1 Harnessing biodiversity

From diets to landscapes

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Introduction

There is an increasing sense that we are at a global crossroads, at the peak of human potential while on the edge of global disaster. Several authors highlight critical planetary thresholds that have been largely surpassed (Rockstrom et al., 2009), particularly the loss of biodiversity, the failure to meet the 2010 Convention on Biological Diversity targets (Butchart et al., 2010), and the increasing scepticism that we will attain many of the Millennium Development Goals. Amongst these goals, halving the number of people who regularly go hungry is prominent. Novel solutions are urgently required to confront these issues.

There are also refreshingly new perspectives on these problems that offer both guidance and hope that solutions are within reach if we are committed. The most exciting of these solutions are those that are the product of interdisciplinary collaborations aimed at integrated solutions, rather than disciplinary band-aids that offer solutions at the expense of other development problems. These solutions often come from a combined process of divergent and convergent thinking (DeHaan, 2011). Divergent thinking is fostered by brainstorming freely on a problem using a defocused, intuitive approach, while maintaining a particular receptiveness to a broad range of associations (i.e. thinking across disciplinary boundaries). Convergent thinking is then used to synthesize these ideas and bring them back into focus. One way to foster this kind of thinking is by encouraging disciplinary scientists to consider how their specific skill set or knowledge base could be applied to tackle an issue or problem outside of their disciplines (DeClerck et al., 2011a).

This practice has become increasingly common with ecologists, amongst other fields, leading to novel interdisciplinary realms such as ecosystem services (Daily, 1997; Naeem et al., 2009), eco-nutrition (Deckelbaum et al., 2006), eco-health (Borer et al., 2012) and eco-agriculture (McNeely and Scherr, 2003) for example (Table 1.1). Ecosystem services blend the domains of ecology, economic and social sciences; eco-nutrition brings together the science of nutrition, agronomy and ecology; eco-agriculture calls on close collaboration with landscape planners, political leaders, farmers and community groups and a broad

Table 1.1 Definition of four interdisciplinary communities of practice, their core disciplines and groups involved, stated goals and key references regarding select examples of ecology's integration in other disciplines

Integrated efforts	*Core disciplines/groups*	*Goals*	*Reference*
Eco-nutrition	• nutrition • agronomy • ecology • economics	Integrate nutrition and human health, agriculture and food production, environmental health, and economic development to jointly reduce malnutrition, increase agricultural productivity, protect the environment, and promote economic development.	Deckelbaum et al., 2006
Eco-agriculture	• ecology • agriculture • economics • development practitioners • community groups	Rural communities jointly manage their resources to enhance rural livelihoods, conserve biodiversity and ecosystem services; and develop more sustainable and productive agricultural systems.	McNeely and Scherr, 2003
Ecosystem services	• ecology • countless other fields	To recognize the contribution of natural and managed ecosystems to human well-being and livelihood. In the broadest sense these include services such as clean water, clean air, agricultural productivity through pollination and pest control services for example.	Daily, 1997 MEA, 2005
Eco-health	• ecology • health sciences	To better understand the connections between nature, society, and health, and how drivers of social and ecosystem change ultimately will also influence human health and well-being.	Wilcox et al., 2004

range of professionals from ecology, agronomy, and economics amongst other disciplines within mixed-use landscapes. In each case, traditional disciplinary boundaries are broken and interaction between disciplines is fostered. The first step in fostering this interaction is 'semantic mediation', or creating a common language. More importantly it requires participants to focus on process and to hold off on considerations of specific contexts until a broader interdisciplinary perspective is developed. This chapter explores how integrating ecology and ecological thinking into nutrition and agricultural development can be used to develop novel solutions to development problems by particularly focusing on ecology, nutrition and agriculture.

