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Ecosystem Services in Farmland and Cities

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Abstract

Ecosystems sustain human life through the provision of four types of ecosystem services (ES) – a central tenet of the United Nations' Millennium Development Goals (MDGs). These categories are, with examples: supporting (water and nutrient cycling), provisioning (food production, fuel wood), regulating (water purification, erosion control), and cultural (aesthetic and spiritual values). A recent trend has been a decline in ES globally, largely due to ignorance of their value to human well-being and inadequate socioeconomic valuation mechanisms that encourage individuals/governments to invest in maintaining them. Engineered ecosystems from farmland and cities are the most important providers of ES for the world population. However, they are largely left outside the decision-making process in managing agriculture and urban areas, due to the general low awareness of how the ES associated with these systems can and have been quantified. As nearly half of the world population is dependent on agriculture for its livelihood and cities are expanding at a faster rate than ever before, it is vital to understand, measure and incorporate ES into decision making and planning of agriculture and cities. This chapter discusses the concept of ES, their valuation methods, the types of engineered systems and how ES can be adopted by them to enhance them and ensure an equitable and sustainable future.

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Introduction

Natural and modified ecosystems support human life through functions and processes known as ecosystem services (ES; Daily, 1997). These are the life-support systems of the planet (Myers, 1996; Daily, 1997; Daily et al., 1997) and it is evident that human life cannot exist without them.

The importance of ecosystem goods and services in supporting human life and as a life-support system of the planet (Myers, 1996; Daily, 1997; Costanza et al., 1997; Millennium Ecosystem Assessment, 2005) is now very well established and ES were demonstrated to be of very high economic value 15 years ago (US $33 trillion year^{-1}; Costanza et al., 1997). Although that value-transfer approach has been heavily criticized (Toman, 1998), no subsequent attempt to quantify ES globally has been made. However, for particular biological groups, such as insects, value transfer has again been used (Losey and Vaughan, 2006) or for one taxon for one region, experimental techniques to evaluate animals' populations have been combined with the economic value of the support they provide (e.g. earthworms and soil formation; Sandhu et al., 2008). Also, a whole-of-farm approach has been again based on in situ measurements followed by spatial scaling (Porter et al., 2009), in that case for the whole of the European Union in relation to current agricultural subsidies. Yet because most ES are not traded in economic markets, they carry no 'price tags' (no exchange value in spite of their high use value) that could alert society to changes in their supply or deterioration of underlying ecological systems that generate them. Despite this, there has been a recent trend of decline in ES globally, with 60% of the ES examined having been degraded in the last 50 years (Millennium Ecosystem Assessment, 2005). Global efforts to halt this decline in ES have increased considerably since the completion of the Millennium Ecosystem Assessment (MEA) in 2005. The United Nations has established the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to translate science into action world-wide in consultation with governments and research partners (IPBES, 2010).

Because the threats to ES are increasing, there is a critical need for identification, monitoring and enhancement of ES both locally and globally, and for the incorporation of their value into decision-making processes (Daily et al., 1997; Millennium Ecosystem Assessment, 2005; IPBES, 2010; UN, 2012). It is well known that agroecosystems and urban areas contribute substantially to the welfare of human societies by providing highly demanded and valuable ES. Many of these, however, remain outside conventional markets. This is especially the case for public goods (climate regulation, soil erosion control, etc.) and external costs related to the active protection and management of these ecosystems. The capacity of ecosystems to deliver ES is already under stress (Millennium Ecosystem Assessment, 2005) and additional challenges imposed by climate change in the coming years will require better adaptation (Mooney et al., 2009).

What are ecosystem services?

