Oil Palm Bulletin 55 (November 2007) p. 1 - 14

Biodiversity, Agricultural Development and Valuation of Ecosystem Services

Jonathan Anderson*

ABSTRACT

There have been significant losses of biodiversity in the tropics at ecosystem, species and genetic levels as a consequence of agricultural development resulting in simplified landscapes with large areas dominated by crop monocultures. While it is suggested that many ecosystem services can be maintained by a few key species under present environmental conditions, particularly in tree-dominated systems, a larger reservoir of diversity is required to ensure ecosystem resilience to disturbance and future climate changes. Decisions on management or changes in land use have economic implications for different goods, services and other needs of stakeholders that biodiversity provides. These values are aggregated in the Total Economic Value (TEV) and discussed in terms of the direct use values (material goods), indirect use-values (ecosystem services), option values (uses in the future of genes, plant pharmaceuticals, etc.*) and intrinsic or existence values (moral, religious and aesthetic reasons for conserving biodiversity). It is concluded that biodiversity provides many essential life-support functions and therefore conservation is a sound precautionary principle for an uncertain future.*

ABSTRAK

Pembangunan dalam sektor pertanian di kawasan tropika telah mengakibatkan kemusnahan ekosistem, spesies dan genetik. Ini mengakibatkan terhasilnya landskap kasar yang didominasi oleh satu jenis tanaman. Walaupun tidak dinafikan bahawa kemandirian ekosistem mampu dipelihara dengan mengekalkan beberapa spesies utama dalam persekitaran sedia ada terutamanya dalam ekosistem yang dilitupi pohon, bekalan kepelbagaian semula jadi yang besar diperlukan untuk memastikan ekosistem dapat bertahan dari pelbagai gangguan dan perubahan cuaca pada masa akan datang. Sebarang tindakan yang diambil untuk pengurusan dan perubahan dalam penggunaan tanah memberi kesan ekonomi terhadap hasil, perkhidmatan dan keperluan lain yang diperoleh dari kepelbagaian semula jadi. Nilai ini dijumlahkan dalam Nilai Ekonomi Keseluruhan dan dibincangkan dalam terma nilai kegunaan langsung (hasil material), nilai kegunaan tidak langsung (peranan ekosistem), nilai pilihan (kegunaan masa hadapan bahan genetik dan tumbuhan ubatan) dan, nilai kewujudan dan jati diri (sebab moral, keagamaan dan estetika memelihara hutan). Kepelbagaian semula jadi menyediakan banyak fungsi penting untuk sokongan hidup dan pemeliharaannya adalah langkah terbaik untuk masa hadapan.

Keywords: biodiversity, agriculture, ecosystem services, economic valuation.

INTRODUCTION

The term biodiversity is popularly used to refer to the numbers of plant and animal species in the biosphere. However, more specifically it encompasses not only the complement of genetic variability within and between species, but also the different types of ecosystems making up the landscape (Swift *et al*., 2004). Over the last few decades, there has been destruction of all three components of biodiversity at rates and at scales that are unprecedented for millennia since the great Ice Ages and other catastrophic global events. The main drivers of these declines have been changes in land use and management resulting from the expansion of agriculture and forestry to meet rising demands by human populations for ecosystem goods (food, fuel, fibre) to improve human livelihoods (Pimentel and Pimentel, 2006). In addition to this loss of our natural heritage, there are also concerns as to whether this global depletion of biodiversity could also compromise the provision of ecosystem services (*e.g.* climate regulation, clean air and water supplies) that are essential for human welfare (Matson *et al*., 1997). The expansion of the oil palm plantations in Southeast Asia, and soyabean production in Brazil, illustrate the conflicts of interests that can arise between stakeholders who place different values on natural and production systems. On one hand

* School of Biosciences,
University of Exeter,
Exeter EX4 4PS,
United Kingdom.

tropical forests are estimated to contain about 80% of the animals and plant species on land, many as yet unknown to science, and there is global concern by conservationists to protect the heritage of this dwindling resource for future generations. On the other hand, a burgeoning international demand for GM-free soya, and palm oil for food, manufacturing processes and 'green' biofuels, create pressures too for extensive development of crop monocultures to intensify production through mechanization and the use of agrochemicals. If this development compromises biodiversity and/or the provision of ecosystem services, should the replacement costs of services and the profit forgone for conservation be met by local, national or global communities? This review describes the patterns of agricultural development, that have resulted in a simplification of systems providing ecosystem goods and services, and relationship between biodiversity and these functions. Finally the valuation of biodiversity is briefly considered since decisions on conserving natural systems or changes in land use have economic implications for different stakeholders, as indicated above.

ECOSYSTEM GOODS AND SERVICES

Ecosystem functions are the physical, chemical and biological processes that maintain what an ecosystem does such as carbon and nutrient cycling, hydrologic functions and providing a habitat for wildlife. Ecosystem functions are value-neutral to human society unless they relate to transaction costs, *i.e.* changes in function related to land use or management that then provide a service of some economic value. Ecosystem services are therefore defined by values society places on beneficial outcomes for the natural environment (*e.g.* tourism), provision of resources (food, fuel and fibre production, regulation and quality of water supplies, *etc.*) and bioremediation (detoxification of waste materials, carbon sequestration). The goods and services provided by ecosystems are outlined in *Table 1*. These range from global processes involved in the regulation of atmospheric composition and climate, through landscape-level processes such as water supplies, to the local provision of materials by natural and agroecosystems. Ecosystems do not therefore operate in isolation so that the flow of species, nutrients, water and gasses across their boundaries approach long-term equilibrium across natural landscapes. However, efforts and interventions to manipulate these systems to provide specific goods often involve a simplification of the systems, biological communities and functional groups of organisms that ultimately carry out these processes (Vandermeer *et al.*, 1998; Swift *et al.*, 2004).

AGRICULTURAL DIVERSITY AND LANDSCAPE COMPLEXITY

The increasing economic and resource demands of burgeoning human populations has been the main driver of increasing production intensity and has generally been accompanied by reductions in the diversity of different ecosystems types (forest, grassland and the mosaic of different farming systems) in the landscape, as well as the numbers of species and genotypes farmers manage (the *planned biodiversity*) within the farming system. This has consequences for other species, the *associated biodiversity* (pests and beneficial organisms) within the managed system. *Figure 1* illustrates a conceptual framework for different types of farming system classified on the basis of the diversity of the biota in the production system and the complexity production units in the landscape. This classification reflects the gradients of diversity from systems in the top left that are species diverse and spatially complex, to landscapes dominated by mono-specific cropping systems in the bottom right. Tree-based production systems range from the high complexity of forested landscapes to plantation monocultures, such as oil palms, rubber, cocoa or fruit. These plantation systems retain important ecosystem functions because they maintain a large and persistent woody biomass compared with short rotation, arable monocrops (indicated by the diagonal arrow).