A rapid review of the problem

Nutrition

Unfortunately, the first similarity between the fields of nutrition, agriculture and environment is the current gloomy outlook! It is often cited that more than one billion of the world's population lack access to food or are chronically malnourished. On the flip side, a 2006 World Health Report predicts that by 2015 there will be 2.3 billion overweight adults and more than 700 million obese. This 'double burden' suggests that nearly half (47 per cent) of the global population is suffering from some form of nutritional disorder. The poor are particularly hard hit with these two paradoxical problems, hunger and obesity. In many parts of the world, the poor are dependent on subsistence systems subject to the vagaries of rainfed agriculture where the primary challenge is a struggle to simply produce enough calories to survive. In contrast, many of the urban poor, including in the United States, are faced with levels of obesity tapering off at 35 per cent for adults. Again, in developed countries such as the United States, rates have risen to nearly 60 per cent among non-Hispanic black women and to nearly 45 per cent among Mexican American women since 2004. Among children and teens, about 21 per cent of Hispanics and 24 per cent of blacks are obese compared with 14 per cent of non-Hispanic whites (Ogden et al., 2012; Flegal et al., 2012). Several studies have suggested that the poor cannot afford to eat healthily, which at times is due to a lack of access to food (calories), or which can be driven by a lack of access to dietary diversity (Franco et al., 2009) leading to literal food deserts typically found in poor urban neighbourhoods (Gordon et al., 2011; though see recent articles discrediting this notion: An and Sturm, 2012). There is growing recognition however that the food we eat has a direct impact on our own health, as well as the health of the environment (Nugent, 2011).

Agriculture

Agriculture is faced with similar challenges. Recent reviews and analyses highlight the current twin challenges of feeding the 9 billion global inhabitants projected for 2050 while decreasing the growing environmental footprint of agriculture (Tilman et al., 2011; Foley et al., 2011; Rockstrom et al., 2009). While agriculture has met the challenge of producing for growing populations in the past, notably through the Green Revolution, this increase has come at tremendous environmental cost. Agricultural expansion is the primary driver of biodiversity loss with more than 70 per cent of global grasslands, 50 per cent of savannahs, 45 per cent of temperate deciduous forests, and 27 per cent of tropical forests converted to agriculture. Global fertilizer use has increased more than 500 per cent leading to significant impacts on global water and nitrogen cycles in particular. In terms of disruptions to the carbon cycle, agriculture has contributed to 30–35 per cent of global greenhouse gases (Foley et al., 2011) and is likely to be one of the industries most impacted by global climate change. The focus on agricultural intensification has also led to a singular focus on a handful of crop species, primarily in the grass family. Three crops, wheat, maize and rice, occupy approximately 40 per cent of the global agricultural landscape (Tilman, 1999a). Not only is tremendous crop diversity lost though agricultural intensification, the intraspecific, or genetic diversity of both major and minor crop species is lost, eroding the capacity of agricultural systems to weather shocks.

Agricultural systems are increasingly vulnerable to climate change, globalization, the increasing price of inputs such as water and fertilizer, and the degradation of the natural resource base. These problems are likely to be significant obstacles, particularly for small-scale farmers. The free pass that agriculture has enjoyed over the past decades regarding agricultural productivity at any cost is coming to a close with increasing public pressure for food production systems that contribute to environmental protection while supporting farming communities. The agriculture of the next three decades will need to continue its impressive yield increases while halting or reversing its negative impact on the environment. Agricultural landscapes must become net producers of ecosystem services rather than consumer services. This necessitates a movement towards multifunctional landscapes.

Environment

As with human nutrition and agriculture, global environmental concerns are rising. Butchart et al. (2010) highlight that most indicators of the state of biodiversity are declining with no significant reductions in rates observed. In contrast, indicators of pressures on biodiversity continue to increase. In many cases, the negative declines are tied to agriculture and include the direct impact of agricultural expansion on the loss of habitat for biodiversity. Although species extinctions are natural, never in the history of the earth has one species, our own, been the cause of the mass extinction of so many others. Current extinction rates are 1,000–10,000 times greater than background extinction rates (Rockstrom et al., 2009); a disaster that E.O. Wilson (1994) argues has far greater consequences than economic collapse or nuclear war. Rockstrom et al. (2009) evaluated nine critical planetary thresholds that require the effort of a global collective and which must not be surpassed in order to maintain a stable and resilient human society. Of the nine thresholds identified (phorphorus/nitrogen cycle, climate change, global freshwater use, change in land use, biodiversity loss, atmospheric aerosol loading, chemical pollution, stratospheric ozone depletion and ocean acidification), two have been significantly surpassed: the rate of biodiversity loss is more than ten times the proposed threshold value; and disruption to the nitrogen cycling is approximately 3.5 times the proposed threshold value. It is hard not to see the impact of agriculture in both of these out-of-bounds indicators in addition to the environmental impacts mentioned above.

