Food security: why is biodiversity important?

T.C.H. SUNDERLAND

Centre for International Forestry Research, Jl. CIFOR, Situ Gede, Sindang Barang, Bogor 16680, Indonesia

Email: t.sunderland@cgiar.org

SUMMARY

Agriculture and biodiversity have often been regarded as separate concerns. Although biodiversity underpins much of modern agriculture, the development of contemporary production systems has resulted in extensive land conversion and concomitant biodiversity loss. In order to feed an ever growing population, innovative and acceptable ways of integrating biodiversity conservation and food production need to be identified. Maintaining diversity within agricultural systems is not a novel approach but one practiced by many smallholder farmers globally, in many different ways. The nutritional and livelihood benefits of diverse production systems are one way of achieving food security. Such systems are also more resilient to climate induced events or other shocks. Forests represent an important repository of food and other resources that can play a key role in contributing towards food security, especially if integrated into complex systems that are managed for multiple benefits.

Keywords: Food security, forests, biodiversity, agriculture, ecosystem services

Sécurité des aliments: pourquoi la biodiverstiré est-elle importante?

T.C.H. SUNDERLAND

L'agriculture et la biodiversité ont souvent été considérées comme des questions différentes. Bien que la biodiverstité soutienne une grande partie de l'agriculture moderne, le développement des systèmes de production contemporains a résulté en une conversion poussée de la terre, et en une perte de la biodivesrité s'y attachant. Pour nourrir une population en croissance permanente, il est nécessaire d'identifier des manières innovatives et acceptables d'intégrer la conservation de la biodiversité à la production alimentaire. Le maintien de la diverstiré au sein des systèmes d'agriculture n'est pas une nouvelle approche, étant déjà pratiquée par par nombre de petits fermiers globalement, de toutes sortes de façons. Les bénéfices nutritionnels et pour les revenus de divers systèmes de production ne sont qu'une manière de parvenir à la sécurité alimentaire. De tels systèmes sont également plus résistants aux évènements résultant du climat et à d'autres chocs. Les forêts représentent un dépôt important de nourriture et d'autres ressources pouvant jouer un rôle clé dans la contribution à la sécurité alimentaire, et ce, particulièrement s' il est intégré dans des systèmes complexes gérés en vue de bénéfices multiples.

Seguridad alimentaria: ¿por qué es importante la biodiversidad?

T.C.H. SUNDERLAND

A menudo las preocupaciones por los temas de agricultura y biodiversidad han seguido caminos separados. Aunque la biodiversidad es en gran medida una de las bases de la agricultura moderna, el desarrollo de los sistemas de producción actuales ha resultado en una considerable conversión del suelo y una pérdida de biodiversidad concomitante. Para poder alimentar a una población cada vez mayor, es necesario identificar maneras innovadoras y aceptables de integrar la conservación de la biodiversidad con la producción de alimentos. El mantenimiento de la diversidad dentro de los sistemas agrícolas no es una idea novedosa, pero es algo que practican de diferentes maneras un gran número de pequeños productores en todo el mundo. Los beneficios de los sistemas de producción diversos en cuanto a nutrición y a los medios de subsistencia son una manera de alcanzar la seguridad alimentaria. Dichos sistemas son al mismo tiempo más resistentes y adaptables a eventos climáticos u otros impactos. Los bosques representan un almacén importante de alimentos y otros recursos que pueden tener un papel clave a la hora de contribuir a la seguridad alimentaria, especialmente cuando están integrados en sistemas complejos gestionados con vistas a obtener múltiples beneficios.

INTRODUCTION

Although long considered mutually exclusive (Tscharntke *et al.* 2005, Brussard *et al.* 2010), biodiversity conservation and food security are two sides of the same coin. Although ecologists and conservation biologists focus primarily on biodiversity conservation in non-agricultural lands it has been recognized that a strictly conservation focus is limited in scope, particularly in terms of fulfilling production requirements (Schroth *et al.* 2004, Chappell and LaValle 2011, Godfray *et al.* 2010). This is pertinent given that the majority of the world's biodiversity remains outside of protected areas, often in complex, multi-functional landscapes occupied by people and their associated farming systems, particularly in the tropics (Alcorn 1993, Putz *et al.* 2001, Sayer and Maginnis 2005, Padoch and Pinedo-Vasquez 2010).

The conventional model to achieve food security has been to convert wild lands to intensive commercial agricultural use (Goklany 1998, Thrupp 2000, Green *et al.* 2005) leading to the increased homogenisation of natural landscapes (Heitala-Koivu *et al.* 2004). An immediate result of this model of land use has been a drastic loss of wildlands, the biodiversity they contain and the ecosystem services they provide (Tscharntke *et al.* 2005; Lamarque *et al.* 2011). Perrings *et al.* (2010: 263) suggest that society has "traded off biodiversity" to achieve food security. Approximately 30–40% of the earth's surface is now under some sort of agricultural system (Scherr and McNeeley 2005, Chappell and LaValle 2011). Although the Green Revolution was intended to intensify production in existing agricultural lands, it is estimated that 20% of the yield increases resulted in direct land conversion (Evenson and Gollin 2003). In addition, these increases in production have been achieved through industrial agriculture that is heavily dependent on fossil fuels and agro-chemicals further indirectly affecting biodiversity and a wide range of ecosystem services, arguably contributing to climate change processes (Perrings *et al.* 2010). With the human population estimated to grow to nine billion by the year 2050 (Godfray *et al.* 2010), it is suggested that there is a concomitant need to increase agricultural production two- to three-fold (Green *et al.* 2005) and that any marked increase in production will undoubtedly be at the expense of currently unproductive lands (Kaimowitz and Angelsen 1998, Tscharntke *et al.* 2005, Ewers *et al.* 2009,). However, further expansion of industrial agriculture through land conversion could have a continuing devastating effect of the world's remaining biodiversity (Lambin and Meyfroidt 2011).