Rural communities practicing traditional agriculture, often rely upon extensive use of the landscape for fuel, fibre, medicines and animal protein, with staple foods grown in short crop phases followed by with long periods of natural fallow regeneration. Yield is thus managed on a long-term basis, rather than maximization in the short-term, and the diversity of alternative foods and other resources available in space and time spreads the risk to traditional, rural livelihoods from external (economic and climatic) perturbations. Higher population densities require larger, more productive farming systems with increased duration in the time that a piece of land is cultivated. In many areas of the tropics this often involves compound farms with a mixture of land-use systems under the control of the same household involving home gardens and outreach plots of monocrops (such as paddy rice), that may be some distance from the homestead. The home gardens with a very high *planned diversity* (species selected by the farmers) of 30-100 species of fruit, vegetables, spices and medicinal plants (Ramakrishan, 1992). The diversity of managed species, together with the complex habitat structure formed by trees, shrubs and herbs, also supports a high associated diversity (pests, pollinators,

TABLE 1. ECOSYSTEM GOODS AND SERVICES OF NATURAL AND SEMI-NATURAL ECOSYSTEMS

Functions	Ecosystem process and components	Goods and services
Regulation functions	***Maintenance of essential ecological processes***	Life support systems.
Gas regulation	Role of ecosystems in biogeochemical cycles.	Air quality, UV protection.
Climate regulation	Influence of land cover on biophysical processes.	Favourable climate (temperature, rainfall) supporting human habitation, health and agroecosystem production.
Water regulation and supply	Role of vegetation regulating run-off and river levels; filtering, storage and retention of water.	Drainage and natural irrigation. Availability and quality of drinking water. Transportation.
Soil retention	Vegetation cover and roots reduce wind and water erosion.	Maintenance of cropping systems, prevention of damage from erosion/siltation.
Soil formation	Weathing of rock, stabilization of soil organic matter.	Maintenance of soil fertility in natural and agroecosystems.
Nutrient cycling	Role of biota and biophysical properties in nutrient supply and conservation of nutrient capital.	Maintenance of productive soils.
Waste treatment	Role of biota in capture and breakdown of contaminants.	Filtering of dust, detoxification of xenobiotics.
Pollination	Movement of gametes.	Pollination of wild and crop species.
Biological control	Population regulation through trophic interactions.	Control of crop pests and pathogens, and human diseases.
Habitat functions	***Providing habitats (suitable living space) for wild plants animals and microorganisms***	Maintenance of biological and genetic diversity.
Refugia	Suitable habitats for reproduction.	Maintenance of commercially harvested species, species pool for recolonizing disturbed habitats.
Production functions	***Provision of natural resources***	-
Food	Primary and secondary production	Gathering of fish, animals, fruits and other non-timber products.
Raw materials	Primary and secondary production	Timber, fuel, fodder, organic fertilizers.
Genetic and medicinal resources	Genetic material, evolution, plant defense compounds, *etc*	Drugs and pharmaceuticals.
Information functions	***Providing opportunities for cognitive development.***	-
Aesthetics	Natural landscapes, ecosystems and species.	Well being, tourism, recreation.
Cultural and artistic	Natural landscapes, ecosystems and species.	Use of nature in books, films, historic purposes, heritage values.
Spiritual and historic	Natural features with historic and spiritual values.	Use of nature for religious and historic purposes.
Science and education	Variety of ecosystems, species and genomes.	Scientific and educational opportunities and inspiration.

Source: After De Groot *et al*. (2002).

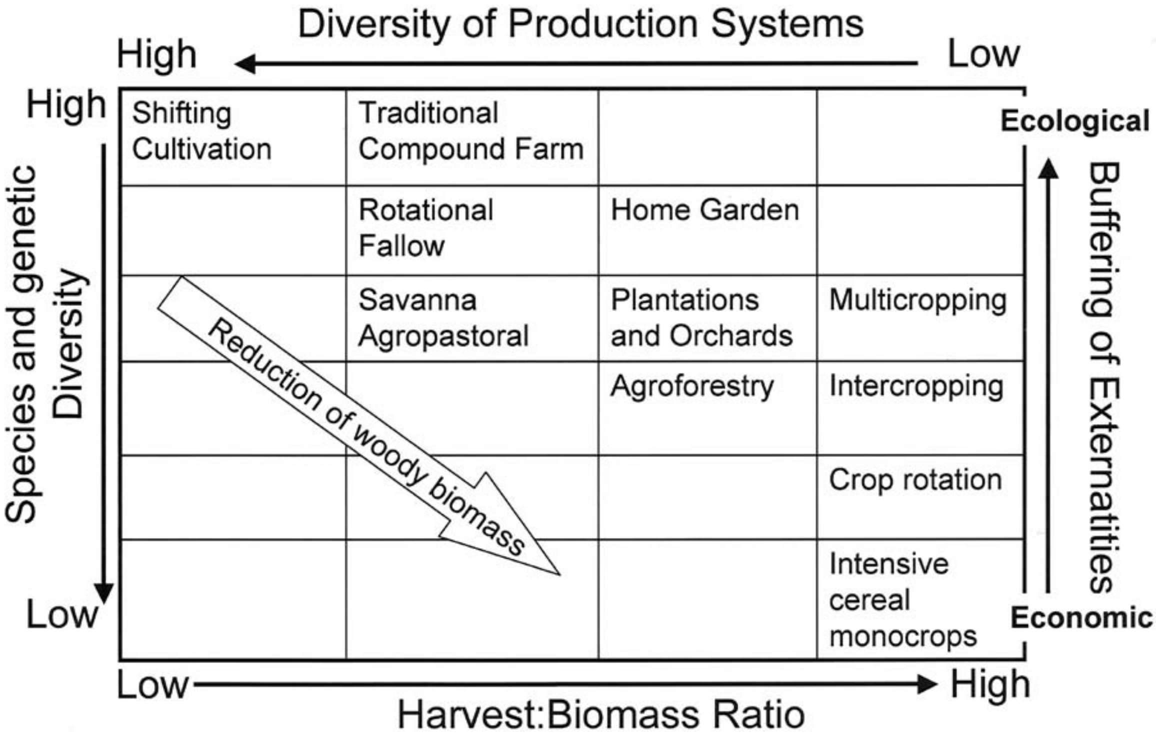

Figure 1. A classification of agricultural systems on the basis of their biological diversity and complexity. The vertical axis on the left grades systems in relation to the species richness of the productive biota, while the axis across the top represents the diversity of the structure of the farming systems. The axis across the bottom reflects the amount of non-harvested material (see text) as systems move from tree to arable crops (diagonal). The vertical axis on the left suggest that human livelihoods dependant on diverse natural systems are ecologically buffered against externalities while production systems coupled to markets have to be economically buffered. After Swift and Anderson (1992).

biological control agents, soil organisms, *etc*.) as well as some elements of natural wildlife. However, here to, the process of modernization involves a decrease in tree/shrub diversity, a gradual increase in the focus on the number of cash crop species, an increase in ornamental plants, a gradual homogenization of home garden structure and an increased use of agrochemicals (Peyre *et al*., 2006).

