

A NARRATIVE OF AGRICULTURE AND BIODIVERSITY LOSS

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h' fui por el mundo buscando la vida:

pájaro a pájaro conocí la tierra'

'I've wandered the world in search of life:

bird by bird I've come to know the earth'

PABLO NERUDA

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INTRODUCTION

As agriculture increasingly focused on mass production during the last century, land use intensified, ecosystems were degraded, and some ecosystem services were lost. The twin problems of a rapidly growing population and acute malnourishment increased the demand for agroecosystems to rapidly produce more food. The current term for this increase in agricultural productions is 'sustainable intensification' (Pretty et al. 2011). Agricultural ecosystems have been modified so they are now monocultures rich in nutrients, allowing crops to be grown in previously unsuitable conditions (Tilman 1999). For example, dairy farming is now common in Mediterranean climates and lettuce can be grown in the dry climate of Arizona (Swaminathan 2012). Traditional agriculture has been a practice of high external cost and damage to the natural environment. To increase food production, researchers produce new, higher-yield crop cultivars that grow faster but place increased demands on the land. Thus, more nitrogen and phosphorus fertilisers are applied, a higher proportion of land is being cultivated and irrigated for crops, and the use of pesticides has greatly increased (Tilman 1999; Calonne et al. 2011); for example, in Talamanca County in Costa Rica, economic pressures for greater yields has prompted increased use of pesticides in the banana industry and small-scale plantain farms (Barraza et al. 2011).

These chemical additions, particularly nitrogen (N) and phosphorus (P), are particularly vexing (Tilman et al. 2001) because only about half the N and P from fertiliser is absorbed by harvested crops (Vitousek et al. 1997; Carpenter et al. 1998). Another major source of N and P is livestock waste, and because this is seldom treated to remove these macronutrients, they enter surface and ground waters (Howarth et al. 1996; Carpenter et al. 1998). In surface waters the excess P and N causes eutrophication (Carpenter et al. 1998) and ensuing loss of biodiversity as anoxic conditions increase (Howarth et al. 1996; Vitousek et al. 1997); in groundwater the increase of nitrate and nitrite increases the greenhouse gases NO_x and N_2O ; and N is also volatilised in the atmosphere as ammonia (Howarth et al. 1996; Bouwman et al. 1997). The eventual results of these processes are smog, acidification of soils and fresh water (Howarth et al. 1996; Holland et al. 1999), and climate change. Nutrient pollution from agriculture also degrades the marine environment by threatening marine biodiversity (National Research Council 2000), causing increases in toxic algal blooms in many coastal systems, and creating

hypoxic zones in coastal waters (Joyce 2000).

In addition to water and air pollution, pesticides directly affect the health of humans and other species (World Health Organization 1990). Some pesticides accumulate in food webs (Kidd et al. 1995), persist over long periods, and affect organisms over great distances. Because pesticides are applied frequently, pests and pathogens evolve resistance, so newer chemicals must be applied – the so-called 'pesticide treadmill'. Furthermore, most insecticides do not target a particular species and are often aimed at invertebrates in general, killing not just the pest but also the natural enemies that would help control it.

Agriculture's high demand for water means land must be irrigated, thus increasing salt and nutrient loading in downstream waterways, while dams used to store water for irrigation also impact on rivers and streams (Alexandratos 1999; Søndergaard and Jeppesen 2007). In addition to this reliance on ample water, farming usually depends heavily on fossil fuels (Anderson 2003). However, the global supply of oil has declined markedly and its cost has increased, raising the potential for increases in food prices (Headey & Fan 2008).

In a pivotal paper, Costanza et al. (1997) used value transfer to determine the annual value of global ecosystem services as US\$33 trillion – a figure considered by many to be a gross underestimate. Whatever the true value, the implications are particularly troubling because, of the ecosystem services that have been studied, 60% have been degraded in the last 50 years (MEA 2005). To help halt this decline, the United Nations in 2005 established the Millennium Ecosystem Assessment (MEA). Nevertheless, farmland is still largely left out of ecosystem services decision-making, despite its high direct and indirect value. This omission must be addressed, particularly because the strain on the environment, rising fuel costs, and other demands on farms insist that we develop new methods for more sustainable and less costly production of food and fibre.