In response to the conversion-driven biodiversity crisis, there has been an exponential increase in the number of protected areas in recent years (Chape *et al.* 2005). The global network of protected areas now covers 11.5% of the worlds' surface area with the majority of these falling within categories I-IV of the IUCN's classification, (Rodrigues *et al.* 2004, Schmitt *et al.* 2009); the highest levels of protection, effectively annexing large areas of land from human use and productivity (Ferraro and Hanauer 2011), although the reality is that many of these protected areas are in fact encroached upon for agricultural production (Scherr and McNeely 2005). Hence, no matter how expansive, this protective area network has fundamentally failed to halt biodiversity loss (Coad *et al.* 2009, Mace *et al.* 2010). It might be argued that the clear disaggregation of conservation goals with those of agricultural production (Perrings *et al.* 2010, Brussard *et al.* 2010) have led to limited outcomes for either food security or biodiversity (Steiner 2011). In order to achieve biodiversity conservation and food security goals, more integrated and inclusive approaches need to be more actively pursued (Scherr and McNeely 2005, Pretty 2008, Brussard *et al.* 2010, Chappell and LaValle, 2011, Lambin and Meyfroidt 2011).

Biodiversity: a fundamental feature of agricultural systems and human well-being

Biodiversity at three levels, ecosystems, the species they contain and the genetic diversity within species, underpins much of modern agriculture as well as the livelihoods of many millions of people. The majority of today's modern crop and livestock varieties are derived from their wild relatives and it is estimated that products derived from genetic resources (including agriculture, pharmaceuticals etc.) is worth estimated $500 billion/annum (ten Kate and Laird 1999). Biodiversity provides an important safety-net during times of food insecurity, particularly during times of low agricultural production (Anglesen and Wunder 2003, Karjalainen *et al.* 2010) during other seasonal or cyclical food gaps (Arnold 2008, Vinceti *et al.* 2008) or during periods of climate-induced vulnerability (Cotter and Tirado 2008). Wild harvested meat provides 30–80% of protein intake for many rural communities (Pimentel *et al.* 1997, Fa *et al.* 2003, Nasi *et al.* this issue), particularly in the absence of domesticated alternative sources of protein. The World Health Organisation estimates that in many developing countries up to 80% of the population relies on biodiversity for primary health care (Herndon and Butler 2010) and the loss of biodiversity has been linked to the increased emergence and transmission of infectious diseases with deleterious impacts on human health (Keesing *et al.* 2010).

Around one billion people rely on wild harvested products for nutrition and income and the "invisible" trade in wild resources is estimated to generate $90 billion/annum (Pimentel *et al.* 1997). In India alone the livelihoods of around 6 million people are maintained by the harvest of forest products (Tuxill 1999) and many studies highlight just how important wild harvested plants and animals are to the economy of the world's rural poor, particularly from forests (de Beer and McDermott 1989, Nepstad and Schwartzman 1992, Prance 1992, Colfer 1997, Pimentel *et al.* 1997, Shanley *et al.* 2002, Scherr and McNeely 2005, Belcher and Schreckenberg 2007, Paumgarten and Shackleton 2009). In many rural locations, particularly areas that lack basic infrastructure and market access, the collection of wild resources provides considerable subsistence support to local livelihoods (Delang 2006). In addition, the harvest and sale of wild products often provides one of the only means of access to the cash economy (Ros-Tonen and Wiersum 2005). Access to markets is particularly important for food security: it is not enough to be able to collect or grow food, but the ability to purchase food is also a major factor in ensuring food security, hence the more vulnerable and poorest members of society are particularly at risk from lack of access to food (Arnold 2008). Highly urbanised societies such as Hong Kong and Singapore that have no agricultural base are food secure because of their considerable purchasing power, while India, although self-sufficient in agriculture, has much of its population that is food insecure primarily due to social inequity and poverty (Schmidhuber and Tubiello 2007).

Although more needs to be understood regarding biodiversity providing the "natural capital" (Jackson *et al*, 2007: 197) for ecosystem services, ecological processes such as the maintenance of watershed services, soil fertility, pollination, seed dispersal, nutrient cycling, natural pest and disease control etc. all rely to a greater or lesser extent on biodiversity, or components of it; processes that are critical to the maintenance of agricultural systems (Thrupp 2000, Benton 2007). Most high-intensity agricultural systems seek to remove wild species in the hope that potential weeds, predators and other pests are not compromising production (Scherr and McNeely 2005). The immediate effects of intensification or expansion of agriculture leads to a considerable decline in avian diversity and numbers, often to local extinction for habitat specialists (Green *et al.* 2005, Benton 2007) and pollinator diversity is reduced (Steffan-Dewenter *et al.* 2005) primarily due to the homogenization of insect populations (Ekroos *et al*, 2010). Commercial agriculture often favours synanthropic species (those that are adapted to live in anthropogenic landscapes), often causing a reduction in both species diversity and ecosystem function.

Despite the value of ecosystem goods and services to production systems (Rahel et al 2009), there are clear trade-offs between the economic value of agricultural conversion compared to the ecosystem services provided by a diversified environment (Perrings *et al.* 2010, Brussard *et al.* 2010). These trade-offs are only recently being recognised, stimulated in part by the increasingly adverse effects of climate change and the recognition of the need for greater resilience of productive ecosystems (Scherr and McNeely 2005, Brussard *et al.* 2010). Reward schemes that focus on the maintenance of biodiversity in agricultural landscapes and the associated provision of ecosystem services have gained considerable attention in recent years (Pascual and Perrings, 2007). However, such financial incentives will not only have to be sufficient to out-compete other source of incomes, but will need to ensure the right people are actually rewarded (Campbell 2009).

What is food security?

Most definitions related to food security refer to the availability of food and one's access to it. For example, the World Bank defines food security as "*access by all people at all times to sufficient food for an active, healthy life*" (Maxwell and Wiebe 1999: 828). The most commonly accepted and used definition for food security, agreed upon at the World Food Summit is as follows: "*Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life*". (Pinstrup-Andersen 2009: 5).

However, these definitions infer that access to *enough* food is an adequate criterion to achieve food security at the household, national or global scales (Pinstrup-Anderen 2009) yet access to food must be sustainable in the long term. A household cannot be considered food secure if it has current access to sufficient food to meet immediate nutritional requirements while depleting the natural capital that would have provided future resources (Maxwell and Wiebe 1999, Perrings *et al.* 2010). In addition, some commentators point out that even if food availability is satisfactory, the attainment of human well-being is closely related to access to wider environmental health such as access to clean water, sanitation and diverse productive ecosystems, therefore food security does not always equate to *nutritional* security (Swaminathan 2001, Schmidhuber and Tubiello 2007, Pinstrup-Andersen 2009). Indeed, any rural societies share this more holistic approach, with little distinction being made between food security, general health and the environment (Karjalainen *et al.* 2010). Due to the strong cyclical links between nutrition and infection, nutritional security is also dependant on the diverse ecosystem services biodiversity and forests provide that serve to limit infection and disease transmission (Semba and Bloem 2001).