Specialization in the intensive production of food crops, such as cereals, can result in the ultimate reduction of planned diversity to a uniform land cover of a single, genetically uniform species. The associated diversity in arable crops is generally low because the harvesting of arable crops removes the habitat for insects, birds and mammals living above ground, and the frequency and intensity of tillage reduce the diversity of weeds and organisms living in the soil. Also, in order to maintain great control over the functioning of the ecosystem, inorganic fertilizers and pesticides replace the natural functions of the biota in recycling nutrients to crops and biological control of pests and diseases. Areas of natural vegetation, if present in these landscapes, are effectively isolated islands in a sea of crops that form hostile environments for the plant and animal species from one forest refuge to another.

This fragmentation of natural habitats by managed systems is a major factor causing the decline in the diversity of birds, mammals and insects because the size of the remaining habitat patches may be too small to support viable species population, and the structure of the landscape mosaic inhibits natural dispersal. Habitat fragmentation also alters the forest climate on a local scale (< 1 km) leading to wind disturbance and elevated desiccation (with increased fire potential) near the forest margins. These changes in microclimate can alter tree mortality and gap dynamics, plant species community composition, biomass dynamics and carbon storage (Laurance *et al.*, 2004). There have been extensive studies of these processes in Amazonia where rainforest are being cut at rates of up to 20 000 km^2 yr^{-1} leading to isolated forest fragments of 1-100 ha (Stouffer *et al*., 2006). Studies of understorey birds showed that the habitat structure (secondary growth, agroforestry or pasture) was often as important as the size of the forest fragment for bird species abundance.

Some fragments surrounded by 100 m of open pasture resulted in the reduction of insectivorous bird populations by 95% even where these pastures were themselves surrounded by continuous forest and old regrowth (Stouffer *et al.,* 2006).

An important axis of *Figure 1*, in relation to biodiversity and the functioning of ecosystems, is therefore proportion of (persistent) woody plant species versus (transient) arable crops supporting the community. Agricultural development at forest margins, including shifting cultivation, traditional compound farms and rotational fallows, usually involve harvesting an insignificant proportion of the total tree and shrub biomass for food, fibre, fodder and other non-timber products. Hence, the structural complexity and persistence of vegetation cover in the landscape, maintained over ecologically significant time periods (tens to hundreds of years), is a key factor in conserving high species diversity of these systems. In addition, the large proportion of non-harvested biomass from the utilized- and non-utilized plant species not only provides complex food resources for animal communities above- and below-ground, but also maintains ecosystem services for humans, such as shelter, soil conservation and clean water supplies (*Table 2*). At the other extreme, extensive cereal monocrops have much lower above-ground biomass and habitat complexity than woody vegetation, and a harvest ratio of 50%-100% (yield/above ground biomass). Consequently the associated diversity is low during the growing season, unless there is a ground cover of weeds, and decimated when the crop habitat is destroyed at harvest and the soil cultivated. In contrast, a relatively small proportion of the above-ground biomass is harvested from plantations of tree crops, such as oil palm, rubber, cocoa and fruits, and so the habitat structure of the ecosystem remains intact for many years. This long-term persistence of tree crops, the structural complexity of trees (providing a wide variety of micro-habitats) and the associated diversity of epiphytes and ground flora, can support a species diverse community despite the mono-specific dominance of the stand. The less intensively managed systems (*i.e.* with fewer agrochemicals, less mechanization and more crop species) of smallholder coffee, cocoa and rubber agroforests have provide a favourable habitat for birds, insects and many other groups, and may also enhance certain ecosystem functions such as biological pest control by ants (Philpott and Armbrect, 2006; Vandermeer *et al.,* 1998).

BIODIVERSITY AND ECOSYSTEM PROCESSES

Natural ecosystems are persistent because they have been selected to withstand the normal range of perturbations caused by the environmental regime of fires, weather and biological events, such as outbreaks of pests and diseases. Despite impacts of these disturbances, the vegetation biomass and the nutrient capital of the system remain fairly constant when considered over large areas (tens of hectares) and long periods of time (several decades). This ecological stability is conferred by two key attributes of the system: resistance and resilience (*Figure 2*). Resistance is the capacity of the system to absorb short-term weather events or local disturbances, such as tree falls, without a significant loss of the nutrient capital (and soil) from the system. Resilience is the rate at which the system recovers its previous state after extreme event such as wildfires, storms and human impacts such as extensive logging or harvesting. Both attributes are affected by the ecological characteristics of species maintaining processes of production, decomposition and nutrient cycling, but not necessarily the total number of species (as considered below). Following disturbance, the residual biota (including seed banks) and the distance from species refugia, are important determinants of regeneration rates (*Table 3*). However, ecosystems also include non-living, biophysical constituents [wood, dead plant materials, soil organic matter and the exchange capacity (EC) of mineral soil]. These biophysical constituent have critical roles in buffering carbon, nutrient and hydrological fluxes and operate at a higher regulatory level on system function that community diversity (*Figure 3*). For example, if the soil organic matter and nutrients are relatively unaffected by commercial logging, regeneration of closed-canopy forest could take less than 100 years but natural forest regeneration on exposed subsoil or bedrock could take centuries (Nussbaum *et al*., 1995).

Three conceptual relationships between biodiversity and function have been proposed for natural systems as shown in *Figure 4* (Vitousek and Hooper, 1993). The Type I curve implies that one species in a functional group (*e.g*. a plant, a herbivore, a predator or a decomposer species) is sufficient to carry out that ecosystem process. Type II implies that a finite number of species are needed to optimize that function, while Type III implies that system processes increase continuously as a function of diversity with no saturation point.

