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Valuing Ecosystem Services to Agricultural Production to Inform Policy Design: a Introduction

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1 Introduction

There is an ongoing policy debate regarding both how much government intervention there should be to protect ecosystems or natural resources affected by agriculture (Pannell, 2008), and how the costs of these interventions should be distributed across different interest groups. In Australia and elsewhere in the world, there has been significant policy emphasis on encouraging private landholders to manage their natural resources sustainably and in ways that enhance the provision of ecosystem services to the wider community.[1] However, the Australian approach - particularly Landcare - is distinctive in also emphasizing collective action among farmers at a local level. Such an approach can be effective when the actions of one farmer directly affect ecosystem flows to themselves or others.

In accordance with the policy focus in most countries, the vast majority of the valuation literature on ecosystem services and agriculture aims to assess the benefits that managed agricultural landscapes can provide to the rest of society. We argue, however, that the efficiency and equity of policies for ecosystem services related to agriculture can also be enhanced by an understanding of the value of the ecosystem services that agricultural production *receives*.

The concept of ecosystem services is described in the next Section, with particular reference to ecosystem services which provide value to agricultural production. In the subsequent Section 3, we build on neoclassical economic theory to differentiate between different types of ecosystem service flows to agriculture and to explain which of these flows are priorities for valuation to improve policy design. In Section 4, a number of market-based approaches which may be used to estimate the value of ecosystem services to agricultural production are discussed. Using the classification framework from Section 3, a number of previous valuation studies of ecosystem services related to agriculture are detailed in Section 5, indentifying knowledge gaps and suggesting priorities for future research. The final Section 6 concludes that

[1] Examples such as the Australian 'Caring for our Country' initiative (DEWHA, 2010), the Environment Protection and Biodiversity Conservation Act (DEWHA, 1999), agro-environmental measures in the European Union (Dobbs and Pretty, 2008) or the US Farm Bill (USDA, 2007) mostly focus on market-based approaches to pay farmers for protecting environmental benefits to the rest of society produced by rural landscapes, or to reduce negative externalities produced by agriculture (Baylis et al., 2008).

studies estimating the value of ecosystem service flows to agriculture are currently lacking but technically feasible, and likely to be a useful aid to efficient policy-making.

2 Conceptualizing ecosystem services and agriculture

"The lack of effective incorporation of ES values into
resource allocation decisions can lead to
inefficient use of many unpriced resources
and unnecessarily large ecosystem losses" *(Kroeger and Casey, 2007).*

The concept of ecosystems goods and services is attracting increased attention as a way to communicate agriculture's dependence on the environment (Gomez-Baggethun *et al.*, 2010). Ecosystem services include, for example, pollination by insects; water provision and purification; healthy, productive soils; and protection from pests.

The concept of ecosystem services highlights the long-term role that healthy ecosystems play in the sustainable provision of human wellbeing, economic development, and poverty alleviation across the globe (Turner and Daily, 2008). Ecosystem services are the benefits that people obtain from ecosystems (MA, 2005: 26). They have been defined as 'the conditions and processes through which natural ecosystems, and the species that make them up, sustain, and fulfil human life" (Daily, 1997: 6). There are many approaches to classifying the services that ecosystems provide to human beings (see, for example, Daily *et al.*, 1997; or de Groot *et al.*, 2002). An often quoted framework is the Millennium Ecosystem Assessment, which identified four classes of ecosystem services (MA, 2005: 26-29 and Figure 1):

1. Supporting services are those that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation.
2. Provisioning services are the products people obtain from ecosystems, such as food, water, genetic resources, and fuel.
3. Regulating services are the benefits people obtain from the regulation of ecosystem processes, such as climate regulation, water purification, and erosion control.

