The future of farming: the value of ecosystem services in conventional and organic arable land. An experimental approach

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Abstract

In the current work, a novel, experimental 'bottom-up' approach is used to quantify the economic value of ecosystem services (ES) associated with highly modified arable landscapes in Canterbury, New Zealand. First, 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 in contrast with the earlier value transfer methods. Total annual economic value of ES in organic fields ranged from US \$1610 to US \$19,420 ha^{-1} $yr^{-1}$and that of conventional fields from US \$1270 to US \$14,570 ha^{-1} yr^{-1}. The non-market value of ES in organic fields ranged from US \$460 to US \$5240 ha^{-1} yr^{-1}. The range of non-market values of ES in conventional fields was US \$50 – 1240 ha^{-1} yr^{-1}. There were significant differences between organic and conventional fields for the economic values of some ES. Next, this economic information was used to extrapolate and to calculate the total and non-market value of ES in Canterbury arable land. The total annual economic and non-market values of ES for the conventional arable area in Canterbury (125,000 ha) were US \$332 million and US \$71 million, respectively. If half the arable area under conventional farming shifted to organic practices, the total economic value of ES would be US \$192 million and US \$166 million annually for organic and conventional arable area, respectively. In this case, the non-market value of ES for the organic area was US \$65 million and that of conventional area was US \$35 million annually. This study demonstrated that arable farming provides a range of ES which can be measured using field experiments based on ecological principles by incorporating a 'bottom-up' approach. The work also showed that conventional New Zealand arable farming practices can severely reduce the financial contribution of some of these services in agriculture whereas organic agriculture practices enhance their economic value.

Keywords: Arable land; Avoided cost; Economic value; Ecosystem services; Engineered ecosystems; Organic farming.

1 Introduction

Change is inevitable in nature (Disraeli, 1867). And so a long journey from a subsistence existence to abundance and providing food for billions has changed the nature of farming from 5000 BC to 2000 AD (Fussell, 1965; Pretty, 2002; Bruinsma, 2003). Modern agriculture in the last century and currently, is the most advanced form of farming humans have ever practised (Federico, 2005). This has potentially offered to banish hunger. However, at present, the world population is nearly 6.5 billion with 800 million malnourished and is projected to grow to 9 billion by 2050 (Pimentel and Wilson, 2004). All the nations of the world have pledged to achieve the Millennium Development Goals by 2015 that include the eradication of hunger (UN, 2005).

Modern agriculture made it possible to grow more food per unit area as dreamed by Jonathan Swift (1726) in Gulliver's Travels "…and he gave it for his opinion, that whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together". It is presumed that Swift was not aware of the consequences of the science of growing more from the same piece of land using modified seeds and chemical inputs (Norse and Tschirley, 2003). Although, agricultural science has made enormous progress to increase productivity as well as to measure and alleviate some of its negative consequences (Altieri, 1995; Thrupp, 1996; Pretty and Hine, 2001; Tilman et al., 2002; Gurr et al., 2004; Pretty, 2005), the current challenge is to meet the food demands of a growing population by maintaining and enhancing the productivity of agricultural systems without further damaging (and ideally, enhancing) their ES provision (Tilman et al., 2002; Robertson and Swinton, 2005).

One approach to achieving farm sustainability is to utilise nature's services on farmland to increase productivity by replacing most external inputs such as pesticides, fertilisers (Gurr et al., 2004). These nature's services or ecosystem services (ES) support life on earth through a wide range of processes and functions (Myers, 1996; Daily, 1997; Daily et al., 1997b). Overuse of natural resources has led to their decline worldwide and this has resulted in the loss of valuable ES (Reid et al., 2005). Research literature provides information on the economic value of global and regional ES (Costanza et al., 1997; de Groot et al., 2002; Millennium Ecosystem Assessment, 2003) based on 'top-down' approaches, including value transfer (Costanza et al., 1997; Pimentel et al., 1997a; Patterson and Cole, 1999; Anielski and Wilson, 2005; Losey and Vaughan, 2006). Significant amount of information is provided about the differences and similarities of conventional, organic and other land management practices (Higginbotham et al., 1996; Higginbotham et al., 2000; Kaval, 2004). However, there is a lack of detailed understanding of the ES associated with highly-modified or 'engineered'/designed landscapes (Balmford et al., 2002; Robertson and Swinton, 2005) such as arable land and also of changes in ES when agricultural production shifts from conventional to organic methods.

The role of ES in farming is investigated in the current study by calculating its economic value under organic and conventional arable systems in Canterbury, New Zealand by using a 'bottom-up' approach comprising field experiments to quantify ES. It focuses on one sector (arable farming) of an 'engineered' ecosystem (agriculture). The work attributes economic values to a suite of ES which were quantified experimentally, in contrast with earlier evaluations of ES, which have used 'value transfer' approaches. The total economic value of ES in arable land in the province of Canterbury, New Zealand is also calculated here by using 'bottom-up' approach

(Sandhu et al., 2005) and extrapolation using GIS techniques. It also provides information on the change in the economic value of ES in a scenario in which conventional farming shifts to organic farming.

2 Materials and methods

2.1 Study site

The province of Canterbury is the major arable area (dedicated to the production of crops) of New Zealand consisting of 125,000ha (Statistics New Zealand, 2003). The rest of the agricultural land consists of land in horticulture, grasslands, forest plantations, tussock used for grazing, native bush and native scrub. In this work, 29 arable fields were selected in September 2004, distributed over the Canterbury Plains and comprising 14 organic and 15 conventional fields with a mean area of 10 ha. Of the 14 organic fields, seven were certified by AgriQuality, New Zealand (www.agriquality.co.nz) and seven by BIO-GRO, New Zealand (Anon., 1994). Both certifiers are accredited with IFOAM, the International Federation of Organic Agriculture Movements (www.ifoam.org).

A list of arable farmers in Canterbury was obtained from the Foundation for Arable Research, Lincoln (www.far.org.nz) and OPENZ (Organic Products Exporters of New Zealand; www.organicsnewzealand.org.nz) provided the contacts for all organic farmers. There are 490 conventional arable farmers and 25 organic arable farmers in Canterbury (MAF, 2006). The latter were contacted first by a letter, followed by a telephone call and a meeting to collect detailed information about the farming practices and the crops grown, as well as soil type, crop rotation practices etc. Arable organic farms were selected from the above list, one to three fields being selected per farm based on there being an arable crop grown at the time of the survey. After this, conventional arable farms that were within 5 km of the organic fields were contacted. The latter were selected because they were growing similar crops and had similar soil types. Codes O1-O14 were assigned to the organic fields and C1-C15 to the conventional ones. The crops were wheat, barley, carrots for seed, process peas, field beans, white clover for seed and onions.

2.2 Field assessment of ES on arable fields

The assessment of ES associated with arable land in this work follows the typology provided by Reid et al. (2005). The work is based on the premise that developing a deeper scientific understanding of the complex relationships between 'engineered' ecosystems and the types of ES they affect will provide a better informed basis for ecosystem service management in agricultural landscapes (Farber et al., 2006). An example is conventional arable farming that involves high inputs in the form of pesticides can suppress the ability of farmland to provide a key ES, i.e., biological control of pests (Gurr et al., 2004; Sandhu et al., 2005). However, organic farmers depend to a greater extent upon natural pest control services to keep pest populations below economic threshold levels. This information is being used to practise 'ecological engineering' to enhance this key ES in conventional and organic farmlands (Gurr et al., 2004).

ES associated with arable farming in Canterbury, New Zealand were assessed by conducting field experiments using 'bottom-up' assessment methods (Sandhu et al., 2005; 2007), i.e., by conducting a series of field experiments to assess each ES.