There has been considerable debate as to whether the Type III relationship occurs in natural systems since evidence has largely been derived from manipulative experiments that have limitations of design, small scale, short duration or species selection (Hooper *et al*., 2005). There is, however, more consensus that the Type II curve reflects is a widespread relationship between biodiversity and ecosystem functioning where

TABLE 2. ECOSYSTEM SERVICES MAINTAINED BY NON-HARVESTED COMPONENTS OF FARMING SYSTEMS. NOTE THAT MANY OF THESE SERVICES ARE LISTED IN *TABLE 1* AND THEREFORE THE LEVEL OF THESE FUNCTIONS ARE HIGHEST IN TREE-COVERED LANDSCAPES AND DECREASE AS THE HARVESTED BIOMASS INCREASES.

Component of biomass	Agroecosystem services
Trees	Shade.
	Aesthetics.
	Habitat for diverse associated biodiversity of fauna, flora and microbes.
	Wind breaks.
	Litter (with similar properties to crop residues).
	Affect water infiltration, ground water recharge and catchment hydrology.
	Maintainance of soil fertility.
	Build up of soil organic matter.
Weeds and cover legumes	Capture plant nutrient excess (*e.g.* in fallow period).
	Protection of soil surface against splash erosion, improved infiltration.
	Habitat and resources for associated biodiversity (pests, pathogens and control agents).
	Resources supporting the diversity of soil organisms maintaining soil processes.
	Nitrogen fixation by legumes.
	Creation of microclimate and reduction of wind speed in boundary layer.
	Entrainment of wind and water bourne sediment.
	Dung from grazing livestock improves plant nutrient availability.
Crop residues	Effects of mulching on soil temperatures and moisture.
	Protection of soil surface against splash erosion, improved infiltration.
	Microbial and soil animal products promoting aggregate stabilization.
	Nutrient carry over between crops.
	Habitat and resources for associated biodiversity (pests, pathogens and control agents).
	Maintenance of soil organic matter.
	Dung from domestic livestock.
Roots	Binding soil structure.
	Creation of macropores and water conduits.
	Major contribution to soil organic matter.
	Nutrient carry over between crops.
	Resources for associated biodiversity (pests, pathogens and control agents).

Source: Vandermeer *et al*. (1998).

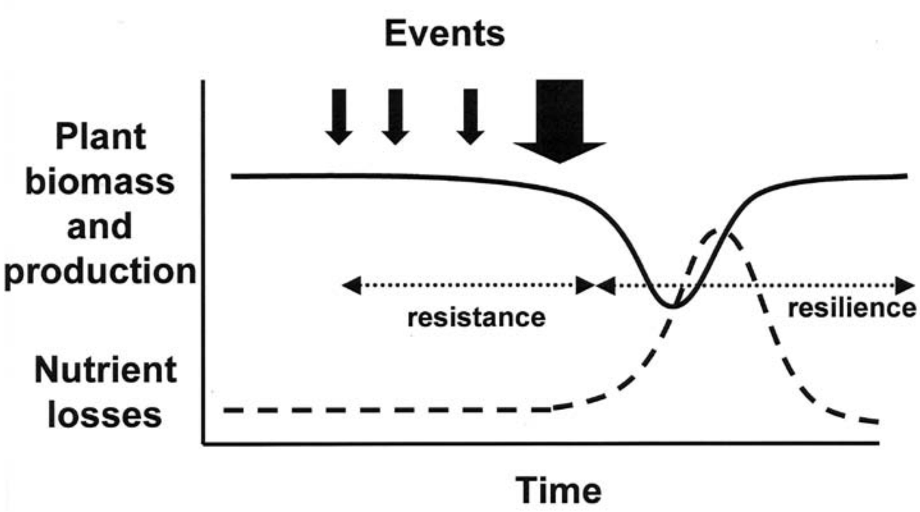

Figure 2. A conceptual model of ecosystem stability. The biophysical properties of the system largely buffer the effects of small perturbations on the system biomass, production and nutrient retention. The rate of recovery from major perturbations (resilience), such as drought, fire or clear felling, is more closely related to the diversity of functional groups able to restore the integrity of the system.

rates of ecosystem processes (net production, nutrient cycling, soil protection/erosion control and hydrologic functions) do not increase significantly above about four to five species in a functional group (Vitousek and Hooper, 1993). This relationship implies that many species in diverse communities are 'redundant', in the sense that their removal appears to have little effect on ecosystem processes and the functioning of the system can be maintained by a smaller number of 'key species'. However, the concept of 'species redundancy' must be considered with caution since it is defined by human perceptions of how the system functions on our time scale. Species that may appear redundant at one period of time may become important when some environmental changes occur; *i.e.* they are 'ecosystem buffers'. Conservation of diverse communities is therefore a sound precautionary strategy for the future.

The Type 1 relationship does occur in nature, notably where temperate and boreal forests are dominated by a single tree species, and illustrates the point that there is no universal relationship between biodiversity and ecosystem processes. For example, net primary production in terrestrial ecosystems is a function of climate (solar radiation and precipitation) and is similar for natural ecosystems in the same ecoclimatic zone irrespective of their floristic diversity at scales

TABLE 3. ROLE OF LANDSCAPE MOSAICS IN ECOSYSTEM RESILIENCE

System	Perturbations		Mosaic function
	Short	Long	Area /distance
Natural forest	Seasonality	Climate	Community gap dynamics
Forestry	Selective logging	Clear fell	Protected seedlings' seed source distance
Cropping system	Tillage Weeding Harvest	Erosion	Local refugia (bunds, *etc.*) and distance to natural habitats
Associated diversity	Management	Land use change	Habitat refugia for species colonization

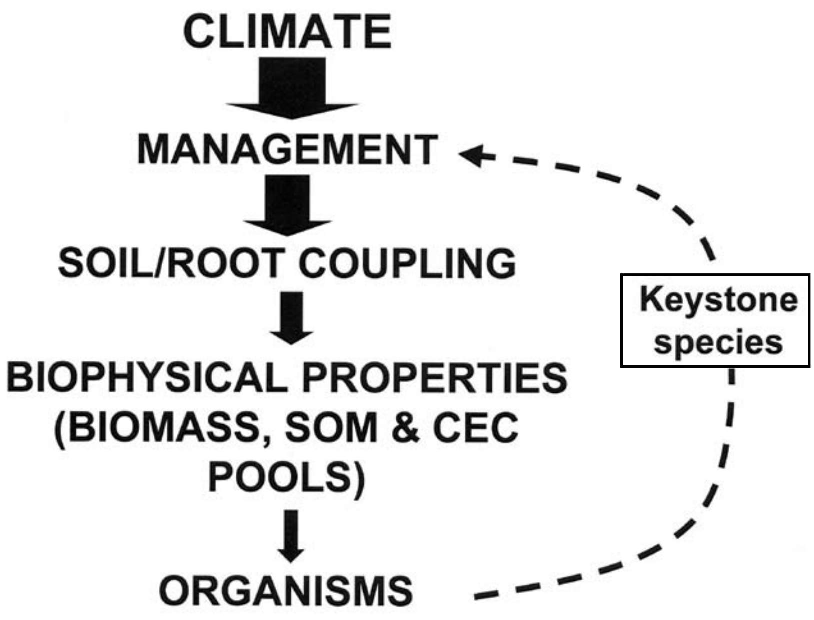

*Figure 3. Hierachy of controls over ecosystem stability. Organisms actually carry out most ecosystem functions but biophysical processes buffer changes in their process rates affecting carbon, nutrient and water fluxes. However, the plant/soil interface has a higher-level function in maintaining the integrity of ecosystem rather than biological diversity (*e.g. *oil palm plantations) and this coupling is affected by management practices. This in turn affects the impact of climatic events on the system (*e.g.*soil erosion).*

