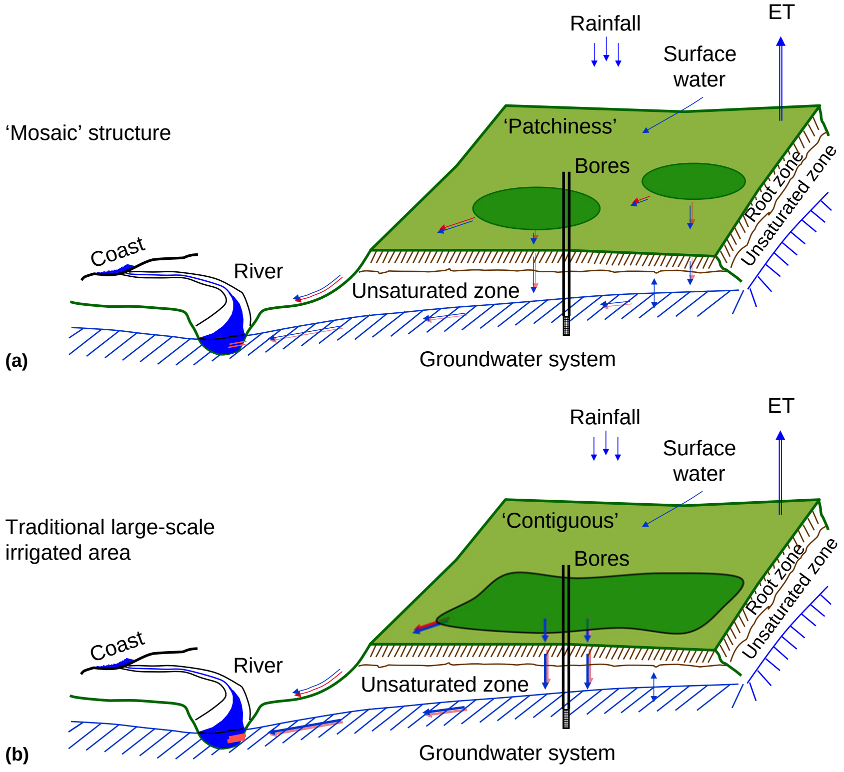

Figure 8 Schematic showing the basic features of irrigation mosaics compared to large contiguous irrigation developments. Reproduced from Paydar, Z., Cook, F.J., Xevi, E., Bristow, K.L., 2007. Review of the current understanding of irrigation mosaics. CRC for Irrigation Futures Technical Report No. 08/07. CSIRO Science Report 40/07. Available at: http://www.irrigationfutures.org.au/imagesDB/news/CRCIF-TR0807-web.pdf (accessed 06.01.10).

processes and functions are able to be traded in markets, if the integrity of the ecological infrastructure that produces ecosystem services is maintained, the services will continue to flow.

A key operational aspect of investing in ecological infrastructure is the development of newly built infrastructure and the reconfiguration of existing built infrastructure, so that these contribute toward ecological integrity. This is particularly important in the case of agroecosystems. One approach that can be used for both new and existing irrigation developments is based on the concept of mosaics (Figure 8). This approach, which involves developing smaller discrete patches of irrigated land dispersed across the landscape, may offer an alternative to large-scale contiguous irrigation systems (Paydar *et al.*, 2007). Zones of transition between adjacent ecological systems are important characteristics of natural mosaics and play a key role in energy and material fluxes (Paydar *et al.*, 2007). Irrigation mosaics could be used to create or enhance zones of transition in the agricultural landscape, leading to greater biodiversity and improved microclimates. Improved zones of transition also help to minimize erosion and absorb surplus nutrients, sediments, and solutes that flow from the surrounding crop fields, thus decreasing the discharge of irrigation 'waste' out of the irrigation area (Paydar *et al.*, 2007). Understanding the likely performance of irrigation mosaics can also help to identify how existing irrigation systems could be reconfigured for improved harmonization with natural systems (Figure 8) (Story *et al.*, 2008).

To sum up, one cannot escape the reality of a finite planet with limited resources, growing human populations, and increasing demands for ecosystem services. Unless the approaches to NRM include programs for restoring, maintaining, and enhancing ecological infrastructure, the world's ecosystems, including the agroecosystems, will continue to be fragmented and destroyed.