Economic value of each ES was then calculated for each of the 29 fields based on US dollar for the year 2005. Total economic value of ES for each field was calculated by summing the total of all the individual ES values measured. These were: biological control of pests, ES_1; soil formation, ES_2; mineralisation of plant nutrients, ES_3; pollination, ES_4; services provided by shelterbelts and hedges, ES_5; hydrological flow, ES_6; aesthetics, ES_7; food, ES_8; raw material, ES_9; carbon accumulation, ES_{10}; nitrogen fixation, ES_{11}; soil fertility, ES_{12} (Eq.1) which will be detailed on the following pages.

$$ES_{total} = \sum ES_n = \sum ES_{market} + \sum ES_{non\text{-}market} \quad \text{(Eq.1)}$$

The market value of ES included the economic value of product and raw material produced (Eq. 2). These are the only two which are products (grains, seed, peas for processing, onions, straw bales) traded by farmers in the market. The rest of the ES comprised non-market values (Eq. 3) (McTaggart et al., 2003). These market and non-market values are the two components of total economic value of ES (Eq. 1).

$$ES_{market} = ES_8 + ES_9 \quad \text{(Eq. 2)}$$

$$ES_{non\text{-}market} = \sum ES_{1\text{-}12} - \sum ES_{8\text{-}9} \quad \text{(Eq.3)}$$

Assuming a shift of half of the conventional area to organic, the change in the value of ES for Canterbury arable land is calculated by using the value of organic and conventional areas (Eq. 4).

$$\Delta ES = \sum ES_{organic} - \sum ES_{conventional} \quad \text{(Eq.4)}$$

ES here include goods and services (Daily, 1997) that are consumed and/or produced on arable land (Cullen et al., 2004). The methods used to estimate their economic value in each of the 29 fields are described below.

2.2.1 Biological control of pests

The process of pest removal by soil-surface predators (one of many natural-enemy guilds; Root, 1967) was assessed in the current work by using real pests and 'prey surrogates' to assess 'predation rate' (detailed methods in Sandhu et al., 2007); this provided information on one subset of biological control carried out by natural enemies in arable farmland, that of soil-surface predation of aphids and of eggs of the carrot rust fly (*Psila rosae* Fab.), using egg 'surrogates' in the latter case.
Predation rate was calculated from the removal of 'prey' types per 24 h period during spring (November 2004) and summer (January 2005) study periods. In each period, two prey densities for each prey type were assessed. The aphid densities were selected in November 2004 ($1/25cm^2$ and $4/25cm^2$) and January 2005 ($4/25cm^2$ and $10/25cm^2$) based on previous studies in arable land (Ekbom *et al.*, 1992; Winder, 1990; Winder *et al.*, 1994). Two densities of blowfly eggs were used, based on the literature on the abundance of carrot rust fly egg populations. Published egg densities are in the range of $3–8/25cm^2$ (Burn, 1982) in the field.

Predation rate was assessed using 'prey surrogates' comprising $25cm^2$ water-proof sandpaper squares pinned to the soil surface by wooden toothpicks (Merfield *et al.*, 2004; Frank *et al.*, 2007). Live aphids (dorsal side uppermost) were glued onto the sandpaper (P150, Norton) using 3M repositionable glue in a grid pattern with 1cm between aphids. The blowfly eggs were not glued onto the surface but were placed in a similar pattern. The sandpaper sheets were pinned at the field boundary, the field centre and midway between the two in two transects (5m apart) in each field and had a 225 cm^2 metal plate supported 10cm above to protect them from rain.

Predation rate was calculated from the removal of 'prey' types per 24 h period during the two study periods. At each site, each type of 'prey' at both densities (minimum and maximum) were positioned 1m apart at the locations described above. For each prey type for each period, overall mean prey disappearance was calculated separately from the means of the two prey densities.

The economic value of this 'background' (i.e., unmanipulated) biological control of aphids and the fly was estimated by using avoided cost (AC) (de Groot et al., 2002; Wilson et al., 2004) of pesticides, based on their cost in New Zealand (conventional farmers' spending to control aphids; Chapman, 2004), and total avoided cost (TAC) of pesticides, described by Sandhu et al. (2006).

2.2.2 Soil formation

Soil formation is an important ecosystem service provided by soil biota (Breemen and Buurman, 2002). Earthworms are the most important component of this soil in this respect and in the maintenance of soil structure and fertility (Stockdill, 1982; Lee, 1985; Edwards, 2004). Earthworm populations in each of the selected fields were assessed to estimate the quantity of soil formed $ha^{-1}yr^{-1}$ (Sandhu et al., 2005).

The economic value of earthworms in soil formation was calculated based on the assumptions that the mean biomass of an earthworm is 0.2g (Fraser, 1996) and that one tonne of earthworms forms 1000 kg of soil $ha^{-1}yr^{-1}$ (Pimentel et al., 1995). The value of purchased top-soil in New Zealand is US \$23.60 $tonne^{-1}$ (City Care, 2005; www.citycare.co.nz).

2.2.3 Mineralisation of plant nutrients

Organic matter breakdown by soil micro-organisms and invertebrates (Brady and Weil, 2004) is one of the most important services provided by soil. Through this process, plant residues are broken down, releasing previously organically-bound nutrients such as nitrogen for use by plants (Edwards and Arancon, 2004). The rate and economic value of mineralisation of plant nutrients was assessed in all the fields using bait-lamina probes (Kratz, 1998; Torne, 1990) as described by Sandhu et al. (2005). The economic value of plant nutrient mineralisation provided by soil micro-organisms and invertebrates is assessed using data on mineralisation of organic matter obtained from field experiments. Total organic matter content in the fields was estimated using the total weight of soil (obtained from bulk density at 10cm depth) and total nitrogen obtained from soil testing results. It was based on the assumptions that the ratio of organic matter to nitrogen is 20:1 (Brady, 1990). The amount of organic matter mineralised in each field was calculated from this by using nutrient mineralisation rate from the bait-lamina probes. The total amount of nitrogen mineralised was estimated from this and valued at the equivalent price of N kg^{-1} (US \$0.84 kg^{-1}; Ravensdown, 2005) providing the economic value of nutrient mineralisation.

2.2.4 Pollination

The transfer of pollen grains from anthers to stigmas is pollination (Free, 1970) and is accomplished by insects (bees, wasps, beetles, flies, moths), vertebrates (birds, bats), wind, water. The dependence of important food crops on pollination makes this service crucial in agriculture. Earlier work provides information on the value of pollination services (Matheson, 1987; Pimentel et al., 1997a; Kremen et al., 2002; Ricketts et al., 2004). Extensive use of insecticides in agriculture, and habitat loss are leading to a decline of this ES (Nabhan and Buchmann, 1997, 1998) which is worth US $200 billion annually in cropland worldwide (Pimentel et al., 1997a). The value to New Zealand is estimated to be in the range of US $1.4-2 billion annually (Matheson, 1987; Matheson and Schrader, 1987). New Zealand arable land produces high-value seed crops including clovers and requires bees for pollination. The grain and seed industry in New Zealand is worth US $300 million annually (www.maf.govt.nz/mafnet/rural-nz/overview/nzoverview012.htm). To provide increased pollination services for this industry, farmers rent honey-bee hives every year, adding to the costs of production. Any major reduction in populations of pollinators will lead to severe losses to the seed industry. This ES therefore plays a vital role in the economy of New Zealand, especially of Canterbury province.

The economic value of this service was estimated by using the direct cost incurred by farmers to buy pollination service by hiring honey bee-hives for the period of pollination. The economic value of this ES is considered as zero for the fields where the crops do not require pollinators.

2.2.5 Services provided by shelterbelts and hedges

Shelterbelts are the barriers usually made up of one or more rows of trees or shrubs planted around the edges of fields on farms. Shelterbelts on farmland benefit crops and farm animals by improving crop yields and quality (Sturrock, 1969; Kort, 1988). This is because of reduced wind speed, minimising soil erosion, improving microclimate and giving higher levels of soil moisture (Kort et al., 1988). They also provide shelter and pollen/nectar resources to pollinators (Norton, 1988) and to natural enemies that perform biological control of pests and diseases (Thomas et al., 1991; Landis et al., 2000; de Groot et al., 2002; Heal and Small, 2002;). In Canterbury, New Zealand, good shelter can increase crop yield by up to 35 per cent (Sturrock, 1981).

The potential permeability was quantified by digital images of three sections of each shelterbelt; each section measured 2m long and 1.5 m high. These digital images were analysed automatically to give the percentage of the image that was occupied by leaves, branches, fence posts, etc. using the hardware and software described by Varley et al. (1994). The mean percentages of the three sections that were dark in the images were calculated and used to determine the permeability percentage of each shelterbelt. In Canterbury, New Zealand, shelterbelts are usually on the north-west side of the fields to protect crops, animals and soils as most of the potentially destructive winds come from that direction (Sturrock, 1969). Based on the study by Sturrock (1981), the increased yield derived from shelterbelt was estimated for each crop type for each field depending upon the permeability of shelterbelt. The value of that increased yield is the economic value of services provided by shelterbelts and hedges in each of the 29 fields.

2.2.6 Hydrological flow

Hydrological flow in the plant-soil-atmosphere plays a critical role in arable farming. The hydrological cycle renews the earth's supply of water by distilling and distributing it (Gordon et al., 2005).

