available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Review

Organic agriculture and ecosystem services

Harpinder S. Sandhu[a,*], *Stephen D. Wratten*[b], *Ross Cullen*[c]

[a] *CSIRO Sustainable Ecosystems, PMB No 2, Glen Osmond, Adelaide, SA 5064, Australia*
[b] *Bio-Protection Research Centre, PO Box 84, Lincoln University, Lincoln 7647, New Zealand*
[c] *Department of Accounting, Economics and Finance, Faculty of Commerce, PO Box 84, Lincoln University, Lincoln 7647, New Zealand*

ARTICLE INFO

Published on line 9 December 2009

Keywords:
Economic value
Ecosystem services
Organic agriculture

ABSTRACT

Ecosystem services (ES), such as biological control, pollination, soil formation, nutrient cycling in agriculture are vital for the sustainable supply of food and fibre. The current trends of decline in the ability of agricultural ecosystems to provide ES pose great threat to food security worldwide. This paper discusses the concept of ES and identifies ES associated with agriculture. It discusses the economic and ecological benefits of these ES on farmland in general and its linkages with organic agriculture. The provision of ES on farmland may help to motivate the redesign of small-scale farms using new eco-technologies based on novel and sound ecological knowledge. This has potential to meet the food demand of growing population without damaging human health and the environment.

1. Introduction

Intensive agriculture that utilises large quantities of inputs in the form of fertilisers, pesticide, labour and capital) made it possible to grow enough food to meet the current global needs (Smil, 2000). However, these practices made agriculture a major driver of land use change (Vitousek et al., 1997; Goldewijk and Ramankutty, 2004; UNEP, 2005), leading to environmental damage and degradation of several ecosystem services (ES) (Heywood, 1995; Costanza et al., 1997; Daily, 1997; Krebs et al., 1999; Tilman et al., 2001). ES related to terrestrial ecosystems include such processes as biological control of pests, weeds and diseases, pollination of crops, prevention of soil erosion, the hydro-geochemical cycle, capture of carbon by plants and by soil, cultural services, etc. They ensure the production of ecosystem goods, such as food, forage and biofuels (Daily, 1997). These ES provide major inputs to many sectors of the global economy and have been demonstrated to be of very high economic value (US \$33 trillion yr^{-1}; Costanza et al., 1997). Yet because most of these services are not traded in economic markets, they carry no ‘price tags’. There is 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. However, ES worldwide are being degraded more rapidly than ever before and this degradation poses serious threats to quality of life and therefore to sustainability of economies. The recent Millennium Ecosystem Assessment (MA; Reid et al., 2005) pointed to the very high rate of ES loss and the consequences for global stability if that rate continues. The current trends, if continued unabated, threaten to alter radically not only the capabilities to produce food and fibre but also the delivery of ES by agro-ecosystems (Pretty, 2002).

The key challenge is to meet the food demands of a growing population to achieve Millennium Development Goals (MDGs) by 2015 that include the eradication of hunger (UN, 2005) and yet maintain and enhance the productivity of agricultural systems (UN, 1992). As the economic value of the direct and indirect benefits of ES are substantial (Costanza et al., 1997; Daily et al., 1997; Sandhu et al., 2008; Porter et al., 2009), there is growing awareness of the importance of the utilization of

* *Corresponding author*. Tel.: +61 8 8303 8595; fax: +61 8 8303 8436.
E-mail address: Harpinder.Sandhu@csiro.au (H.S. Sandhu).

1462-9011/$ – see front matter
doi:10.1016/j.envsci.2009.11.002

these services for the long-term sustainability of agro-ecosystems and their ability to provide increased production while maintaining ES (Daily, 2000; Pretty and Hine, 2001; Gurr et al., 2004).