Global trends in agriculture and impact on biodiversity

Agriculture began around 12,000 years ago and approximately 7,000 plant species and several thousand animal species have been used historically for human nutrition and health requirements (Ehrlich and Wilson 1991, Tuxill 1999, Toledo and Burlingame 2006). Since 1900, there has been a significant global trend towards diet simplification (Frison *et al.* 2006, Johns 2006). Today, 12 plant crops and 14 animal species today provide 98% of world's food needs with wheat, rice and maize alone account for more than 50% of the global energy intake (Ehrlich and Wilson 1991, Thrupp 2000).

Uniformity of production and wider biodiversity destruction has led to the loss of many wild relatives of crop plants (Tuxill 1999) and livestock (Pilling 2010). The FAO suggests that three-quarters of the varietal genetic diversity of agricultural crops has been lost in the past 100 years (FAO 2008). Since the 1960's it is estimated that China and India have lost thousands of landraces of rice and Mexico more than 80% of its maize diversity (Tuxill 1999). Diverse and genetically unique livestock species, those that are probably more resilient to emerging diseases, are also being lost at an alarming rate (Pilling 2010). This biological loss has been exacerbated by concomitant cultural loss as society becomes increasingly globalised (Pretty *et al.* 2008).

The genetic erosion of our nutritional base has considerable implications for food security, nutrition and health (Vinceti *et al.* 2008). Relying on a narrow genetic base for nutrition makes society considerably vulnerable to risk and there are many examples of the dangers of monoculture

BOX 1 Selected policy and legislative frameworks related to biodiversity and food security:

Universal Declaration on Human Rights Article 25: "*Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food*". http://www.un.org/en/documents/udhr/index.shtml

Efforts to link biodiversity, food and nutrition issues are expected to contribute to achieving the **Millennium Development Goals**, in particular number 1C: which aims to "*reduce by half, by 2015, the proportion of people who suffer from hunger*". Also linked to Goal 7A: "*Integrate the principles of sustainable development and reverse the loss of environmental resources*". http://www.un.org/millenniumgoals/

Convention of Biological Diversity: Main conclusions on the CBD cross-cutting initiative on biodiversity for food and nutrition: "*Biodiversity is essential for food security and nutrition and offers key options for sustainable livelihoods. Existing knowledge warrants the sustainable use of biodiversity in food security and nutrition programmes as a contribution to the achievement of the Millennium Development Goals*". http://www.cbd.int/agro/food-nutrition/

International Covenant on Economic Cultural and Social Rights (Article 11): *the right to adequate food from productive land or other natural resources.* (Article 12): *the right to the highest attainable standard of health. Conditions to achieve this include access to adequate food and nutrition.* http://www2.ohchr.org/english/law/cescr.htm

FAO's Strategic Framework 2000–2015 stipulates that the Organization is expected to take fully into account "*progress made in further developing a rights-based approach to food security*" in carrying out its mission "*helping to build a food-secure world for present and future generations.*" http://www.fao.org/righttofood/

Chennai Declaration: "*Biodiversity is the raw material for food and health security, as well as for the biotechnology industry, and it must be conserved to ensure that it can continue in this function so that farming systems become climate resilient*". http://www.fao.org/nr/giahs/giahs-home/chennai-declaration/en/

Rome Declaration on World Food Security: "*Agricultural production increases need to be achieved while ensuring both productive capacity, sustainable management of natural resources and protection of the environment*" http://www.fao.org/docrep/003/w3613e/w3613e00.HTM

IFPRI 2020 Vision: "*is a world where every person has access to sufficient food to sustain a healthy and productive life, where malnutrition is absent and where food originates from effective, efficient and low-cost food systems that are compatible with the sustainable use of natural resources*". http://www.ifpri.org/book-753/ourwork/program/2020-vision-food-agriculture-and-environment

agriculture leading to past recorded crop failures and ultimately, famine, due to genetic uniformity (Thrupp 2000). Despite considerable advances in agriculture in terms of quantity (Pretty 2008), a reduction in crop diversity has reduced diet quality and there are considerable nutritional effects resulting from diet simplification. Thus an issue of concern is not *how much* food is required to achieve food security but *what kind* of food; thus food composition is as important as food access and availability (Goklany 1998, Frison *et al.* 2006). Increased availability and consumption of cereals, particularly in developing countries have led to increased micronutrient deficiencies (Frison *et al.* 2006). An estimated one billion people suffer from deficiencies in micro-nutrients such as vitamin A, iron, and zinc (Goklany 1998, Dangour and Uauy 2006, Vinceti *et al.* 2008). The diversity of forest, fallow and agricultural margin foods can often help provide the range of micronutrients needed for the human diet (High and Shackleton 2000, Padoch and Pinedo-Vasquez 2010).

In many instances, the underlying causes of food insecurity are not due to limits of agricultural production but are rooted in political, social and economic influences (Pinstrup-Andersen and Pandya-Lorch 1998). For example, although in much of the world, catastrophic famine has been eliminated, the three major famines that have recently occurred in sub-Saharan Africa were largely preventable (Devereaux 2009). Food inequity is also a major global problem. Although more than 800 million people are classified as under-nourished (Toledo and Burlingame 2006, Pinstrup-Andersen 2009) and in 2009, one billion people were classified as "hungry", the highest number in human history (FAO 2009) there is an equal number of people who are overweight or obese (Dangour and Uauy 2006, Pinstrup-Andersen 2006). Fuelled by urbanisation and increasingly sedentary lifestyles, the health impacts over food over-consumption are also a major cost to society with greater incidences of cardio-vascular disease and adult-onset diabetes in particular, notably in developing or transitional economies (Dangour and Uauy 2006, Raymond *et al.* 2006, Mitra *et al.* 2009, Dixon 2009). Ultimately, an unlimited increased calorie intake does not result in better human health. Clearly there is something awry with our means of agricultural production if poor nutrition and over-consumption co-occur, accompanied by negative human health implications at both ends of the food security spectrum (Dixon 2009). Such inefficiencies are particularly problematic as much of this agricultural production is at the expense of biodiversity and the wider environment (McMichael 2005, Pretty 2009).