The economic value of this service on fields is calculated by estimating the input (based on rainfall and irrigation data of each of the 29 fields) and output of water (water use by crops in each of the 29 fields; Pimentel et al., 1997b) and the amount of water that is recharged into the ground in each of the fields (Allen et al., 1998). The cost of applying water is calculated at the rate of US $33.00 per 75 mm water ha^{-1} (Farm Management Group, 2006). The water recharged into the ground is estimated and valued from the cost of applying water and this gives the economic value of this ES for each field.

2.2.7 Aesthetics

Cultural services contribute to the maintenance of human health and well-being by providing recreation, aesthetics and education (Costanza et al., 1997; de Groot et al., 2002; Reid et al., 2005). Agriculture provides these services as some farmers conserve field-boundary vegetation or enhance landscapes by planting hedgerows, shelterbelts or trees. Arable farms in Canterbury are characterised by highly managed shelterbelts. Some farms also provide accommodation and recreational activities for family members as well as for national and international visitors.

There was no direct method available to estimate the economic value of this ES. However, Takatsuka et al., 2005 have estimated the aesthetic value of improved landscape on New Zealand arable farms to be US $ 21 ha^{-1} using the contingent valuation method. This value is used here as a standard value of aesthetic services provided by New Zealand arable farms.

2.2.8 Food

Modern agriculture is feeding the current population of more than 6 billion people worldwide and it is estimated that with an increase in the population to 9 billion by 2050, global food demand will double (Pimentel and Wilson, 2004). Agriculture has played a major role in shaping the environment as well as the economy of the world. Although natural ecosystems are sources of a considerable amount of wild foods, including fish, the needs of the growing population will be largely fulfilled by agriculture. The economic value is calculated here by the farm gate prices of the products (grains, beans, seed, peas and onions) for each field.

2.2.9 Raw materials

Agriculture also produces raw materials in the form of fibre, fuel wood, pharmaceuticals and industrial products (Daily et al., 1997b). Arable farming in Canterbury, New Zealand produces straw, fuel wood, medicinal plants etc., as well as food and seeds. The economic value has been calculated here by the farm gate prices straw bales as this was the only secondary by product produced in studied fields in Canterbury.

2.2.10 Carbon accumulation

Carbon accumulation in soils is being considered as an alternative to offset the emissions of carbon dioxide in the atmosphere by industry and other human activities. Practices such as crop residue management, zero or minimum tillage or conservation agriculture can increase carbon accumulation in soils (Garcia-Torres et al., 2003; Magdoff and Weil, 2004).

The amount of crop and root residue was estimated (crop residue is 1.5 times the crop grain yield and 40% of this is carbon; Johnson et al., 2006) and then amount of carbon accumulated by tissue in the soil was calculated based on soil carbon analysis by using the Walkley-Black chromic acid wet oxidation method (McLeod, 1973). This was used to calculate the economic value of carbon accumulation in each field. The economic value of carbon accumulated by crop and root residue is estimated based on US $ 21 tonne^{-1} of carbon accumulated (www.niwascience.co.nz). This is the price at which the New Zealand Government would begin carbon trading.

2.2.11 Nitrogen fixation

Nitrogen fixation by growing legumes is a widely used practice in arable farming world wide. Clovers are common features in Canterbury arable rotations because of this nitrogen fixation. These are used as a restorative phase between phases of crop cultivations. The economic value of nitrogen fixed by different crops was estimated by the amount of nitrogen fixed per hectare which was then valued at the unit price of urea (US $0.84 kg^{-1}) in New Zealand.

2.2.12 Soil fertility

The ability of a soil to provide nutrients to plants is known as soil fertility (Brady, 1990). In this study, an economic value is attributed to the ability of soil to provide nitrogen.

Nitrogen is one of the main requirements of all crops. Of the total nitrogen present in soil, the amount in available forms in the soil is small. Under natural conditions 2% yr^{-1} (Brady, 1990) of this nitrogen becomes available to plants. The amount of nitrogen available to the crops next year was estimated for each field based on soil nutrient analysis that gives the total nitrogen percentage. This information was used to calculate the economic value of nitrogen availability in each field valued at the unit price of urea (see above).

2.3 Economic valuation and spatial mapping of ES for Canterbury arable land

The total economic value of ES for Canterbury arable land was calculated by extrapolating ES values compiled for the 29 study fields to the total arable area (125,000 ha) in the Canterbury province, stratified by the nine administrative districts within Canterbury (Fig. 1). Each of the districts had a different suite of crops. The market and non-market values of ES were calculated from the means of the organic and conventional fields. These values were used to calculate the total ES value in each of the nine districts based on the total area of each crop, by district, derived from New Zealand agricultural census data (Statistics New Zealand, 2003). ES values were then recalculated under the scenario that half the arable area of Canterbury was converted to an organic (Anon., 1994) regime. Based on this scenario, the predicted change in the economic value of ES for the whole province was estimated using market and non market values for each organic field, by crop type.

Next, total and non-market ES values for both the full conventional and half conventional/half-organic scenarios were spatially extrapolated and mapped across Canterbury using a spatial analysis within the ArcGIS 9.0 (ESRI, 2004) Geographic Information System (GIS) software and displayed at a 10x10 km grid resolution. This exercise was carried out in several steps:

1. A GIS layer containing up-to-date agricultural data for farm properties in Canterbury (AgriBase™ Farms Data, 2005) was used to calculate the overall proportion of arable farming currently occurring on each farm.
2. A 10x10 km resolution polygon grid and a GIS layer demarcating district boundaries were spatially combined with the AgriBase dataset. This resulted in a spatial layer containing farm polygons with associated data, such as: farm and grid cell identification, district name, total area, and proportion of arable farming.
3. The effective area of each of the five crop types occurring within each farm, by district, was calculated by multiplying the overall proportion of each crop type censused within each district (Statistics New Zealand, 2003) by the total area per farm polygon derived in step 2.
4. Total and non-market ES values were calculated for each farm polygon by multiplying the per-hectare ES values per crop type, as quantified via the field study, by the total effective area of each crop type occurring on each farm.
5. ES values were summarised and mapped by grid cell.
6. A similar process was carried out to map ES under the scenario of converting half of Canterbury's conventional arable farm areas to organic-based farming. To do this, half of the total area per crop type occurring on each farm (step 3) was instead multiplied by field-derived organic ES values at step 4. The percent

change in total and non-market ES relative to the full conventional scenario was calculated and mapped in the ArcGIS 9.0.

3 Results

Total economic value of ES in organic fields ranged from US \$1610 to US \$19,420 $ha^{-1} yr^{-1}$ and that of conventional fields from US \$1270 to US \$14,570 ha^{-1} yr^{-1} (Fig. 1). The total non-market value of ES ranged from US \$460 to US \$5240 ha^{-1} yr^{-1} in organic fields and from US \$50-1240 ha^{-1} yr^{-1} in conventional ones (Fig. 1). There were significant differences between organic and conventional fields for the economic values of 3 ES (biological control of aphids; $p<0.001$ and fly eggs; $p<0.001$ and services provided by shelterbelts and hedges; $p<0.05$ (Table 1). The non-market economic value of ES was significantly greater ($p<0.05$) in organic fields than in conventional ones.

3.1 Economic value of ES in Canterbury arable land by district

The total and non-market economic value of ES for conventional arable crops in Canterbury was US \$332 million and US \$71 million annually, respectively (Table 2). If half the area is converted to organic farming in Canterbury, the total economic value of ES for organics is US \$192 million and US \$166 million annually for the conventional area (Table 3). The corresponding non-market economic value of ES are US \$65 million and US \$35 million for organic and conventional arable area, respectively (Table 3).

Assuming the minimum and maximum values of total and non-market values of organic and conventional fields, the economic value of Canterbury arable land was calculated. The range of total economic value for the 125,000 ha area (conventional) is from US $0.15 to 1.8 billion and for the non-market values it is US $6 to 154 million annually. If half the area is converted to organics, the total economic value for the organic part ranged from US $0.1 to 1.2 billion (conventional US $0.08 to 0.9 billion). For the non-market component it was US $28 to 227 million (organics) and from US $3 to 77 million (conventional).

3.2 GIS mapping of the value of ES across Canterbury

Under the fully-conventional scenario, the GIS-based analysis produced an estimated total ES for Canterbury of *c.*US $468 million annually, with non-market ES accounting for *c.* US $100 million of the annual total. With a conversion to a half-organic scenario, the estimated total Canterbury ES was *c.* US $505 million annually, with non-market ES comprising US $142 million of total annual ES This was an increase in total and non-market ES of US $37 million and US$ 42 million, respectively.