This paper deals with the concept of ES and its application to organic agriculture to help alleviate some of the negative impacts of intensive agriculture and ensure food security (Ericksen et al., 2009). In the following sections, we discuss the concept of ES in relation to organic agriculture. We also discuss the conceptual model of the linkages between ES and organic agriculture, economic value of ES in organic agriculture, citing examples from global studies. We conclude with comments on future research directions.

2. The concept of ES

Natural and modified ecosystems support human existence on the planet through various functions and processes known as ES (Daily, 1997). In recent years, the concept of ES has gained wide acceptance within the international scientific community (Costanza et al., 1997; Daily, 2000; Tilman et al., 2002; Palmer et al., 2004; Robertson and Swinton, 2005). It led to the adoption of the ES concept by the United Nations' sponsored Millennium Ecosystem Assessment (MA) program. Key recent work has estimated the value of global ecosystem goods and services (Costanza et al., 1997; de Groot et al., 2002; Millennium Ecosystem Assessment, 2003), generating increased awareness of their classification, description, economic evaluation and enhancement (Gurr et al., 2004). ES value has been assessed using a 'top-down' approach by Costanza et al. (1997) to be in the range of US \$16–54 trillion yr^{-1}, with an annual mean of US \$33 trillion which was twice the annual global GDP (gross domestic product) of the world at that time. This study provoked meaningful debate about the economic value and the appropriate ways to value ES (Toman, 1998; Turner et al., 1998; Farber et al., 2002). In another study, Pimentel et al. (1997) estimated the annual economic and environmental benefits of biodiversity in the world to be about US \$3 trillion yr^{-1}.

High economic value of ES led to a paradigm shift in ways of thinking about conservation. However the thinking at that time was concentrated on natural ecosystems and attributed low values to agro-ecosystems. Now there is growing realisation that ES from farmland are of vital importance in sustaining world food production with human population growing to 9 billion by 2050. Because agriculture covers such a significant portion of the globe, evaluating ES from this sector is very important given the damage being done to these vital services by high-input agriculture worldwide. The need is to address the under-estimation of ES in modified ecological systems such as farmland and explore developing concepts, policies and methods of evaluating ES, as well as the ways in which ES in these systems can be maintained and enhanced to sustain human population without damaging human health and the environment.

Researchers and policy makers are using the concept of ES to enhance farm sustainability worldwide (Matson et al., 1997; Gurr et al., 2004; Kremen, 2005; Robertson and Swinton, 2005; Sandhu et al., 2008). The Millennium Ecosystem Assessment also promotes the adoption of land management practices that maintain agricultural sustainability without compromising yield and profitability. Increasing concerns about intensive agriculture and its detrimental effects have led to the development of sustainable agricultural practices such as organic farming (Lampkin and Padel, 1994; FiBL, 2000; Reganold et al., 2001; FAO/WHO, 2001; IFOAM, 2002). Organic agriculture is defined as "*a holistic production management (whose) primary goal is to optimize the health and productivity of interdependent communities of soil, life, plants, animals and people*" (UNCTAD, 2006). Therefore, it aims to utilise and maintain ES by improving the natural environment, increased water retention, reduced soil erosion and increased agro-biodiversity (UN, 2008). At present, this is practised on 31 million ha worldwide with a global market of US \$26.8 billion, which is increasing at 20% per year (Willer and Yussefi, 2006).

ES associated with agriculture can be classified into four groups (provisioning, supporting, regulating and cultural services) as explained by Reid et al. (2005). Based on the ES literature and discussion with experts, several ES have been identified in agro-ecosystems which are discussed briefly below (Cullen et al., 2004; Reid et al., 2005; Sandhu et al., 2007; Zhang et al., 2007; UN, 2008).

2.1. *Provisioning goods and services*

These include food and services for human 'consumption', ranging from food, forage, biofuels and fuel wood to the conservation of species and agro-biodiversity (de Groot et al., 2002; Reid et al., 2005). These goods and services are produced in agricultural landscapes.