Integrated approaches to solutions

Traditionally, issues of hunger have been the domain of nutrition, crop production, the domain of agronomy, and environmental conservation, the domain of ecology. The review of emergent global concerns above however demonstrates the important role of agriculture in all three issues. The majority of the foods that provide us with our nutrition come from agricultural fields that compete with biodiversity for space. There are deeper relationships that are not as obvious however. The nutritional value and the flavours of our foods are ultimately the result of complex interactions between crops and their environment. The protein content of beans is the result of a symbiotic relationship with bacteria inhabiting the roots of legumes; the pungent flavour of peppers is the result of an antagonistic interaction between the chilli pepper, a weevil and a fungus. Most of the flavours that spice our meals are the result of these negative interactions, or arms races, between plants and their pests and diseases. These are all interactions that have occurred on evolutionary timescales.

On shorter timescales, the production of many fruits such as almonds, apples and pears is wholly dependent on a host of bees and other insects that pollinate the flowers facilitating fruit production. The conversion of leaf litter to soil organic matter is the result of a host of invisible, and underappreciated communities of soil microflora and fauna (whose value we would quickly learn to appreciate if they disappeared). Whether the nutritional value of the foods we eat, or simply the production of many of these crops within farmers' fields, we quickly realize that food production and nutrition are tied to ecosystem services, and that human nutrition is a component of human well-being that is ultimately dependent on numerous ecosystem services that operate from microscopic to landscape scales (Figure 1.1; Table 1.2).

Ecosystem services

The late 1990s brought a fresh look at humans and their interactions with the environment starting with a renewed realization of society's dependence on nature's services. Daily's (1997) multi-authored volume *Nature's Services* and the more recent synthetic work of the Millennium Ecosystem Assessment (MEA, 2005) were key to highlighting this dependence. Ecosystem services

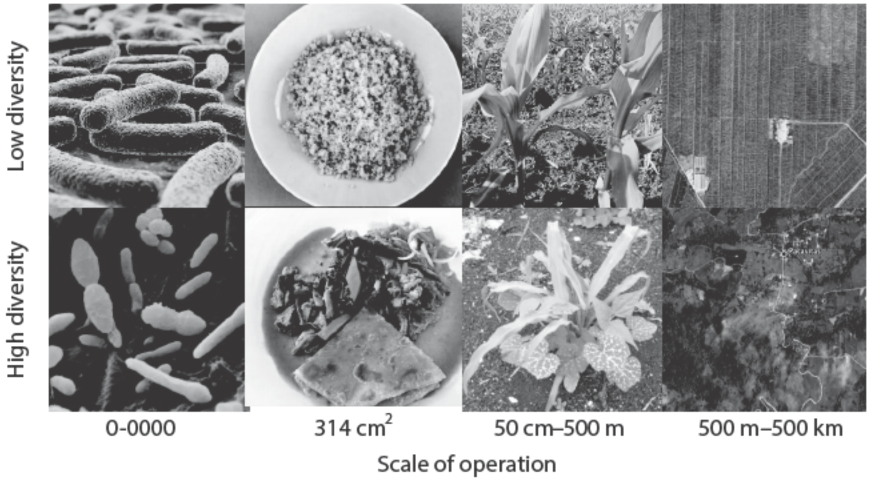

Figure 1.1 Different levels of species richness contribute to nutritionally important ecosystem services at different scales, increasing from left to right in this figure. Species poor systems (top row) may be well suited for singular functions, but generally fail at maintaining the stability of the function, and at the provision of multiple functions where species rich communities (lower row) are better suited. From left to right: (1) the microbiome of the human gut with the obese gut (above), and the lean gut (below); (2) the species richness of the food we eat; (3) field scale monocultures (above) or polycultures such as the Mayan three-sister system (below); and (4) landscape scale land use diversity such as the simplified banana monoculture (above) and the diversified landscape of a biological corridor (below), both in Costa Rica.