Calculated and mapped at the 10 x 10 km grid cell resolution, the total conventional arable ES values for Canterbury ranged from less than US $10,000 to over US $15 million annually (Fig. 2). Depending on the grid cell, the spatial pattern of total conventional ES across Canterbury was highly heterogeneous, reflecting the interspersion of arable with pastoral farms across this region; the highest levels of total ES were found in the Canterbury plains region of the Selwyn and Ashburton districts, while the Banks Peninsula, Hurunui, and Mackenzie districts contributed the least to total Canterbury ES (Fig. 2). Non-market conventional arable ES for each grid cell in the region ranged from less than US $1,000 to over US $4 million annually; the spatial distribution of this non-market ES generally mirrored that for total ES, with the exception of several grid cells in the Timaru, Ashburton, Selwyn, and Waimakariri districts (Fig. 3).

Under the ‘half-organic’ scenario, there was a 1% to 12% increase in total Canterbury ES based on the GIS analysis (Fig. 4). Spatially, the extent of increase in total ES varied by district, with a trend of increasing ES from northeast to southwest Canterbury (Fig. 4). By comparison, results suggest that a 1% to 45% increase in non-market ES would occur in Canterbury as a result of a conversion of half of the conventional arable farms to organic practices, with the exception of the Banks Peninsula district which would experience a predicted decrease in non-market ES (Fig. 5). Spatially, relatively large gains of > 25% in non-market ES would occur across most of Canterbury, with exception of the Mackenzie, Christchurch, and Banks Peninsula districts (Fig. 5).

4 Discussion

‘Engineered’ ecosystems such as arable farmland use ES as ‘subsidies’ provided by nature and facilitated by governments to generate food and raw materials. Most of these services remain outside routine decision making, are in a state of decline and above all are not paid for or traded (Daily, 1997; Costanza, 1998; Reid et al., 2005; Heal et al., 2005). This approach to ES will have to change to make farms more sustainable and to be able to feed the estimated 9 billion human population by 2050 (Tilman et al., 2002; Robertson and Swinton, 2005). Farmers need to modify their role from being primarily producers of food and fibre to being managers and providers of a range of ES (Porter and Steen, 2003).This awareness has led to an increasing interest in the economic value of ES in agriculture. The current study was designed to quantify this in arable land experimentally under different land management practices using a ‘bottom-up’ measurement approach, which is in contrast to earlier studies that have used ‘top down’ techniques. Costanza et al. (1997) estimated aggregate values of ES for each biome using broad scale value transfer methodologies (Wilson et al., 2004). In the Costanza study, cropping land did not receive much consideration, as only three ES were evaluated for it, and the remaining potential services were considered either negligible or not to occur. One plausible reason for this conclusion is that the valuation was heavily weighted towards natural ecosystems rather than ‘engineered’ ones, which are actively modified by humans (Balmford et al., 2002). These ‘engineered’ or designed ecosystems do, however, provide a range of important ES (Cullen et al., 2004; Takatsuka et al., 2005). Current intensive and high-input agricultural practices affect the ability of these systems to provide some ES, which in the longer term can offset their ability to produce large amounts of food and fibre (Tilman et al., 2001). A key future challenge is to improve the understanding of biological processes and environmental consequences of agricultural intensification, so that they can be managed and enhanced to ensure sustained food production for the growing human population (Tilman et al., 2002; Robertson and Swinton, 2005).

The total economic value of ES in Canterbury arable land was estimated by using experimentation and extrapolation from field to province using both direct numeric and GIS-based extrapolation methods. The arable economy of Canterbury takes into consideration the market value of ES (food and raw materials) but the remaining of the ES are never considered as a part of general accounting and remain outside economic decision making (Heal et al., 2005). This approach used here demonstrates the value of non-market ES at the field level in addition to the usual market value of ES in arable land.

This exercise was necessary because of the increasing importance of the economic value of ES in 'engineered' landscapes (Matson et al., 1997; Gurr et al., 2004; Kremen, 2005; Robertson and Swinton, 2005). Evidence of ecological disturbances sometimes does not generate much attention unless the evidence includes dollar values (Daly, 1998). The information generated in the present work can be used by researchers and policy makers to increase ecological and economic wealth in a sustainable way and a greater awareness of the ES provision of farmland can contribute to the 'future-proofing' of agriculture in an increasingly uncertain food-production environment (Kristiansen et al., 2006).

Some researchers argue that the market value of the products in agriculture also represents the value of those ES which help in its production (Heal and Small, 2002). But unless it is known how much each of these services is contributing towards the production of food, it is difficult to plan for their maintenance and conservation (Daly, 1998). In the present study, the value of individual ES on arable farmland was estimated (as well as the food and fibre values) and this forms the non-market value of ES. These are the 'shadow prices' (Little and Scott, 1976) of ES which are not normally exchanged in markets but are traded off against each other in agricultural landscapes. The present work demonstrates that conventional farming results in a decline in some of these services compared with organic farming, with an associated lower economic value for ES in conventional farms. The current work put forward a new approach to look at the future of farming by considering ES as an important factor in production and indicates that it should be included in decisions concerning the future of agricultural production (Reid et al., 2005).

The economic value of ES in Canterbury arable land were calculated for current practices and also by assuming half of the arable area shifts to organic farming. It is reasonable to provide such estimates in view of the global trends of organic agriculture (increasing 20 % yr^{-1}; Willer and Yussefi, 2006). This increase in area will result in an increased supply of organic products and this may possibly bring down the market value of that produce. However, it is expected that the non-market value of ES will increase as ES become scarce in future (Costanza et al., 1997; Batabyal et al., 2003).

This work also demonstrates the utility of GIS-based methods in using a spatial approach to the distribution of ES across a region. The main benefit of this is that district-level census data on arable crop composition can be spatially extrapolated and visualised, directly reflecting the spatial distribution of farms, their sizes and management activities, and the resultant impact of these factors on ecosystem services. The differences in total and non-market ES values calculated via GIS, as compared with direct numerical extrapolation, reflects the impact of using spatially-explicit farm data to carry out ES calculations for a given region. Ultimately, the GIS approach facilitates the exploration and visualisation of how potential changes in management practices and crop types may result in gains or losses of future ES, thereby providing a useful tool for decision-making, discussion and policy.

5 Conclusion

The benefits of ES in ‘engineered’ ecosystems are substantial as demonstrated by their economic value in arable land in Canterbury, New Zealand. The ecological and economic value of some of the ES can be maintained and enhanced on arable farmland by adopting sustainable practices such as organic farming (Lampkin and Measures, 2001; Sandhu et al., 2005; Kristiansen et al., 2006). This study makes clear that arable farmland provides a range of ES which can be measured using field experiments based on ecological principles by incorporating a ‘bottom-up’ approach. It provides information for policy and decision makers to consider the financial contribution of different farming practices towards the sustainability of arable farming.

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References

AgriBase™ Farms Data, 2005. AgriQuality Ltd., Auckland, New Zealand.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Rome.

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

Anielski, M., Wilson, S., 2005. Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystem Services. Canadian Boreal Initiative, Canada. http://www.borealcanada.ca/pr_docs/Boreal_WealthReport_Nov_2005.pdf

Anonymous, 1994. Certified BIO-GRO Organic Production Standards, Northcote, Auckland, New Zealand, Biological Producers and Consumers Council (Inc.)

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rossendo, S., Roughgarden, J., Trumper, K., Turner, R.K., 2002. Economic reasons for saving wild nature. Science 297, 950–953.

Batabyal, A.A., Kahn, J.R., O'Neill, R.V., 2003. On the scarcity value of ecosystem services. Journal of Environmental Economics and Management 46, 334-352.

Brady, N.C., 1990. The Nature and Properties of Soils. Macmillan Publishing Company, New York.

Brady, N.C., Weil, R.R., 2004. Elements of the Nature and Properties of Soils. Prentice Hall, New Jersey.

Breemen, N.V., Buurman, P., 2002. Soil Formation. Kluwer Academic Publishers, Dordrecht.

Bruinsma, J., 2003. World agriculture: Towards 2015/2030. Earthscan Publications Ltd., London.

Burn, A.J., 1982. The role of searching efficiency in carrot fly egg loss. Annals of Applied Biology 101, 154–159.