2.2. *Supporting services*

These are the services that are required to support the production of other ecosystem goods and services. In this case they support the production of grain, wool, fruit and vegetables, etc. Key supporting ES associated with agriculture are biological control of pests (natural enemies of insect pests control the pest populations), biological control of diseases and weeds (natural suppression by soil microbes of soil-borne diseases and weed seed removal by predators), pollination (for seed production), nutrient supply (availability of nutrients by soil microbial activity), carbon sequestration (storage of carbon in soils and vegetation), soil formation (soil turnover by earthworms) etc. The global economic value of these ES was estimated to be \$100, \$80, \$100, \$90, \$135 and \$25 billion annually, respectively (Pimentel et al., 1997).

2.3. *Regulating services*

Ecosystems regulate essential ecological processes that maintain temperature and precipitation (Costanza et al., 1997; Daily, 1997). Regulating services associated with agriculture regulate fluctuations in water provision and temperature.

2.4. *Cultural services*

Cultural services contribute to the maintenance of human health and well-being by providing recreation, aesthetics and education opportunities (Costanza et al., 1997; de Groot et al., 2002; Reid et al., 2005). Agriculture is a single largest employer of people worldwide if one takes the whole food chain (production, processing, distribution, retailing, etc.) and contributes on a massive scale to human well-being (Millstone and Lang, 2008). Agriculture also provides aesthetic services as some farmers conserve field-boundary vegetation or enhance landscapes by planting hedgerows, shelterbelts or trees. Some farms provide accommodation and recreational activities for family members as well as for national and international visitors. 'Biodiversity trails' in agriculture are not common but have had an increasing impact in New Zealand vineyards by offering unique landscape that once existed ('Greening Waipara' http://bioprotection.org.nz/sustainable-bioprotection). Visitors can experience a range of species that reside in the different habitats as they walk the trail in vineyards. For example—wetlands, dry land scrub forests with weta motels, lizard refuges as well as biodiversity within vine rows. Participation of farms in research and education enhances this cultural service (Warner, 2006).

3. The ES concept and organic agriculture

Agriculture is both a consumer and a producer of ES (Fig. 1) (Heal and Small, 2002; Sandhu et al., 2005; Takatsuka et al., 2009). A number of ES are utilised to produce other ES such as food, which is supported by the maintenance of soil fertility, plant protection, water regulation and many other services (Daily et al., 1997; Pimentel et al., 1997). By using the concept of ES, researchers and practitioners aspire to strike a balance between production and consumption of ES in agriculture for long-term farm sustainability (Bjorklund et al., 1999; Firbank, 2005).

Sustainable agriculture involves the use of nature's goods and services while maintaining them for future generations (Altieri, 1995; Thrupp, 1996; Pretty et al., 2003; Pretty, 2005; Pretty and Hine, 2001; Tilman et al., 2002). Organic agriculture is considered to be one of the production systems that aim to achieve sustainability (Reganold et al., 1990; Lampkin and Measures, 2001; Mäder et al., 2002) by utilising and maintaining ES. The estimated magnitude (scale 1–5; in the ratings, 1, 3, and 5 represent the lowest, medium, and highest levels of ES, respectively) of several ES is very high in organic agriculture compared with high-input substitution agriculture (Takatsuka et al., 2009; Sandhu et al., 2005). It is well established that organic farming delivers more environmental benefits than does conventional agriculture. The economic value of ES in New Zealand organic fields was found to be $1516 ha^{-1} yr^{-1} as compared to $670 ha^{-1} yr^{-1} in conventional ones (Sandhu et al., 2008). These values comprised reduced variable (labour,