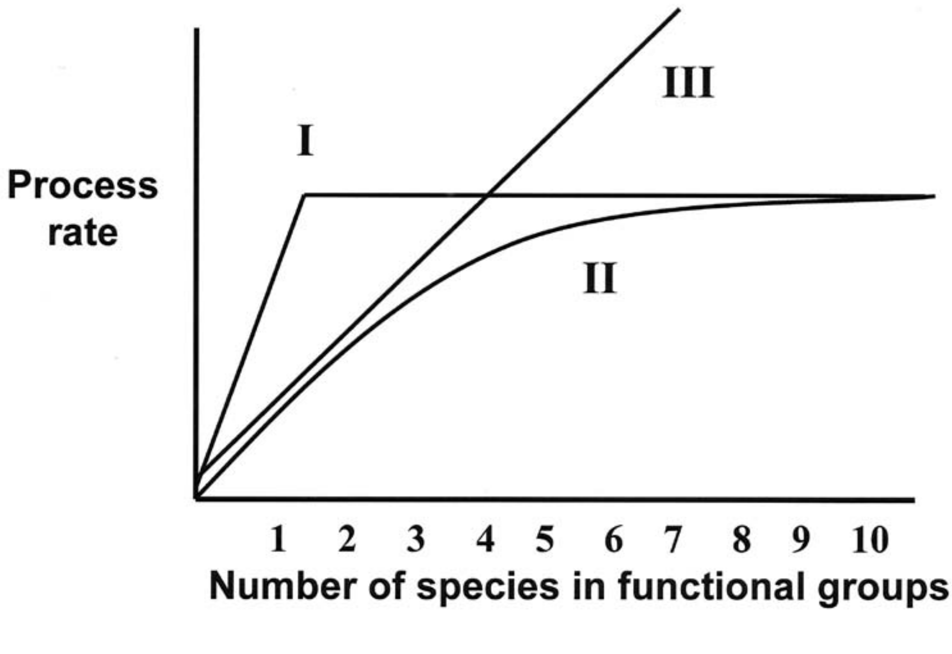

Figure 4. Conceptual relationships between numbers of species in functional groups and ecosystem processes (Vitousek and Hooper, 1993). The functional attributes of the three curves are discussed in the text.

of a hectare and above. The main determinant of photosynthetic efficiency at these scales is the interception of light determined by leaf area and its stratification. This can be optimized by a few species forming the canopy, sub-canopy, shrub and ground layers, or a large number of plant species sub-dividing these niches. However, extensive areas of plant communities dominated by a single species are potentially at risk from outbreaks of pests and diseases that can cause extensive defoliation, or even death of key species, which can disrupt the functioning of the system. The spread of these outbreaks are greatly reduced in multi-species communities because damage by a specific pest or disease is localized so other species can compensate for the loss of function. Similar principles apply in multi-species agroecosystems and even in cereal monocrops where intimate mixtures of genetic varieties can reduce the spread of fungal pathogens (Swift *et al*., 1996). Hence, the question of relationships between biodiversity and function is not so much the question of the numbers of species *per se* but their functional characteristics (perennials, annuals), structure (trees, shrubs, herbs) and the spatial relationships between functional groups in the vegetation profile, in the spatial distribution of intercrops or as a landscape mosaic of different monocultures.

Functional Roles of Planned Biodiversity

The switch from complex agricultural systems, with a multiplicity of productive species, to less complex systems including crop monocultures (Type I above) has been global trend in agricultural development over the last 50 years. This transition has been largely driven by market forces with monocultures perceived as economically more efficient than more complex systems. However, there is an issue whether this loss of complexity also results in an increase in economic and ecological stability. Recent concerns over sustainability, and the effects of global change, have awakened interest in production systems with intermediate levels of crop diversity (Type II) such as intercrops and agroforestry systems. The yield advantages of intercropping two or more arable species, such as legumes and non-legume mixtures, have been considered in detail by Vandermeer *et al*. (1998). They conclude that there appear to be few direct production gains from intercropping, *vs.* rotations of monocrops, and where there are advantages of mixtures these are often associated with beneficial (*facilitative*) effects on the companion crop enhancing the associated diversity of pollinators, or predators and parasitoids involved in pest control. These facilitative interaction have been manipulated to particular effect in the 'push-pull' strategy of pest management (Cook *et al.*, 2007). For example, intercropping of the ground cover legume *Desmodium intortum* with sorghum (*Sorghum bicolour*) significantly reduced the effects of the parasitic weed *Striga hermonthica* and cereal stem borers on the growth and yield of sorgum (Khan *et al*., 2006).

There is more evidence for the higher productivity and functional stability of agroforestry systems, compared to arable monocrops and intercropping systems, as a consequence of greater capture of light, water and nutrients by the more complex vegetation structure above and below ground (Vandermeer *et al*., 1998). In the seasonal tropics, arable crops all begin to produce their root systems at the same time after germination starts with the onset of rains. However, whetting up of the soil also causes an early flush of nutrients that may be lost from the system in leachates or runoff before they can be captured by the developing rooting system. The inclusion of trees in an intercrop provides a permanent, deeper rooting system that improves resource capture throughout the year - including after harvest when the ground is otherwise bare. The tree roots also stabilize the soil, reducing erosion, the canopy cover protects the soil from rain, and infiltration is often improved under tree cover resulting in better soil water recharge. Despite these advantages, farmers in the tropics have not widely adopted tree/crop mixtures on the same plot because of the labour involved in managing the tree component, problems of cultivation around trees, competition for water during dry periods, and a number of social issues such as land tenure.