are defined as the conditions and processes through which ecosystems and the species that comprise them sustain and contribute to human livelihoods (Table 1.1; Daily, 1997). The MEA (2005) further classifies these into four broad categories: provisioning, regulating, cultural, and support services (Table 1.2). The fundamental understanding here is that ecosystems, including agricultural ecosystems, or other managed ecosystems are comprised of a community of species (or biodiversity) interacting with each other, and with their environment. The product of these interactions, which include competition, predation, reproduction, and cooperation for example, can be considered ecosystem services when they benefit humanity (Table 1.1; nicely summarized in Loreau et al., 2002; Naeem et al., 2009, 2012). When the species composition of ecological communities is altered, the functions provided by those communities are likewise altered. As a general rule, though there are exceptions, increasing the number of species in a community will increase the number of functions provided by that community (Hector and Bagchi, 2007; Isbell et al., 2011), and will increase the stability of the provisioning of those functions.

A subset of these ecosystem functions are identified as essential to human well-being – and are called ecosystem services (Tables 1.1 and 1.2). In the simplest sense, ecosystem services are the ecosystem functions with human

Table 1.2 Adaptation of the Millennium Ecosystem Assessment classification of ecosystem services.

Those services that have ties to human nutrition are italicized and the scale at which the service operates is identified: human body (B), field (F), and landscape (L). Human nutrition is a function of provisioning services which provide us with the raw materials of our diets, the fuels and clean water with which it is often prepared. Regulating services ensure the stability of food production systems (on farm) and nutrient absorption (within the human body). The recipes and food traditions that are prevalent in most cultures are the result of long-term interactions between human societies, the ingredients of the agroecological landscapes of our ancestors, and trade systems. Supporting services in agricultural landscapes are often overlooked and include soil formation, pollination, nutrient cycling, and soil formation. The microbiome of the human gut also provides numerous supporting services, including transforming the food we consume into forms that can be taken up by our bodies and serving as a first line of defence against disease.

Provisioning services	*Regulating services*	*Cultural services*
Products obtained from Ecosystems	*Benefits obtained from regulation of ecosystem processes*	*Non-material benefits obtained from ecosystems*
Food (F, L) Freshwater (F, L) Fuelwood (F, L) Fibre (F, L) Biochemicals (B, F, L) Genetic resources (F, L)	Climate regulation (L) Disease regulation (B, F, L) Water regulation (L) Water purification (F, L) Pollination (F, L)	Spiritual and religious Recreational and tourism Aesthetic Inspirational Educational Sense of place (B) Cultural heritage (B) Traditional recipes and culinary heritages (B)

Supporting services
Services necessary for the production of all other ecosystem services
Soil formation (F) Nutrient cycling (B, F) Primary productivity (F)

value including non-economic values. Understanding the *concepts* and *processes* through which biodiversity provides ecosystem services, from human nutrition to landscape scale services (Figure 1.1), generates novel insights and promising solutions to global problems as we will see below.

Ecosystem services represent one of the most exciting examples of interdisciplinary integration. The initial idea with its focus on ecosystems falls squarely in the disciplinary realm of ecologists though the evolution of the concept was to communicate the benefits of conservation to non-ecologists (Daily, 1997). Considering the services that ecosystems provide brings social scientists and human interests to the table. The recent growth of programmes on payments for ecosystem services has involved economists and political scientists when the economic valuation of these services is warranted. Whereas ecosystem services that have received the most attention to date include carbon sequestration for climate mitigation, water quality, and regulation of hydrological cycles, there is a growing interest in ecosystem services in agricultural landscapes, including pollination and pest control services. Less evident from a contextual point of view, but clear from a process-based interpretation, human nutrition is dependent on several ecosystem services including provisioning, regulating, supporting and cultural services (Table 1.2), and alternatively may even be considered one of the most fundamental ecosystem services (DeClerck et al., 2011b). The capacity of ecosystems to provide us with the energy and nutrition needed to go about our daily lives fully depends on the foods that agriculture provides us. The means by which our internal ecosystems, or the bacterial communities that reside in the human gut, process and make nutrients and calories available (Turnbaugh et al., 2009; Jumpertz et al., 2011) is also very much an ecosystem service.