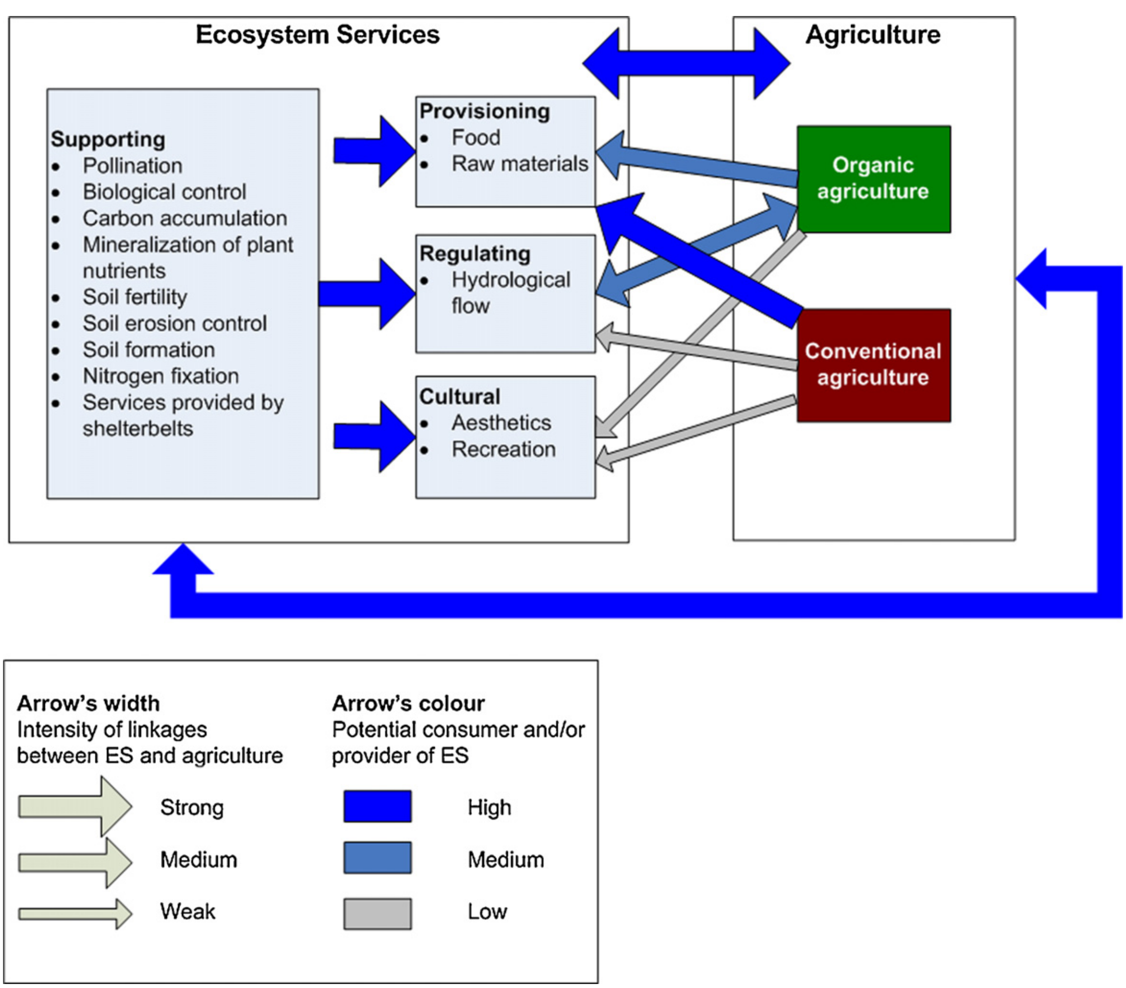

Fig. 1 – Linkages between ES and agriculture (adapted from Reid et al., 2005).

Plate 1 – Strips of buckwheat (soba) are being sown between vine rows in New Zealand to provide nectar and pollen for beneficial insects to enhance biological control of vine pests.

Plate 2 – Strips of flowering alyssum in California lettuce crops to enhance biological control of pests. Photo: Dr. C. Picket, CDFA, USA.

fuel, pesticides) and lower external costs to human health and the environment.