The Millennium Ecosystem Assessment sponsored by the United Nations (Millennium Ecosystem Assessment, 2005) defines ecosystem services (ES) as the benefits people obtain from ecosystems. There is a general lack of understanding of what an ecosystem actually is, however; for example, among university undergraduates and even researchers it is probably worth remembering that single species can provide ES, albeit as part of their place in a trophic web. The facts that honey bees pollinate crops and ladybugs (ladybirds) eat insect pests are often a simple way of illustrating the power of ES to land owners, among others. In these circumstances, 'nature's services' can be a more useful phrase. These benefits sustain human existence through four types of service that include supporting (e.g. water and nutrient cycling), provisioning (e.g. food production, fuel wood), regulating (e.g. water purification, erosion control), and cultural (e.g. aesthetic and spiritual values) services. Benefits arise from managed as well as natural ecosystems. Recent studies have contributed to further understanding of ES for natural resource management (Wallace, 2007), for accounting purposes (Boyd and Banzhaf, 2007), for valuation (Fisher and Turner, 2008), and for policy-relevant research (Fisher et al., 2008; Balmford et al., 2011). Sagoff (2011) points out the differences in ecological and economic criteria in assessing and valuing ES and advocates for a conceptual framework to integrate market-based and science-based methods to manage ecosystems for human well-being.

Ecosystem functions, goods and services

Ecosystem functions can be defined as 'the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly' (de Groot, 1992). Using this definition, ecosystem functions are best conceived as a subset of ecological processes and ecosystem structures. Each function is the result of the natural processes of the total ecological subsystem of which it is a part. Natural processes, in turn, are the result of complex interactions between biotic (living) and abiotic (chemical and physical) components of ecosystems through the universal driving forces of matter and energy (de Groot et al., 2002).

One of the key insights provided by the MEA (2005) is that not all ES are equal – there is no one single category that captures the diversity of what fully functioning ecological systems provide humans. Rather, researchers must recognize that ES occur at multiple scales, from climate regulation and carbon sequestration at the global scale, to soil formation and nutrient cycling more locally. To capture the diversity of ES, the MEA (2005) grouped them into four basic services based on their functional characteristics.

1 Regulating services: ecosystems regulate essential ecological processes and life support systems through biogeochemical cycles and other biospheric processes. These include climate regulation, disturbance moderation and waste treatment.
2 Provisioning services: the provisioning function of ecosystems supplies a large variety of ecosystem goods and other services for human consumption,

ranging from food in agricultural systems, raw materials and energy resources.
3 Cultural services: ecosystems provide an essential 'reference function' and contribute to the maintenance of human health and well-being by providing spiritual fulfilment, historical integrity, recreation sites and aesthetics.
4 Supporting services: ecosystems also provide a range of services that are necessary for the production of the other three service categories. These include nutrient cycling, soil formation and soil retention.

The ES framework

The ES framework has been increasingly used to explain the interactions between ecosystems and human well-being. Several studies classified ES into different categories based on their functions (Costanza et al., 1997; Daily, 1997; de Groot et al., 2002). The MEA assessed the consequences of ecosystem change for human well-being and provided a framework to identify and classify ES (Millennium Ecosystem Assessment, 2005). It established the scientific basis for actions needed to balance nature and human well-being by sustainable use of ecosystems. In the following section, we follow MEA typology and discuss the ES approach and ecosystem-based adaptation.

The ecosystem services approach

An ES approach is one that integrates the ecological, social and economic dimensions of natural resource management (Cork et al., 2007). Cork and colleagues (2007) have described an ES approach as the following.

- An ES approach helps to identify and classify the benefits that people derive from ecosystems. It also includes market and non-market, use and non-use, tangible and non-tangible benefits.
- It also explains consumers and producers of ES for maintenance and improvement of ecosystems for human well-being.
- This approach helps to describe and communicate benefits derived from natural and modified ecosystems to a wide range of stakeholders.

Ecosystem-based adaptation (EbA)

This approach integrates biodiversity and ES into an overall adaptation strategy to help people to adapt to the adverse effects of, for example, climate change (Colls et al., 2009). EbA can be applied at different geographical scales (local, regional, national) and over various periods (short to long term). It can be implemented as projects and as part of overall adaptation programmes. It is most effective when implemented as part of a broad portfolio of adaptation and development interventions (Colls et al., 2009). It is cost-effective and more accessible to rural or poor communities than measures based on hard infrastructure and engineering. It can integrate and maintain traditional and local knowledge and cultural values, such as in the New Zealand Maori concept of *Kaitiakitanga*.