Eco-nutrition

In 2006, a paper was published introducing the concept of eco-nutrition (Deckelbaum et al., 2006; Deckelbaum, 2011). The fundamental goal of eco-nutrition was to show the linkages between agriculture, human well-being, and environmental sustainability. Eco-nutrition was defined as the interrelationships among nutrition and human health, agriculture and food production, environmental health, and economic development (Deckelbaum et al., 2006). It argued that individuals and families caught up in the poverty trap find themselves in a negative feedback loop, unable to practise productive agriculture because of lack of access to resources leading to environmental degradation through unsustainable agricultural practices; that environmental degradation leads to low yields which further provokes problems of malnutrition which leads to increased incidence of disease, or simply insufficient caloric intake to provide the human energy needed for labour-intensive sustainable field management. The cycle thus repeats itself. Central to the proposal of eco-nutrition is that reversing this negative feedback requires integrated and targeted solutions that simultaneously address the agricultural, nutritional and environmental dimensions of the problem; that is that human nutrition in subsistence communities cannot be resolved without addressing agricultural problems, which in turn cannot be resolved without addressing environmental degradation.

A classic example of eco-nutrition in subsistence systems is the indigenous 'American three-sisters' polyculture where farmers simultaneously sow maize, beans and squash not only in the same field, but in the same planting hole (Figure 1.1). The critical element of the system is not that it includes three distinct taxonomic species, but that it includes three species that are functionally distinct. A three-species system comprised of rice, maize and wheat for example, would not feature the same environmental or nutritional benefits. Focusing on processes from the agro-ecological point of view, the species represent three distinct functional groups. Maize is a C4 grass with highly efficient ability to convert sunlight to energy in tropical environments. Very few plant families outside the grass family have the C4 photosystem. Beans are C3 herbs, unique in their ability to convert abundant atmospheric nitrogen into plant useable forms. Very few plant families other than the bean, or legume family (Fabaceae to botanists) have the ability to capture and use atmospheric nitrogen. Bean cover crops are often used in agricultural systems as a nature source of nitrogen fertilizer. Squash in contrast, has a photosystem as with beans, but does not share its nitrogen fixing ability. When grown in combination, the maize provides the primary productive elements, but also provides the physical support structure, a trellis of sorts, for the climbing bean. Mayan farmers have suggested that the beans growing on the corn provide the additional benefit of hiding the ripe ears of corn from crop pests. The beans and the maize capture the majority of the sunlight, but not all; the remaining light that reaches the ground is captured by the third species, squash, which as a prostrate plant occupies the space remaining and whose less efficient C3 photosystem may be benefited by the shade and increased micro-environment humidity offered by the other species.

The combination of these three species harnesses several important ecological processes. Resources are partitioned between the niches of the three species, and complementary interactions are also favoured, particularly in the support provided by maize to the beans, the nitrogen provided to the maize and squash by the beans, and the more humid micro-environment provided to the squash. Nutrient flows are maintained and managed within the system, with little overflow into adjacent areas, or requirements for external inputs. The more efficient partitioning of resources and great occupation of niche space by the three species also benefits the provision of ecosystem services such as soil conservation and fertility.

There is also important nutritional complementarity between the three crop species of the three-sisters system. Carbohydrates and energy are primarily provided by the maize, protein by the beans, and vitamin A by the squash. The combination of these three crops is nearly nutritionally complete. One critical point however is that the protein provided by the system is derived from the unique ability of the bean family to convert atmospheric nitrogen to plant usable forms through a symbiotic relationship with a bacteria found in the plants' roots – the trait that makes beans ecologically unique is the same trait that makes the species agronomically unique as a source of biological nitrogen fertilizer, and the same trait that makes the family nutritionally unique as a source of plant-based protein. Mayan farmers, traditionally consume their meals with sauces (salsas) prepared with lime juice from citrus plants grown in their home gardens (DeClerck and Negreros-Castillo, 2000). The beans supply amino acids lacking in corn, while the addition of lime makes the niacin within the beans bio-available.