Challenges to biodiversity-friendly agriculture

Population growth

The world's population is expected to grow to nine billion by the year 2050 (Perrings *et al.* 2006). If the current model of commercialised monoculture is to be followed, feeding the global population is stated to require the conversion of yet more wild lands, at the expense of biodiversity and ecosystem service provision (Kaimowitz and Angelsen 1998, Green *et al.* 2005, Lambin and Meyfroidt 2011). Scherr and McNeely (2005) estimate that a billion hectares of natural habitat will need to be converted to agricultural production, especially once the effects of climate change on crop yields are taken into account. However, Molden (2007) and Pretty (2008) argue that while current levels of food production are indeed adequate to feed the growing population, the diversion of food crops for non-nutritional uses and changing diets from grains to meat, compounded by with increased economic wealth and trends towards urbanisation will result in a concomitant need to increase agricultural production and associated biodiversity loss.

Demand for meat is increasing globally, particularly from the burgeoning urban populations of India and China, and as the world becomes increasing prosperous. Meat production is a notoriously inefficient use of resources and the implications of this are that a greater proportion of grains and oilseeds are being used to feed livestock and poultry, rather than people (Scherr and McNeely 2005, United Nations 2011). A significant rise in greenhouse gas emissions is also a major side effect of the increased production in meat and dairy products (Dixon 2009). The diversion of foodstuffs to biofuel production also has an impact on food security. For example, nearly a third of all corn produced in the United States is now used for fuel and in 2010 this diverted more than 100 million tonnes of corn to ethanol production (Dapice 2011). Fuelled by considerable subsidies, ethanol production also contributes to price rises in grain and meat. Overall, it is argued, biofuel production does not improve energy security, increases environmental degradation, raises basic food prices and thus threatens food security (Pimentel 2003, 2011). Finally, a considerable proportion of food is simply wasted in both developing and developed countries, but for different reasons. Loss of food in developing countries is often the result of pre- and immediate post-harvest losses due to pests and disease and poor market access, while waste in developed countries is primarily due to the availability of large quantities of relatively cheap food, which is simply uneaten and discarded once it has reached the table, be it within the household or the commercial kitchen. Reappraising the non-consumptive uses of agricultural produce and mitigating food waste could result in an equivalent rise in agricultural output, lessening the need for further land conversion and further biodiversity loss (Scherr and McNeely 2005).

Climate change

Climate change and its potential impacts represent one of the greatest contemporary threats to food security (Bohle *et al.* 1994, Sanchez 2000, Schmidhuber and Tubiello 2007, Gregory *et al.* 2010). Extreme and unpredictable weather will affect crop yields and it is estimated that agricultural yields in Africa alone could decline by more than 30 percent by 2050 (Juma 2010). Such yield decline will primarily affect the world's poor, who will not only lose direct access to food but are less capable of absorbing the global commodity price changes that characterise a reduction in supply (Sanchez 2000, Cotter and Tirado 2008). Three of the most recent famines in sub-Saharan Africa, although primarily precipitated by non-production or supply issues, were exacerbated by unexpected weather patterns that pushed already vulnerable livelihoods into major food insecurity and, ultimately, famine (Devereaux 2009).

Climate-related events are being blamed for the recent spike in the price of staple foods (Dapice 2011), which are now at an all-time high (FAO 2011a). Extreme weather can have a devastating effect on crops as the recent droughts in Russia and China, and floods in Australia, India, Pakistan and Europe indicate. The impacts of rising temperatures and more-extreme weather events will likely hurt the poor, especially rural farmers (Schmidhuber and Tubiello 2007, Juma 2010) and the World Bank (2011) estimates that 44 million more people have slipped back into poverty since June 2010. Urban populations who are more vulnerable to reductions in purchasing power are particularly vulnerable to increases in basic food prices. Food riots in Cameroon and Haiti in 2008 and the recent regime changes in Tunisia and Egypt have been directly linked to increased prices of basic foodstuffs (FAO 2011b).

Biodiverse multi-functional landscapes are more resilient to extreme weather effects and can provide a "*natural insurance policy against climate change*" (Cotter and Tirado 2008: 3). Greater crop diversification by integrating a diversity of crops and varieties into small-holder systems in particular will increase resilience to severe changes in weather patterns leading to calls for "sustainable agriculture" (Pretty 2008), "conservation agriculture" (Hobbs *et al.* 2008: 543), "agro-ecological" (United Nations 2011) and "eco-agriculture" (Scherr and McNeely 2005) approaches. Such approaches rely on a broader agricultural base integrated with diverse ecosystems and are thus more analogous to "natural" ecological processes. More diverse agricultural systems not only increase resilience against extreme climate-related events but can also increase yields. But recognition of this is not new. Small scale shifting cultivators have been practicing biodiversity friendly for generations (Padoch and Pinedo-Vasquez 2010) and farmers around the world clearly understand and use agrobiodiversity to mitigate against environmental and climatic uncertainty (Powell *et al.* this issue). In a survey of eco-farming projects in 57 different countries, the integration of natural pest control and improving soil fertility resulted in yield increases of up to 80% (United Nations 2011). And in Africa, a review of "agro-ecological" approaches showed that cereal yields improved by 50–100% when more integrated methods of production were promoted (Rosengrant and Cline 2003).

Gender inequity

Women are pivotal to ensuring food security (United Nations 2011). It is estimated that women produce more than 50% of the food grown worldwide, primarily in small-scale farming systems (Maxwell and Wiebe 1999). Indeed women tend to grow a greater diversity of products, experiment more with folk varieties and landraces and are often reliant on biodiversity for the family herbal (Agarwal 1992, Dhali 2008). Although women comprise up to 80% of farmers in sub-Saharan Africa and 60% in Asia, ratios that are increasing due to male out-migration and moves towards off-farm sources of income, their access and control over land and resources is generally inferior to that of men in the same household or community (Mathur 2011). Where women do have access to land, they will generally use it for food production and income generated from such land is more likely to be utilised for the well-being of the household, whether for nutritional, health or other benefits. Women are also primarily responsible for food preparation and allocation and, as such, are usually the "*guardians of household food security*" (Maxwell and Wiebe 1999: 836). In times of food insecurity, maternal food deprivation can impact the long-term productivity of the wider community through childhood malnutrition and ill-health, effects that can linger long into adulthood, ultimately affecting their productivity and ability to feed themselves (Osmani and Sen 2003).