Commercial oil palm plantations with a low planned diversity of one tree species and one species of ground cover legume (up to canopy closure) (Type 1 relationship) maintain many of the ecosystem services characteristic of natural forest cover such as carbon sequestration, soil conservation, regulation of water flow and storage. The magnitude of the vegetation and soil pools and flux rates differ because oil palms do not form the structurally complex vegetation with the magnitude of biomass, soil properties and other biophysical characteristics of undisturbed natural forest. However, at the end of the rotation resilience of the plantation system is low, under conventional management since felling and processing (chopping/shredding) of the palm biomass, and the associated soil disturbance, compaction and erosion, results in the destruction of vegetation cover and much of the nutrient capital of the system being lost (Malmer, 1996). In natural systems resilience through nutrient capture is accelerated by the vegetative regrowth of seedlings and damaged vegetation, or a succession of different functional groups of plants colonizing from surrounding areas. In commercial oil palm plantations regeneration involves large energy subsidies in the form of fertilizers, herbicides, fuel, cultivation of nursery stock and labour to reduce soil erosion, re-estabilish plant/soil integrity and fruit bunch production. Alternative management practices that reduce the need for biomass processing for control of key pests (*Oryctes*) and pathogens (*Ganoderma*), and which improve the transfer of the nutrient capital between rotations (Haron *et al*., 1996; Mackensen *et al*., 2003) have important implications for the maintenance of ecosystem services at catchment scale.

Functional Roles of Associated Diversity

The undisturbed ground cover of fronds and weeds, over the long plantation cycle of oil palm (c. 25 years) supports highly diverse soil animal communities (Lavelle and Pashanari, 1989), that have important roles in biological control (*e.g.* ants) and for maintaining soil structure and functions. Complex microbial communities developed under *Pueria javanica* progressively build up natural suppression of *Fusarium oxysporum* (Johnson, 1999). On the other hand, as with crops, the presence of one or two species, compared to multi-species communities, can enhance their specific attributes because they are released from competitive interactions with other species. For example, inoculation of legumes with improved N-fixing strains of *Rhizobium leguminosarum* is intended to effectively reduce the natural biodiversity of rhizobia that perform comparatively poor (Materon *et al*., 1995). Similarly, a single biological control agent may be more effective than two or more because of competitive interference in complex species associations (Hawkins, 1994). Alternatively the inclusion of a generalist as well as a specialist may enable the generalist to effect control during normal times while the specialist can respond to pest outbreaks (Levins, 1986). However, the whole history of agriculture shows the emergence of new pests and the resurgence of old ones that have developed pesticide resistance. Conservation of diverse insect communities, *e.g.* by encouraging weeds, can therefore provide potential natural enemies that might currently be considered redundant at the present time.

VALUES PLACED ON BIODIVERSITY

As considered above, the global threats to biodiversity through the destruction of natural habitats, reduction of landscape complexity and intensification of production systems are driven by the interests of some stakeholders but conflict with the interests of others concerned with conserving biodiversity at ecosystem, species and genetic levels. Similar issues arise for ecosystem services: for example, erosion and agrochemical land use caused by stakeholders upstream may compromise the quality of water supplies for consumers downstream. Also local or national interests may be served by planting oil palms on deep peats but the carbon mobilized also contributes to global environmental change (Melling *et al*., 2005). In all these situations there are economic implications for different stakeholders in adopting, or forgoing, one land use against another - which raise issues of who pays for what and how? The field of environmental economics has expanded exponentially in the last decade or so as economists try to tackle the complexities of biodiversity and its values for human well-being into categories that are simple and tangible enough to be adopted by stakeholders and policy makers. The literature is vast but useful reviews are provided by Nunes and Van den Bergh (2001), de Groot *et al*. (2002), Swift *et al*.(2004). Different authors use various terminologies but a general scheme for different values of biodiversity and functions outlined by Mountford and Keppler (1999) is illustrated in *Figure 5* where the total economic value (TEV) of biodiversity is the sum of 'use values' and 'non-use values':

Non-use, intrinsic or existence values are the social, cultural, aesthetic and ethical benefits gained from biodiversity. Some groups attach social and religious values to individual species, such as the hornbill in Borneo. Others gain value from simply knowing the existence of certain species (pandas, gorillas, tigers), or species-rich tropical rainforests, and are prepared to give significant funding for species and habitat protection even if they never actually visit the areas. Nunes and van den Burgh (2001) review examples of this willingness to pay (WTP).

The direct use, or utilitarian, values refer to those elements of species, or their genes, that can be directly consumed (food, fuel, fibre, plant medicines), traded or used in manufacturing processes. These benefits, including amenity values of tourism and hunting, usually accrue to farmers, local community or government who mange the land. Forest provide traditional societies with many products used by the household, or harvested sustainability for local markets. *Table 4* lists economic uses of nearly 6000 plant species found in Southeast Asian forests. There have been many assessments of the long-term, sustainable economic values of these non-timber resources, versus the immediate gains from harvesting timber. Unfortunately short-term interests often win either because the benefits tend

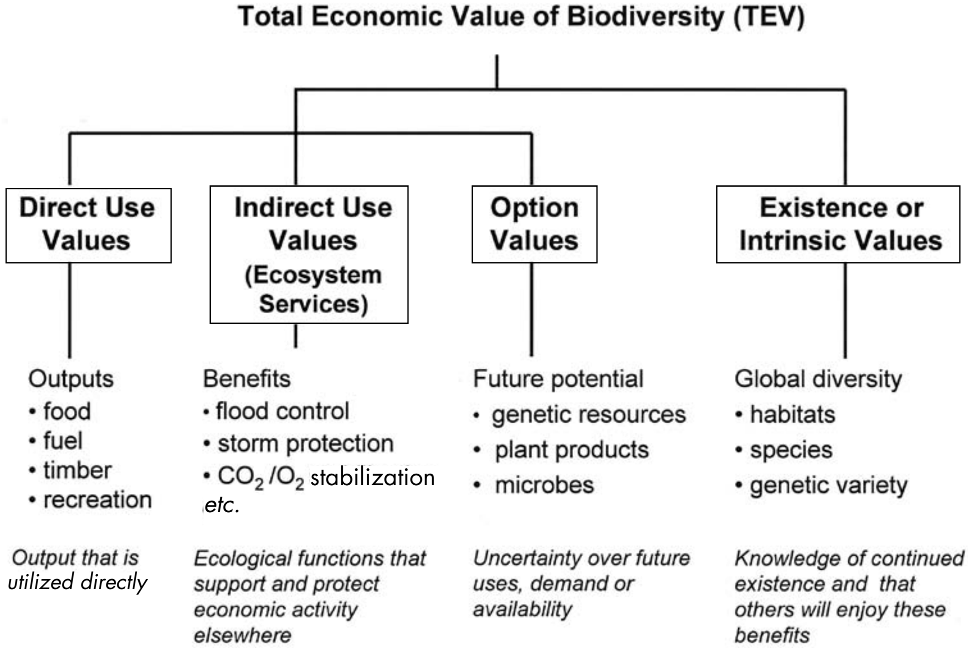

Figure 5. Economic values of bioderversity.

