EVALUATING ECOSYSTEM SERVICES ON FARMLAND: A NOVEL, EXPERIMENTAL, 'BOTTOM-UP' APPROACH

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1 INTRODUCTION

Human life is supported by natural ecosystems and species that constitute them through conditions and processes which are known as ecosystem services or nature's services (Daily, 1997: 3). Ecosystem services (ES) are the life-support systems of the planet (Myers, 1996; Daily, 1997; Daily *et al.,* 1997) and it is very well understood that human life cannot exist without these services and functions. However, human activity is rapidly changing the ability of ecosystems to provide ES (Millennium Assessment, 2005). In the next 50 years, the human population is projected to grow to 9 billion and the global grain demand will double. Also, the economic and environmental external costs of modern agriculture are immense (Pretty *et al*., 2000). The challenge is to meet the food demands of a growing population without compromising environmental integrity or public health (Tilman *et al.*, 2002: 671).

To date, ES value has been assessed using a 'top-down' approach, i.e., the economic value of 17 ES in 16 biomes was calculated by Costanza *et al.* (1997) to be in the range of US$16-54 trillion per year, with an annual average of US$33 trillion based on published studies, supported by a few original calculations, Pimentel *et al.* (1997) estimated the annual economic and environmental benefits of biodiversity in the world to be about US$ 3 trillion per year, while in New Zealand, Patterson and Cole (1999) estimated the economic value of that country's ES to be US$30 billion for 1994 using the value transfer method. However, there is lack of detailed understanding of the ES associated with highly-modified or 'engineered' landscapes (Balmford *et al*., 2002). An engineered or designed ecosystem is one that has been extensively modified by humans explicitly to provide a set of ecosystem goods and services (Takatsuka *et al.*, unpublished).

2 ECOSYSTEM SERVICES ASSOCIATED WITH ARABLE FARMING

As pointed out above, there is useful information on the ES provided by natural ecosystems (Costanza *et al.,* 1997; De Groot, 1992; De Groot *et al.*, 2000; Millennium Assessment, 2005) but there is a general lack of information on the ES associated with modified landscapes, such as farmland. However, Cullen *et al.* (2004) and Takatsuka *et al.* (unpublished) have recognized the potentially high value of ES associated with arable farming systems and, after reviewing the definitions of ES and discussing the flows of ES associated with New Zealand arable land, it became clear that arable farming has an 'ecological footprint' as well as being an ES provider.

In contrast with the above mentioned broad, value transfer approaches, current work assesses three key ES (biological control of pests, soil formation, and mineralization of plant nutrients) experimentally and focuses on one sector of an engineered ecosystem, arable farming, and addresses both conventional and organic systems attributing dollar values to some of their key ES. A subsidiary aim was to assess the provision of ES on organic as well as conventional fields, which are ranked according to their ES level. The experiments were conducted on 29 arable fields (14 organic and 15 conventional) in Canterbury region of New Zealand.

2.1 BIOLOGICAL CONTROL OF PESTS: Stability of agricultural systems worldwide is maintained by natural pest control services (Naylor and Ehrlich, 1997: 151). According to De Bach (1974), 99% of agricultural pests and diseases are controlled by their natural enemies - predators, parasites, and pathogens. Such 'natural' suppression is of great significance in organic agriculture as that system is more dependent on such services to keep pest populations low. Intensification of agriculture, with associated habitat destruction has led to a severe reduction of this ES, which is worth US$ 100 billion annually in cropland worldwide (Pimentel *et al.*, 1997). Severe detrimental effects from increasing pesticide applications in agriculture are also well known. Pimentel *et al.* (1992) estimated the environmental and economic costs of pesticide use in the USA to be US $ 8 billion annually. The process of pest removal by soil-surface predators (one of many ecological guilds of predators and parasitoids) was assessed in the current work by using 'prey facsimiles' to assess the 'predation rate'; this provides information on one subset of biological control carried out by natural enemies in arable farmland.

Assessing the predation rate of aphids and fly eggs in arable fields in Canterbury: Aphids in cereals and many arable crops and the carrot rust fly (*Psila rosae*) in carrots are important pests in Canterbury.