Use for Policy Making at the Regional Scale

In developed countries around the world, government bodies responsible for NRM are increasingly under pressure from the general public to deliver higher environmental standards when managing land for sustained use of resources. For example, in New Zealand over the past 50+ years, investment in soil conservation in agroecosystems has run into billions of dollars. Soil conservation policies aim to reduce the risk of soil erosion in vulnerable land (e.g., hill and steepland country), the downstream costs associated with nutrient losses and sediment loadings to waterways, and damage to productive farmland and towns. Current evaluation of soil conservation policy and justification for the associated expenditure is limited to an assessment of the reduction in the loss of productive capacity, soil loss, and sediment and downstream impacts on community of flooding and sedimentation. Until the full range of ecosystem services below and above ground is considered in the analysis, the true cost of erosion, beyond productivity loss, and full value of soil conservation is not available for informed land-use decision making.

In the case of soil conservation, an ecosystem services approach offers a methodology that can answer such questions, through the following steps:

- Quantify the provision of ecosystem services from the agroecosystems of interest (e.g., hill country sheep and beef farming) to assess the baseline flows of ecosystem services under current land use on uneroded soil, before implementation of a soil conservation programe, based on information from existing planning tools.
- Compare these baseline flows with an assessment of the provision of ecosystem services from a similar agroecosystem with well-developed soil conservation plan and practices, for example, wide-spaced poplars on steep hill for sheep and beef pastures, to see how the soil conservation policy impacts the provision of ecosystem services.
- Use the quantitative information for both systems in an economic valuation of the provision of ecosystem services from the two base-line scenarios.
- Quantify and value the provision of ecosystem services from eroded land to evaluate the loss of services compared to an undisturbed pedosphere and ecological infrastructure.
- Characterize and quantify the recovery profile of the provision of ecosystem services in the years following an erosion event (0–1000s years) based on soil recovery data to assess how the provision of ecosystem services recovers.
- Implement a cost–benefit analysis of investment in soil conservation on steep hill pasture prone to erosion compared with no conservation, using an ecosystems services approach, to assess the return on investment from the soil-conservation policy.
- Inform the 'full value of the soil-conservation policy,' enabling a more holistic assessment of flood and catchment management, by allowing, for example, a comparison of the value of a dollar spent on conservation practices (e.g., tree planting) with engineers' structures, such as stop banks.

Such studies address actual conservation issues and show how an ecosystem services approach can be used to advance existing governance frameworks to solve resource management challenges. Understanding how current investments in built capital and current and future investments in ecological infrastructure are likely to change the flow of ecosystem services from managed landscapes is critical to assess the efficiency, cost effectiveness, and sustainability of resource management policies, and for a more complete understanding of the socialecological value of our land.

Conclusion

The ecosystem services approach to NRM is undoubtedly an increasingly influential tool, which is very useful to highlight the holistic and long-term value of agroecosystems. Challenges remain for its implementation. Future NRM needs to focus concurrently on:

- Addressing dual purpose served by agroecosystems: producing socioeconomic goods, as well as underpinning the continued provision of essential ecosystem services.
- Restoring, maintaining, and enhancing the capacity of current ecological infrastructure to continue providing ecosystem services.
- If and when economic valuation of environmental change is needed, increasingly using valuation techniques that answer concerns about fairness and equity.
- Providing solutions based on sound science to minimize potential damage, on top of looking for solutions to overcome limitations.

The ecosystem services approach to NRM has a tremendous potential to help achieve goals, such as Green Growth and the sustainable use of finite natural resources, while enabling agroecosystems to be adaptable and more resilient to uncertainty, change, and shocks.

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See also: Agricultural Policy: A Global View. Agroforestry: Conservation Trees and Erosion Prevention. Biodiversity and Ecosystem Services in Agroecosystems. Economics of Natural Resources and Environment in Agriculture. International and Regional Institutions and Instruments for Agricultural Policy, Research, and Development. Land Use: Management for Biodiversity and Conservation. Market-Based Incentives for the Conservation of Ecosystem Services in Agricultural Landscapes: Examples from Coffee Cultivation in Latin America. Soil: Conservation Practices

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