This embraces the philosophy and practice of valuing inherited places and practices and aims to pass them on undamaged or improved. Some examples of EbA activities (CBD, 2009; Colls et al., 2009) are:

- coastal defence through the maintenance and/or restoration of mangroves and other coastal wetlands to reduce coastal flooding and coastal erosion;
- sustainable management of upland wetlands and floodplains for maintenance of water flow and quality;
- conservation and restoration of forests to stabilize land slopes and regulate water flows;
- establishment of diverse agroforestry systems to cope with increased risk from changed climatic conditions;
- conservation of agrobiodiversity to provide specific gene pools for crop and livestock adaptation to climate change.

Engineered systems

Engineered systems are landscapes such as farmland and cities that are actively modified to supply a particular set of ES. Farmland has been modified or 'engineered' to provide food and fibre, whereas cities have been actively managed to accommodate a human population. 'Engineered' or modified ecosystems are providers and consumers of different types of ES. Optimally managed 'engineered' or 'designed' ecosystems can provide a range of important ES; for instance, more fresh water, cleaner air and greater food production, as well as fewer floods and pollutants (Palmer et al., 2004). However, pursuit of commercial gains often reduces the ability to supply other vital ES. In this section and indeed in the following chapters, we discuss two modified or designed systems – agricultural and urban.

Agricultural systems

'Engineered' or modified ecosystems such as farmland are providers and consumers of different types of ES. Farmland comprises highly modified landscapes designed to generate revenue for farmers. Farmers use many inputs as well as natural inputs to produce food and fibre. The production of these is an ES. Intensive agriculture replaces many other ES with chemical inputs, resulting in a decrease in these services and their importance on farmland (Sandhu et al., 2008, 2010a, 2010b, 2012). This 'substitution agriculture' has to a large extent replaced these ES world-wide in the twentieth century. Severe environmental destruction, increasing fuel prices and the external costs of modern agriculture have resulted in increased interest among researchers and farmers in using ES for the more sustainable production of food and fibre (Daily, 1997; Costanza et al., 1997; Tilman, 1999; Cullen et al., 2004; Gurr et al., 2004, 2012; Robertson and Swinton, 2005). The above global trends have led to world-wide concerns about the environmental consequences of modern agriculture (Millennium Ecosystem

Assessment, 2005; De Schutter, 2010). There is also an additional concern that as the world approaches ‘peak oil’ and is already experiencing high oil prices, agriculture may no longer be able to depend so heavily on oil-derived ‘substitution’ inputs (Pimentel and Giampietro, 1994). Such a grave situation does not detract from the responsibility of agriculture to meet the food demands of a growing population but it does question its ability to increase yields without further ecosystem damage (Escudero, 1998; Tilman, 1999; Pimentel and Wilson, 2004; Schröter et al., 2005; UN, 2012). Therefore, the current challenge is to meet the food demands of a growing population and yet maintain and enhance the productivity of agricultural systems (UN, 1992). There is, therefore, currently an increasing interest in the services provided by nature.

It is now urgent that ES on farmland be enhanced as part of global food policy because increasingly dysfunctional biomes and ecosystems are appearing and agriculture, which largely created the problem, has become more intensive in its use of non-renewable resources, driven by a world population which is likely to reach nine billion people by 2050 (Foley et al., 2005). This intensification is compounded by a grain demand which is rising super-proportionally to human population increase and which is largely caused by biofuels development and a rapid rise in per capita meat consumption in parts of Asia (Rosegrant et al., 2001). Continuing with the current energy-intense (Pimentel et al., 2005), wasteful (Vitousek et al., 2009), polluting and unsustainable ‘substitution agriculture’, with its associated problems, which are likely to be exacerbated by climate change, is not an option for future world food security and productivity. There is, therefore, an urgent need for enhanced biodiversity-driven ES in world farming. Different types of agricultural systems and ES interactions are discussed in following chapters. More information is provided by Orre-Gordon et al., Sandhu et al. and Jordan and Warner in Chapters 4, 8 and 9, respectively. The relationship between aquaculture and ES is discussed in detail by Baulcomb in Chapter 5.