Chapman, B., 2004. Insect pest control. In: Fleming, P.H. (Ed.), Farm Technical Manual, Farm Management Group, Lincoln University. The Caxton Press, Christchurch.

City Care, 2005. Rock and Landscape Supplies, Christchurch, New Zealand.

Costanza, R., 1998. The value of ecosystem services. Ecological Economics 25, 1-2.

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. Lincoln University, Agribusiness and Economics Research Unit, Discussion Paper 151, 84–91.

Daily, G.C., 1997. Introduction: what are ecosystem services? In: Daily, G.C. (Ed.), Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington DC, pp. 1-10.

Daily, G.C., Matson, P., Vitousek, P., 1997a. Ecosystem Services Supplied by Soil. In: Daily, G.C. (Ed.), Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington DC, pp. 113-132.

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., 1997b. Ecosystem services: benefits supplied to human societies by natural ecosystems.

Issues in Ecology 2, pp. 18.

Daly, H.E., 1998. The return of Lauderdale's paradox. Ecological Economics 25, 21-23.

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

Disraeli, B., 1867. Speech on Reform Bill of 1867, Edinburgh, Scotland.

Edwards, C.A., 2004. The importance of earthworms as key representatives of the soil fauna. In: Edwards, C.A. (Ed.), Earthworm Ecology, CRC Press, Florida, pp. 3-11.

Edwards, C.A., Arancon, N.Q., 2004. Interactions among organic matter, earthworms, and microorganisms in promoting plant growth. In: Magdoff, F., Weil, R.R. (Eds.), Soil Organic Matter in Sustainable Agriculture. CRC press, Florida, pp. 327-376.

Ekbom, B.S., Wiktelius, S., Chiverton, P.A., 1992. Can polyphagous predators control the bird cherry-oat aphid (*Rhopalosiphum padi*) in spring cereals? A simulation study. Entomologia experimentalis et applicata 65, 215–223.

ESRI, 2004. ArcGIS software, version 9.0. Environmental Systems Research Institute Inc., Redlands, California, USA.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson, C., Kahn, J., Pincetl, S., Troy, A., Warren, P., Wilson, M.A., 2006. An ecosystem services framework that links science, values, and environmental decision making. Bioscience 56, 121-133.

Farm Management Group, 2006. Financial Budget Manual, Lincoln University. The Caxton Press, Christchurch.

Federico, G., 2005. Feeding the World: An Economic History of Agriculture, 1800-

2000. Princeton University Press, Princeton.

Frank, S.D., Wratten, S.D., Sandhu, H.S., Shrewsbury, P.M., 2007. Video analysis to determine how habitat strata affects predator diversity and predation of Epiphyas postvittana (Lepidoptera: Tortricidae) in a vineyard. Biological Control 41, 230-226.

Fraser, P.M., Williams, P.H., Haynes, R.J., 1996. Earthworm species, population size and biomass under different cropping systems across the Canterbury Plains, New Zealand. Applied Soil Ecology 3, 49–57.

Free, J.B., 1970. Insect Pollination of Crops. Academic Press, London.

Fussell, G.E., 1965. Farming Technique from Prehistoric to Modern Times. Pergamon Press, Oxford.

Garcia-Torres, L., Benites, J., Martinez-Vilela, A., Holgado-Cabera, A., (Eds.), 2003. Conservation Agriculture. Kluwer Academic Publishers, Dordrecht.

Gordon, L.J., Steffen, W., Jonsson, B.F., Folke, C., Falkenmark, M., Johannessen, A., 2005. Human modification of global water vapour flows from the land surface. Proceedings of the National Academy of Sciences USA 102, 7612-7617.

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.

Heal, G.M., Barbier, E.B., Boyle, K.J., Covich, A.P., Gloss, S.P., Hershner, C.H., Hoehn, J.P., Pringle, C.M., Polasky, S., Segerson, K., Schrader-Frechette, K., 2005. Valuing Ecosystem Services: Towards Better Environmental Decision-Making. The National Academic Press, Washington DC.

Higginbotham, S., Noble, L., Joice, R., 1996. The profitability of integrated crop management, organic and conventional arable regimes. In: *Rotations and cropping systems*. Aspects of Applied Biology 47, 327-333.

Highinbotham. S., Leake, A.R., Jordan, V.W.L., Ogilvy, S.E., 2000. Environmental and ecological aspects of Integrated, organic and conventional farming systems. Aspects of Applied Biology 62, 15-20.

Johnson, J.M.F., Allmaras, R.R., Reicosky, D.C., 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. Agronomy Journal 98, 622-636.

Kaval, P., 2004. The profitability of alternative cropping systems: a review of the literature. Journal of Sustainable Agriculture 23, 47-65.

Kort, J., 1988. Benefits of windbreaks to field and forage crops. Agriculture, Ecosystems and Environment 22/23, 165-190.

Kort, J. Collins, M., Ditsch, D., 1988. A review of soil erosion potential associated with biomass crops. Biomass and Bioenergy 14, 351-359.

Kratz, W., 1998. The bait-lamina test: general aspects, applications and perspectives. Environmental Science and Pollution Research 5, 94–96.

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

Kremen, C., Williams, N.M., Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences USA 99, 16812-16816.

Kristiansen, P., Taji, A., Reganold, J., 2006. Organic agriculture: opportunities and challenges. In: Kristiansen, P., Taji, A., Reganold, J. (Eds.) Organic Agriculture: A Global Perspective. CSIRO Publishing, Australia, pp. 421-441.

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

Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology 45, 175-201.

Lee, K.E., 1985. Earthworms: their Ecology and Relationships with Soils and Land Use. Academic Press, Sydney.

Little, I.M.D., Scott, M.FG., 1976. Using Shadow Prices. Heinemann Educational, London.

Losey, J.E., Vaughan, M., 2006. The economic value of ecological services provided by insects. BioScience 56, 311-323.

MAF, 2006. Arable Monitoring Report. New Zealand Ministry of Agriculture and Forestry, Wellington.

Magdoff, F., Weil, R.R., (Eds.) 2004. Soil Organic Matter in Sustainable Agriculture. CRC press, Florida

Matheson, A., 1987. The value of honey bees to New Zealand. The New Zealand Beekeeper 194, 29.

Matheson, A., Schrader, M., 1987. The value of honey bees to New Zealand's primary production. Ministry of Agriculture and Fisheries, New Zealand.

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

McLeod, S. 1973. Studies on wet oxidation procedures for the determination of organic carbon in soils. CSIRO Division of Soils, *Notes on Soil Techniques* 73-79.

McTaggart, D., Findlay, C., Parkin, M., 2003. Economics. Pearson Education, Australia.

Merfield, C.N., Wratten, S.D., Navntoft, S., 2004. Video analysis of predation by polyphagous invertebrate predators in the laboratory and field. Biological Control, 29, 5-13.

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

Myers, N., 1996. Environmental services of biodiversity. Proceedings of the National Academy of Sciences USA 93, 2764–2769.

Nabhan, G.P., Buchmann, S.L., 1997. Services provided by pollinators. In: Daily, G.C. (Ed.) Nature's Services: Societal Dependence on Natural Ecosystems Island Press, Washington, pp. 133-150.

Nabhan, G.P., Buchmann, S.L., 1998. Forgotten Pollinators. Island Press, Washington.

Norse, D., Tschirley, J., 2003. Agriculture and the environment: changing pressures, solutions and trade-offs. In: Bruinsma, J. (Ed.) World Agriculture: Towards 2015/2030. An FAO Perspective. Earthscan Publications and Food and Agriculture Organization of the United Nations, London, pp. 331-356.

Norton, R.L., 1988. Windbreaks: benefits to orchard and vineyard crops. Agriculture, Ecosystems and Environment 22/23, 205-213.

Patterson, M., Cole, A., 1999. Assessing the value of New Zealand's biodiversity. Massey University, School of Resource and Environmental Planning, Occasional Paper no. 1.

Pimentel, D., Wilson, A., 2004. World population, agriculture and malnutrition. World Watch 17, 22–25.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117–1125.

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

Pimentel, D., Houser, J., Preiss, E., White, O., Fang, H., Mesnick, L., Barsky, T., Tariche, S., Schreck, J., Alpert, S., 1997b. Water resources: agriculture, the environment, and society. Bioscience 47, 97-106.

Porter, J., Steen, E., 2003. European farmer of tomorrow-a provider of service. In: Proceedings of the International conference on ecosystem services in European agriculture – theory and practice, Falkenberg, Sweden.