The important contribution of eco-nutrition to human nutrition is in defining the relationship between crop diversity, nutritional diversity and human health. DeClerck et al. (2011b) working with subsistence farmers of Western Kenya, found that farmers who had greater in-field crop nutritional diversity, where the unit of measure was not species diversity but the nutritional diversity of the crops, were less likely to suffer anaemia than farmers with lower field-based nutritional diversity. Other studies have also shown ties to agricultural diversity and human nutrition (Remans et al., 2011a; Penafiel et al., 2012). However, available crop nutritional diversity is not necessarily linked to improved nutrition (Termote et al., 2012) because it must pass through important social filters such as cultural preferences, social pressures, and other elements of human behaviour, highlighting the need for eco-nutrition to add social and behaviour scientists to the equation.

Eco-nutrition as an interdisciplinary field of study considers human nutrition to be a function of multiple ecosystem services. Considering the definition of ecosystem services, the benefits that humans receive from ecosystems, and the MEA (2005) distinction of four categories of services, multiple nutrition entry points become evident.

- The production of foods in agro-ecologically intensified systems is a primary provisioning service.
- Maintaining soil fertility or the inter-annual productivity of cropping systems are defined as regulating services.
- Soil microflora and fauna that convert soil organic matter into nutrients available to plants play important support services.
- Cultural services are central to nutrition – how you eat may be as important as what you eat (Pollan, 2009) as diets are the product of an evolutionary interaction between groups of people and the edible species found in our environments.

Most cultures can identify with a traditional dish, such as the Mayan meal of corn-based tortillas, with whole or fried beans, and tomato salsa prepared with citrus. Cultures that took corn from Latin America without the beans or the lime missed added value obtained from the combination of these species with important nutritional consequences such as pellagra. As with mixed cropping systems described earlier, traditional foods are more than the sum of their parts (Figure 1.1).

Eco-agriculture

The third 'eco' concept introduced earlier is that of eco-agriculture. Eco-agriculture is the management of landscapes for both the production of food and the conservation of ecosystem services and wild biodiversity (McNeely and Scherr, 2003). The concept explicitly recognizes the multifunctional role of agricultural landscapes arguing that they should contain space for nature (biodiversity), food (agricultural productivity), people (livelihoods), and that they should contain the institutions that support these multiple goals. Like eco-nutrition, it highlights the relationship between three elements and suggests that a focus on any single element in isolation deviates from the path of sustainable development.

Inherent in the notion of eco-agriculture is the recognition that productive agriculture is dependent on biodiversity through the provision of ecosystem services such as pollination, pest control services and healthy soils (also important elements of eco-nutrition); that human livelihoods are dependent on agricultural land uses, not only for the production of healthy foods, but also for the production of clean water and other ecosystem services; and that both the conservation and production goals of eco-agricultural landscapes are dependent on human communities. Eco-agriculture takes us away from the paradigm that conservation should only occur in natural reserves and protected areas, with agriculture parsed to designated production areas. Rather, eco-agriculture suggests that landscapes should provide both production and conservation functions, and that the additive value of this integration is greater than their segregation. Eco-agriculture values the contribution that agricultural landscapes can make to conservation (complementing reserves), and recognizes the contribution of conservation to agricultural production and sustainability.

Why diversity struggles as a strategy

Eco-nutrition, eco-agriculture, and ecosystem services all feature elements of managing diversity whether this be genetic diversity, species diversity, or landscape diversity (Figure 1.1). Managing for biodiversity can be complicated, particularly when attempting to understand the details of all possible interactions. Ecologists revel in complexity, describing ecosystems as 'complex adaptive systems' (Levin, 1999). Ecology is often hard-pressed to be predictive, with solutions that are often complex and context specific. Nutrition is similar, because as we shall see, the human body is in many ways its own complex adaptive system. As Pollan (2009) says, 'eating in our times has gotten complicated'. The diversity and often changing recommendations of nutritionists are enough to be mind-boggling, not unlike recommendations made by ecologists which frequently are so context specific and complex to be wholly unusable. Complexity should not lead to inaction however, by focusing on processes rather than contexts, and when managing for diversity we may find that the solution is simpler than we think, much in the same way that Pollan (2009) reduces nutrition to three simple rules: eat food, not too much, mostly plants.

Despite the advantages of using diversity as a development tool, the concept still struggles to find greater adoption in the face of more targeted interventions in part because of the focus on complexity rather than simplification and on context rather than process. The focus on complexity means that diversity-based strategies tend to be knowledge intensive. Two key ecological processes are focused on below, resource partitioning and resource acquisition. Both of these processes are comparable to concepts of harvest or yield in agronomy, and nutrient capture in nutrition.