4. Cultural services are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

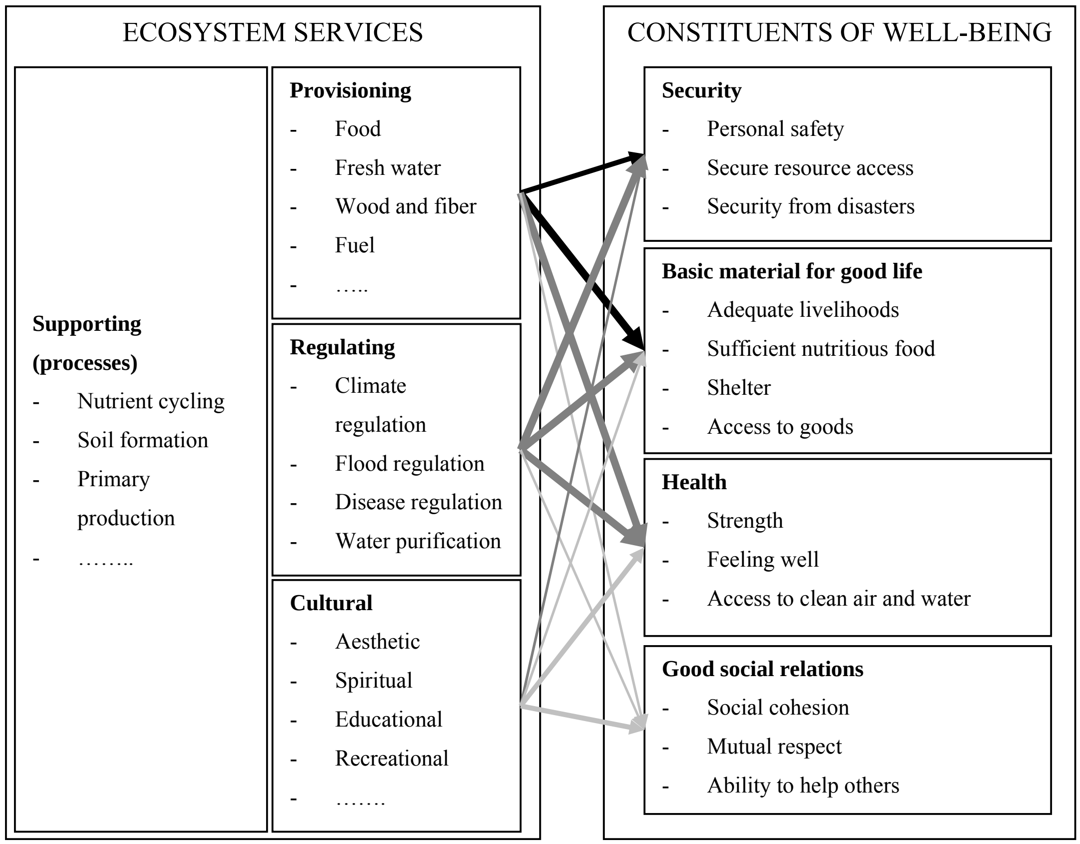

Figure 1 The contribution of ecosystem services to human well-being (Based on MA, 2005)

Note that these four classes are not mutually exclusive. Some services may be categorized as both ‘supporting’ and ‘provisioning’ or ‘regulating’, depending on the scale at which the service and its impacts are considered (Godden, 2010). De Groot *et al.* (2002) warn for the possibility of ‘double counting’ of ecosystem services when services are interconnected or overlap. The authors stress that the interdependencies between ecosystem services should be understood to avoid double counting of the benefits provided to human beings.

The literature on agriculture and ecosystem services is largely focused on agricultural areas as the supplier of ecosystem services which are of benefit to the wider community, such as conservation of biodiversity (Daily, 1997). A literature search concerning ecosystem services and agriculture[2] yielded many publications that analysed the impacts of agricultural activities *on* ecosystems (see, for example, Adger and Whitby, 1991; Skinner *et al.*, 1997; van der Werf and Petit, 2002; Zedler, 2003; Swift *et al.*, 2004; Tegtmeier and Duffy, 2005; Collard and Zammit, 2006; Butler *et al.*, 2007; Dale and Polasky, 2007; Nelson *et al.*, 2009); or publications that assessed the ecosystem services that can be *provided by* agricultural landscapes (see, for example, Campbell *et al.*, 2006; Collard and Zammit, 2006; Scott *et al.*, 2006; Swinton *et al.*, 2007a; Swinton *et al.*, 2007b; Sandhu *et al.*, 2008; Porter *et al.*, 2009). There is considerable research focus on possibilities to compensate farmers for the provision of ecosystem services through the creation of markets (see, for example, Kroeger and Casey, 2007; Engel *et al.*, 2008; Wunder *et al.*, 2008; Layton and Siikamäki, 2009; FAO, 2010; Pagiola *et al.*, 2010; Pascual *et al.*, 2010; Ribaudo *et al.*, in press).

The majority of existing studies focuses on the impacts of agriculture on ecosystem conditions, or on agriculture as a source of ecosystem services supply. However, ecosystem services also provide important services *to* agricultural production, for example through soil structure and fertility; nutrient cycling; soil retention; crop pollination; food sources; water provision and purification etc. (see Figure 2). Various authors (see, for example, Cork and Shelton, 2000; Cullen *et al.*, 2004: 86-88; Sandhu *et al.*, 2007; or Zhang *et al.*, 2007: 255-256) have provided qualitative discussions of the ecosystem processes and services on which agriculture might depend. There are, however, few studies available that have attempted to quantify the contribution of one or more ecosystem services to agricultural production (see Section 5). A recent review by Power (2010) describes some of the ways in which ecosystem services contribute to agricultural yields, but provides limited value estimates.