Pretty. J.N., 2002. Agri-Culture: Reconnecting People, Land and Nature. Earthscan Publishing Ltd., London.

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: a Summary of New Evidence. 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/CESOccasional Papers/SAFErepSUBHEADS.htm

Ravensdown, 2005. National Price List, Ravensdown Fertiliser Co-operative Limited, New Zealand.

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.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R., Michener, C.D., 2004. Economic value of tropical forest to coffee production. Proceedings of the National Academy of Sciences USA 101, 12579-12582.

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

Root, R.B., 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecological Monographs 37, 317–350.

Sandhu, H.S., Wratten, S.D., Cullen, R., 2005. Evaluating ecosystem services on farmland: a novel, experimental, 'bottom-up' approach. In: Proceedings of the 15th International Federation of Organic Agriculture Movements (IFOAM) Organic World Congress, Adelaide, Australia.

Sandhu, H.S., Wratten, S.D., Cullen, R., 2007. Field evaluation of ecosystem services in organic and conventional arable land. International Journal of Agricultural Sustainability, in press.

Statistics New Zealand, 2003. Agricultural production statistics. Statistics New Zealand, Wellington.

Stockdill, S.M.J., 1982. Effects of introduced earthworms on the productivity of New Zealand pastures. Pedobiologia 24, 29–35.

Sturrock, J.W., 1969. Aerodynamic studies of shelterbelts in New Zealand-1. Low to medium height shelterbelts in mid-Canterbury. New Zealand Journal of Science 12, 754-756.

Sturrock, J.W., 1981, Shelter boosts crop yield by 35 per cent: also prevents lodging. New Zealand Journal of Agriculture 143, 18-19.

Swift, J., 1906. Gulliver's Travels. E.P. Dutton and Co., New York.

Thomas M.B., Wratten, S.D., Sotherton, N.W., 1991. Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. Journal of Applied Ecology 28, 906-917.

Takatsuka, Y., Cullen, R., Wilson, M., Wratten, S., 2005. Using choice modelling to value ecosystem services on arable land. In: Proceedings of the 49th Australian Agricultural and Resource Economics Society (AARES) Annual Conference, Coffs Harbour, Australia.

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.

Torne, E., 1990. Assessing feeding activities of soil-living animals: I. Bait- lamina tests. Pedobiologia 34, 89–101

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

Varley, M.J., Copeland, M.J.W., Wratten, S.D., Bowie, M.H., 1994. Parasites and predators. In: Wratten, S.D. (Ed.), Video Techniques in Animal Ecology and Behaviour. Chapman and Hall, London, pp. 33-63.

Willer, H., Yussefi, M., (Eds.), 2006. The World of Organic Agriculture 2006: Statistics and Emerging Trends. International Federation of Organic Agriculture Movements (IFOAM), Bonn.

Wilson, M., Troy, M., Costanza, R., 2004. The economic geography of ecosystem goods and services: revealing the monetary value of landscapes through transfer methods and geographic information systems. In: Dieterich, M., van der Straaten, J. (Eds.), Cultural Landscapes and Land Use: the Nature Conservation–Society Interface, Kluwer Academic Publishers, Dordrecht, pp. 69-94.

Winder, L., 1990. Predation of the cereal aphid *Sitobian avenae* by polyphagous predators on the ground. Ecological Entomology 15, 105–110.

Winder, L., Hirst, D.J., Carter, N., Wratten, S.D., Sopp, P.I., 1994. Estimating predation of the grain aphid *Sitobion avenae* by polyphagous predators. Journal of Applied Ecology 31, 1–12.

Table 1 - Summary of mean and range of economic value of ecosystem services in organic and conventional fields.

		Economic value (range) in US $ $ha^{-1}yr^{-1}$	
	Ecosystem services	Organic fields	Conventional fields
1	Biological control of pests	50 (0-100)	0 (0-0)
2	Mineralization of plant nutrients	260 (26-425)	142 (30-349)
3	Soil formation	6 (0.7-11)	5 (2-9)
4	Food	3990 (1150-18900)	3220 (840-14000)
5	Raw materials	22 (0-224)	38 (0-298)
6	Carbon accumulation	22 (0-210)	20 (0-210)
7	Nitrogen fixation	40 (0-92)	43 (0-92)
8	Soil fertility	68 (53-82)	66 (54-73)
9	Hydrological flow	107 (-111 – 190)	54 (-118 – 194)
10	Aesthetic	21 (21-21)	21 (21-21)
11	Pollination	62 (0-438)	64 (0-455)
12	Shelterbelts	880 (0-472)	200 (0-617)
	Total economic value of ES	4600 (1607-19412)	3680 (1263-14570)
	Non-market value of ES	1480 (452-5237)	670 (48-1235)

Table 2 - Total economic and non-market value of ecosystem services in Canterbury conventional arable land.

	Area ha	Total US \$ yr^{-1}	Non-market US \$ yr^{-1}
Hurunui District	3,750	10,034,070	2,202,900
Waimakariri District	5,625	15,854,740	3,357,120
Christchurch City	1,250	2,322,430	709,450
Banks Peninsula District	625	1,255,630	380,630
Selwyn District	2,1250	57,691,200	12,381,950
Ashburton District	63,125	170,855,390	35,924,440
Timaru District	14,375	37,788,720	7,998,680
Mackenzie District	1,875	3,511,470	1,034,380
Waimate District	13,125	32,726,800	7,225,050
Total	1,25,000	332,040,450	71,214,600

Table 3 - Total economic and non-market value of ecosystem services in Canterbury, New Zealand when half of the arable area is converted to organic farming.

Economic value	Organic area Total (US $ yr^{-1})	Conventional area Total (US $ yr^{-1})	Organic area Non-market (US $ yr^{-1})	Conventional area Non-market (US $ yr^{-1})
Hurunui District	5,497,800	5,017,030	1,771,380	1,101,450
Waimakariri District	8,621,550	7,927,370	2,796,100	1,678,560
Christchurch City	1,415,490	1,161,220	443,910	354,730
Banks Peninsula District	634,380	627,820	184,630	190,320
Selwyn District	32,957,050	28,845,600	11,073,550	6,190,980
Ashburton District	99,452,810	85,427,700	33,942,190	17,962,220
Timaru District	22,053,980	18,894,360	7,570,930	3,999,340
Mackenzie District	2,074,540	1,755,730	642,350	517,190
Waimate District	19,519,770	163,633,400	6,764,300	3,612,530
	192,227,370	166,020,230	65,189,340	35,607,320

Figure captions

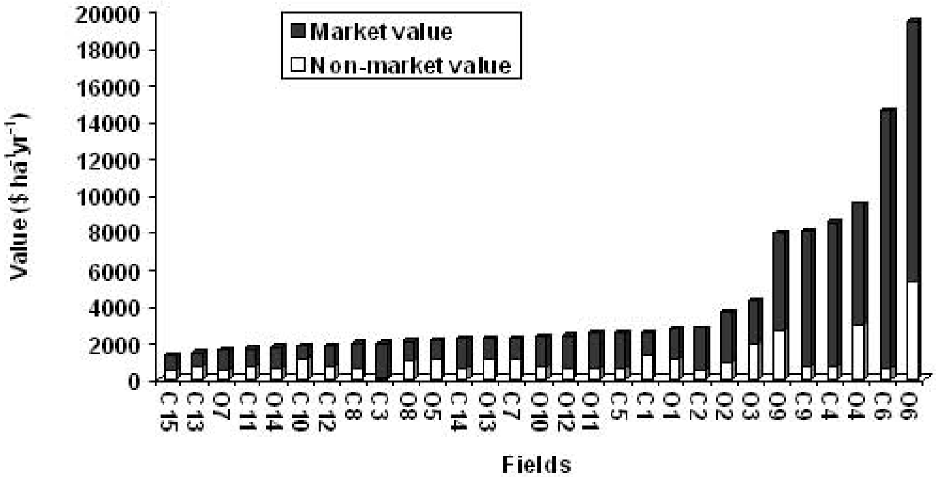
Fig. 1 Total and non-market economic value of ecosystem services in organic and conventional fields.

Fig. 2 The total economic value of ecosystem services provided by conventional farming practices for arable land in Canterbury, New Zealand.

Fig. 3 The non-market economic value of ecosystem services provided by conventional farming practices, for arable land in the Canterbury region.

Fig. 4 The increased percentage in total economic value of ecosystem services when half of the conventional area is converted to organic farming.