THE GREEN REVOLUTION AND THE EVERGREEN REVOLUTION

In the 1940s, Norman Borlaug, the 'Father of the Green Revolution', initiated a movement that began increasing agricultural production around the world. The Green Revolution reached its peak in the late 1960s and has been credited for greatly reducing world hunger (Tilman et al. 2001). Crops could now be mass-produced, but this involved developing high-yielding

cereals, expanding irrigation, and creating hybridised seeds, synthetic fertilisers, and pesticides, and this improved form of agriculture marked a change from farming for subsistence to farming for commercial gain.

Although the Green Revolution increased food supplies, it has been severely criticised for its effects on food security and its impacts on the environment and health. More food does not mean better access to food, and critics of the Green Revolution argue it does not take into account natural events such as famines, nor socio-economic or political situations in developing countries. The Green Revolution's negative impacts on the environment are largely undisputed and include pollution by pesticides and fertilisers, and loss of agricultural biodiversity as a result of monocropping. Although evidence on the long-term health impacts of pesticide consumption by humans is conflicting, poisoning caused by improper safety equipment and techniques while applying pesticides is well documented. For example, India's Punjab region has been highly affected by the increased use of water and pesticides: groundwater in the Punjab cotton region is contaminated with low levels of most pesticides applied, with two pesticides, carbofuran and monocrotophos, reaching near maximum contamination levels (Tariq et al. 2004). Additionally, the water table in the Punjab has been decreasing by 1 metre per year, and 90 of 138 blocks in the state have declared extreme water shortage (Singh 2004). All these criticisms of the Green Revolution address one main point: current techniques are unsustainable.

In response to the shortcomings of the Green Revolution, Indian Prime Minister Manmohan Singh initiated a new approach called the Evergreen Revolution (Swaminathan 2000; Wratten et al. 2013). The problem was particularly urgent in India, where malnourishment is rife (International Food Policy Research Institute's 2011 World Hunger Index) and the Punjab represents one of the more famous cases of negative health impacts from pesticides (Ejaz et al. 2004). With support from United States President Barack Obama, the two countries agreed to develop, test, and extend food security, and to form the Partnership for an Evergreen Revolution (Office of the Press Secretary 2010). This partnership means Indian and American researchers and scientists will cooperate to investigate and improve technologies to extend food security in India, Africa and around the world (USAID 2010).

WHAT TO DO?

Costanza et al. (1997) estimated the ecosystem services of world cropland to be US\$92 ha⁻¹ year⁻¹. This was in stark contrast to the services of other ecosystems, which in other terrestrial ecosystems ranged from US\$232 ha⁻¹ year⁻¹ for grass/rangelands to US\$19,580 ha⁻¹ year⁻¹ for swamps/floodplains. However, Costanza et al. recognised this as a severe underestimate due to the lack of data. While 17 ecosystem services were recognised for agricultural systems, only three were estimated: pollination, biological control, and food production.

These earlier low estimates of farmland ecosystem services failed to acknowledge that food provision is an ecosystem service, and they also ignored pertinent ecosystem services like pollination, pest and disease biocontrol, soil formation and maintenance, carbon capture, and human well-being (Costanza et al. 1997). In contrast, Losey and Vaughan (2006) estimated the economic value of four ecosystem services from insects – dung burial, pest control, pollination, and wildlife nutrition – in the United States alone as US\$57 billion, and this was probably an underestimate.

The difference between the estimates of Costanza et al. (1997) and Losey and Vaughan (2006) confirms that the ecosystem services value of agriculture has been greatly underestimated. Sandhu et al. (2008) estimated the economic value of earthworms in soil formation and found that 1 tonne of earthworms can form 1000 kg of soil per hectare per year and the purchase value of 1 tonne of topsoil in New Zealand is US\$23.60.

AGROECOLOGY

In a report to the United Nations Human Rights Council in 2011, Special Rapporteur Olivier de Schutter identified agroecology as the key to ensuring the human right to food in a sustainable manner (de Schutter 2011). Agroecology combines agronomy and ecology to create sustainable agricultural ecosystems, achieving this by reinstating and enhancing natural processes like recycling nutrients and energy, by integrating crops and livestock, and by diversifying species (see Box 1). Internationally, agroecology is garnering increasing support, with the United Nations Food and Agriculture Organization (FAO) (www.fao.org), United Nations Environment Programme (UNEP) (IPBES 2010) and Bioversity International (2012) now promoting its benefits.