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[2] A literature search was conducted in Google Scholar; publishing websites such as Science Direct, Wiley, and Springer link; specific Environmental and Agricultural Economics journals (Agricultural Economics, Australian Journal of Agricultural and Resource Economics, American Journal of Agricultural Economics, Environmental and Resource Economics, Ecological Economics) and the EVRI environmental valuation database (http://evri.ca) using the following keywords and combination thereof: environmental or ecosystem services and agricultural production, productivity or economics. This initial search yielded more than 6,000 papers. Papers were subsequently screened for relevance to this study based on their titles.

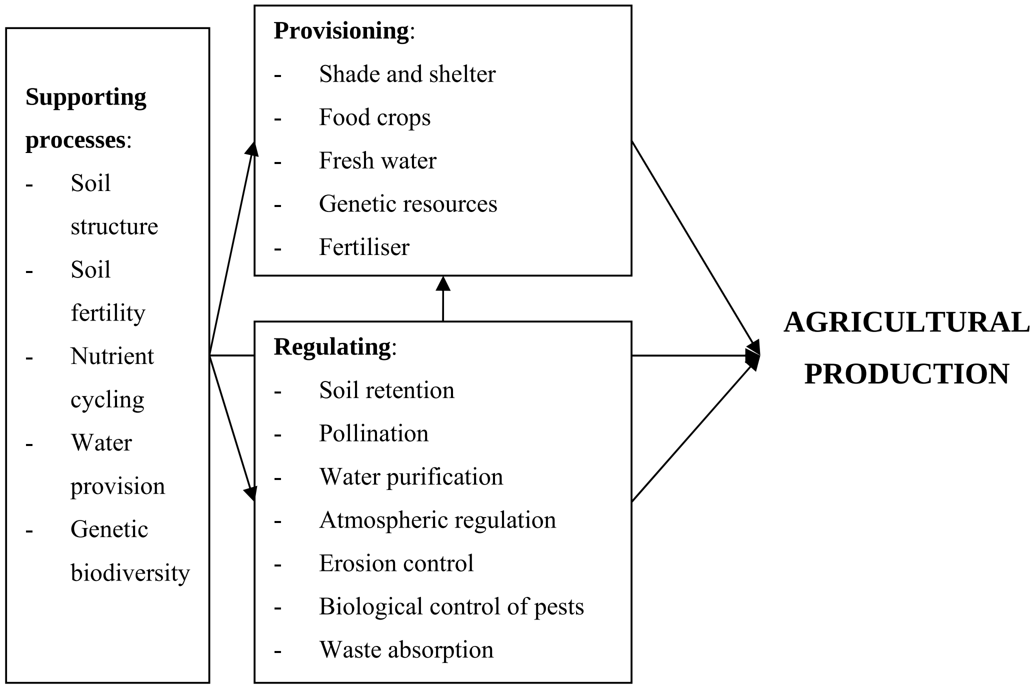

Figure 2 Example ecosystem services and their contribution to agricultural production

3 An economic perspective on the implications of ecosystem services to agriculture for government policy.

The valuation of ecosystem services is of interest to policy-makers because market imperfections (indeed, at times the complete absence of markets) means that the marginal social costs and benefits of ecosystem service provision will usually not be equated in the absence of government intervention. In other words, welfare improvements may possible through government interventions that aim to manage the provision of ecosystem services, provided the cost of the government intervention does not exceed the potential allocative benefits. Below we apply this economic approach in more detail to the issue of ecosystem services and agriculture. We identify different types of ecosystem service flows to agriculture based on which groups of economic agents bear the costs and benefits of the service provision. This approach allows us to identify which ecosystem service flows are most important to quantify for efficient policy design.

3.1 A model of ecosystem service flows in relation to agriculture

One way to conceptualize ecosystem service flows of relevance to agriculture is to define stylized groups who bear the costs and benefits of ecosystem service provision to and from agricultural land (Figure 3). In our terminology the agricultural sector is comprised of many individual farms. The agricultural sector is embedded within a society of interest, for example, Australia

