ORCHARD ECOSYSTEM SERVICES: BOUNTY FROM THE FRUIT BOWL

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ABSTRACT: The ecological infrastructures that underpin the production of New Zealand's fruit comprise valuable natural-capital assets. From these stocks flow ecosystem services that are valuable to the whole community. We use the ecosystem service typology of Dominati et al. (2010) to assess the value of orchard ecosystem services. The three services that flow from natural capital are thus identified as being provisioning, regulating, and cultural, all of which are sustained by supporting processes in the soil. Horticulture generates NZ$3.5 billion of export revenue for New Zealand annually and NZ$2.9 billion of domestic revenue. All of this provisioning service comes from just 70 000 hectares of orchards and vineyards. Certainly there is bounty coming from the orchards of New Zealand's regional fruit bowls. The ecological infrastructures of New Zealand's horticulture also provide valuable regulating and cultural services. The value of these services enable eco-verification of New Zealand's fruit and fruit products, such that they secure shelf access and eco-premium prices in the world's top supermarkets. We outline the nature and value of the regulating services in orchards in relation to carbon sequestration, gaseous exchange, plus the buffering and filtering of nutrients. We highlight how the ecological infrastructures of orchards and vineyards provide valuable cultural services through aesthetics and recreation.

Key words: cultural services, earthworms, greenhouse gases, land ethic, macroporosity, provisioning services, regulating services, soil carbon, soil nitrogen, supporting processes.

INTRODUCTION

The Millennium Ecosystem Assessment (2005) classified ecosystem services into four typologies: the supporting services of soil formation and nutrient cycling; the provisioning services of food, fuel and fibre production; the regulating services around the buffering and filtering of water, carbon and gases; and the cultural services of heritage, recreation and spiritual well-being. Costanza et al. (1997) assessed the global flow of ecosystem services from the world's natural capital stocks of materials and energy, and concluded that the sum value of terrestrial and marine ecosystem services was 1.8 times the value of gross global production. Nature, it would seem, is highly valuable.

Horticulture generates NZ$3.5 billion of export revenue for New Zealand annually and NZ$2.9 billion of domestic revenue (www.freshfacts.co.nz). All of this comes from just 70 000 hectares of orchards, vineyards and farms. Certainly there is bounty coming from the orchards of New Zealand's regional fruit bowls. The ecological infrastructures underpinning the production of New Zealand's fruit comprise valuable natural-capital assets. But this value is not only because of the provisioning ecosystem service that generates this level of economic activity and rewards the landowners and growers.

The three other types of ecosystem services generated by orchards are not simply of value only to the growers, as the wider community also benefits. Indeed they depend on them. For this reason, resource regulations, like New Zealand's Resource Management Act (RMA) of 1991 (Ministry for the Environment 2013), seek '... to promote the sustainable management of natural and physical resources [whilst] managing the use, development and protection of natural and physical resources to enable people and communities ... to provide for their social economic and cultural well being and for their health and safety while ...

a) sustaining the potential and natural physical resources ...
b) safeguarding the *life-supporting capacity* of air, water, soil, and ecosystems; and
c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.'

So the RMA presaged the natural capital and ecosystem services thinking contained in the Millennium Ecosystem Assessment (2005). Yet, the promotion of the use, development and protection of natural capital assets to safeguard the life-supporting capacities of the ecosystem services that flow from them can be clearly seen in the land ethic thinking developed by Aldo Leopold in 1949 (Flader 2011). Leopold (1949) spoke of the A–B cleavage where '... one group (A) regards the land as soil, and its function as community production, [whereas] another group (B) regards the land as a biota, and its function as something broader'. It is this cleavage that today still leads to contention and conflict (Mackay et al. 2011), as recently seen with the judicial proceedings in relation to Horizons Regional Council's One Plan (Horizons Regional Council 2008). The proposed One Plan seeks to make intensive farming an activity controlled by resource consent, rather than a permitted activity. This is in essence a conflict between the provisioning ecosystem service and the three other ecosystem services. It is therefore instructive to delve deeper into Leopold's land ethic and explore the link between it and ecosystem services

Leopold (1949) wrote: '... plants absorb energy from the sun. This energy flows through a circuit called the biota, which may be represented by a pyramid consisting of layers. The bottom layer is the soil. A plant layer rests on the soil, an insect layer on the plants, a bird and rodent layer on the insects, and so on up through various animal groups to the apex layer, which consists of the larger carnivore.' Leopold's description of this 'energy circuit' essentially describes that which we now call our interconnected ecological infrastructure. Bristow et al. (2012) define ecological infrastructure as how natural capital is arranged, and it comprises landscape elements, ecosystems, ecological processes and functions, and ecological connectivity.

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Leopold (1949) continues'... land is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants and animals.' In modern parlance, we would describe this as the flow of ecosystem services from the natural capital stocks comprising our ecological infrastructure.

Then Leopold (1949) espoused his land ethic, which '... simply enlarges the boundary of the community to include soils, waters, plants, and animals, or collectively: the land. An ethic, ecologically, is a limitation on freedom of action [and] has its origin in the tendency of interdependent individuals or groups to evolve modes of cooperation'. But he lamented, '... there is as yet no ethic dealing with man's relation to the land, and to the animals and plants which grow on it. Land is still property.' The reason for this pessimism was that he considered '... perhaps the most serious obstacle impeding the evolution of a land ethic is the fact that our educational and economic system is headed away from, rather than toward, an intense consciousness of land'. Sadly, Leopold died in tragic circumstances the year before his book was published (Flader 2011). He was right nonetheless in his pessimism, for during the 1950s and '60s the industrialisation of agriculture had meant, as he foresaw, that '... your true modern is separated from the land by many middlemen, and by innumerable physical gadgets. He has no vital relation with it. Turn him loose for a day on the land [and] he is bored stiff'. Sales of his book were initially low. But, as Flader (2011) noted, '... in 1970 during the environmental awakening of the first Earth Day, sales skyrocketed.' This has continued, and to date over two million copies have been purchased, and it has been translated into 12 languages.