A large-scale study, commissioned by the Foresight Global Food and Farming Futures project of the UK Government (Pretty et al. 2011), reviewed 40 projects in Africa that employed agroecology in the 2000s. The projects included crop improvement, integrated pest management, soil conservation, and agro-forestry. By 2010, average crop yields had doubled and 10.39 million farmers had documented improvements in farming and food yields (Pretty et al. 2011). The ability of agroecology to improve the sustainability and lessen the environmental impact of agricultural systems has also been implemented outside Africa; for example, conservation biocontrol of pests in Australasian vines employs buckwheat (*Fagopyrum esculentum*) sown between rows of vines (Sandhu et al. 2010).

OTHER BENEFITS OF AGROECOLOGY

Well-being from agriculture and agro-ecotourism has become an important aim of countryside initiatives in the United Kingdom, and similar programmes are just beginning in New Zealand (see Box 2). These initiatives are showing that the ecosystem services value of agriculture is far greater than previously recognised, with 'green' areas providing physical and mental benefits and projects such as 'care farming' providing 'green' outlets for the public (Pretty et al. 2007).

The Department for Environment, Food and Rural Affairs (DEFRA) in the United Kingdom is responsible for many countryside initiatives to promote well-being in agricultural areas. One of these, 'Make Space for Nature', is based on a review of England's wildlife sites by Professor Sir John Lawton, who investigated the connections that would be needed between the sites to achieve a healthy natural environment (Lawton et al. 2010). He found many sites to be too small and isolated, and this could cause key wildlife species to decline. To combat this, the Make Space for Nature programme aims to protect and manage designated and non-designated wildlife sites, and to establish new 'ecological restoration zones'. Farmlands are important for achieving these aims, with the Higher Level Stewardship (HLS) scheme considered one of the most important factors in managing England's ecological network. The HLS is in turn part of the Environmental Stewardship agri-environment scheme, which subsidises farms to conserve wildlife, enhance the landscape, promote public access, and protect natural resources. The HLS has delivered many

BOX 1 Modifying habitats for pollinators

Agroecological methods such as conservation biological control (CBC) can increase the ecosystem services value of agriculture while reducing negative impacts from the use of pesticides, fertilisers, and fuel (Jonsson et al. 2008). CBC enhances the effectiveness of natural enemies by modifying habitat, an approach easily remembered by the acronym SNAP: shelter, nectar, alternative prey, and pollen. During the last decade, research in this area has yielded many beneficial results. Innovative research using CBC is continually being conducted in Australasia and elsewhere.



The provision of flowering plants to enhance natural enemy fitness is a key aspect of CBC. In a review of current habitat management strategies, Fiedler et al. (2008) found that this management relied heavily on four plant species, with plants native to the area and perennial plants largely underrepresented. Two case studies were researched in depth: habitat management in southern Michigan, USA, and native plants in New Zealand vineyards. In southern Michigan in 2003, studies on habitat management aimed to help control pests by enhancing natural enemy effectiveness (Fiedler and Landis 2007). These studies investigated plant species that grew in declining prairie and oak savannah; if these species enhanced natural enemies, the initiative would provide not only an economic gain for farmers but also a conservation gain for savannah restoration. The case study revealed that a modest number of native plants can attract just as many natural enemies as non-natives. However, enhanced pest control is not achieved just by increasing opportunities to feed from flowers; success must be measured against a hierarchy that includes the use of floral resource by adult parasitoids or agents, how compatible the agent is with the use of some pesticides, improved fitness of individual agents and whether this improved fitness applies to males and females, a decrease in pest populations, and ultimately whether the CBC improves the farmer's profits (Wratten et al. 2003).

Vineyards are typically monocultures with a low provision of ecosystem services; however, in New Zealand a government-funded initiative is aiming to combat this problem. A key example of habitat modification in the vineyard ecosystem is a study in which buckwheat, phacelia, and alyssum were planted to provide nectar resources for key parasitoid wasps, which subsequently increased sufficiently to reduce the number of pests below the economic threshold (Berndt and Wratten 2005). In addition to pest control, other ecosystem services were enhanced; for example, New Zealand endemic plants were used as mulch to disrupt the life cycle of grey mould or to suppress weeds.