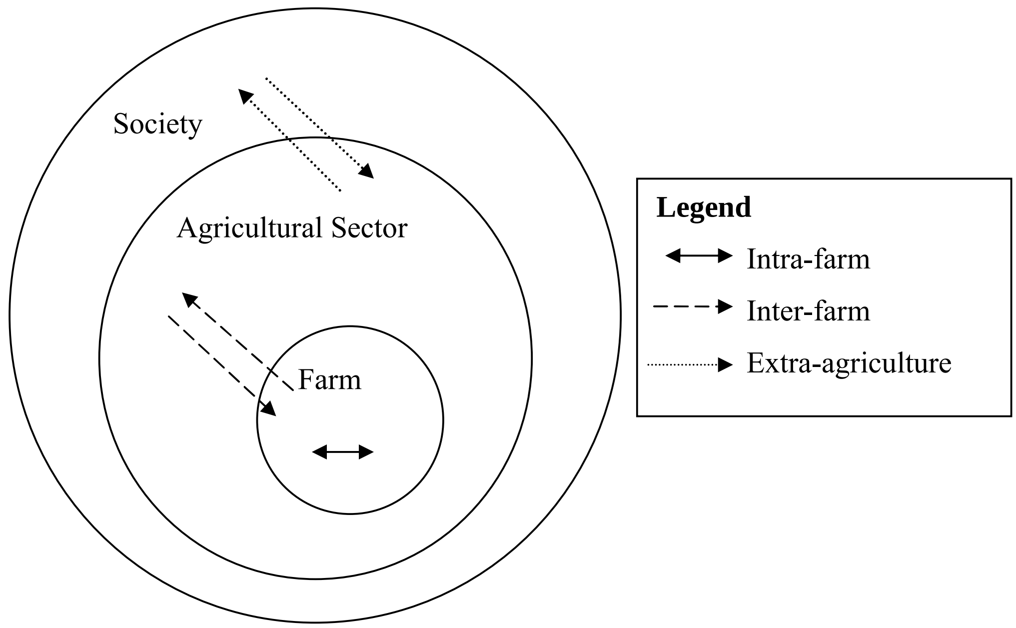

Figure 3 Schematic of Ecosystem Service Flows in relation to Agriculture

Actions of an individual farmer can affect the ecosystem services provided to his private agricultural operation (e.g. planting shade trees increases livestock productivity). Individual actions can also affect ecosystem services values to other farms in the industry (e.g. planting trees lowers the water table, decreases salinity, and increases the productive capacity of the land) as well as the ecosystem services provided to society as a whole (e.g. planting trees increases carbon capture). For ease of exposition later, we label these different ecosystem service flows as 'intra-farm', 'inter-farm' and 'extra-agriculture' flows respectively. The flows are illustrated graphically in Figure 3.

Ecosystem services can also flow in the opposite direction to those described above. That is, the actions of other farmers and other parts of society can affect the ecosystem services available to an individual farm. Thus a farm may receive inter-farm ecosystem service flows if trees planted by a neighbouring farmer lower the water table. Similarly a farm may receive increased extra-agriculture ecosystem services if regulation improve air-quality or national parks provide habitat for pollinating insects, wind breaks, and salinity control.

3.2 Which ecosystem service values are relevant for policy design?

A corollary of the first welfare theorem is that social welfare will generally not be optimized when the actions of one agent provide an uncompensated stream of benefits (or costs) to one or more other agents. In such cases, government intervention to counteract the externality may be welfare improving.[3] In order to determine the optimal level and form of intervention, the government needs to know the values of the uncompensated benefits or costs involved. The economic approach thus suggests that the quantification of uncompensated ecosystem service flows is most relevant to government decisions, but does not provide a rationale for valuing flows whose costs and benefits are fully internalized by economic agents.

Application of the logic of economics to the illustrative model discussed earlier suggests that valuation of intra-farm ecosystem service flows (i.e. those arising from the actions of an individual farmer and accruing to that same farmer) are of no interest to public policy making.[4] However, in the absence of markets or compensation mechanisms, valuation of inter-farm and extra-agriculture flows between agents may help policy makers to make more efficient decisions. A general review of existing ecosystem services valuation literature (see Section 1), suggests that there has been relatively little attention paid to inter-farm ecosystem service flows.

4 Methods for valuing ecosystem services

Many authors have discussed the values of ecosystem services and approaches to quantify these values (see, for example, Bingham *et al.*, 1995; Costanza *et al.*, 1997; Cork and Shelton, 2000; Guo *et al.*, 2001; Villa *et al.*, 2002; Evan *et al.*, 2003; Turner *et al.*, 2003; Takatsuka *et al.*, 2005; Baskaran *et al.*, 2007; Matero and Saastamoinen, 2007; Fisher and Turner, 2008; Mäler *et al.*, 2009; Raymond *et al.*, 2009; Godden, 2010). A brief summary of the approaches available to value ecosystem services flows is provided in this section.

[3] Provided the costs of the government intervention, including transactions costs, are sufficiently small.