As we are increasingly challenged today by the A–B cleavage, Leopold's description of the land ethic in his *Sand County Almanac* provides a beacon. A modern compilation of recent research findings, entitled "*What is land for? The food, fuel and climate change debate"* (Winter and Lobley 2009), picks up where Leopold left off. This book uses an ecosystem services approach to advance the debate (Clothier 2011). Indeed, one chapter is on 'The land debate – Doing the right thing: Ethical approaches to land-use decision making' (Carruthers 2009). The overall focus of that book was, as is our focus in this chapter, on the three ecosystem services of supporting, regulating and cultural, rather than that of simply provisioning.

In this chapter, we explore the value of the sum of all of the ecosystem services flowing from vineyards and orchards, for these provide bounty from the fruit bowls of New Zealand to the whole community. In addition, we add another perspective to the provisioning service – that of an eco-premium return from the marketplace for these fruits. New Zealand's fruit is destined for the shelves of the world's top supermarkets. Increasingly, environmentally conscious consumers are seeking out those supermarkets[1] that sell only eco-verified products that have been ethically produced. This fruit will receive eco-premium pricing in these discerning markets.

But there is also a new and emerging dynamic that is linking producers and supermarkets – so-called producer networks. Tesco's Group Food Sourcing Commercial Director, Matt Simister, has just launched the Tesco Producer Network under the strap-line of 'Tesco & Producers – We are better together' (www.tescoandproducers.com). He said at its launch:

...the Tesco Producer Network is a new website for agricultural producers and Tesco teams world-wide to communicate with each other, sharing best practice, experience and expertise. We are launching the Producer Network to strengthen our ways of working through the supply chain so that we can best meet the growing demand for food across the world. The Network will allow Tesco and producers to share knowledge and experience from farm to store so that we become more productive, work better together and make Tesco global markets more accessible to more producers.

An analysis of orchard ecosystem services can be used to provide that best practice information the supermarkets are now demanding from their producers and suppliers of fresh fruit and fruit products. This then enables the supermarkets to provide eco-verification credentials for the products on their shelves to meet the consumers' demands and expectations.

NATURAL CAPITAL, ECOLOGICAL INFRASTRUCTURE AND ECOSYSTEM SERVICES

Stocks of natural materials and energy are our natural capital assets. The natural-capital concept integrates economic thinking with ecological principles by considering nature's stocks of materials and energy as capital. Natural capital stocks are our soils, our vegetation, our biodiversity, our aquifers, lakes, streams and rivers, plus the elements of our weather. They are our inventory of natural capital stocks. Nature comprises an assemblage of natural capital stocks, and they, in sum, form our ecological infrastructures.

In the economic world, interest or rent flows from financial or built capital. So by analogy in the ecological world, the ecosystem services that benefit mankind flow from our ecological infrastructures (Clothier et al. 2011). These ecosystem services are massively valuable. And not just in the way we have traditionally thought – that of the yield of food, fibre and fuel. The value of that ecosystem service – the provisioning service – is easily quantified and amenable to classical economic analyses. Using neo-classical economics, other types of ecosystem services have been quantified as being very valuable to mankind (Costanza et al. 1997; Daily 1997). However, no one pays for them, or is paid for them. As yet!

The Millennium Ecosystem Assessment of the United Nations (2005) classified ecosystem services into four kinds. Beyond the provisioning ecosystem service there are:

- The supporting service of soil formation, nutrient cycling and biological activity
- The regulating service of water filtering, flood regulation and climate regulation
- The cultural service of heritage, aesthetics, recreation and spirituality.

Burgeoning research efforts into the nature and value of ecosystem services has seen a reassessment of the four-way classification of the 2005 Millennium Ecosystem Assessment (Robinson et al. 2009, 2012, 2013a, b; Dominati et al. 2010a, b; Robinson and Lebron 2010). Here we use the ecosystem-services framework proposed by Dominati et al. (2010a) (Figure 1) as the basis for our assessment of orchard ecosystem services – the value of the bounty we derive from our fruit bowls.

This soil-based ecosystem-services framework differs from that of the Millennium Ecosystem Assessment (2005) through its five interconnected components of: (1) the use of extant soil properties to define the inherent and manageable characteristics of natural capital; (2) the supporting processes (not a service) of soil formation, maintenance, and degradation; (3) the natural and anthropogenic drivers impacting on soil properties and processes; (4) the three services of provisioning, regulation and culture that flow from natural capital; and (5) how these services meet human needs.