ES associated with agriculture

Costanza et al. (1997) estimated, with limited available data, the ES of world croplands to be only US\$92 ha^{-1} $year^{-1}$. This was in marked contrast with other world biomes, for which ES were estimated to be worth US\$23 000 ha^{-1} $year^{-1}$ for estuaries, US\$20 000 ha^{-1} $year^{-1}$ for swamps and US\$2000 ha^{-1} $year^{-1}$ for tropical forests (Costanza et al., 1997). There are, however, two recent experimental agroecological approaches that can be used to demonstrate how this croplands figure can be much higher. The first involves agroecological experiments to measure ecosystem functions combined with value-transfer techniques to calculate their economic value. These studies demonstrate that some current farming practices have much higher ES values than in the Costanza et al. (1997) work. For example, recent data show that the combined value of only two ES (nitrogen mineralization and biological control of a single pest by one guild of invertebrate predators) can have values of US\$197, \$271 and \$301 ha^{-1} $year^{-1}$ in terms of avoided costs for conventional (Sandhu et al., 2008), organic (Lampkin, 1991) and integrated (Porter et al., 2009) arable farming systems, respectively. The above values comprise reduced variable costs (labour, fuel and pesticides) and lower external costs to human health and the environment. Paying for these variable costs is a charge to society, not to the individual farmer and although they contribute to GDP, that is a poor indicator of sustainability and of human well-being (Costanza, 2008).

The second recent realization that can transform ES on farmland is that a better understanding of ecological processes in agroecosystems can generate protocols which do not require a major farming system change but which enhance ES by returning selective functional agricultural biodiversity (FAB) to agriculture (Landis et al., 2000). For example, the role of leguminous crops in nitrogen fixation is a well-known enhancement of farmland ES and can have a value of US\$40 ha^{-1} year^{-1} in terms of reduced oil-based fertilizer inputs (Vitousek et al., 2009), without including the value of reduced ES damage. More recent farmland ES improvements are illustrated by agroecological research on biological control of insect pests. In New Zealand and Australia, strips of flowering buckwheat *Fagopyrum esculentum* (Moench.) between vine rows provide nectar in an otherwise virtual monoculture and thereby improve the ecological fitness of parasitoid wasps that attack grape-feeding caterpillars. This in turn leads to the pest population being brought below the economic threshold. An investment of US\$3 ha^{-1} year^{-1} in buckwheat seed and minimal sowing costs can lead to savings in variable costs of US\$200 ha^{-1} year^{-1} as well as fewer pesticide residues in the wine, higher well-being for vineyard workers and enhanced ecotourism (Fountain and Tomkins, 2011).

Although the ecotechnologies now exist to improve farming sustainability when the negative consequences of oil-based inputs are well recognized, farmers world-wide are still largely risk averse (Anderson, 2003). They have traditionally rejected the idea that non-crop biodiversity on their land can improve production and/or minimize costs. The challenge now for agroecologists and policymakers is to use a range of market-based instruments or incentives, government interventions and enhanced social learning among growers to accelerate the deployment of sound, biodiversity-based ES-enhancement protocols for farmers. These protocols need to be framed in the form of service-providing units (Luck et al., 2003), which precisely explain the necessary ES-enhancement procedures and which should ideally include cost–benefit analyses. Such a requirement invites the design of new systems of primary production that ensure positive net carbon sequestration, are species diverse, have low inputs and provide a diverse suite of ES. An experimental example of such a system is a combined food, energy and ecosystem services (CFEES) agroecosystem in Denmark that uses non-food hedgerows as sources of biodiversity and biofuel. This novel production system is a net energy producer, providing more energy in the form of renewable biomass than is consumed in the planting, growing and harvesting of the food and fodder (Porter et al., 2009).