Methods used by community ecologists often call for measuring the number of species, species composition, or the abundance of distinct species in an ecological community (or ecosystem). We then try to understand how changes in these community attributes affect ecosystem services. The positive effect of biodiversity in ecosystem services is most notably observed in those that relate resource acquisition and productivity (Hector et al., 1999; Hooper and Dukes, 2004). There are two primary mechanisms identified for the effects of diversity on the delivery of an ecosystem service, and one example of the effects of nutrient enrichment and impacts on biodiversity, which have parallels to human nutrition.

First, there are two mechanisms that relate biodiversity to the provision of ecosystem services. The first of these is the sampling effect (Tilman, 1999b), which notes that increasing species richness (the number of species in an ecological community), also increases the probability of including a species that is particularly good at providing a specific ecosystem service. The fundamental notion behind this concept is chance, and that increasing diversity is simply a matter of hedging one's bets. The maximum level of ecosystem service provision evidenced in the sampling effect is equal to the provisioning level of a monoculture of the dominant species. For example, under the rules of the sampling effect, the community productivity cannot exceed the productivity of the most productive species in the species pool. In other words, the total productivity is the sum of the parts.

The second mechanism is through species complementarity. Complementarity occurs when increasing species richness increases the number of niches that are filled, increasing resource use efficiency and productivity, as well as increasing the probability of positive interactions such as symbioses. This complementarity increases the efficiency of the system and yields a service provisioning that is greater than the sum of its parts. The quantity of ecosystem service provided in a diverse community is greater than the quantity provided by a monoculture of even the most productive species. There are numerous examples of both mechanisms in the ecological literature.

One problem with many of these studies is that they have focused on singular ecosystem services such as productivity, carbon sequestration, or pollination for example. It is often the case that when focusing on a single service, there is a single species that is best able to provide that service. A classic example is for carbon sequestration. If the land management objective is to store carbon, then a dense plantation of a fast growing, high wood density species such as eucalyptus is ideal. Bunker et al. (2005) demonstrated this with their study of carbon storage in a diversified tropical forest of Panama. This is exactly the strategy of conventional agricultural systems – a singular focus on the most productive species which has led to the use of strategies focused on the sampling effect: identify the species with the greatest production potential, provide the conditions that maximize the productivity of this singular species, often at the expense of others, and focus on it. This is similar to nutrition professionals focusing on fortification of vitamin A for example, a singular focus on the most limited nutritional element, and a targeted solution through fortification or enrichment.

Increasingly however there is recognition of the environmental harm that this strategy has caused in agricultural landscapes (Foley et al., 2011), and renewed interest in the notion of multifunctional landscapes (Hector and Bagchi, 2007). Agricultural landscapes, which currently occupy 38 per cent of terrestrial landscapes, must do more than provide abundant food sources. Farmers and those who work with them urgently need to recognize that agricultural landscapes must become multifunctional, producing water, sequestering carbon, supporting pollinators, and providing corridors for wild biodiversity amongst others. As we increase the number of services expected or desired from ecosystems, we find that the value or contribution of biodiversity also increases (Isbell et al., 2011). That is, while we might find a singular species that is ideally suited for carbon sequestration, such as the eucalyptus, we would be hard pressed to find a single species ideally suited to providing multiple ecosystem services. The eucalyptus plantation mentioned above is ideally suited for carbon sequestration, but is particularly poor at providing important hydrological services, or habitat for species other than koalas.

Nutrient enrichment can also affect species richness and composition of ecological communities. Species are able to partition their niches when there are multiple limiting resources, or multiple niches to be occupied. Flooding a system with one of these limiting resources can alter community composition, favouring a limited number of species and driving biodiversity loss (Harpole and Tilman, 2007). Although the total productivity of such systems can be increased, their resilience to change and the provision of multiple services is often lost. The effects of such nutrient enrichment have been studied in field-scale experiments but the impacts can be seen at landscapes scales, often crossing from terrestrial to aquatic systems; one of the most famous examples is the effects of nutrient run-off from mid-western, and southern California agriculture into the gulfs of Mexico and California which drive massive algal blooms that devastate the marine ecosystems and fisheries located hundreds to thousands of miles away from agricultural lands where the nutrients originated.