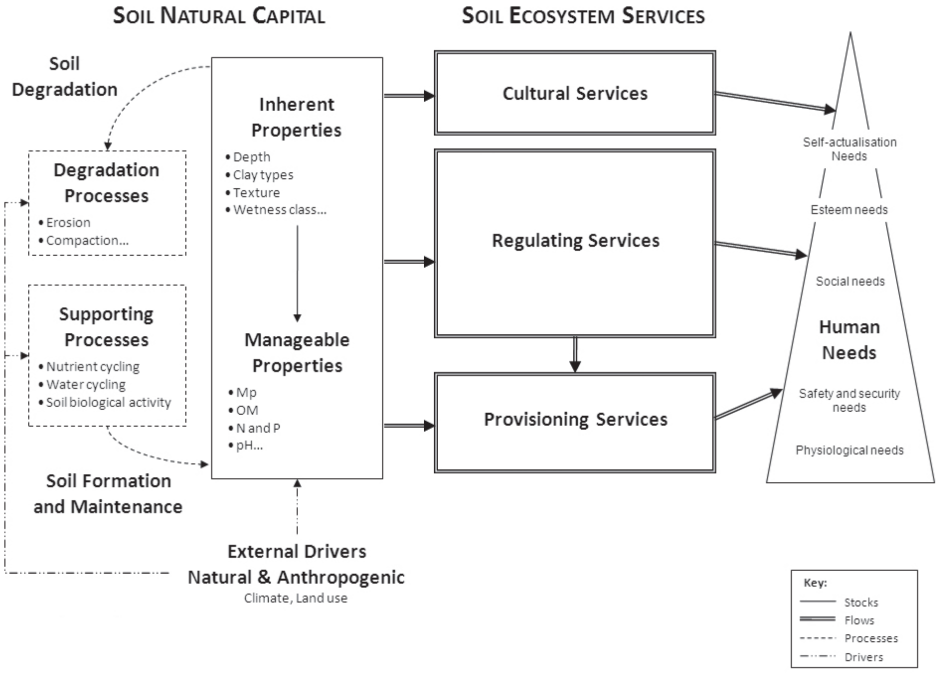

FIGURE 1 Framework for the provision of ecosystem services from soil natural capital (from Dominati et al. 2010a).

Here we will focus on the supporting processes operating in orchards, along with the regulating and cultural services flowing from the natural capital components comprising the ecological infrastructure of orchards. We will not, however, discuss the value of orchard provisioning services, which in sum amount to NZ$6.4 billion a year, as these are well documented annually in Fresh Facts (www.freshfacts.co.nz).

Investment into ecological infrastructures

Natural capital stocks sum to form our ecological infrastructures (Bristow et al. 2010; Jury et al. 2011), which Bristow et al. (2012) define as "... how natural capital is arranged". They highlight that it is the connectedness within and between the various landscape elements comprising ecological infrastructure that is critical for the delivery of ecosystem services. Bristow et al. (2010) mused:

...the recent financial crisis led to massive investments in built infrastructure as a means of stabilising and reinvigorating the economy, [so] one wonders why given the worsening water and food crises similar levels of investment are not being made in ecological infrastructure. Just as built infrastructure delivers the socio-economic services that underpin modern societies, so does ecological infrastructure deliver the ecosystem services that not only sustain the ecological infrastructure itself, but also support a wide range of socio-economic benefits.

We now show how orcharding systems, if well managed, can actually provide investment opportunities into ecological infrastructures so as to maintain and enhance supporting processes, and thereby increase the value of the regulating and cultural services that flow from orchard ecological infrastructures.

SUPPORTING PROCESSES

In the natural capital framework of Dominati et al. (2010) both natural and anthropogenic drivers can influence supporting and degrading processes, and these can affect the manageable properties of the soil's natural capital (Figure 1).

'Growing' soil

Dominati et al. (2010) have highlighted that 'soil formation and maintenance' is the mechanistic link between supporting processes and manageable properties. Here we show how the anthropogenic driver of land-use change can actually enhance soil formation. On the deep volcanic soils of New Zealand's Bay of Plenty, the hub of our kiwifruit industry, we have found that kiwifruit vines can actually facilitate the 'growing' of soil.

Holmes et al. (2012) extended the soil carbon sequestration work of Deurer et al. (2010) by 'deep-C' drilling down to 9 m under a kiwifruit orchard, and they compared the carbon profile there with one down to 9 m in the neighbouring pasture, which was the antecedent land use some 30 years earlier. Their measured profiles of soil carbon are reproduced here in Figure 2, and show that kiwifruit vines have extended the zone of carbon well down through the soil profile. Chabbi et al. (2009) have noted that deep-soil organic matter is an important yet poorly understood component of the terrestrial carbon cycle. They consider that this deep and stabilised soil carbon could be because of the occlusion within soil aggregates of the soil organic matter whose origin derives from root processes. They considered that this spatial separation of soil organic matter from microorganisms, extracellular activity, and the absence of a priming effect leads to stabilised soil carbon deep in the profile. The sequestration rate of soil carbon in this 'growing' soil described in the kiwifruit study of Holmes et al. (2012) was 6.3 t-C ha^{-1} yr^{-1}.

Biological activity

Land-use change in this kiwifruit orchard has altered a manageable property of soil – its organic matter content, which

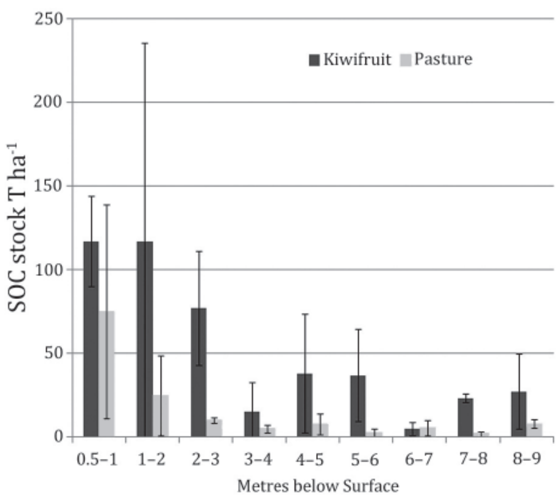

FIGURE 2 Soil organic carbon (SOC) stocks in t-C ha^{-1} in profile layers down to 9 metres deep in a 30-year-old kiwifruit orchard and an adjacent pasture block. The rows are the means of three profiles and the error bars denote one standard deviation (from Holmes et al. 2012).