[4] However there may be other reasons that valuing intra-farm ecosystem services could be welfare improving. For example, it may be that farmers systematically under-estimate the value of these services and therefore under-provide them to themselves. Alternatively, it may be that the value of intra-farm ecosystem services is long-run and farmers under-supply them because they are not able to capture their full benefits.

In general, a comprehensive study of ecosystem services values requires the use of non-market and market-based valuation techniques. However, since there are markets in place for agricultural products, market-based valuation techniques are the most appropriate to value ecosystem services flows to agricultural production. Typical market-based valuation techniques include (but are not restricted to) production functions, hedonic pricing, and replacement cost techniques.[5] We describe each of these briefly below with particular emphasis on their applicability to valuing ecosystem services to agricultural production. For more detailed discussion of these techniques, including their limitations, the reader is referred to the references listed in the previous paragraph.

A **production function** (PF) specifies the feasible output of goods and services that can be produced with a given set of inputs (labor, machinery, natural resources, etc. - Tallis and Polasky, 2009). Production function-based valuation approaches are based on the contribution of a given ecosystem service to the production of a commodity that is traded in existing markets.[6]

The PF approach generally consists of a two-step procedure (Hanley and Barbier, 2009: 116-141). The first step is to determine the physical effects of changes in a biological resource or ecosystem service on an economic activity. In the second step, the impact of these changes is valued in terms of the corresponding change in marketed output of the traded activity. Hence, the PF approach requires scientific knowledge about the 'production function' of ecosystem services, to quantify how much of a service is produced, or how changes in ecosystem condition or function will translate into changes in the ecosystem services delivered (Daily *et al.*, 2009; Hanley and Barbier, 2009: 124). Adequate data and understanding about the cause-effect linkages between the ecosystem service(s) being valued and the output level of marketed commodities is often lacking (Daily *et al.*, 2000), complicating the application of PF approaches to value these services.

Replacement cost techniques are based on estimating the costs that would be incurred by replacing ecosystem services with artificial technologies (Garrod and

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[5] Another popular set of market-based valuation techniques are market-price based approaches. These are not discussed here, however, as they are only appropriate when the commodities produced by ecosystem *provisioning* services are sold directly in well-functioning markets (through, for example, game, fish and other wild foods). By definition agricultural production is not directly provided by ecosystem provisioning services.

[6] An extensive discussion of the production function approach is provided by Hanley and Barbier (2009).

Willis, 1999). For example the value of the ecosystem service ‘soil fertility’ could be estimated based on the cost of replacing the service with fertilizer purchases. Another cost-based approach is the mitigation or restoration cost method, which refers to the cost of mitigating the effects caused by to the loss of ecosystem services or the cost of having those services restored (TEEB D0, forthcoming). For example salinity mitigation costs could be used to partially value lower water tables.

Hedonic pricing (HP) techniques can be used to determine how ecosystem services impact agricultural land values. Formally, HP assumes that land values can be completely described by the vector of its component attributes (such as site, neighbourhood, or environmental characteristics - Johnston *et al.*, 2001). The contribution of environmental characteristics - such as soil quality, open space, or biodiversity - to agriculture can be measured if agricultural land prices reflect the quality or quantity of (nearby) ecosystem. Multiple regression analysis allows the researcher to estimate a *hedonic price function* that shows the relationships between land values and environmental characteristics (including ecosystem services) (Tietenberg, 2008: 41; Hanley and Barbier, 2009: 100). The hedonic price function can then be used to calculate the implicit price for each of the statistically significant services. The increase in the price of agricultural lands due to a change in ecosystem services is given by the derivative of the implicit price function with respect to the service considered.

The process for estimating a hedonic price function that relates agricultural land prices to the quantity or quality of ecosystem services provided is reasonably straightforward. Application of HP uses observable market data on prices and property characteristics. However, the assumptions made in HP studies can be problematic in ecosystem services valuation: environmental conditions are assumed to be reflected in property prices, buyers and sellers are assumed to know about the ecosystem services provided at various locations, and buyers are assumed to be able to move to any utility-maximizing position (Hanley and Barbier, 2009: 111).

5 Studies of the value of ecosystem services to agriculture

Notwithstanding the recognized contribution of ecosystem services to agriculture (see Section 2), there are few studies available that have quantified the values of ecosystems services to agricultural production. Examples of available studies are briefly reviewed below. Most ecosystem services studies focus on a single service such as ‘pollination’ or ‘remnant vegetation’.