Fig. 5 The increased percentage in non-market economic value of ecosystem services when half of the conventional area is converted to organic farming.


Market value
Non-market value
Value ($ ha-1yr-1)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
C15
C13
O7
C11
O14
C10
C12
C8
C3
O8
O5
C14
O13
C7
O10
O12
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O6
Fields

Fig 1

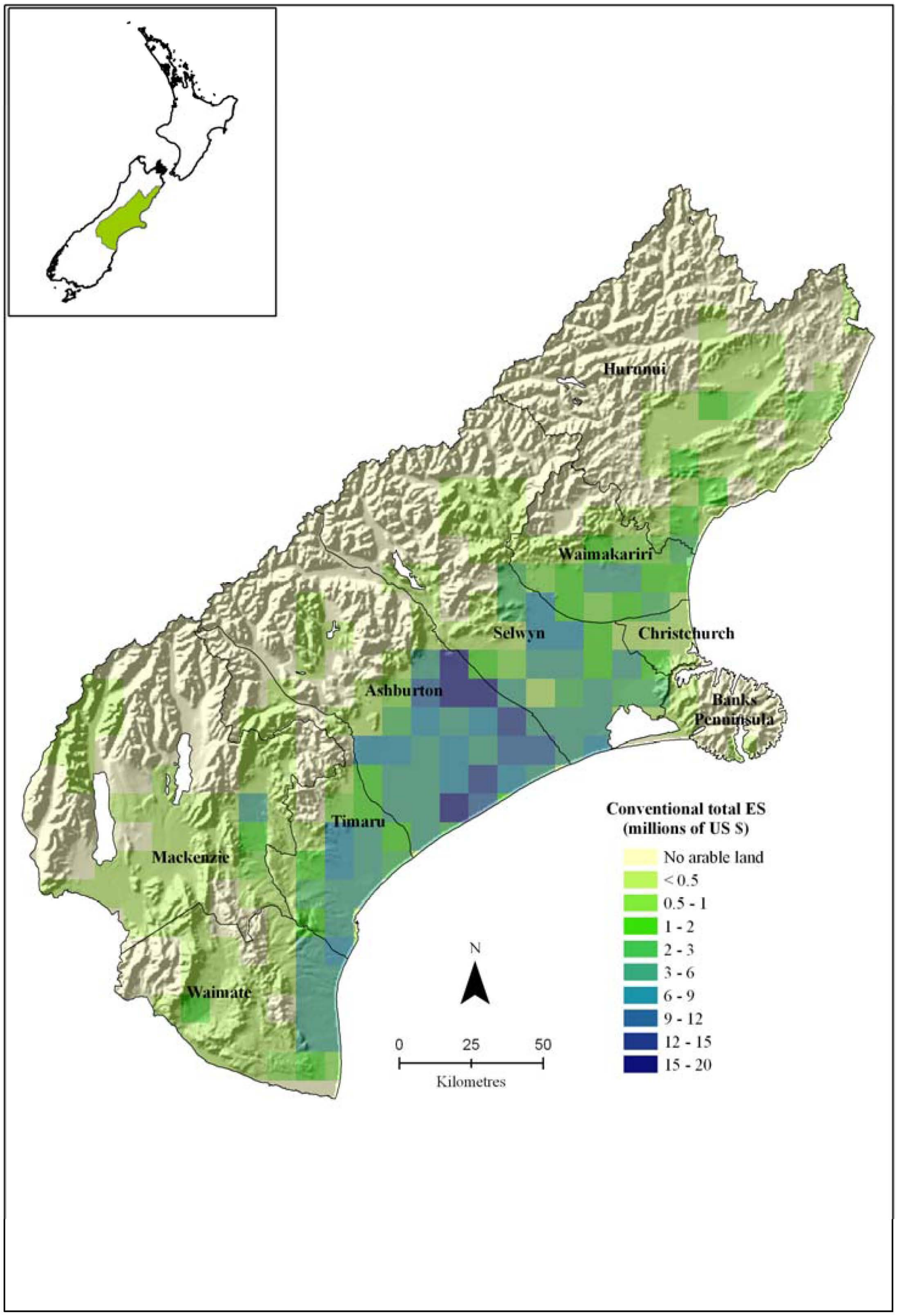
Hurunui
Waimakariri
Selwyn
Christchurch
Ashburton
Banks Peninsula
Timaru
Mackenzie
Waimate
Conventional total ES (millions of US $)
No arable land
< 0.5
0.5 - 1
1 - 2
2 - 3
3 - 6
6 - 9
9 - 12
12 - 15
15 - 20
N
0
25
50
Kilometres

Fig 2

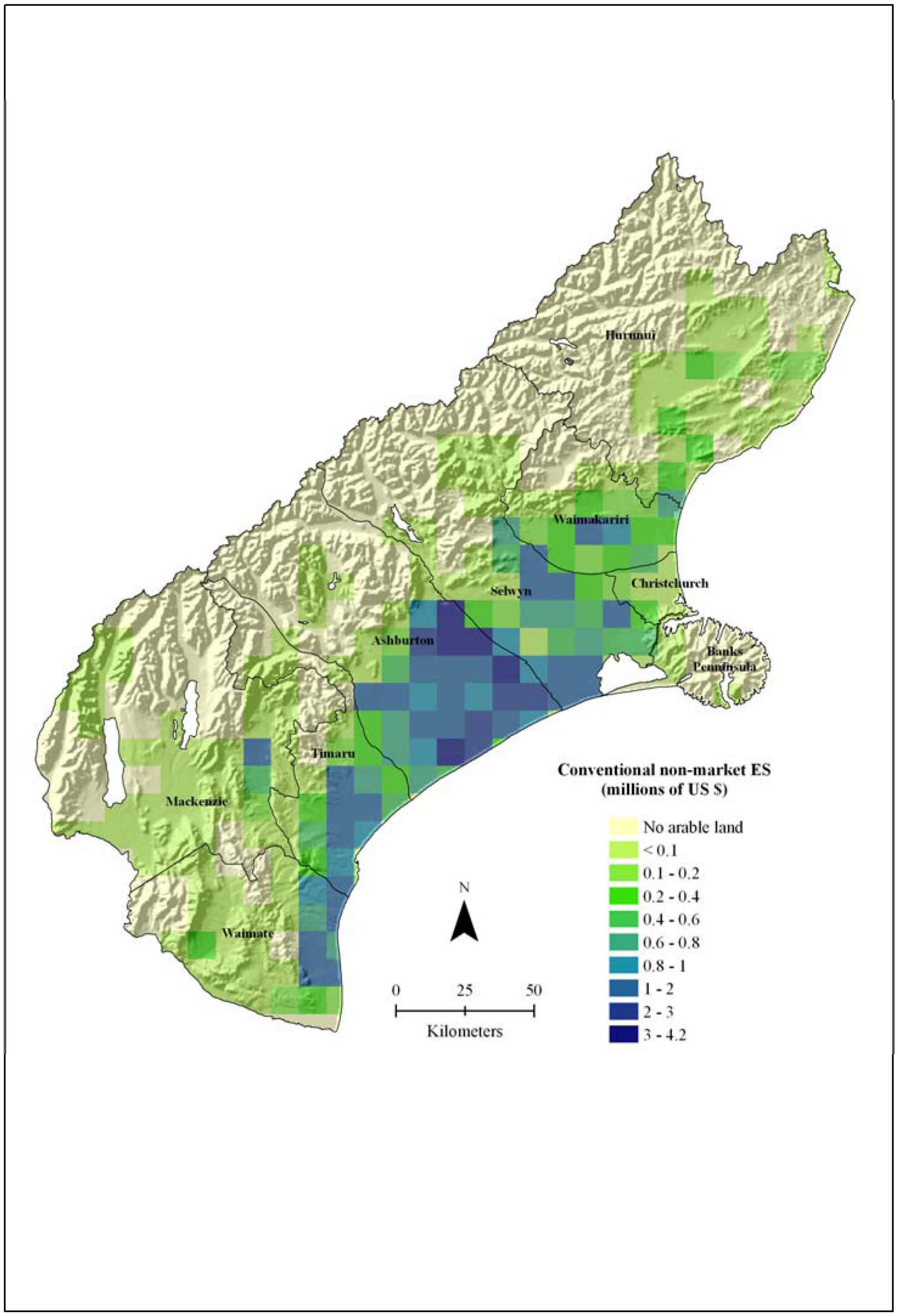
Hurunui
Waimakariri
Christchurch
Selwyn
Ashburton
Banks Peninsula
Timaru
Mackenzie
Waimate
Conventional non-market ES
(millions of US $)
No arable land
< 0.1
0.1 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
1 - 2
2 - 3
3 - 4.2
N
0
25
50
Kilometers