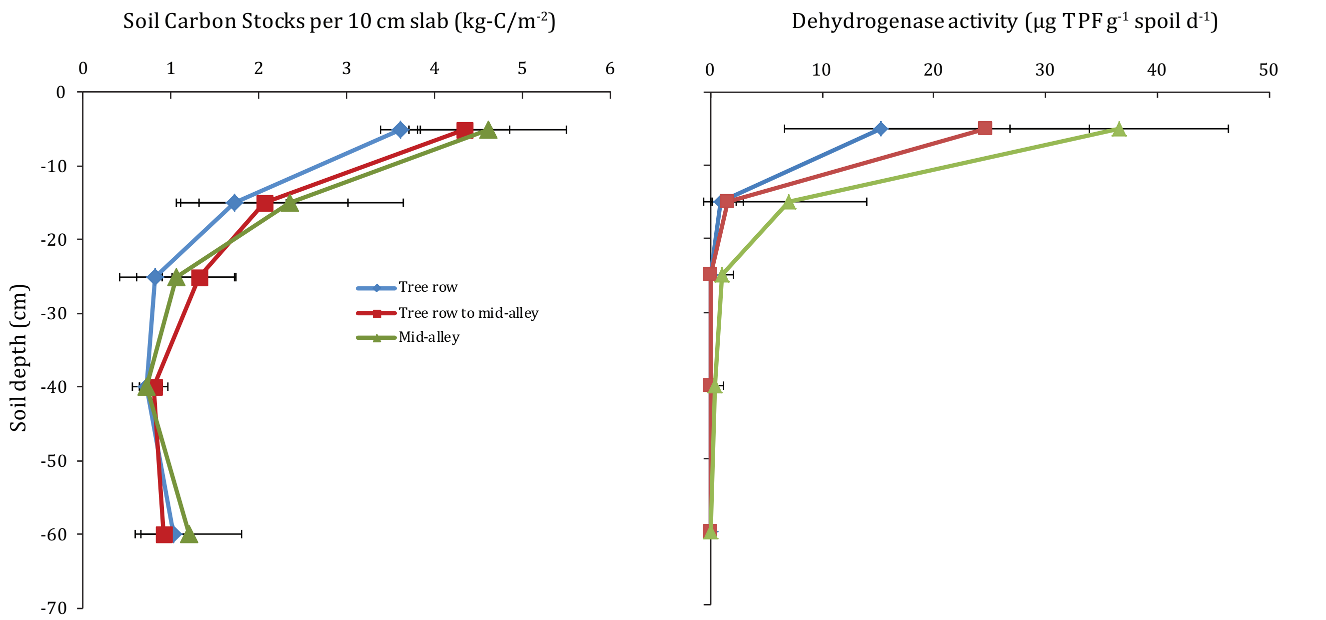

FIGURE 3 Left. Profiles in soil carbon stocks (kg-C m^{-2} per 10-cm slab) in an apple orchard at Lenswood in the Adelaide Hills of South Australia. Three profiles were sampled at positions in herbicide strips of the row, between the row and mid-alley, and in the mid-alley. *Right*. Dehydrogenase activity in the soil samples obtained from the orchard at Lenswood.

is a property of natural capital that is closely linked to the soil's supporting process of biological activity.

We are carrying out a study of soil carbon and soil health metrics across the apple-orcharding regions of Australia in a programme called PIPS (Production Irrigation Pests and Soil), which is funded by APAL (Apple and Pear Australia Ltd). In the duplex soil of an apple orchard near Lenswood in the Adelaide Hills we found a rapid drop-off in soil carbon stocks with depth (Figure 3, left). Soil health characteristics were measured at each of these sampling depths including an assay for dehydrogenase activity. Dehydrogenase is an oxidising enzyme commonly used as an indicator of microbial activity in soil. It is present in all microorganisms and is closely related to soil microbial biomass. It is determined by measuring the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to triphenylformazam (TPF) in a soil assay. Dehydrogenase activity, a measure of soil biological activity, decreased rapidly with soil profile depth in concert with the decline in carbon (Figure 3, right). By inference, the 'growth' in the depth of carbon-enhancement in the soil under kiwifruit, as shown in Figure 2, is likely to have led to an increase in the depth of biological activity as well. The natural capital value of the soil here has been enhanced through land-use change.

Nutrient cycling

The supporting process of nutrient cycling will be closely linked to that of biological activity, which will be related, among other things, to the manageable property of soil organic matter content. Deurer et al. (2009) quantified the carbon status of two neighbouring apple orchards in Hawke's Bay, New Zealand. The orchards were planted at the same time about 10 years earlier. One orchard used an organic programme of orchard management; the other employed integrated fruit production practices. In the organic orchard some 5–10 t ha^{-1} of compost were applied annually to provide for the trees' nutrient requirements. In the other no organic compost and only small amounts of inorganic fertiliser were used and a herbicide strip was maintained along the tree row. Due to the different carbon-management processes, the soil carbon stocks of the top 0.1 m in the tree rows of the two orchards had become quite different: 3.8 kg-C m^{-2} for the organic orchard, and 2.6 kg-C m^{-2} for the integrated orchard.