However, many female farmers lack access to credit, extension services despite evidence suggesting that investment aimed at women leads to the increase of both farm and non-farm incomes at the household level (Godfray *et al.* 2010). Although development policy makers and agencies increasingly recognize the crucial contributions of women farmers to food security, contemporary agricultural policies and research do not often directly address the needs of women farmers, focusing more on traditionally male dominated cropping practices. Such "gender blindness" in the context of agricultural development is a major risk to future food security (Mathur 2011, United Nations 2011).

Tenure

Although it is argued that tenure rights in agricultural landscapes are less ambiguous for forested regions (Campbell 2009), greater clarity of tenure is needed across the entire biodiversity-agriculture nexus (Maxwell and Wiebe 1999). Tenure rights have figured prominently in debates surrounding conservation (Campese *et al.* 2009), land tenure and food security have both, separately, been the subject of extensive research yet critical links between the two remain somewhat unexplored (Maxwell and Wiebe 1999). Secure tenure is critical for food security in a number of ways. The lack of secure access rights and land tenure may be a disincentive for many poor or marginalised communities to invest in managing land more productively, investing in required inputs and making the raising of capital that much more difficult (Godfray *et al.* 2010). Inadequate or unclear tenure regimes also limit the efficient delivery of payments for environmental services and other reward mechanisms. Such incentive schemes will undoubtedly favour landowners with secure tenure, including the state and the private sector, with smallholder farmers marginalised (Campbell 2009).

Agricultural investment

International funding for agricultural development has dropped significantly over the last decade and is now at an historic low, representing around 3% of total overseas aid (Pinstrup-Andersen and Pandya-Lorch 1998). Crop yields have fallen in many regions primarily due to declining investments in agricultural research, irrigation and infrastructure (Rosegrant and Cline 2003) and Juma (2010) estimates that the lack of agricultural development investment has led to yield declines in Africa of ca.10% since 1960. National investment in agricultural development also remains very low, often representing less than 0.5% of agricultural GDP, despite the significant contribution of farming to most developing countries' economies ((Pinstrup-Andersen and Pandya-Lorch 1998). This is primarily due to the gradual withdrawal of state support to agriculture under structural adjustment conditionalities (Devereaux 2009). Structural adjustment programmes also disaggregated agriculture from wider natural resource management (NRM) initiatives. Thus NRM and agriculture have been artificially divided. Unfortunately for the millions of small-holder farmers who are responsible for the vast majority of food production, bio-cultural diversity and agricultural production these lines are considerably less well-defined.

CONCLUSION

Although food security is dependent on issues of sustainability, availability, access and utilisation, and not production alone, it is evident that a "new agriculture" (Steiner 2011) needs to be found to feed the world's population both efficiently and equitably. Increases in food production over the past fifty years have been at the cost of biodiversity and ecosystem service provision, yet there is considerable evidence that diverse agro-ecological systems can be equally productive, if not more so in terms of actual yield outputs, notwithstanding the biodiversity benefits of such approaches. As such, the United Nations (2011) vision of an "agro-ecological" approach that combines biodiversity concerns along with food production and provides a more compelling vision of future food production. The integration of biodiversity conservation and agricultural production goals must be a first step. Conservation and restoration in human dominated ecosystems must strengthen connections between agriculture and biodiversity (Novacek and Cleland 2001). Managing landscapes on a multi-functional basis that combines food production, biodiversity conservation and the maintenance of ecosystem services should be at the forefront at efforts to achieve food security.

In order for this to happen, knowledge from biodiversity science and agricultural research and development need to be integrated through a systems approach. This provides a unique opportunity for forestry and agricultural research organisations to coordinate efforts at the conceptual and implementation levels to achieve more sustainable agricultural systems. A clear programme of work on managing landscapes and ecosystems for biodiversity conservation and food security should be central to development aid.

ACKNOWLEDGEMENTS

I am grateful to a number CIFOR colleagues for discussion and advice related to forests and food security particularly Frances Seymour, Christine Padoch, Robert Nasi, Andrew Taber and Esther Mwangi. Bronwen Powell, Patricia Shanley and three anonymous reviewers provided invaluable comments on the draft. I thank Titin Suhartini for reference searching and providing invaluable assistance in the preparation of this paper.

REFERENCES

AGARWAL, B. 1992. The gender and environment debate: lessons from India. Feminist Studies **18**(1): 119–158.

ALCORN, J. 1993. Indigenous peoples and conservation. *Conservation Biology* **7**: 424–426.

ANGELSON, A. and WUNDER, S. 2003. *Exploring the forest-poverty link: key concepts, issues and research implications*. CIFOR Occasional Paper No. 40, Centre for International Forestry Research, Bogor

ARNOLD, J.E.M. 2008. *Managing ecosystems to enhance the food security of the rural poor*. A situation analysis prepared for IUCN, Gland. 33 p.

BELCHER, B. and SCHRECKENBERG, K. 2007. Commercialisation of non-timber forest products: a reality check. *Development Policy Review* **25**: 355–377.

BENTON, T.G. 2007. Managing farming's footprint on biodiversity. *Science* **315**: 341–342.

BOHLE, H.G., DOWNING, T.E. and WATTS, M.J. 1994. Climate change and social vulnerability: towards a sociology and geography of food insecurity. *Global Environmental Change* **4**: 37–48.

BRUSSARD, L., CARON, P., CAMPBELL, B., LIPPER, L., MAINKA, S., RABBINGE, R., BABIN, D. and PULLEMAN, M. 2010. Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. *Current Opinion in Environmental Sustainability* **2**: 34–42.

CAMPBELL, B.M. 2009. Beyond Copenhagen: REDD+, agriculture, adaptation strategies and poverty. *Global Environmental Change* **19**: 397–399.