5.1 Studies valuing extra-agriculture ecosystem service flows

Air Quality

There have been numerous studies that assessed the impacts of air quality changes on agricultural crop production (see, for example, Spash, 1997 for an overview). In these studies, individual farmers receive ecosystem service value flows, affecting their private operations. Crop damages caused by ozone air pollution from motor vehicles were analysed by Murphy et al (1999). The authors used the production function approach (described in the previous section) to estimate the benefits of a reduction in motor-vehicle emissions in the continental United States. A modified version of the AOM8 model of agricultural production and demand was used to predict the welfare effects of changes in agricultural production in the markets for eight major crops: corn, soybeans, wheat alfalfa hay, cotton, gray sorghum, rice and barley. The estimated annual damages to the eight crops from ozone formed by motor-vehicle emissions ranged between $2.0 and $3.3 billion (1990 US$). Estimates varied significantly across agricultural production regions (see, Murphy *et al.*, 1999, Table 3) The impacts of ozone concentrations on grain production in China, Japan and South Korea are summarised by Wang and Mauzerall (2004). Biophysical models and agricultural production functions were used to assess the changes in wheat, rice, corn, and soybeans yields at varying levels of ozone exposure. The total estimated costs of ozone-induced crop production losses ranged from (1990) US$0.24 billion in South Korea to US$1.2 billion in Japan and US$3.5 billion in China. More recent publications (see, for example, Feng and Kobayashi, 2009; or Van Dingenen *et al.*, 2009) have also assessed the impacts of rising ozone concentrations on (global) crop yields, but these studies did not qualify the economic impacts of changed production on the agricultural sector.

Pollination Services

Pollination services are another category of ecosystem services for which a number of valuation attempts have been made. Ricketts *et al.* (2004) estimated the values of pollination services supplied by tropical rainforest to coffee production in Costa Rica. The authors found that forest-based pollinators in two nearby (<1km away) remnants of rainforest could increase coffee yields by 20 percent. Multiplying the increase in yield by the plantation area and the net income per unit of coffee, rainforest pollination services were estimated at approximately US$62,000 per year for one Costa Rican farm. This estimate incorporated both increased income from greater production and increased costs of harvesting the larger crop (Ricketts *et al.*, 2004). Losey and Vaughan (2006) assessed the contribution of native insects to crop production in the USA, and estimate that the total annual value of ecological services provided by native insects is approximately $3.07 billion. A study by Gallai et al. (2009) assessed the contribution of insect pollination to agricultural output worldwide, and claimed that the total economic value of pollination services amounts to approximately Euro 153 billion.

Biological Pest Control

Reviews of ecological services contributing to pest control are provided by, for example, Power (2010), Landis et al. (2008) and Losey and Vaughan (2006). Landis et al. (2008) estimate that the value of biological control of soybean aphid (a major pest in soybean production) is at least $239 million in four US States alone. Estimates by Losey and Vaughan (2006) show that the annual value of pest control services provided by native insects in the whole of the USA is approximately $4.49 billion. Both estimates are based on the assumption that pest control by native insects could reduce production losses as a result of predation by pest species

5.2 Studies valuing inter-farm ecosystem service flows

While there are a large number of studies which estimate the value of ecosystem-related goods such as irrigation water[7], the literature search conducted for this study did not identify any which specifically referred to valuing 'ecosystem service' inputs to agriculture. One reason for this is likely to be the difficulty in distinguishing the value of water from that the irrigation system which supplies it to farms.[8] Similarly, the approaches used to value ecosystem services such as biological pest control, pollination and water supply have typically not allowed separation of the contribution

[7] A typical example of this literature is a paper by Faux and Perry (1999) who applied hedonic price analysis to agricultural land sales in Treasure Valley, Oregon, to estimate the value of irrigation water. The authors estimated a marginal value of $9 (1995 US$) per acre-foot of irrigation water. The study further showed that soil capability had a significant impact on agricultural land prices, indicating that soil class should be taken into account when analysing the values of other ecosystem services for agriculture.

[8] These sort of difficulties are discussed at length by Sagoff (2008).

to service provisions which is attributable to agricultural versus non-agricultural areas and practices (e.g. on-farm natural resource management versus conservation areas). Thus it is difficult to identify the value of extra-agriculture versus inter-farm (or indeed intra-farm) flows.

5.3 Studies valuing intra-farm ecosystem service flows

Miles *et al.* (1998) estimated the costs and benefits of maintaining remnant native vegetation to individual farmers in Victoria and New South Wales. Landholders were interviewed about the direct costs of vegetation management (including fencing; removal of fallen timber; and weed and pest control measures) and the benefits associated with maintaining native vegetation areas on their lands (including increased stock production owing to shelter and shade; increased agricultural production arising from mitigation of land degradation; increased crop production; and production of timber for firewood and fencing - Lockwood and Walpole, 1999: 7). The direct management costs associated with remnant native vegetation management varied from \$16/ha in New South Wales to \$44/ha for Victorian landholders. Various possible benefits of native vegetation on agricultural yields were assessed (see Appendix). The value of these benefits was computed using the gross margins of different activities (such as livestock or crop production) and projected changes in yields resulting from native vegetation management. The average per hectare benefits of remnant vegetation for Victorian landholders were approximately \$46year, while average benefits for New South Wales properties were approximately \$59/year (Miles *et al.*, 1998: 28).