While habitat modification is pertinent for CBC, it also plays a key role in other ecosystem services such as attracting pollinators and enhancing their fitness (Wratten et al. 2012). This is important because a reduction in pollinators can have drastic, negative impacts on biodiversity and crop production (Kevan and Phillips 2001). The rapid decline of managed honey bee populations from colony collapse disorder has focused attention on this problem, and has also drawn attention to the loss of other, wild bees from their historical range. Habitat modification may offer a partial remedy, and also has conservation benefits. For example, the butterfly *Lycena salustrius* has co-evolved with the plants *Veronica 'Youngii'* and *Fagopyrum esculentum*, and field and laboratory trials showed that individuals of *L. salustrius* feeding on these plants have greater

fitness than those feeding on other exotic plant species (Gillespie and Wratten 2013). Therefore, planting these floral resources in vineyards and farmlands may increase the population of butterflies (Gillespie 2010), thereby helping butterfly conservation. Other potential benefits from habitat modification for pollination in agricultural systems include an increase in farmland ecosystem services such as soil quality, pest reduction, and aesthetic enhancement (Wratten et al. 2012).

BOX 2 Māori kaupapa values from agriculture

The Māori cultural belief system has links with the physical, natural and spiritual realms and includes natural resources such as food. The link with food includes concepts such as *kaitiakitanga* (guardianship or trusteeship, referring specifically to a way of managing the environment), *mahinga kai* (ability to access the resource for food gathering or a place where food is gathered), and *tikanga* (custom, method, plan, or practice). For Māori, traditional agriculture was used not only for sustenance but also for trade and as a sign of prestige (Roberts et al. 2004).

Since the 1980s Māori horticulture has begun to move into the commercial sector, particularly in the kiwifruit, apple and wine industries. This adaptation to commercial production has seen some of the more traditional practices abandoned for greater economic gains. However, with the wider use of organic farming many Māori are aligning themselves with organic practices, which are more consistent with their beliefs and values (Roskrug 2007).

Recently, new agroecology initiatives such as Greening Waipara have included species traditionally valued by Māori (*taonga*) to introduce traditional belief systems into agriculture. For example, the Pegasus Bay biodiversity trail in Waipara incorporates a pond and stream with short-finned eels, *Anguilla australis*, which have been an important traditional food source for Māori. The start of this trail has a pou (totem pole) which depicts the owner's whakapapa (family history; in this case, Ngāi Tahu).

benefits, including increases in populations of farm birds and the area of priority habitats such as hay meadows. On the other hand, while agri-environment schemes in five European countries benefited common species, they rarely benefited uncommon species (Kleijn et al. 2006), suggesting that while these schemes can be modified fairly easily to suit common species, endangered species may require more intensive measures.

The wide range of human health benefits from green areas has been well researched in England. A study conducted on the mental health benefits of countryside walks has shown that walking in a green environment is more beneficial to mood and self-esteem than general social club activities or activities in non-green areas (Barton et al. 2012). Additionally, 'green exercise' – walking in nature – improves physical health while reducing stress and lifting mood (Barton et al. 2009), and the catch phrase 'a dose of nature' has been introduced to encourage 'green exercise' for improved physical and mental health (Pretty et al. 2005; Barton and Pretty 2010).

'Care farming' refers to the use of normal farming activities on commercial farms and in agricultural landscapes to promote physical and mental health and social and/or educational benefits (Hine et al. 2008). The scope of care farms ranges from providing ample opportunities for interaction between the public and farms funded by charitable organisations and therapeutic communities, to activities like green exercise and educating communities about ecology.

CONCLUDING REMARKS

By promoting the views of a wide range of experts, the Royal Society of New Zealand (RSNZ) aims to inform policymakers and bring information to public attention. It offers a wide range of reports on ecosystem services policy and implementing ecosystem services in agriculture, and one of these reports addresses the rising concern about changes in land use (RSNZ 2011). This report focuses mainly on rural and urban spaces and recommends national land use planning as a way to help resolve land resource conflicts, suggesting that policies and guidelines should be integrated so they can be implemented at both a regional and district level. Furthermore, working directly with landowners and land users can help create desired outcomes for food production, biosecurity, biodiversity, climate change, water management, economic development, and recreational access.