CAMPESE, J., SUNDERLAND, T., GREIBER, T. and OVIEDO, G. (eds.) 2009. *Rights Based Approaches: Exploring Issues and Opportunities for Conservation*. Center for International Forestry Research, Bogor. 305 p.

CHAPE, S., HARRISON, J., SPALDING, M. and LYSENKO, I. 2005. Measuring the extent and effectiveness of protected areas as an indicator of meeting global biodiversity targets. *Phil Trans R Soc (B)* **360**: 443–455.

CHAPPELL, M.J. and LAVALLE, L. 2011. Food security and biodiversity: Can we have both? An agroecological analysis. Agriculture and Human Values **28**(1): 3–26.

COAD, L., BURGESS, N., FISH, L., RAVILLIOUS, C., CORRIGAN, C., PAVESE, H., GRANZIERA, A. and BESANÇON, C. 2009. Progress towards the Convention of Biological Diversity terrestrial 2010 and marine 2012 targets for protected area coverage. *Parks* **17**: 35–42.

COLFER, C. 1997. *Beyond slash and burn: building on indigenous management of Borneo's tropical rain forests*. Advances in Economic Botany. Vol. II, New York. 183 p.

COTTER, J. and TIRADO, R. 2008. *Food security and climate change: the answer is biodiversity*. Greenpeace Research Laboratories Report, June.

DANGOUR, A.D. and UAUY, R. 2006. Nutrition challenges for the twenty-first century. *British Journal of Nutrition* **96** Suppl. 1 S2–S7.

DAPICE, D. 2011. As food prices cause pain, nations need to bring crisis-solving policies to the table. *Jakarta Globe*, February 21st. http://www.thejakartaglobe.com/commentary/extreme-food-prices-require-crisis-solving-menu/423778.

DE BEER, J. and MCDERMOTT, M. 1989. The economic value of non-timber forest products in Southeast Asia. Netherlands Committee for IUCN, Amsterdam. 197 p.

DELANG, C.O. 2006. The role of wild plants in poverty alleviation and biodiversity conservation in tropical countries. *Progress in Development Studies* **4**: 275–286.

DEVEREAUX, S. 2009. Why does famine persist in Africa? *Food Security* **1**: 25–35.

DHALI, H.H. 2008. Deforestation and its impacts on indigenous women: a case from the Chittagong Hill Tracts in Bangladesh. *Gender, Technology and Development* **12**: 229–246.

DIXON, J. 2009. From the imperial to the empty calorie: how nutrition relations underpin food regime transitions. *Agriculture and Human Values* **26**: 321–333.

ECONOMIST. 2011. The future of food: crisis prevention. *The Economist Magazine*. http://www.economist.com/node/18229412?story_id=18229412.

EHRLICH, P.R and WILSON, E.O. 1991. Biodiversity studies: science and policy. *Science* **253**: 758–762.

EKROOS, J., HELIÖLÄ, J. and KUUSSAARI, M. 2010. Homogenisation of Lepidopteran communities in intensively managed agricultural landscapes. *Journal of Applied Ecology* **47**: 459–467.

EVENSON, R.E. and GOLLIN, D. 2003. Assessing the impact of the Green Revolution, 1960 to 2000. *Science* **300**: 758–762.

EWERS, R.M., SCHARLEMANN, J., BALMFORD, A. and GREEN, R. 2009. Do increases in agricultural yield spare land for nature? *Global Change Biology* **15**: 1716–1726.

FA, J.E., CURRIE, D. and MEEUWIG, J. 2003. Bushmeat and food security in the Congo Basin: linkages between wildlife and people's future. *Environmental Conservation* **30**: 71–78.

FAO. 2008. *Biodiversity to curb world's food insecurity*. Food and Agriculture Organisation, Rome. http://www.fao.org/newsroom/en/news/2008/1000841/index.html.

FAO. 2009. *1.02 million hungry: one sixth of humanity undernourished – more than ever before*.

Food and Agriculture Organisation, Rome. http://www.fao.org/news/story/0/item/20568/icode/en/.

FAO. 2011a. *Tight cereal markets as food prices increase again***.** Food and Agriculture.

Organisation, Rome. http://www.fao.org/news/story/en/item/51913/icode/.

FAO. 2011b. *Forests for improved nutrition and food security*. Food and Agriculture Organisation, Rome. http://www.fao.org/docrep/014/i2011e/i2011e00.pdf.

FERRARRO, P.J. and HANAUER, M.M. 2011. Protecting ecosystems and alleviating poverty with parks and reserves: "win-win" or tradeoffs? *Environmental Resource Economics* **48**: 269–286.

FRISON, E.A., SMITH, I.F., JOHNS, T., CHERFAS, J., and EYZAGUIRRE, P. 2006. Agricultural biodiversity, nutrition and health: making a difference to hunger and nutrition in the developing world. *Food and Nutrition Bulletin* **27**(2): 167–179.

GODFRAY, C.H., BEDDINGTON, J., CRUTE, I., HADDAD, L., LAWRENCE, D., MIUR, J., PRETTY, J., ROBINSON, S., THOMAS, S. and TOULMIN, C. 2010. Food security: the challenge of feeding 9 billion people. *Science* **327**: 812–818.

GOKLANY, I.M. 1998. Saving habitat and conserving biodiversity on a crowded planet. *BioScience* **48**: 941–953.

GREEN, R., CORNELL, S., SCHARLEMANN, J. and BALMFORD, A. 2005. Farming and the fate of wild nature. *Science* **307**: 550–555.

GREGORY, P.J., INGRAM, J.S.I. and BRKLACICH, M. 2010. Climate change and food security. *Phil. Trans. R. Soc. B.* **360**: 2139–2148.

HEITALA-KOIVU, R., LANKOSKI, J. and TARMI, S. 2004. Loss of biodiversity and its social cost in an agricultural landscape. *Agriculture, Ecosystems and Environment* **103**: 75–83.

HERNDON, C.N. and BUTLER, R.A. 2010. Significance of biodiversity to human health. *Biotropica* **42**: 558–560.

HIGH, C. and SHACKLETON, C.M. 2000. The comparative value of wild and domestic plants in home gardens of a South African rural village. *Agroforestry Systems* **48**: 141–56.

HOBBS, P.R., SAYRE, K. and GUPTA, R. 2008. The role of conservation agriculture in sustainable agriculture. *Proc. Trans. Roy. Soc. B.* **363**: 543–555.