5.4 Studies valuing a combination of ecosystem service flows

A challenge in environmental valuation is to estimate the combined value of the multiple services that ecosystems may provide to agricultural production. Some authors argue that valuation of individual ecosystem services fails to capture the value that a bundle of services provides and may underestimate the value of ecosystem services "as a whole" (Wam, 2010). We discuss two such comprehensive studies below. Note that it is sometimes difficult to distinguish between intra- and inter-farm service provision for the ecosystem services identified.

A study that assessed the value of multiple ecosystem services is described in Sandhu *et al.* (2008). The authors used a combination of valuation techniques (such as market prices, avoided costs, and replacement costs approaches) to estimate economic values for 12 different ecosystem services on arable farming lands in Canterbury, New Zealand: biological control of pests, soil formation, mineralisation of plant nutrients, pollination, services provided by shelterbelts and hedges, hydrological flow, aesthetics, food provision, provision of raw materials, carbon accumulation, nitrogen fixation, and soil fertility. Their findings are summarised in Table 1. As shown in Table 1, there is a considerable range in value estimates, with values varying significantly between organic and conventional fields as well as across districts (see Table 2 in Sandhu *et al.*, 2008).

Table 1 Economic value of ecosystem services on arable farming lands in Canterbury, New Zealand (Source: Sandhu *et al.*, 2008).

Ecosystem service	Economic value*			
	Organic farming		Conventional farming	
Biological control of pests	50	(0–100)	0	(0–0)
Mineralisation of plant nutrients	260	(26–425)	142	(30–349)
Soil formation	6	(0.7–11)	5	(2–9)
Food	3,990	(1,150–18,900)	3,220	(840–14,000)
Raw materials	22	(0–224)	38	(0–298)
Carbon accumulation	22	(0–210)	20	(0–210)
Nitrogen fixation	40	(0–92)	43	(0–92)
Soil fertility	68	(53–82)	66	(54–73)
Hydrological flow	107	(−111–190)	54	(−118–194)
Aesthetic	21	(21–21)	21	(21–21)
Pollination	62	(0–438)	64	(0–455)
Shelterbelts	880	(0–472)	200	(0–617)
Total	4,600	(1,607–19,412)	3,680	(1,263–14,570)

* Means of calculated values in US$/ha/yr, range of mean estimates in parentheses.

In an Australian context, Walpole *et al.* (1996) assessed the impacts of land degradation on various agricultural areas in New South Wales. A production function approach was used to estimate the relationships between land area, labour, fertiliser, and degradation on the gross value of agricultural production (defined as a three year average 1987/88 to 1989/90). Using this approach, the authors calculated the opportunity costs for different types of land degradation (wind erosion, soil acidity, gully erosion, woody shrub infestations, and dryland salinity). These results showed that land degradation has a significant negative impact on agricultural production and incomes. Benefit-cost ratios of investments in soil conservation and land rehabilitation programs were also calculated, showing that—in some cases—the private benefits of conservation (i.e. an increase in agricultural incomes) exceed the (combined private and public) costs, suggesting net social benefits from land rehabilitation programs (Walpole *et al.*, 1996: 202-203).

5.5 Assessment of existing literature and identification of priorities for future research

As discussed in Section 1, the flow of extra-agriculture ecosystem service provision to other parts of society has been the subject of the majority of valuation studies and focus of policy to date. As a consequence there are relatively few studies which estimate values ecosystem service inflows *to* agriculture, and an even smaller set which use Australian data. There also appears to be a particular dearth of work estimating the value of inter-farm ecosystem service flows. Some of the lack of valuation studies on ecosystem services to agriculture may be due to the difficulty of distinguishing between ecosystem services, and human inputs into production (see Section 5.2). Another challenge arises from the absence of a widely accepted definition of what constitutes 'ecosystem services' (see, for example, Boyd and Banzhaf, 2007; Wallace, 2007; Fisher et al., 2009; Dominati et al., 2010; for a discussion). A key challenge is to find a set of indicators that can capture the ways in which ecosystem services affect agriculture (Dale and Polasky, 2007).