An approach to encouraging the uptake of ES-enhancing farming systems such as CFEES is through ‘payment for ecosystem services’ (PES) to private landowners (Food and Agriculture Organization, 2007). In this approach, those that benefit from the provision of ES make payments to those that supply them, thereby maintaining ES. Examples of working PES schemes currently in practice are found in different areas of the world. The current focus of these schemes is on water, carbon and biodiversity in addressing environmental problems through positive incentives to land managers (Food and Agriculture Organization, 2007). Such schemes would not only help to improve the environment and human well-being but also ensure food security and long-term farm sustainability (Rosegrant and Cline, 2003).

Although agricultural ecosystems may have low ES values per unit area when compared with others such as estuaries and wetlands, they offer the best chance of increasing global ES by developing appropriate goals for agriculture and the use of land management regimes that favour ES provision. This is because agriculture occupies 40% of the earth's land area and is readily amenable to changing practices, if the sociopolitical impediments are met. Agriculture can be considered to be the largest ecological experiment on Earth, with a high potential to damage global ES but also to promote them via ecologically informed approaches to the design of agroecosystems that value both marketed and non-marketed ES. The extensive Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) of global ecosystems completed by science and policy communities provided a new framework for analysing socioecological processes and suggested that agriculture may be the 'largest threat to biodiversity and ecosystem function of any single human activity'. As 45% of the global population is engaged in farming activities, and such a large proportion of the global land area is in agriculture, achievement of human well-being as agreed by the UN-led Millennium Development Goals (MDGs) (UN, 2000) is not possible without clear pathways for the design of future agroecosystems. There are major global advantages of enhancing ES on farmland through adoption of ES-enhancement protocols. Therefore, global agricultural systems that utilize and maintain high levels of ES are required so that they can provide sustainable economic well-being and food security within ecological constraints (Royal Society, 2009). To condense this discussion into a simple goal, the farmer of the future needs to be encouraged to re-define his/her role to 'I am a photosynthesis manager and an ecosystem-service provider'.

Urban systems

Urbanization and urban growth are major drivers of ecosystem change globally. Urban areas are providing habitats for more than half the human population. In spite of these trends, the ecosystem idea has generally been applied to locations distant from the places where people live. However, knowledge about ecosystems is important for maintaining the quality of life in cities, suburbs and the fringes of metropolitan areas. Urban ecosystem concepts remind citizens and decision makers that we all ultimately depend on our ecosystems and their services (Daily, 1997). As the 'ecological footprint' of cities will increase in the coming decades, because they 'sequester' the products of ES from elsewhere, there is need to incorporate ES into decision making during planning and management of urban areas.

Urban ecosystems have been neglected due to the lack of understanding of the complex processes involved, the lack of mechanisms to govern them, and the failure to incorporate ES into day-to-day decision making. Urban development trends pose serious problems with respect to ES and human well-being. The Millennium Ecosystem Assessment (2005) treated urban systems as ecosystems necessary for human welfare. As they are dominated by humans, these systems can be classified on the basis of population size, economic condition and location. Nearly half the world's population lives in cities of less than half a million people and about 10% lives in those with more than 10 million (Millennium Ecosystem Assessment, 2005). The ES challenges within cities are enormous and are discussed in this chapter below and later in this book.

ES in urban systems

Urban systems are not functional or self-contained ecosystems. They depend largely on surrounding ecosystems in rural areas or more distant ecosystems to fulfil their daily needs including food, water and material for housing and other needs. In cities, urban parks, forests and green belts have their strategic importance for the quality of life. They provide essential ES such as gas regulation, air and water purification, wind and noise reduction, etc. They also enhance social and cultural services such as feelings of well-being, and provide recreational opportunities for urban dwellers (Miller, 1997; Smardon, 1988; Botkin and Beveridge, 1997; Bolund and Hunhammar, 1999; Lorenzo et al., 2000; Tyrväinen and Miettinen, 2000).

Towns and cities are also both consumers and producers of ES. However, the net flow of ES is invariably into rather than out of urban systems. Even if they are not major producers of ES, urban activities can alter the supply and flow of ES at every scale, from local to global level. Urban development threatens the quality of the air, the quality and availability of water, the waste processing and recycling systems, and many other qualities of the ambient environment that contribute to human well-being.