3.1. *Economic value of ES in organic agriculture*

Sandhu et al. (2008) investigated the role of land management practices in the maintenance and enhancement of ES in agricultural land by quantifying the economic value of ES at the field level based on an experimental approach. The study sites included 29 arable fields, distributed over the Canterbury Plains in New Zealand and comprised 14 organic and 15 conventional fields. In this study, an experimental 'bottom-up' approach was used to quantify the economic value of ES associated with highly modified arable landscapes in Canterbury, New Zealand. The role of land management practices in the maintenance and enhancement of ES in agricultural land was investigated by quantifying the economic value of ES at the field level under organic and conventional arable systems. This quantification was based on an experimental approach at field level in contrast with earlier global level value transfer methods. The mean economic value of provisioning services, regulating services, cultural and supporting services are presented in Table 1. There were significant differences between organic and conventional fields for the economic values of some ES (supporting and regulating services). This study showed that conventional New Zealand arable farming practices can severely reduce the level of some of these services in agriculture whereas organic agriculture practices enhance their economic value.

Table 1 – Economic value of ecosystem services in organic and conventional fields (adapted from Sandhu et al., 2008).

Ecosystem services	Economic value in US $ ha^{-1} yr^{-1}	
	Organic fields	Conventional fields
Provisioning services	4012	3258
Regulating services	107	54
Cultural services	21	21
Supporting services	1388	540

Box 1.

Service providing unit (SPU): This is a clear protocol (Luck et al., 2003) which shows end-users exactly how to improve a particular ES, e.g., conservation biocontrol of pests in Australasian vines: 45 kg of buckwheat (*Fagopyrum esculentum*) seeds/ha, sown in one vine inter-row in 10, three times/season from November to March, with dying inflorescences removed in each plant cohort to induce new flowering shoots from axillary buds (agricultural and horticultural habitats are manipulated to increase the availability of pollen, nectar, alternative prey/hosts, or shelter for pests' natural enemies. http://bioprotection.org.nz/ sustainable-bioprotection). An example of a SPU is discussed below.

Biological control of insect pests: *Epiphyas postvittana* (Walker) is a common leafroller pest in New Zealand and Australian vineyards that results in a lower grape yield and economic loss for growers. Biological control of this pest has been shown to be enhanced by providing floral resource subsidies (flowering buckwheat) for its natural enemy, the parasitic wasp *Dolichogenidea tasmanica* (Cameron). Buckwheat plants provide food and habitat sources for parasitic wasps. Sowing one in every tenth inter-row with buckwheat (@ 45 kg ha^{-1}) reduced the prevalence of this key pest by 50% to a level where agrichemical sprays were not required, as determined by the New Zealand viticultural industry (Scarratt, 2005). An investment of \$2 ha^{-1} yr^{-1} in buckwheat seed and minimal sowing costs can lead to savings in annual variable costs of \$250 ha^{-1} yr^{-1} in New Zealand.

New technologies based on sound ecological knowledge (Plates 1 and 2) are substituting ES for unsustainable inputs and are enhancing the value of the products.

3.2. *Case study: economic value of a key ES*

Biological control of insect pests is a key ES crucial to the production of crops. Ninety-nine per cent of the populations of agricultural pests and diseases are controlled by their natural enemies—predators, parasites, and pathogens (de Bach, 1974). It is estimated that 2.5 million tonnes (active ingredients) of pesticides are used worldwide in crop production (Pimentel et al., 1992). Biological control, if properly utilised on farmland can result in annual savings worth billions of dollars and these services can be enhanced using 'ecological engineering' principles (Gurr et al., 2004). There are several examples of successful biological control practices adopted worldwide. In Kenya, the push–pull system has been tested on farms in six districts and has now been released for use by the national extension systems in East Africa. The 'push–pull' eco-technologies whereby plant and insect chemistry is used to deter pests ('push') and attract ('pull') pests' natural enemies has improved yields to such an extent that milk production has increased and benefits have been community-wide (IAPPS, 2001). An example of successful biological control of insect pests in New Zealand vineyards is discussed in Box 1.

