Sustaining the Multiple Functions of Agricultural Biodiversity

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Summary

The present paper is a contribution to the FAO/Netherlands Conference on the "Multifunctional Character of Agriculture and Land-MFCAL" that will take place in Maastricht, The Netherlands, in September 1999. The objective of the paper is to critically review the relationships between agricultural biodiversity and the functions of agro-ecosystems at different spatial and temporal scales. Selected examples are used to highlight the multiple functions of agricultural biodiversity and its links with rural livelihoods in a range of ecological and economic settings. In the first part of the paper the multiple functions of agricultural biodiversity are discussed in terms of its contributions to :

1) Food and livelihood security. Dynamic and complex livelihoods usually rely on plant and animal diversity, both wild and in different stages of domestication. Different types of agricultural biodiversity ("cultivated", "reared" or "wild") are used by different people at different times and in different places, and so contribute to livelihood strategies in a complex fashion. Understanding how cultivation, herding, fishing, collection, use and marketing of different types of agricultural biodiversity are differentiated by wealth, gender, age and ecological situation is essential to evaluate their overall economic value.
2) Production and environmental sustainability. In addition to contributing to environmental sustainability, agricultural biodiversity helps sustain many production functions both in low external input and high input-output agriculture. Available evidence is summarised for the following functions: soil organic matter decomposition, nutrient cycling, pollination, pest control, yield functions, soil and water conservation, action on climate and water cycling, biodiversity conservation and influence on landscape structure.
3) Rural development. In addition to its contribution to food and livelihood security, agricultural biodiversity can provide the basis for eco-tourism and the regeneration of localised food systems and rural economies.

The forces which undermine agricultural biodiversity are then summarised in order to identify some of the policy and institutional reforms needed to sustain agricultural biodiversity and agroecosystem functions. The rationale for each major policy reform is presented in the concluding part of the paper along with specific options and suggestions for action.

Introduction

Throughout the world human communities have played a central role in shaping nature's diversity and its associated functions. Cultural and biological diversity have evolved together, the one shaping the other. For example the gourd shows tremendous varietal diversity: it has been selected for a multitude of use and functions, including containers, pipes, scrubbers, floats, musical instruments, penis sheaths, ornaments and food. Plants and animals, both wild and cultivated, have been combined in complex and diverse agroecosystems in terrestial and aquatic environments. At the broader landscape level, recent scientific evidence suggests that virtually every part of the globe- from boreal forests to the humid tropics- has been inhabited, modified and managed for millenia. Over time, human agency has shaped the expression of agricultural biodiversity at the genetic, species, ecosystem and landscape levels.

The present paper is a contribution to the FAO/Netherlands Conference on the "Multifunctional Character of Agriculture and Land-MFCAL" that will take place in Maastricht, The Netherlands, in September 1999. This background paper focuses on the relationships between agricultural biodiversity and the functions of agro-ecosystems at different spatial and temporal scales. Selected examples are used to highlight the multiple functions of agricultural biodiversity and its links with rural livelihoods in a range of ecological and economic settings. The paper is divided into three parts. Part one focuses on the contribution made by agricultural biodiversity to 1) food and livelihood security 2) production and environmental sustainability and 3) rural development. Part two identifies the forces which impact on agricultural biodiversity. Part three concludes by outlining some of the policy and institutional reforms needed to sustain agricultural biodiversity and agroecosystem functions.

The multiple functions of agricultural biodiversity

Agroecosystem functions are partly determined by the social goals of farmers, pastoralists, forest dwellers, fisherfolk and gardeners,- men, women and children with their own definitions of well being and their different priorities, rights, capabilities and knowledge. These social goals include economic, cultural and often aesthetic values as well as those of biological production. Depending on circumstances, preference may be given to short term maximisation of specialised productivity based on a single crop or to the diversity and persistence of production. These factors influence the way in which biodiversity is managed at the level of a discrete production unit (pond, field, swidden garden) right up to the larger landscape that is continuously transformed through the interplay between human agency and ecological processes (e.g forests, pastoral landscapes, coastal zones and mangroves). Both natural processes and human management have generated and sustained a vast array of genetic, species and ecological diversity. In turn, this agricultural biodiversity performs many different socio-economic and environmental functions which are closely interrelated.

Given this strong historical link between rural livelihoods and the components of biodiversity that are managed in different ways for different purposes, agroecosystems necessarily include by definition people and their institutions as well as the agro-biodiversity that they co-create and use. This inclusive view is implicit in the concepts and definitions jointly developed by the FAO-SCBD (see Box 1). Considering agricultural biodiversity through such a holistic framework encourages the kind of methodological pluralism that is key to understanding the structure and functions of agricultural biodiversity in time and space.

Box 1. Key concepts and definitions

Agricultural biodiversity or agrobiodiversity. Agricultural biodiversity refers to the variety and variability of animals, plants, and micro-organisms on earth that are important to food and agriculture which result from the interaction between the environment, genetic resources and the management systems and practices used by people. It takes into account not only genetic, species and agroecosystem diversity and the different ways land and water resources are used for production, but also cultural diversity, which influences human interactions at all levels. It has spatial, temporal and scale dimensions. It comprises the diversity of genetic resources (varieties, breeds, etc.) and species used directly or indirectly for food and agriculture (including, in the FAO definition, crops, livestock, forestry and fisheries) for the production of food, fodder, fibre, fuel and pharmaceuticals, the diversity of species that support production (soil biota, pollinators, predators, etc.) and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic), as well as the diversity of the agro-ecosystems themselves