JACKSON, L.E., PASCUAL, U. and HODGKIN, T. 2007. Utilising and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems and Environment* **121**: 196–210.

JOHNS, T. 2006. Linking biodiversity, diet and health in policy and practice. *Proceedings of the Nutrition Society* **65**: 182–189.

JUMA, C. 2010. *The new harvest: agricultural innovation in Africa*. Oxford University Press. 296 p.

KAIMOWITZ, D. and ANGELSEN, A. 1998. *Economic models of tropical deforestation: a review*. Center for International Forestry Research, Bogor. 137 p.

KARJALAINEN, E., SARJALA, T. and RAITO, H. 2010. Promoting human health through forests: overview and major challenges. *Environmental Health and Preventive Medicine* **15**: 1–8.

KEESING, F., BELDEN, L.K., DASZAK, P., DOBSON, A., HARVELL, C.D., HOLT, R.D., HUDSON, P., JOLLES, A., JONES, K.E., MITCHELL, C.E., MYERS, S.S., BOGICH, T. and OSTFELD, R.S. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* **468**: 647–652.

LAMARQUE, P., QUÉTIER, F. and LAVOREL, S. 2011. The diversity of the ecosystem services concept and its implications for their assessment and management. *Comptes Rendus Biologies* doi:10.1016/j.crvi.2010.11.007.

LAMBIN, E.F. and MEYFROIDT, P. 2011. Global land use change, economic globalisation and the looming land scarcity. *Proceedings of the National Academy of Sciences* **108**: 3465–3472.

MACE, G.M., CRAMER, W., DIAZ, S., FAITH, D.P., LERIGAUDERIE, A., LE PRESTRE, P., PALMER, M., PERRINGS, C., SCHOLES, R., WALPOLE, M., WALTHER, B., WATSON, J. and MOONEY, H.A. 2010. Biodiversity targets after 2010. *Current Opinion in Environmental Sustainability* **2**: 1–6.

MATHUR, A. 2011. *Women and food security: a comparison of South Asia and Southeast Asia*. Asia Security Initiative Policy series, Working Paper No. 12.

MAXWELL, D. and WIEBE, K. 1999. Land tenure and food security: exploring dynamic linkages. *Development and Change* **30**: 825–849.

MCMICHAEL, A.J. 2005. Integrating nutrition with ecology: balancing the health of humans and biosphere. *Public Health Nutrition* **8**: 706–715.

MITRA, A., BASU, B. and MUKHERJEE, S. 2009. Significance of different dietary habits in sections of Indian diabetics. *Journal of Human Ecology* **26**: 89–98.

MOLDEN, D. (ed.) 2007. *Water for food, water for life*. Earthscan, London. 275 p.

NEPSTAD, D.C. and SCHWARTZMAN, S., (eds.) 1992. Non-timber products from tropical forests: evaluation of a conservation and development strategy. *Advances in Economic Botany* **9**. 164 p.

NOVACEK, M.J. and CLELAND, E.E. 2001. The current biodiversity extinction event; scenarios for mitigation and recovery. *Proceedings of the National Academy of Science* **98**: 5466–5470.

OSMANI, S. and SEN, A. 2003. The hidden penalties of gender inequality: fetal origins of ill-health. *Economics and Human Biology* **1**: 105–121.

PADOCH, C. and PINEDO-VASQUEZ, M. 2010. Saving slash and burn to save biodiversity. *Biotropica* **42**: 550–552.

PARDEY, P.G., ALSTON, J.M., CHRISTIAN, J.E. and FAN, S. 1996. *Hidden harvest: US benefits from international research aid*. Food Policy Report: The International Food Policy Research Institute (IFPRI), Washington DC. 17 p.

PASCUAL, U. and PERRINGS, C. 2007. Developing incentives and economic mechanisms for in situ biodiversity conservation in agricultural landscapes. *Agriculture, Ecosystems and Environment* **121**: 256–268.

PAUMGARTEN, F. and SHACKLETON, C. 2009. Wealth differentiation in household use and trade in non-timber forest products in South Africa. *Ecological Economics* **68**: 2950–2959.

PERRINGS, C., JACKSON, L., BAWA, K., BRUSSARD, L., BRUSH, S., GAVIN, T., PAPA, R., PASCUAL, U. and DE RUITER, P. 2010. Biodiversity in agricultural landscapes: saving natural capital without losing interest. *Conservation Biology* **20**: 263–264.

PILLING, D. 2010. Threats to animal genetic resources for food and agriculture – approaches to recording, description, classification and analysis. *Animal Genetic Resources* **47**: 11–22.

PIMENTEL, D., MCNAIR, M., BUCK, L., PIMENTEL, M. and KAMIL, J. 1997. The value of forests to world food security. *Human Ecology* **25**: 91–120.

PIMENTEL, D. 2003. Ethanol fuels, energy balance, economics and environmental impacts are negative. *Natural Resources Research* **12**: 127–134.

PIMENTEL, D. 2011. Ethanol fuels; energy security, economics and the environment. *Journal of Agricultural and Environmental Ethics* DOI: 10.1007/BF02229143.

PINSTRUP-ANDERSEN, P. 2006. Agricultural research and policy to achieve nutrition goals. *Poverty, Inequality and Development* **1**: 353–370.

PINSTRUP-ANDERSEN, P. 2009. Food security: definition and measurement. *Food Security* **1**: 5–7.

PINSTRUP-ANDERSEN, P. and PANDYA-LORCH, R. 1998. Food security and sustainable use of natural resources: a 2020 vision. *Ecological Economics* **26**: 1–10.

PRANCE, G.T. 1992. Rainforest harvest: an overview. In: Counsell, S. and Rice, T. (eds). *The rainforest harvest: sustainable strategies for saving the tropical forests*. Friends of the Earth Trust, London, pp 21–25.

PRETTY, J. 1998. Agricultural sustainability: concepts, principles and evidence. *Phil. Trans. Roy. Soc. B*. **363**: 447–465.

PRETTY, J. 2009. Can ecological agriculture feed nine billion people? *Monthly Review*, November.