Live pea aphids (*Acyrthosiphon pisum*) were used and frozen eggs of the blow fly (*Calliphora vicina)* were simulated carrot rust fly eggs. Predation of these two prey items was assessed in all the fields on each of two dates: November 2004 (27 fields, when pest populations are low in cropping fields) and January 2005 (23 fields, when pest populations are often at their peak). On each date, two prey densities were assessed.

Predation rate was assessed using 'prey facsimiles' comprising $25cm^2$ sandpaper pinned to the soil surface by toothpicks. Live aphids had to be glued on the water-proof sandpaper (P150, Norton) using 3M repositionable glue.

The sandpaper sheets were pinned at the field boundary, the field centre and midway between the two in two transects and had a metal plate supported 10cm above to protect them from rain.

Aphid predation: Studies in cereal fields have indicated that polyphagous predators are able to reduce aphid populations considerably (Lys, 1995). Many of these predators forage mainly on the ground. Their contribution is partly because a high proportion of aphids can fall from the crop canopy (up to 90% per day, Winder, 1990). The different aphid 'prey' 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 the work of Winder (1990), Ekbom *et al.* (1992), Winder *et al.* (1994).

Fly egg predation: Two densities of eggs were used based on the literature on the abundance of carrot rust fly eggs population on the ground. Published egg densities are in the range of 3-8 per $25cm^2$ (Burn, 1982) in the field. Prey facsimiles were placed on the ground as described above for aphids.

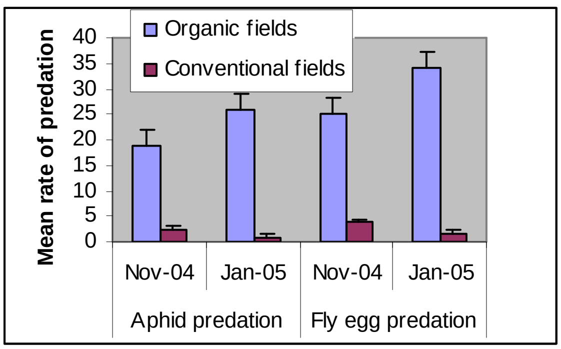

Fig. 1 Predation rates of aphids and fly eggs

		Organic Fields		Conventional Fields	
		Mean	SE of mean	Mean	SE of mean
Aphid predation	Nov-04	18.91	6.39	2.37	0.841
	Jan-05	25.9	5.19	0.97	0.521
Fly egg predation	Nov-04	25.25	4.74	3.86	1.361
	Jan-05	34.08	3.19	1.56	0.855

Table 1 Mean predation rates in organic and conventional fields

The proportions of aphids and fly eggs removed by the soil-surface predators in 24h were recorded. Table 1 shows the mean percentage and standard error of means of aphids and fly eggs removed in organic and conventional fields on the two study dates. Predation rate of aphids was significantly higher in organic fields than the conventional fields ($P=0.025$, significant at 5% level, November 2004; $P=0.001$, January 2005). Predation rate of fly eggs was also significantly higher ($P=0.001$, November 2004; $P<0.001$, January 2005) in organic fields than the conventional fields. Although the data does not satisfy the assumptions for the t test, differences between organic and conventional are so large (and P values so small), that the differences are real. An illustration of aphids and fly egg predation in arable fields is given in Fig 1.

2.2 SOIL FORMATION: Soil formation is an important ecosystem service provided by soil biota. According to Pimentel *et al.* (1995), earthworms bring between 10 and 500 tonnes/ha/year of soil to the surface and it was estimated that soil biota aids the formation of approximately 1 tonne/ha/year of topsoil. Under agricultural conditions it takes approximately 500 years to form 25 mm of soil, whereas under forest conditions it takes approximately 1000 years to form the same amount (Pimentel *et al.,* 1995).

Earthworms are also beneficial by maintaining soil nutrient levels by mixing the soil. Their activities bring sub-surface soil, providing nutrients in the plant root zone. In the current work, soil formation through the activities of earthworms was assessed by sampling their populations to provide an estimate of the quantity of soil formed per ha per year.