Eco-agricultural interventions try to reduce these types of effects by reducing run-off from agricultural fields with multispecies buffer strips placed between fields and waterways as well as by reducing the amounts of fertilizer applied to fields. From a multifunctional perspective, maintaining buffer strips along waterways not only improves water quality, but can also provide numerous additional services such as maintaining biological connectivity in agricultural landscapes, and ensuring the availability of pollinator and pest control services to adjacent fields.

There are at least two ways, if not more, in which the ecological study of biodiversity and ecosystem function can be compared with human nutrition. Each is unique in its own regard, and intellectually very exciting. The first was briefly mentioned above and ties the nutritional diversity of farm fields and landscapes to human health. The second, and more novel still, considers the human gut as an ecosystem, and considers how the diversity of the bacterial community that inhabits the human gut impacts the acquisition and availability of nutrients.

Sampling and complementary effects apply to human nutrition when considering the diversity of foodstuffs that make up the human diet. This can be tied to field and forest diversity in the case of subsistence systems (DeClerck et al., 2011b; Penafiel et al., 2012) or to the availability of nutrient diversity in urban neighbourhoods (Gordon et al., 2011). Nutrition interventions cannot singularly focus on providing caloric requirements, or vitamin A enrichment. As important as these interventions are in crisis situations, they lack long-term sustainability. As with the management of eco-agricultural landscapes, interventions must be multifunctional (Remans et al., 2011b). Certain foods are important for providing specific nutritional requirements; for example grasses such as maize, rice and wheat are critical for providing calories, and legumes for providing plant-based proteins. However we also recognize that the human body cannot subsist on carbohydrates alone, that there is a need not only for high-energy foodstuffs, but also an essential need for those ingredients that provide vitamins and nutrients essential for human health. As a rule of thumb, the greater the diversity of species you eat, the more likely you are to cover all your nutritional bases including complementarity effects. This is evident in the indigenous Mayan three-sisters agriculture example described above; the complementarity between the three species plus lime ensures that all nutritional bases are covered.

The second example, very different from the first, considers the human gut as an ecosystem (Figure 1.1). Turnbaugh et al. (2006) studied the gut microflora of obese and lean mice and found that the relative abundance of two dominant bacterial divisions, the *Bacteroidetes* and the *Firmicutes*, are associated, with the obese dominated by *Firmicutes*. The change in gut microflora is due to change in diet where diets excessively high in sugars and carbohydrates favour the *Firmicutes* which are more effective at processing these food types and converting them to calories. Interestingly, Turnbaugh et al. (2006) use agricultural terminology suggesting that this community is more effective in 'harvesting' nutrients. The results of several studies from this research group demonstrate that the organismal assemblage in the human gut consists of a highly diversified (many species) core microbiome and deviations from this core such as a reduction of species richness are associated with obesity (Turnbaugh et al., 2006, 2009; Jumpertz et al., 2011). It is worth providing Turnbaugh et al.'s (2009) own words here:

> Across all methods, obesity was associated with a significant decrease in the level of diversity. This reduced diversity suggests an analogy: the obese gut microbiota is not like a rainforest or reef, which are adapted to high energy flux and are highly diverse; rather, it may be more like a fertilizer runoff where a reduced-diversity microbial community blooms with abnormal energy input.

Turnbaugh et al. imply that the impact of an 'obese' diet is not unlike flooding an ecological system with phosphorus and nitrogen fertilizer, with impacts similar to natural systems, which reduce the diversity of organisms in the systems and reduce their multifunctionality.

Conclusions

From the human gut to agricultural fields and landscapes (Figure 1.1), we find evidence that the species diversity or composition of an ecosystem operates in similar ways. Interactions between species provide us with multiple functions and are central to the stability of those functions. Ecology, with its focus on complex systems, can make contributions to several global issues of concern, primarily related to agriculture, environment and nutrition. Ecology is but one element of any cross-disciplinary solution. Effective solutions require a continued dialogue between a diversity of fields, and more is gained initially by focusing on process rather than context. Cross-disciplinary thinking is an effective means of discovering novel perspectives on humanity's pervasive problems, further leading to new and sustainable solutions to these problems.

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