ES and their interactions in engineered systems

Both agricultural and urban systems are dependent and impact on the provision of ES. These designed systems are affected by direct and indirect drivers that in turn impact ES (Fig. 1.1). It is very important to understand these interactions between ES and 'engineered systems' for the achievement of equitable and sustainable human welfare (Swaminathan, 2012).

Human society, as part of the planetary system of interacting biomes depends on these ES as life support functions. Yet simultaneously we are impacting negatively on ecosystem goods and services. This is the dilemma facing society as our ecological footprint on planet earth increases. Projected economic expansion to meet the demands of a growing population (projected to be 9 billion by 2050) along with global climate change will jeopardize future human well-being by further degrading ecosystems. There is a great need to incorporate the value of ES into day-to-day decision making, into government policies and in business practices so that sustainable and desirable futures can be achieved. Waste of energy, food and other resources in the 'developed' world points to areas where our current practices can be readily modified.

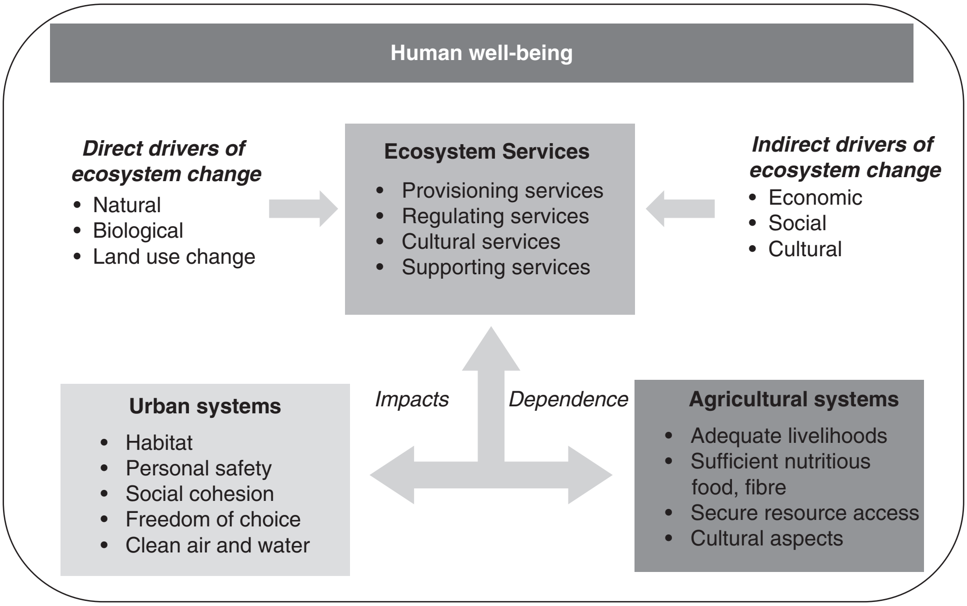

Fig. 1.1 Framework of drivers of ecosystem change and the interaction between ES and two 'engineered systems' – urban and agricultural systems.

In this context, global studies have largely focused on natural ecosystems and biomes, such as the boreal forests and the sea and have put little emphasis on managed ecosystems such as farmland and cities. However, the continued supply of ecosystem goods and services is of vital significance for the survival and productivity of our farmland and our cities. Agricultural systems comprise the largest managed ecosystems on Earth, and are often confronted by ecosystem degradation. Much of the success of modern agriculture has been from provisioning services such as food and fibre. However, the expansion in the demand and supply of these marketable ecosystem goods has resulted in the suppression of other valuable and essential ES such as pollination, climate and water regulation, biodiversity and soil conservation. Similarly, demands from urban areas to support and enhance human lifestyles have resulted in the degradation of other valuable ES in other parts of the world. As economic wealth is underpinned by ecological wealth, we need to recognize and understand the role of ES in sustaining societies, nations and individuals. This can help to achieve food security and environmental sustainability at scales from local to global. It can help ensure a sustainable development and an equitable future. Without the evaluation, protection and enhancement of ES in agriculture and cities, the world's future is bleak indeed.

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