TABLE 4. ECONOMIC USE OF SOUTHEAST ASIAN TROPICAL RAINFOREST PLANTS BY COMMUNITIES LIVING AT THE FOREST MARGINS

Product/community group	No. plant species
Timber trees	1 462
Medicinal plants	1 135
Ornamental plants	520
Edible fruits and nuts	389
Fibres	227
Rattans	170
Poisonous and insecticidal plants	147
Spices and condiments	110
Others	1 790
Total	5 950

Source: Jansen *et al*. (1991).

to accrue to more powerful stakeholders than the local community, or because the poor value cash in hand over future benefits from conservation (Emerton, 2003).

Ecosystem services are *indirect use* or *functional values* that include all those functions of the natural environment which provide direct value to the health and well-being of humans on a local, regional or global level. The value of ecosystem services can be assessed in some situations by calculating the amount which is necessary to substitute them, *e.g.* the price of an equivalent water purification plant would be a proxy for the value of an ecosystem in maintaining the quality of a water supply (Mountford and Keppler, 1999). Constanza *et al*. (1997) estimated the value of the world's ecosystem services between USD 16 and 54 trillion (10^{12})

TABLE 5. ECONOMIC VALUES PLACED ON ECOSYSTEM SERVICES

Services	Value (USD 10^9)
Soil formation	17.1
Recreation	3.0
Nutrient cycling	2.3
Water regulation and supply	2.3
Climate regulation (temperature and precipitation)	1.8
Flood and storm protection	1.1
Food and raw materials production	0.8
Genetic resources	0.8
Atmospheric gas balance	0.7
Pollination	0.4
All other services	1.6
Total value of ecosystem services	**33.3**

Source: Costanza *et al*. (1997).

(*Table 5*). These figures are somewhat controversial but have focussed attention on services that were ignored or discounted in economic terms. For example, carbon sequestration by ecosystems was not valued as an ecosystem service (*i.e.* of human benefit) until society recognized the economic consequences of climate change caused by anthropogenic CO_2 concentrations in the atmosphere. Now carbon trading is a major area of policy development (*e.g.* Izac, 1997) with proposals for tropical countries participating in the Kyoto Protocol to receive 'compensated reduction' for reducing deforestation (Santilli *et al*., 2005).

Option values are attached to potential uses of biodiversity in the future. It is estimated that only about 1.5 million of the estimated 5-30 million species on earth are known to science and less than half a million have been screened for potential economic uses (Nunes and van den Burgh, 2001). Screening of plants over the last two decades have yielded highly effective anti-cancer and anti-leukaemia drugs (Cragg *et al*., 1998) and pharmaceutical companies have agreed contracts worth many millions of dollars for bioprospecting; though there are many concerns over the fairness and ethics of these deals (Nunes and van den Burgh, 2001). Traditional communities have a vast legacy of knowledge about natural products, for example the Murut in Sabah use 338 species of medicinal plants (Kulip, 2003), the Iban in Sarawak use 37 species of palms (Ruano, 1999) and the Penan in Borneo have an intimate knowledge of forest products with a complex indigenous taxonomy (Donovan and Puri, 2004). It is therefore a moral imperative that future generations also have the option of new uses for microorganisms, plants and animals, and their genes. This involves not only the conservation of species rich habitats, but also preserving the diversity of cultural knowledge that has co-evolved over thousands of years.

Because of the complexities involved in attributing values to these different attributes of biodiversity there have been few estimates of the TEV for an entire forest ecosystem or national forest. Emerton (2003) provides a very useful assessment of tropical forest valuation and cites examples of the TEV for Mexico's forests at USD 4 billion a year, forest catchment protection in Ecuador valued at USD 11 - USD 15 million for a hydroelectric scheme alone; and a global net benefit of protecting 650 million ha of Amazonia rainforest as worth USD 70 billion, or approximately 0.2% of global gross domestic product (GDP). Emerton (2003) concludes that until these assessments reflected in conservation, development planning, policies and management practices, there is a risk that forests – a vital source of biodiversity and economic potential – will continue to be degraded and lost to other land uses.

CONCLUSIONS

Human society evolved in a diverse world and conservation of our natural heritage is essential for our moral, spiritual and cultural well-being as well as providing life support functions. Agricultural development to provide improved livelihoods for burgeoning populations has generally resulted in a loss of natural diversity through habitat destruction, the selection of a few economic species with a restricted gene pool, and replacement of natural biological functions with agrochemicals and fossil energy. Many ecosystem processes can be maintained by simplified systems involving five or less key species under present environmental conditions. However, both climate and economic conditions are changing, such as drought frequencies and increasing costs of fossil energy, and it is an unwise presumption that agroecosystems will continue to provide the same goods and services with the same species and management in the future. Having a range of species that respond differently to different environmental perturbations can stabilize ecosystem process rates in response to disturbances and variation in abiotic conditions. Practices that maintain a diversity of organisms in different functional groups, and functional response types, will also help ensure a range of future management options. Hence, the stewardship of tropical forests should include planning, or restoring, landscapes that combine natural habitats for wildlife, tourism and recreation with commercial systems, conserve soils and carbon stocks through appropriate management practices, protect water catchments and respect the traditional needs of local communities. The principles and criteria agreed by Round-table of Sustainable Palm Oil (RSPO, 2005) address many of these critical issues and their adoption would be a significant contribution to the maintenance of landscapes supporting multi-functional services and conservation of biodiversity.

REFERENCES

ABADIE, C; EDEL, V and ALABOUVETTE, C (1998). Influence of a cover-plant on density and diversity of *Fusarium* populations. *Soil Biology & Biochemistry, 30*: 643-649.

COOK, S M; KHAN, Z R and PICKETT, J A (2007). The use of push-pull strategies in integrated pest management. *Annual Review of Entomology, 52*: 375-400.

COSTANZA, R; D'ARGE, R; D E GROOT, R; FARBER, S; GRASSO, M; HANNON, B; LIMBURGH, K; NAEEM, S; O'NEILL, R V; PARULEO, J; RASKINS, R G; SUTTON, P and VAN DEN BELT, M (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*: 353-260.

CRAGG, G M; NEWMAN, D J and YANG, S S (1998). Bioprospecting for drugs. *Nature, 393*: 301.

DE GROOT, R S; WILSON, M A and BOUMANS, R M J (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics, 41*: 393-408.