Kim et al. (2008) obtained soil samples from both orchards and carried out 40-day incubations to determine the nitrogen mineralisation rate in the soils. This provides a measure of the supporting process of nutrient cycling. Their results are reproduced here, as a function of the two orchards (Figure 4: top – integrated; bottom – organic), and were related to the soil properties of temperature and soil-water pressure. Over all the environmental treatments, the soil in the organic orchard mineralised nitrogen at the rate of 0.76 mg-N kg^{-1} d^{-1}, which was 6.5 times higher than that in the integrated orchard at 0.12 mg-N kg^{-1} d^{-1}.

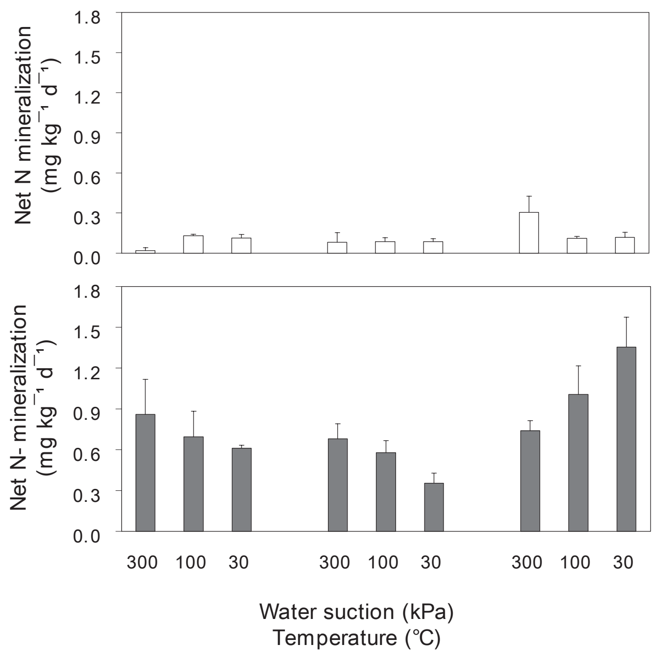

FIGURE 4 Rates of net N-mineralisation for the nine temperature/soil-moisture treatments of neighbouring integrated and organic orchards in Hawke's Bay, New Zealand. The vertical error bars indicate one standard error. *Top*: The integrated orchard, *Bottom*: The organic orchard next door (from Kim et al. 2008).

Water cycling

As seen above, the anthropogenic driver of land-use change can, through changing the manageable property of the soil's carbon content, increase the value of the supporting processes of soil biological activity and nutrient cycling. Another supporting process highlighted in Figure 1 is water cycling, and there have been many studies aimed at determining the impact of soil carbon on soil–water dynamics, and contradictory findings have been reported. Faced with these contradictions, Rawls et al. (2003) hypothesised that the effect of soil carbon on water retention would depend on both the textural make-up of the soil and the level of soil organic matter itself. To test this they used the comprehensive U.S. National Soil Characterization Database, and regression trees and the group method of data handling, to unravel the relationships. Indeed, they did find that the proportion of textural components affected the relationship of water retention to organic carbon content. They found that at low carbon levels, an increase in organic carbon leads to greater water retention in coarse soils, and a decrease in fine-textured soils. At high levels of carbon, an increase in soil organic matter results in an increase in soil water retention for all soils, albeit with a muted response.

So investment of carbon into the ecological infrastructure of the orchard soils can increase the value of the ecosystem services that flow from the natural capital of the soil in orchards.

REGULATING SERVICES

Dominati et al. (2010a) showed that the supporting processes within the natural capital of orchard soils (see above) sustain three types of ecosystem services: regulating, cultural and provisioning services (Figure 1). Here we discuss some of the regulating services provided by the natural capital of orchards.

Carbon sequestration

As noted above, Holmes et al. (2012) found kiwifruit vines to be sequestering deep-C at the rate of 6.3 t-C ha^{-1} yr^{-1} in the deep volcanic soils of the Bay of Plenty. This sequestration provides a regulatory service to the atmosphere by sequestering a fraction of the carbon captured through the vine's photosynthesis. Indeed if this carbon capture was able to be used in a schema for carbon footprinting, this would reduce the carbon footprint of a tray of New Zealand kiwifruit landed in Europe to 42% of that specified in the PAS 2050 protocol of the British Standards Institute. Thankfully, in the soon-to-be-released carbon footprinting protocol of the International Standards Organisation, soil carbon accounting will be allowed. In their study of paired organic and integrated apple orchards in the Hawke's Bay, Deurer et al. (2009) found that organic practices had lifted the carbon stocks of the surface soil to 3.8 kg-C m^{-2}, above that found in the integrated orchard (2.6 kg-C m^{-2}).

Land management practices through carbon investment can enhance both supporting processes and carbon storage regulation. This seems to address the soil-carbon dilemma posed by Janzen (2006) – should we hoard it or use it? The surface carbon inputs from fruit trees and vines, along with orchard management that can supply residues to the surface soil, mean that carbon is 'burned' there to support biological activity and nutrient cycling. Meanwhile, deep-C sequestration in the subsoil can provide the hoarding and the regulation that keeps carbon out of the atmosphere.

With climate change this service might, in a warmer world, actually provide a regulating disservice. The potential to deliver disservices while providing ecosystem services is described by Zhang et al. (2007) for agriculture. And in a significant paper in *Nature*, Cox et al. (2000) predicted that, with the global rise in CO_2 and temperature, the balance between the enhanced vegetation sink through rising CO_2 and increased soil respiration driven by increased temperatures could mean that the land would turn from being a net carbon sink to a net emitter by 2050. Luke and Cox (2011) said this increased respiration of soil carbon, and the atmospheric feedback, had the potential for a runaway influence of temperature on soil respiration, and they called this the 'compost-bomb instability'. They found the criterion for this instability depended on three things: the slope of the temperature response of gross primary production, the q10 for soil carbon respiration, and the global surface temperature response to a doubling in CO_2. For the compost-bomb to 'explode', they predicted global warming would need to be 10°C per century. This seems unlikely. However, it does raise an interesting point. While it is good to sequester carbon in the soil, this might not be a secure store in the future when temperatures will have risen. So there is the likelihood of the soil in the future providing an ecosystem disservice through being a weakened sink for soil carbon storage. This is an area of intense interest and academic debate.