4. Conclusions

Organic agriculture both utilises and maintains ES. It is therefore more sustainable than is conventional agriculture which degrades some ES. Apart from providing ES, organic agriculture is capable of contributing significantly to global food supply. One recent study (Badgley et al., 2006), examined 293 cases from all over the world and compared yields of organic and conventional systems. This study (Badgley et al., 2006) indicated that organic agriculture has potential to contribute significantly to the global food supply. Increasing concerns about food security in least developed and developing countries will require a wide range of sustainable agricultural practices (combining some organic and conventional practices) to fulfill the food demand of a growing population (Ericksen et al., 2009). Organic agriculture offers great potential to develop low cost, low input, locally available eco-technologies (as discussed in Section 3.2) to produce food and fibre (Badgley et al., 2006), without causing damage to human health and the environment (UN, 2008). This type of ecological knowledge can be easily transferred to small-scale farms in least developed and developing countries where the need is much higher due to non-availability of other high-input and costly resources.

The current and future challenge is to develop cost-effective, low-input eco-technologies, for their rapid implementation and uptake by end-users (Porter et al., 2009). This has potential to ensure sustainable food production for the growing human population. There is greater need to dedicate resources for implementation of ES-enhancement strategies by implementing new mechanisms and policies to maintain and enhance agricultural sustainability without compromising yield.

References

Altieri, M., 1995. Agroecology: The Science of Sustainable Agriculture. Westview Press, Colorado.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Jahi Chappell, M., Avilés-Vázquez, K., Samulon, A., Perfecto, I., 2006. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems 22, 86–108.

Bjorklund, J., Limburg, K.E., Rydberg, T., 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. Ecological Economics 29, 269–291.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Cullen, R., Takatsuka, Y., Wilson, M., Wratten, S., 2004. Ecosystem services on New Zealand arable farms. In: Agribusiness and Economics Research Unit. Lincoln University, (Discussion Paper 151), pp. 84–91.

Daily, G.C. (Ed.), 1997. Nature's Services: Societal Dependence on Natural Ecosystems.. Island Press, Washington, DC.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D., Woodwell, G.M., 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues in Ecology 2, 18.

Daily, G.C., 2000. Management objectives for the protection of ecosystem services. Environmental Science and Policy 3, 333–339.

de Bach, P., 1974. Biological Control by Natural Enemies. Cambridge University Press, London.

de Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393–408.

Ericksen, P.J., Ingram, J.S.I., Liverman, D.M., 2009. Food security and global environmental change: emerging challenges. Environmental Science and Policy 12, 373–377.

FAO/WHO Codex Alimentarius Commission, 2001. Guidelines for the production, processing, labelling and marketing of organically produced foods. CAC/GL 32-1999-Rev.1-2001. Rome.

Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41, 375–392.

FiBL, 2000. Organic Farming Enhances Soil Fertility and Biodiversity. Results from a 21 year field trial. FiBL Dossier 1 (August). Research Institute of Organic Agriculture (FiBL), Zurich.

Firbank, L.G., 2005. Striking a new balance between agricultural production and biodiversity. Annals of Applied Biology 146, 163–175.

Goldewijk, K.K., Ramankutty, N., 2004. Land cover change over the last three centuries due to human activities: the availability of new global data sets. GeoJournal 61, 335–344.

Gurr, G.M., Wratten, S.D., Altieri, M.A. (Eds.), 2004. Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods. CSIRO, Victoria.

Heal, G.M., Small, A.A., 2002. Agriculture and ecosystem services. In: Gardner, B.L., Rausser, G.C. (Eds.), Handbook of Agricultural Economics, vol. 2a. Elsevier, Amsterdam, pp. 1341–1369.

Heywood, V.H. (Ed.), 1995. United Nations Environment Program, Global Biodiversity Assessment. Cambridge University Press, Cambridge.