6 Conclusion

This literature review conducted for this study has found that the bulk of the existing literature related to ecosystem services and agriculture focuses on service provision by agriculture to the rest of society, or impacts of agricultural production on ecosystems (extra-agricultural flows).However, agricultural production also receives value from ecosystem service flows. These flows may be affected by actions of the individual farmers (intra-farm), their neighbours (inter-farm), or the rest of society (extra-agriculture).

Government support for initiatives such as Landcare may help achieve improved provision of ecosystem service flows between farms (inter-farm flows), as well as provision of ecosystem service flows to the rest of society. However, an assessment of the net benefits of such initiatives is difficult without evidence on the value of inter-farm ecosystem service flows There are a number of methods available to estimate the value of ecosystem service flows to agriculture, but that there have been very few studies which have applied them in Australia. Work is needed that uses these methods to assess the costs and benefits of changing ecosystem service flows to Australian agriculture, to aid the development of more efficient policies

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Appendix. Effects of native vegetation on plant and animal production (Source: Miles et al., 1998)

Research findings	***Region***	***Reference***
Benefits of trees on crops		
An increase in wheat and crop yields in sheltered zones estimated to be between 22% and 47%.	Rutherglen, VIC	Bird *et al*. (1993)
Crop yields from windbreaks increased by 25% - although trees rob the crop for a distance equal to about twice their own height, they shelter a much larger area, extending downwind for at least 15 times their own height.	not specified	Dengate (1983)
An increase in lupin yield by 19-22% was measured when the area of shelterbelt was included in the net yield/ha, and an increase of 27% on the lupin crop area between the windbreaks.	Gibson, southwest WA	Richmond (1992)
Increased yields of 25%-45% were observed in sheltered crops of wheat, oats and lupins compared with unsheltered crops, and yield increases of 20%-100% in horticultural crops.	not specified	Fitzpatrick (1994)
An increased net cereal yield of 15% per annum was attributed to sheltering effects of windbreaks	USA cereal growing areas	Adamson (1988)
Benefits of trees on pasture growth		
A 20-30% higher yield was obtained in protected than in unprotected areas of a farm, with annual benefits of $38 to $66 per ha.	Mainland Australia	Fitzpatrick (1994)
A 20% increase in average annual pasture growth was estimated for protected areas of a farm.	Australia and overseas	Radcliffe (1983)
Gross value of pasture output is at its highest level when the proportion of tree area is at 34%. Note that this figure relates to natural remnants of bushland rather than shelterbelts or windbreaks.	Gunnedah, northwest NSW	Walpole (1998)
Benefits of trees on livestock production		
Over a 5 year trial, a 31% wool production increase and 6 kg (21%) more liveweight was found in sheltered areas compared with sheep without shelter. This equated to an increase of $4 per head if sold in August 1984. The plots sheltered by barriers had 18% more pasture	Armidale, NSW	Lynch & Donnelly (1980), Bird *et al*. (1984), Dengate (1983), Richmond (1992)
From 10 to 16% more lambs present at marking owing to heat load reduction on ewes at joining and lambing, as well as a faster growth rate and more wool from the lambs over their first 16 months of life.	Northern QLD	Wakefield (1989)

Research findings	***Region***	***Reference***
Benefits of trees on livestock production		
Availability of shelter resulted in a 50% reduction in lambing losses (average losses without shelter were 36% for twins and 16% for single births). When shelter was provided, the figures dropped to 18% for twins and 8% for single lambs.	Southwest VIC, eastern highlands	Bird (1981), Dengate (1983)
Lambing losses decreased from 20% to 10% of the lambs born alive in sheltered areas, (with wind speed halved by adequate windbreaks), resulting in a 5% increase in the percentage of lambs at the end of lambing.	Kangaroo Island	Fitzpatrick (1994)
If the lifetime of the shelter (& fencing) is taken to be 44-60 years, over a 60 years total wool production will increase by 29% and $42/ha of sheltered pasture, and total dairy production will increase by 30% (20% improved pasture growth, 10% improved milk production), and $150/ha of sheltered pasture.	VIC	Fitzpatrick (1994)
Winter lamb mortality from birth to 48 hours was greater in an exposed group of single lambs (14%), than a sheltered group (4%). Likewise, mortality rates of twins was 9% in shelter and 28% when exposed.	Western VIC	Squires (1983)
A 27% increase in survival of single lambs was observed in sheltered areas, but no advantage was evident to twins during periods of rain with temperatures ┌ <5°C.	Southern Australia	Bird *et al.* (1984)
Up to 17% increase in dairy milk production was estimated for sheltered areas.	not specified	Blore (1994)
On a day of 27°C, unsheltered cows will have 26% less dairy milk production than shaded stock.	Australia	Fitzpatrick (1994)