DONOVAN, D G and PURI, R K (2004). Learning from traditional knowledge or non-timber forest products: Penan Benalui and the autecology of Aquilaria in Indonesian Borneo. *Ecology and Society, 9*: Issue 3.

EMERTON, L (2006). Tropical forest valuation: has it been a futile exercise? http://www.fao.org/DOCREP/ARTICLE/WFC/XII/MS3-E.HTM.

HARON, K; ZAKARIA, Z Z and ANDERSON, J M (1999). Effects of oil palm residue management at replanting on soil nutrient dynamics and oil palm growth. *Proc. of the 1999 International Oil Palm Congress*. PORIM, Bangi. p. 43-54.

HAWKINS, B A (1994). *Pattern and Process in Host-Parasite Interactions.* Cambridge University Press, Cambridge.

HOOPER, D U; CHAPIN, F S; EWELL, J J *et al*. (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs, 75*: 3-35.

IZAC, A-M N (1997). Developing policies for soil carbon management in tropical regions. *Geoderma, 79*: 261-276.

JOHNSON, D V (1999). The economic value of palms to people in tropical areas. *Acta Horticulturae, 486*: 267-275.

KHAN, Z R; MIDEGA, C A O; HASSANALL, A; PICKETT, J A; WADHANS, L J and WANJOYA, A (2006). Management of witchweed (*Striga hermonthica*) and stemborers in sorghum (*Sorghum bicolor*) through intercropping with greenleaf desmodium (*Desmodium intortum*). *International Journal of Pest Mangement, 52*: 297-302.

KULIP, J (2005). Similarity of medicinal plants used by two native communities in Sabah, Malaysia. *Bioprospecting and Ethnopharmacology, 675*: 81-85.

LAURANCE, W F; LOVEJOY, T E; VASCONSELOS, H L *et al*. (2004). Ecosystem decay of Amazonian Forests fragments: a 22-year investigation. *Conservation Biology, 16*: 605-618.

LAVELLE, P and PASAHANASI, D (1989). Soil macrofauna and land management in Peruvian Amazonia. *Pedobiologia, 33*: 283-291.

LEVINS, R (1986). Perspectives on IPM: from an industrial to an ecological model. *Ecological Theory and Integrated Pest Management* (M Kogan ed.). Wiley, New York. p. 53-65.

MACKENSEN, J; KLINGE, R; RUHIYAT, D and FLOSTER, H (2003). Assessment of managementdependent nutrient losses in tropical tree plantations. *Ambio, 32*: 106-112.

MALMER, A (1996). Phosphous loading to tropical rainforest streams after clear felling in Sabah, Malaysia. *Water Resources Research, 32*: 2213-2220.

MATERON, L A; KEATINGE, J D H; BEK, D P; YURTSEVER, N; KARUE, K and ALTUNAS, S (1995). The role of rhozobial biodiversity in legume crop productivity in the west Asian highlands. II. *Rhizobium leguminosarum*. *Experimental Agriculture, 31*: 485-491.

MATSON, P A; PARTON, W J; POWER, A G and SWIFT, M J (1997). Agricultural intensification and ecosystem properties. *Science, 277*: 504-509.

MELLING, L; HANATO, R and GOH, K J (2005). Global warming potential from soils in tropical peatlands of Sarawak, Malaysia. *Phyton-Annales Rei Botanicae, 45*: 275-284.

MOUNTFORD, H and KEPPLER, J H (1999). Financing incentives for the protection of biodiversity. *Science of the Total Environment, 240*: 133-144.

NUNES, P A and VAN DEN BURGH, JEROEN, C J M (2001). Economic valuation of biodiversity: sense or nonsense? *Ecological Economics, 39*: 203-222.

NUSSBAUM, R; ANDERSON, J M and SPENSER, T (1995). The effects of selective logging of tropical forest on soil characteristics and implications for forest recovery. *The Ecology, Conservation and Management of South East Asian Rainforests* (R Primack and T Lovejoy eds.). Yale University Press, New Haven. p.105-115.

PEYRE, A; GUIDAL, A; WIERSUM, K F and BONGERS, F (2006). Dynamics of homegarden structure and function in Kerala, India. *Agroforestry Systems, 66*: 101-115.

PHILPOTT, S M and ARMBRECHT, I (2006). Biodoversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. *Ecological Entomology, 31*: 396-377.

PIMENTEL, D and PIMEMTEL, M (2006). Global environmental resources versus world population growth. *Ecological Economics, 59*: 195-198.

RAMAKRISHNAN, P S (1992). *Shifting Agriculture and Sustainable Development: An Interdisciplinary Synthesis from North East India*. UNESCO-MAB Series, Paris.

RSPO (2005). RSPO Principles and Criteria for Sustainable Palm Oil Production. www.rspo.org.

SANTILLI, M; MOUTINHO, P; SCHWARTZMAN, S; NEPSTAD, D; CURRAN, L and NOBRE, C (2005). Tropical deforestation and the Kyoto Protocol. *Climatic Change, 71*: 267-276.

STOUFFER, P C; BIERREGAARD, R O; STRONG, C; *et al.* (2006). Long-term landscape change and bird abundance in Amazonia rainforest fragments. *Conservation Biology, 20*: 1212-1223.

SWIFT, M J and ANDERSON, J M (1992). Biodiversity and ecosystem functioning in agricultural systems. *Functional Attributes of Biodiversity in Ecological Systems* (Schulze ed.). Springer Verlag, Heidelberg. p. 15-41.

SWIFT, M J ; IZAC, A-M N and VAN NOORDWIJK, M (2004). Biodiversity and ecosystem services in agricultural landscapes - are we asking the right questions? *Agriculture, Ecosystems and Environment, 104*: 113-134.

SWIFT, M J; VANDERMEER, J; RAMAKRISHNAN, P S; ANDERSON, J M; ONG, C K and HAWKINS, B A (1996). Biodiversity and agroecosystem function. *Functional Roles of Biodiversity: A Global Review* (HA Mooney, JH Cushman, E Medina, OE Sachs and E-D Schulz eds.). SCOPE, John Wiley & Sons, Chichester. p. 261-298.

VANDERMEER, J; VAN NOORDWIJK, M; ANDERSON, J O; ONG, C and PERFECTO, I (1998). Global change and multispecies agroecosystems: concepts and issues. *Agriculture, Ecosystems and Environment, 67*: 1-22.

VITOUSEK, P M and HOOPER, D U (1993). Biodiversity and terrestrial ecosystem biogeochemistry. *Biodiversity and Ecosystem Functioning* (Schulze and HA Mooney eds.). Springer-Verlag, Berlin. p. 1-14.