IAPPS, 2001. ICIPE develops safe new methods for controlling stem borers, termites and striga. Crop Protection 20, 269–272.

IFOAM, 2002. International Federation of Organic Agriculture Movements Basic Standards for Organic Production and Processing. Tholey-Theley, Germany.

Krebs, J.R., Wilson, J.D., Bradbury, R.B., Siriwardena, G.M., 1999. The second silent spring? Nature 400, 611–612.

Kremen, C., 2005. Managing ecosystem services: what do we need to know about their ecology? Ecology Letters 8, 469–479.

Lampkin, N.H., Padel, S. (Eds.), 1994. The Economics of Organic Farming. An International Perspective. CAB International, Wallingford.

Lampkin, N., Measures, M., 2001. Organic Farm Management Handbook: Organic Farming Research Unit. Institute of Rural Studies, University of Wales, Aberystwyth.

Luck, G.W., Daily, G.C., Ehrlich, P.R., 2003. Population diversity and ecosystem services. Trends in Ecology and Evolution 18, 331–336.

Mäder, P., Fließbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U., 2002. Soil fertility and biodiversity in organic farming. Science 296, 1694–1697.

Matson, P.A., Parton, W.J., Power, A.G., Swift, M.J., 1997. Agricultural intensification and ecosystem properties. Science 277, 504–509.

Millennium Ecosystem Assessment, 2003. Ecosystems and Human Well-being: a Framework for Assessment. Island Press, Washington, DC.

Millstone, E., Lang, T., 2008. The Atlas of Food: Who Eats What. In: Where and Why, Earthscan, UK.

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, B., Kingsland, S., Kranz, R., Mappin, M., Martinez, M., Micheli, F., Morse, J., Pace, M., Pascual, M., Palumbi, S., Reichman, O., Simons, A., Townsend, A., Turner, A., 2004. Ecology for a crowded planet. Science 304, 1251–1252.

Pimentel, D., Acquay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Horowitz, A., D'Amore, M., 1992. Environmental and economic costs of pesticide use. BioScience 42, 750–760.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T., Cliff, B., 1997. Economic and environmental benefits of biodiversity. BioScience 47, 747–758.

Porter, J.R.P., Costanza, R., Sandhu, H., Sigsgaard, L., Wratten, S., 2009. The value of producing food, energy, and ecosystem services within and agro-ecosystem. Ambio 38, 186–193.

Pretty, J.N., 2002. Agri-culture: reconnecting people. In: Land and Nature, Earthscan Publishing Ltd., London.

Pretty, J.N., Morison, J.I.L., Hine, R.E., 2003. Reducing food poverty by increasing agricultural sustainability in developing countries. Agriculture, Ecosystems and Environment 95, 217–234.

Pretty, J.N., 2005. The Pesticide Detox: Towards a More Sustainable Agriculture. Earthscan, London.

Pretty, J., Hine, R., 2001. Reducing food poverty with sustainable agriculture: summary of new evidence. In: Final Report from the ''SAFE - World'' (The Potential of Sustainable Agriculture to Feed the World) Research Project. University of Essex Commissioned by UK Department for International Development (on WWW at http://www2.essex.ac.uk/ces/ResearchProgrammes/CESOccasionalPapers/SAFErep SUBHEADS.htm.

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J., Zurek, N.B., 2005. Millennium Ecosystem Assessment Synthesis Report. Island Press, Washington, DC.

Reganold, J.P., Glover, J.D., Andrews, P.K., Hinman, H.R., 2001. Sustainability of three apple production systems. Nature 410, 929–930.

Reganold, J.P., Papendick, R.I., Parr, J.F., 1990. Sustainable agriculture. Scientific American 262, 112–120.

Robertson, G.P., Swinton, S.M., 2005. Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. Frontiers in Ecology and Environment 3, 38–46.