In August 2011, the RSNZ hosted a workshop entitled 'Ecosystem services in policy'. This aimed to discuss how an ecosystem services approach can help policymakers address issues in policy development, monitoring, and regulation. Participants from a range of disciplines presented talks, and researchers and policymakers were able to build ongoing dialogue and share practical examples of how they fostered ecosystem services. Initiatives like these workshops are imperative if ecosystem services are to be fully utilised. However, while workshops involving researchers and policymakers are important, they still fail to include growers, and until growers are included in partnerships, they are unlikely to acknowledge and act on the true value of ecosystem services (Cullen et al. 2008).

Thus, if farmers are to enhance the provision of an ecosystem service, or at least make best use of it, they must understand it, recognise its benefits, and know how to manage it in practice. A crucial step in achieving this is effective communication with farmers so they learn about the values of ecosystem services. In this respect, and in understanding the new concepts presented in agroecology in general, social learning networks are vital

BOX 3 Beetle banks

Beetle banks are strips of farmland set aside to provide a habitat for wild animals in the hope that some will keep down the numbers of crop pests. The strips can border agricultural land or run through the middle of large fields, and are typically planted with a variety of plant species, including grasses, flowers, and herbs.

Originally developed in the United Kingdom by the Game and Wildlife Trust in the 1990s, beetle banks provide habitat for predatory animals such as lacewings and blue tits. Although the primary function of a beetle bank is pest control, they are also habitats for other beneficial flora and fauna that may provide additional services such as pollinating crops. Bumble bees, butterflies and other nectar feeders may colonise the beetle bank and extend their foraging range to include the crop, while tall plants growing in beetle banks can catch airborne weed seeds that might otherwise drift onto farmland.

While being of considerable benefit to the farmer, beetle banks also provide a habitat for local native wildlife; in this respect they may be particularly important for species endangered through habitat loss, such as the grey partridge. They may also serve as wildlife corridors, allowing passage from one side of a farm to another.



(Warner 2007); for example, in California, social networks – a partnership with growers, a growers' organisation, and scientists – were all pivotal in a 75% reduction in organophosphate use by almond and pear growers (Warner 2006).

In Canterbury, New Zealand, Sandhu et al. (2007) evaluated the perceptions of arable farmers about ecosystem services. Both conventional and organic farmers understood the impacts of agriculture on the environment and had moderate to high knowledge of ecosystem services. Although both farmer types listed ecosystem services as important (mainly pollination, soil fertility, food production, soil erosion control, and, for conventional farmers, hydrological flow), only organic farmers implemented most of the practices important for fostering ecosystem services; however, this was not necessarily because organic farmers were proactive but more probably an indirect result of their organic practices. In New Zealand there is currently no direct incentive for conventional farmers to encourage the provision of ecosystem services; in contrast, government institutions in the United Kingdom offer subsidies and rewards to farmers for maintaining and enhancing ecosystem services on their farmland (Green Food Project 2012).

Farmers depend on the production of crops and fibre for their livelihood, and if ecosystem services on their farmlands are to be fostered, clear protocols must be developed. A good example of these is the concept of a service-providing unit (SPU): a protocol that clearly indicates the characteristics of biodiversity required to deliver a given ecosystem service at the level needed by those who stand to benefit from the service (Luck et al. 2003; Vandewalle et al. 2008). In New Zealand, examples of SPUs include ‘beetle banks’ (see Box 3) and the previously mentioned use of buckwheat as an additional nectar resource for natural enemies, to enhance conservation biocontrol in vineyards (Sandhu et al. 2010). SPUs have been used widely in Europe, where the RUBICODE project compiled a database of all currently available SPUs for easy access and use by service providers (RUBICODE 2008).

If ecosystem services are to be widely accepted, understood, and exploited wisely in the future, a collaborative approach is necessary. Many such services cannot be privately owned and should be treated as public goods, and accommodating this new view will require new institutions, policies, and practices. To move forward will require a focus on the common ground shared by those with a stake in the wise management of ecosystem services, and any methodological disagreements must be resolved by open dialogue between policymakers, scientists, and practitioners. If these requirements are met, perhaps the day may not be far off when most farmers will share the view expressed by Swedish farmer Peter Edlin, who in 2003 epitomised ecosystem services and the goal for ‘future farming’ with a simple statement: ‘I am a photosynthesis manager and an ecosystem-service provider’.

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