Gaseous exchange

The regulating service of gaseous exchange linking soil to the atmosphere, and vice versa, is in turn regulated by the connectedness of the soil's porosity, and in particular its connected macroporosity, being those pores with a diameter greater than 0.3 mm. Using X-ray tomography, Deurer et al. (2009) investigated the macroporous structure of the soils under the different soil-carbon management practices of the two neighbouring apple orchards in Hawke's Bay (organic 3.8 kg-C m^{-2} cf. integrated 2.6 kg-C m^{-2}). Two X-ray tomographs from the study of Deurer et al. (2009) are shown in Figure 5. In the core from the integrated orchard, the volumetric macroporosity is 2.9% and the mean macropore radius is 0.38 mm. For the core from the organic orchard, macroporosity is 8.3% with a mean macropore radius of 0.41 mm. This shows how the anthropogenic driver of land-use management can affect the soil's manageable property of macroporosity. Deurer et al. (2009) also found that the fresh weight of anecic earthworms in the organic orchard was 154 (±47) g m^{-2}, whereas it was significantly *(P* < 0.05) lower at 85 (±47) g m^{-2}

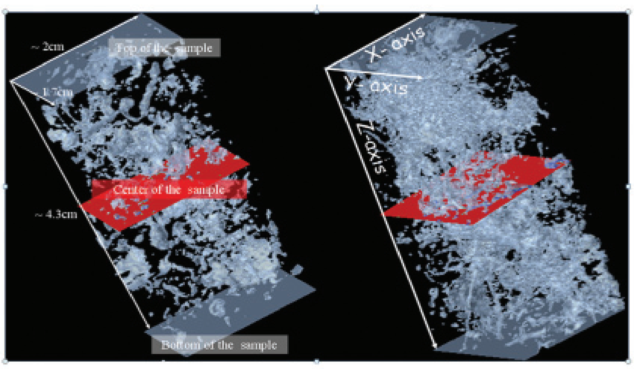

FIGURE 5 Examples of macropore networks in the top 50 mm of soil in the tree rows of two apple orchard systems in Hawke's Bay, New Zealand. The grey-coloured areas are macropores. The three x–y planes are shown to mark the top, centre and bottom of the sample. *Left*: Macropore network of the integrated orchard system. The macroporosity is 2.9 Vol.% and the mean macropore radius 0.38 mm. *Right*: Macropore network of the organic orchard system. The macroporosity is 8.3 Vol.% and the mean macropore radius 0.41 mm (from Deurer et al. 2009).

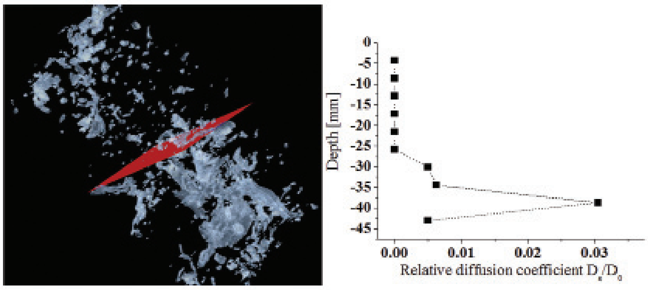

FIGURE 6 Left: The macropore structure of an example sub-column of the integrated orchard. The sub-column is 43 mm long and the in-plane dimensions are 20 mm × 17 mm. *Right*: The respective aggregate-scale relative diffusion coefficients of the sub-column as a function of the depth below the soil surface (from Deurer et al. 2009).

in the integrated orchard soil. So the enhanced macroporosity in the high-carbon soil seems to be both created by and sustained through anecic earthworm activity.

Deurer et al. (2009) then reported on the different gaseous regulating services that these two different macroporous structures would provide. The relative diffusion coefficient, D_r, for the top slab of the integrated soil is shown in Figure 6, along with a tomograph of the macropore structure in one of the cores from the integrated orchard. The relative diffusion coefficient at the column scale was 0.024 ± 0.008 in the organic orchard and 0.0056 ± 0.0009 in the integrated orchard. The authors surmised that the high-carbon soil's connected macroporosity, sustained by the higher activity of anecic earthworms, would indicate less favourable conditions for N_2O production and gaseous emissions. The results of van der Weerden et al. (2012) tend to confirm this, for they found that increased pore continuity reduced the duration of anaerobicity, leading to lower emissions. They found that D_r could explain nearly 60% of the variability in their experiments with two soils. Indeed, considering the two regression equations for their two soils, and the D_r values above, would suggest that N_2O emissions from the high-carbon soil would be 15–35 times lower than those in the low-carbon soil.