PRETTY, J., ADAMS, B., BERKES, F., DUDLEY, N., DE ATHAYDE, S., HUNN, E., MAFFI, L., MILTON, K., RAPPORT, D., ROBBINS, P., SAMSON, C., STERLING, E., STOLTON, S., TAKEUCHI, K., TSING, A., VENTINNER, E. and PILGRIM, S. 2008. How do biodiversity and culture intersect? Plenary paper for Conference "*Sustaining cultural and biological diversity in a rapidly changing world; lessons for global policy*" 5–8 April. AMNH, IUCN and Terralingua.

PUTZ, F.E., BLATE, G.M., REDFORD, K.H., FIMBEL, R. and ROBINSON, J. 2001. Tropical forest management and conservation of biodiversity: an overview. *Conservation Biology* **15**(1): 7–20.

RAHEL, S., VARGHESE, A., BRADBEAR, N., DAVIDAR, P., ROBERTS, S., ROY, P and POTTS, S. 2009. Benefits of biotic pollination for non-timber forest products and cultivated plants. *Conservation and Society* **7**: 213–219.

RAYMOND, S.U., LEEDER, S. and GREENBERG, H.M. 2006. Obesity and cardio-vascular disease in developing countries: a growing problem and an economic threat. *Current Opinion in Clinical Nutrition and Metabolic Care* **9**: 111–116.

RODRIGUES, A.S.L., ANDELMAN, S.J., BAKARR, M.I., BOITANI, L., BROOKS, T.M., COWLING, R.M., FISHPOOL, L.D.C., DA FONSECA, G.A.B., GASTON, K.J., HOFFMANN, M., LONG, J.S., MARQUET, P.A., PILGRIM, J.D., PRESSEY, R.L., SCHIPPER, J., SECHREST, W., STUART, S., UNDERHILL, L.G., WALLER, R.W., WATTS, M.E.J. and YAN, X. 2004. Effectiveness of the global protected area network in representing species diversity. *Nature* **428**: 640–643.

ROS-TONEN, M.A.F. and WIERSUM, K.F. 2005. The scope for improving rural livelihoods though non-timber forest products: an evolving research agenda. *Forests, Trees and Livelihoods* **15**: 129–148.

ROSEGRANT, M.W. and CLINE, S.A. 2003. Global food security; challenges and policies. *Science* **302**: 1917–1919.

SANCHEZ, P.A. 2000. Linking climate change research and food security and poverty reduction in the tropics. *Agriculture Ecosystems and Environment* **82**: 371–383.

SAYER, J.A. and MAGINNIS, S. (eds.) 2005. *Forests in landscapes: ecosystem approaches to sustainability*. Earthscan, London. 257 p.

SCHERR, S.J. and MCNEELY, J.A. 2005. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. *Phil. Trans. R. Soc. B* **363**: 477–494.

SCHMIDHUBER, J. and TUBIELLO, F.N. 2007. Global food security under climate change. *PNAS* **104**: 19703–19708.

SCHMIDT, C.B., BURGESS, N.D., COAD, L., BELOKUROV, A., BESANÇON, C., BOISROBERT, L., CAMPBELL, A., FISH, L., GLIDDON, D., HUMPHRIES, K., KAPOS, V., LOUCKS, C., LYSENKO, I., MILES, L., MILLS, C,. MINNEMEYER, S., PISTORIUS, T., RAVILIOUS, C., STEININGER, M. and WINKEL, G. 2009. Global analysis of the protection status of the world's forests. *Biological Conservation* **142**: 2122–2130.

SCHROTH, G., DA FONSECA, A.B., HARVEY, C.A., GASCON, C., VASCONCELOS, H.L. and IZAC, A-M. (eds.) 2004. *Agroforestry and biodiversity conservation in tropical landscapes*. Island Press, Washington. 523 p.

SEMBA, R.D. and M.W. BLOEM. 2001. *Nutrition and Health in Developing Countries*. Humana Press. New York. 591 p.

SHANLEY, P., LUZ, L. and SWINGLAND, I.R. 2002. The promise of a distant market: a survey of Belém's trade in non timber forest products. *Biodiversity and Conservation* **11**: 615–636.

STEFFAN-DEWENTER, I., POTTS, S.G. and PACKER. L. 2005. Pollinator diversity and crop pollination services are at risk. *Trends in Ecology and Evolution* **20**: 651–652.

STEINER, A. 2011. Conservation and farming must learn to live together. *New Scientist*. http://newscientist.com/article/mg21028085.100-conservation-and-farming-must-learn-to-live-together.

SWAMINATHAN, M.S. 2001. Food security and sustainable development. *Current Science* **81**: 948–954.

TEN KATE, K. and LAIRD, S.A. 1999. *The commercial use of biodiversity*. Earthscan, London. 398 p.

THRUPP, L.A. 2000. Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *International Affairs* **76**: 265–281.

TOLEDO, A. and BURLINGAME, B. 2006. Biodiversity and nutrition; a common path toward global food security and sustainable development. *Journal of Food Composition and Analysis* **19**: 477–483.

TSCHARNTKE, T., KLEIN, A., KRUESS, A., STEFFAN-DEWENTER, I. and THIES, C. 2005. Landscape perspectives on agricultural intensification and biodiversity: ecosystem service management. *Ecology Letters* **8**: 857–874.

TUXILL, J. 1999. Appreciating the Benefits of Plant Biodiversity. In: BROWN, L.R., FLAVIN, C., FRENCH, H. and STARKE, L., *State of the World 1999: a Worldwatch Institute Report on Progress Toward a Sustainable Society*, W.W. Norton, New York. 96–114.

UNITED NATIONS. 2011. *Report submitted by Special Rapporteur on the right to food: Olivier de Schutter.* UN General Assembly Human Rights Council. http://www.srfood.org/index.php/en/component/content/article/1-latest-news/1174-report-agroecology-and-the-right-to-food.

VINCENTI, B., EYZAGUIRRE, P. and JOHNS, T. 2008. The nutritional role of forest plant foods for rural communities. In: COLFER, C.J.P. (ed.) *Human health and forests: a global overview of issues, practice and policy*. Earthscan, London. pp 63–93.

WORLD BANK. 2011. Food price hike drives 44 million people into poverty. Press Release No:2011/333/PREM http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:22833439~pagePK:64257043~piPK:437376~theSitePK:4607,00.html.