Fig 3

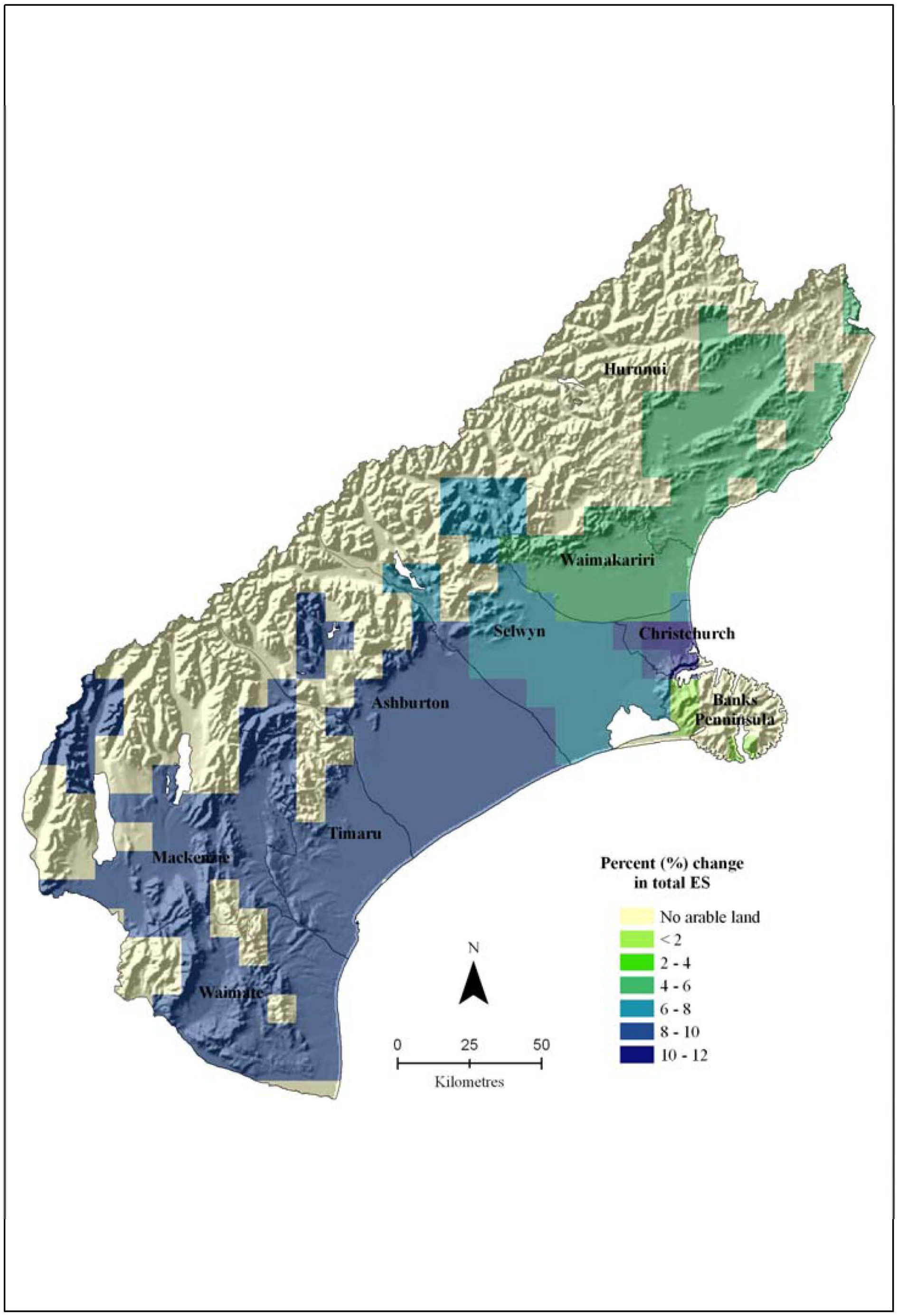
Hurunui
Waimakariri
Selwyn
Christchurch
Banks Peninsula
Ashburton
Timaru
Mackenzie
Waimate
Percent (%) change in total ES
No arable land
< 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
N
0
25
50
Kilometres

Fig 4

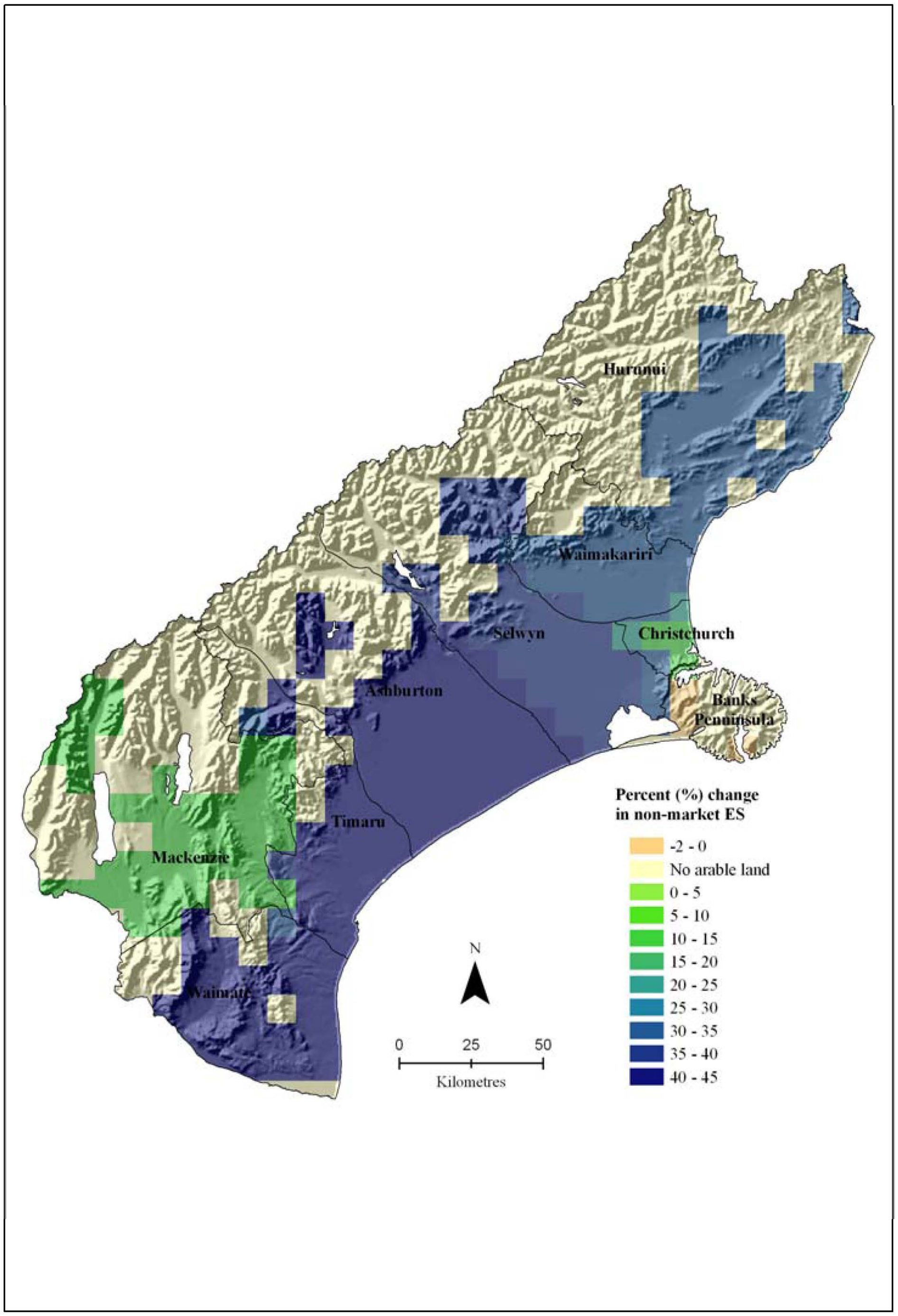
Hurunui
Waimakariri
Christchurch
Selwyn
Ashburton
Banks Penninsula
Timaru
Mackenzie
Waimate
Percent (%) change in non-market ES
-2 - 0
No arable land
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
N
0
25
50
Kilometres

Fig 5