However, a very recent paper has cast doubts on the role of earthworms in providing regulating services for greenhouse gas (GHG) emissions. Lubbers et al. (2013) collated 237 observations of greenhouse gas emissions from 57 published papers. They found there were no indications that earthworms affected soil organic carbon stocks, so earthworms, in themselves, do not appear to provide a carbon sequestration regulating service. Worse, Lubbers et al. (2013) found that the presence of earthworms increased N_2O emissions by 42% and soil CO_2 emissions by 33%. This will generate a lot of research activity to unravel the role of soil carbon and earthworm activity, not only on the supporting processes of biological activity, but also on gaseous regulating services. Lubbers et al. (2013) suggested there be a focus on intact soils without a legacy of earthworm activity, as well as long-term field studies, especially in natural ecosystems, and also studies of systems growing plants, as would happen in orchards like those described by Deurer et al. (2009). Nonetheless, Lubbers et al. (2013) prefaced their paper with the comment that '... earthworms are largely beneficial to soil fertility', although they did provide a cautionary note that with climate change and '... the expected shifts in earthworm communities over the next few decades [this] will significantly affect (and probably enhance) soil GHG emissions'.

Flood mitigation and groundwater recharge

The soil of the rootzone is the nexus between rainfall inputs,

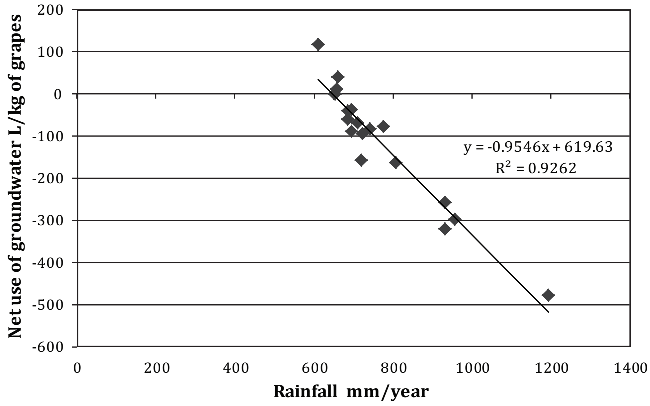

FIGURE 7 A scatter plot showing the relationship of the blue-water footprint calculated from the hydrological approach across the local climatic regions of vineyards within Marlborough, New Zealand, referenced to the local annual rainfall rates (from Herath et al. 2013).

rootzone storage, root uptake, and the drainage recharge of underlying aquifers. The soil's manageable properties of its soil-water characteristic curve and its hydraulic conductivity function provide critical controls on the timing and amounts of groundwater recharge, as well as agrichemical leaching. These properties determine the ecosystem services of groundwater regulation, flood mitigation and the filtering of contaminants and nutrients (Figure 1). The regulating services flow from the interactions between the natural capital stock of rainfall and the natural capital stock of the soil.

Herath et al. (2013) assessed the water footprint of a bottle of Marlborough wine, using a hydrological approach to water footprinting, unlike the consumptive-only approach advocated by the Water Footprint Network (www.waterfootprint.org). Herath et al. (2013) found that every bottle of Marlborough wine, packed and ready for despatch at the winery gate (the functional unit FU), has a negative water footprint of −66.8 L FU^{-1}. In other words, as a result of the production of the average bottle of Marlborough wine there is a contribution of 66.8 litres of water to underlying groundwaters. This is because, on average, the natural capital stock of annual rainfall exceeds the evaporative consumption of water. There is variation, nonetheless, in the net recharge across the region due to variation in the rainfall and the hydraulic properties of the soil (Figure 7). Where the natural capital stock of rainfall is high, groundwater recharge is high, as evidenced by the large and negative water footprints to the right of Figure 7. However, in some vineyards in the drier terroirs of Marlborough, irrigation is used and the vineyard is a net consumer of water, as shown by positive footprint values to the left of Figure 7.

The high variability displayed in Figure 7 is the essence of terroir. So in general, care needs to be exercised when generalising the value of the water regulation services provided by orchards and vineyards.

Buffering and filtering

The supporting processes of nutrient cycling, coupled with the soil's inherent and manageable physico-chemical properties, combine to provide buffering and filtering services for nutrient regulation. Macroporous networks, like those described by Deurer et al. (2009), can either provide a valuable nutrient regulation service by limiting leaching losses (Green et al. 2010) or, indeed, they can supply a disservice (Zhang et al. 2007) by enhancing the preferential loss of nutrients (Cichota et al. 2010). The distinction between service and disservice depends on whether the source of the nutrient is endogenous, that is, it is generated within the soil's

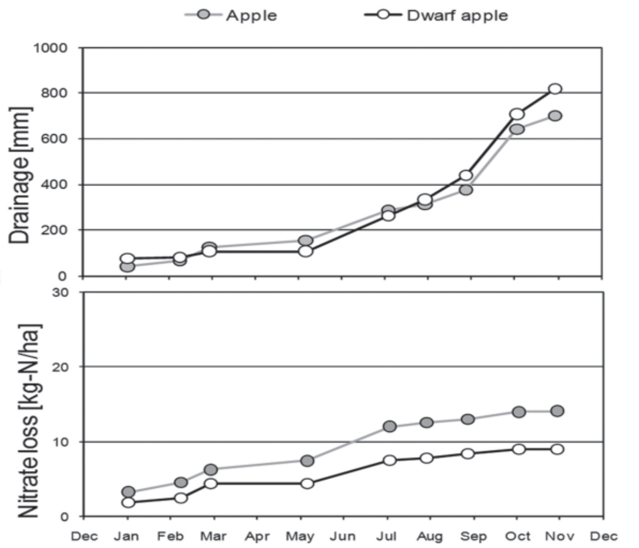

FIGURE 8 Top: The time series of drainage under apple and dwarf apple as measured by a set of six drainage fluxmeters (DFMs) at each site during 2009. The apple trees were irrigated using micro-jet sprinklers. *Bottom*: Cumulative nitrate leaching under apple and dwarf apple as measured by a set of six DFMs at each site (after Green et al. 2010).

matrix by mineralisation, or whether it is applied exogenously to the soil's surface. Here we provide a synopsis of the assessment by Robinson et al. (2013b) of the service values provided by macropores in relation to the buffering and filtering of nutrients.