Sandhu, H.S., Wratten, S.D., Cullen, R., Hale, R., 2005. Evaluating nature's services on Canterbury arable farmland. In: A Report Prepared as part of a Research Programme, Funded by the Foundation for Research, Science and Technology (FRST), entitled: Biodiversity, Ecosystem Services and Sustainable Agriculture (LINX 0303) with PhD Scholarship Support from the BHU Organics Trust. Lincoln University http://www.lincoln.ac.nz/story_images/1542_Farm Report_s4627.pdf.

Sandhu, H.S., Wratten, S.D., Cullen, R., 2007. From poachers to gamekeepers: perceptions of farmers towards ecosystem services. International Journal of Agricultural Sustainability 5, 39–50.

Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B., 2008. The future of farming: the value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics 64, 835–848.

Scarratt, S.L. 2005. Enhancing the biological control of leafrollers (Lepidoptera: Tortricidae) using floral resource subsidies in an organic vineyard in Marlborough, New Zealand. PhD Thesis. Lincoln University, New Zealand.

Smil, V., 2000. Feeding the World. MIT Press, Cambridge, MA.

Takatsuka, Y., Cullen, R., Wilson, M., Wratten, S., 2009. Using stated preference techniques to value four key ecosystem services on New Zealand arable land. International Journal of Agricultural Sustainability 7, 1–13.

Thrupp, L.A., 1996. Partnerships for Sustainable Agriculture. World Resources Institute, Washington, DC.

Tilman, D., Cassman, G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671–677.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D., 2001. Forecasting agriculturally driven global environmental change. Science 292, 281–284.

Toman, M., 1998. Why not to calculate the value of the world's ecosystem services and natural capital. Ecological Economics 25 (1), 57–60.

Turner, R.K., Adger, W.N., Brouwer, R., 1998. Ecosystem services value, research needs, and policy relevancy: a commentary. Ecological Economics 25 (1), 61–66.

UN, 1992. Promoting sustainable agriculture and rural development. In: United Nations Conference on Environment & Development. Rio de Janerio, Brazil, 3–14 June, Agenda 21, 14.1-14.104 (on WWW at http://www.un.org/esa/sustdev/agenda21.htm).

UN, 2005. The Millennium Development Goals Report. United Nations, New York.

UN, 2008. Organic Agriculture and Food Security in Africa. United Nations Conference on Trade and Development-United Nations Environment Programme, Capacity-building Task Force on Trade, Environment and Development. (http://www.unep-unctad.org/cbtf/publications/UNCTAD_DITC_TED_2007_15.pdf).

UNCTAD, 2006. Trade and Environment Review. UN, New York (http://www.unctad.org/en/docs/ditcted200512_en.pdf).

UNEP, 2005. One Planet, Many People: Atlas of Our Changing Environment. UN, New York.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of earth's ecosystems. Science 277, 494–499.

Warner, K.D., 2006. Extending agroecology: grower participation in partnerships is key to social learning. Renewable Agriculture and Food Systems 21, 84–94.

Willer, H., Yussefi, M. (Eds.), 2006. The World of Organic Agriculture 2006: Statistics and Emerging Trends. International Federation of Organic Agriculture Movements (IFOAM), Bonn.
Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. Ecological Economics 64, 253–260.

Harpinder Sandhu is a research scientist (ecologist) with CSIRO Sustainable Ecosystems located in South Australia. His research expertise is in the evaluation of ecosystem services in agricultural landscapes.

Stephen Wratten is a professor of ecology and deputy director of the National Centre for Advance Bio-Protection Technologies, Lincoln University, New Zealand and Visiting Professor at the University of Sydney. Professor Wratten was educated at the universities of Reading, Glasgow, London and Cambridge and holds a DSc from the University of Southampton as well as an honorary DSc from KVL University, Denmark. He is a Fellow of the Royal Society of New Zealand.

Ross Cullen is a professor of resource economics and head of Department of Accounting, Economics and Finance at the Commerce Division, Lincoln University, New Zealand.