Sampling was done during the spring as earthworm populations are generally highest at this time in New Zealand (Martin, 1978). Four $25cm^3$ soil samples were taken from each field. The soil was spread on a plastic sheet and earthworms were extracted and placed in a collection pottle. The results are given in Fig 2. The range of population densities in organic fields was $12\text{-}244/m^2$ (mean $132/m^2$) and $36\text{-}184/m^2$ (mean $99/m^2$) in conventional fields. There was no significant difference between organic and conventional fields.

Dollar value: The economic value of soil formation by earthworms in this work is presented in Fig 2. Populations/m^2 was assessed. Mean earthworm biomass is 0.2g (Fraser, 1996) and on, an average, one tonne of earthworms forms 1000kg of soil annually. The value of top soil in New Zealand is NZ$23.08 per ton (Winstone Aggregates and City Care, pers comm., 18.04.2005). From these assumptions the value of soil formation was calculated and is presented in Fig 2. The range of values for organic fields is NZ$ 0.55 – 11.22/ha/yr (mean $6.06/ha/yr) and for non-organics NZ$ 1.65-8.46/ha/yr (mean $4.56/ha/yr).

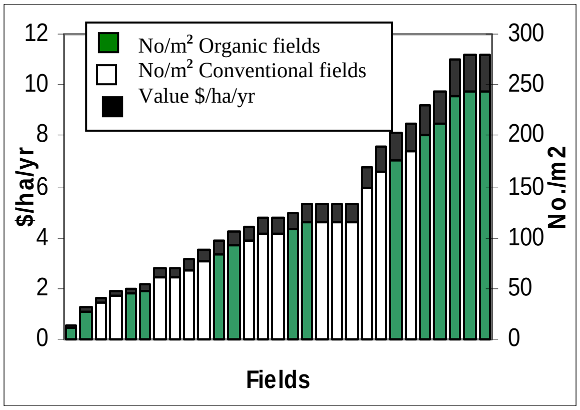

Fig. 2 Earthworm count and dollar value

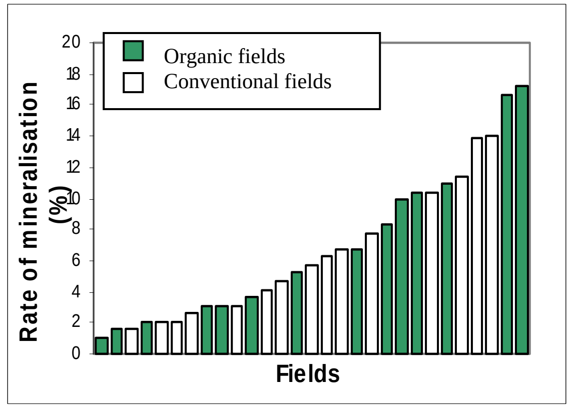

Fig. 3 Mineralisation of plant nutrients using bait lamina probes

2.3 MINERALISATION OF PLANT NUTRIENTS: Organic matter breakdown carried by soil organisms is one of the most important services provided by soil. Through decomposition, plant residues are broken down, releasing previously organically-bound nutrients such as nitrogen for use by plants.
Mineralisation of plant nutrients was assessed in 29 fields using bait lamina probes (Kratz, 1998). These are strips of rigid plastic with a series of 1mm holes (16) drilled into them. These are filled with gel comprising of cellulose (65%), agar-agar (15%), bentonite (10%) and wheat bran (10%) that matches to some extent the key constituents of dead plant material on or in the soil. They were inserted into ground at specials similar to those of the predation baits described above. The probes were left in the ground for 10 days in January 2005. Soil micro-organisms consume the 'bait' and the number of holes that are empty (partially or fully) gives a measure of the rate of mineralisation (Kratz, 1998).
The mean rate of mineralisation is calculated as the mean removal of baits and is given in Fig 3. The percentage removal of baits in organic fields was 1.04-17.18% and in conventional fields was 1.56-14.06%.

3 CONCLUSIONS

Rates of ES were generally higher on organic fields studied. The engineered systems studied are both a consumer and a provider of the three ES. The levels of ES varied between different management practices. Current intensive and high input agricultural practices appears to be affecting the ability of these systems to provide some ES. which offsets their ability to produce large amounts of food and fibre. New technologies based on novel and sound ecological knowledge are required to enhance these ES and to ensure farm incomes can be sustained (Tilman *et al.*, 2002; Gurr *et al.*, 2004).

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