For the surface soil in an integrated apple orchard, Kim et al. (2011) found the endogenous nitrogen mineralisation from within the soil's matrix amounted to 0.12 mg-N kg^{-1} yr^{-1}. This mineralisation is equivalent to the generation of 105 kg-N ha^{-1} yr^{-1}. Green et al. (2010) measured the leaching of nitrogen under two apple orchards, one standard the other dwarf, using six tension drainage fluxmeters at each site. Little fertiliser was applied to these orchards. The drainage regulation can be seen in the top graph of Figure 8. The annual leachate losses in the standard and dwarf apple orchards were 14 and 9 kg-N ha^{-1} yr^{-1} (Figure 8, bottom). Despite some 700 mm of drainage over that year, only 8–13% of the endogenously generated nitrogen was wastefully leached below the roots and into the underlying groundwaters. The macropores in the soil have resulted in the bypass flow of the incident rainfall via the macropores, thereby avoiding contact with the nitrogen generated within the soil's matrix. Here the macropores have performed a valuable regulating service by ensuring that the nitrogen would be available for the trees.

With grazing cows, the deposition of urine patches represents an intense local application of nitrogen, up to 1000 kg-N ha^{-1} in the 'footprint' of the patch. Locally within the patch this represents an intense exogenous application of a plant nutrient. Cichota et al. (2010) studied the leaching of nitrogen from urine patches in four lysimeters. They applied 1000 kg-N ha^{-1} to the surface of the lysimeters and monitored drainage at the base over the 8 months of winter and spring. There was also 700 mm of drainage in this experiment. Large amounts of the applied nitrate were leached below the rootzone, such that some 45–65% of the applied nitrogen was lost to the soil-plant system and despatched to groundwater. Here, a significant fraction of the exogenously applied nitrogen was available at the surface to be picked up by the rainfall and preferentially transported rapidly through the macropores, thereby avoiding being taken up by the plant. So the value of the nutrient regulating service provided by the soil's buffering and filtering capacity is low, and results in the disservice of potentially contaminating the underlying groundwater.

A rudimentary calculation was made by Clothier et al. (2008) suggesting the global net value of the ecosystem services provided by macropores in soil was US$304 billion per year.

CULTURAL SERVICES

Not only do orchards and vineyards provide the supporting processes and regulating services described above, the fruit bowls of New Zealand provide cultural services through aesthetics, sense of place, spirituality, and knowledge (Figure 1). These meet our needs for self-esteem, social exigencies, and self-actualisation. We can add recreation to this mix.

Aesthetic appeal

The terroir of vineyards and orchards is visually pleasing, as the autumnal scene from Rippon Vineyard on the shores of Lake Wanaka reveals (Figure 9). Not only is this a productive vineyard, the winery and events facilities at Rippon Vineyard provides a range of cultural services that are highly valuable, as can be measured through tourism receipts.

Spiritual and recreational

Vineyards and orchard are sought after for the holding of concerts and music festivals, as the poster in Figure 10 shows. The Classic Hits Winery Tour of New Zealand in 2013 involved a range of musicians playing at a number of vineyards and orchards.

CONCLUDING REMARKS

We have used the ecosystem service typology of Dominati et al. (2010) to assess the value of orchard ecosystem services. Dominati et al. (2010) identified supporting processes, rather than classify these as a service, as was done by the Millennium Ecosystem Assessment. The three services that flow from natural capital are thus identified by Dominati et al. (2010) as being provisioning, regulating and cultural. The total value of the provisioning service provided by orchards and vineyards in New Zealand is $6.4 billion per year. While we recognise this figure is large, we considered in more detail the regulating and cultural services.

Although the ecological infrastructures of New Zealand's horticulture cover only 70 000 ha, they provide valuable regulating and cultural services. The value of these services enable eco-verification of New Zealand's fruit and fruit products, such that they secure shelf access and eco-premium prices in the world's top supermarkets. We have outlined here the nature and value of the regulating services in orchards in relation to carbon sequestration, gaseous exchange, plus the buffering and filtering of nutrients. We have highlighted how the ecological infrastructures of orchards

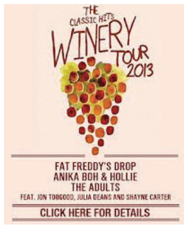

FIGURE 9 The aesthetic appeal of the viticultural landscape of Rippon Vineyards and Winery on the shores of Lake Wanaka, New Zealand (http://www.rippon.co.nz).

FIGURE 10 Vineyards also provide cultural services, such as music festivals.

and vineyards provide valuable cultural services through aesthetics and recreation.

We have also examined the role and impact that orcharding and viticultural land-uses have on supporting processes. Deep-rooted trees and vines can lead to deep sequestration of carbon and soil depth 'grows' as root processes create new biological activity at deeper depths. This carbon investment leads to enhanced biological activity which generates the supporting processes of water and nutrient cycling. Growers benefit from the supporting processes in the soil of their orchards, and furthermore they can enhance the value of these through investment into the ecological infrastructure of the orchard.

The regulating and cultural services that flow from the ecological infrastructures of vineyards and orchards benefit the entire community.

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ENDNOTES

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Tesco: http://www.tescoplc.com/assets/files/cms/Water.pdf ;
Sainsbury's: http://www.j-sainsbury.co.uk/responsibility/our-values/sourcing-with-integrity/
Carrefour: http://www.carrefour.com/cdc/responsible-commerce/sustainability-report/