Agricultural ecosystems or agroecosystems. Agroecosystems) are those "ecosystems that are used for agriculture" in similar ways, with similar components, similar interactions and functions. Agroecosystems comprise polycultures, monocultures, and mixed systems, including crop-livestock systems (rice - fish), agroforestry, agro-silvo-pastoral systems, aquaculture as well as rangelands, pastures and fallow lands. Their interactions with human activities, including socio-economic activity and sociocultural diversity, are determinant. Agroecosystems may be identified at different levels or scales, for instance, a field/crop/ herd/pond, a farming system, a land-use system or a watershed. These can be aggregated to form a hierarchy of agro-ecosystems. Ecological processes can also be identified at different levels and scales. Valuable ecological processes that result from the interactions between species and between species and the environment include, inter alia, biochemical recycling, the maintenance of soil fertility and water quality and climate regulation (e.g. micro-climates caused by different types and density of vegetation). Moreover, the interaction between the environment, genetic resources and management practices influence the evolutionary process which may involve, for instance, introgression from wild relatives, hybridisation between cultivars, mutations, and natural and human selections. These result in genetic material (landraces or animal breeds) that is well adapted to the local abiotic and biotic environmental variation.

Source: *International Technical Workshop organized jointly by the Food and Agriculture Organization of the United Nations and the Secretariat of the Convention on Biological Diversity(SCBD), with the support of the Government of the Netherlands 2-4 December 1998, FAO Headquarters, Rome, Italy.* www.fao.org/sd/epdirect/EPre0063.htm

i) Agricultural biodiversity's contributions to food and livelihood security

Livelihood systems are diverse in rural areas and vary among different cultural groups and in different regions of the world. They commonly rely on a mix of wild foods, agricultural produce, remittances, trading and wage labour. Empirical evidence from many different locations suggests that rural households do engage in multiple activities and rely on diversified income portfolios. Contrary to received wisdom, the actual contribution of agriculture to livelihoods can be quite low in today's fast changing rural areas. In sub Saharan Africa, for example, a range of 30-50 % reliance on non-farm income sources is common but it may reach 80-90% in Southern Africa (Ellis, 1999). Household decision making continually adjusts to the changing nature of the environment, local economies and governance. At higher levels, it is simply impossible to predict the relationships between agroecosystems

and households, particularly in resource-poor areas where there is much biological and social diversity.

The tendency for rural households to engage in multiple occupations is often mentioned, but few attempts have been made to link this behaviour in a systematic way to agricultural biodiversity and its multiple functions. Reflecting sectoral interests and disciplinary specialisations, the conventional point of entry for scientific research, management and policy has been to focus on selected components of agricultural biodiversity (e.g. plant genetic resources). However, this approach often leads to a mismatch between standard development interventions and diverse local realities, needs and priorities. Reversing this approach, requires putting people with their assets, activities, and complex livelihoods at the centre of analysis (Chambers, 1997). The functions of agricultural biodiversity thus need to be situated and mapped out within a total livelihood context (IIED, 1995, 1998; Pimbert 1999).

Dynamic and complex livelihoods usually rely on plant and animal diversity, both wild and in different stages of domestication. (Box 2).

Box 2. Agricultural biodiversity meeting human needs

• There is high intra-specific genetic variation in the date palm oasis agroecosystems of Algeria, Chad and Egypt (Barakat, 1995). The principal varieties differ from one oasis to another. In general, there are more than ten varieties of date palms in each oasis. In a well organised and maintained palm grove, the owner plants different varieties of dry and semi-dry dates that mature in different months to meet the demands of local consumption and the market. Moreover, each genetic variety confers its own unique stamp on i) the taste of the date fruit and the wine made from it ii) the texture of the edible palm centre iii) the properties of the wood from the palm trunk that is used in construction and tool making iv) the mechanical qualities of palm leaves used for ceilings and fences as well as those of the palm's fibrous leaf base used to make ropes and sacks and v) the nutritional values of date stones fed to camels.

• About 25% of the land in the small holding sector are under home gardens in Sri Lanka. The garden system is similar to the complex structure and multiple functions of the forest, though not identical to it. Endemic and naturalised species make up about 40% of Kandyan gardens (named after the city of Kandy in central Sri Lanka). Trees, shrubs, herbs, crops and animals interact and sustain themselves in association with the households. Management activities that enhance agricultural biodiversity are carried out in conjunction with domestic work or during leisure time, particularly by women. The involvement of households in managing homegardens is not limited to harvesting diverse outputs. Specific management practices are used to achieve better use of resources, including gaps and favourable interactions. Branch pruning, coppicing, clearing excess seedlings, nurturing of naturally germinated seedlings or species emerging from garbage heaps, increasing soil nutrients, and using indigenous knowledge to control pests and experiment with new genetic variations are all widespread activities. Local definitions of culture and well being cannot be considered apart from the system because of the strong link between survival of the households and agricultural biodiversity (Wickramasinghe, 1992 and 1995).

• In Cameroon, at least four breeds of domestic fowl (*Gallus gallus*) are kept on a free range system in villages where 70% of the national stock live. Indigenous fowl are kept for food and income generation, for gifts and sacrifices, for breeding stock and for traditional medicine preparations (Gueye, 1998). In south east Mexico, women keep as many as nine breeds of local hen, as well as local and exotic breeds of turkey, duck and broilers in their back gardens. In selecting for the best breeds, they consider eleven different characteristics, - including egg production, ease of sale, appearance, broodiness, heat and cold tolerance, growth rate and eating qualities. Using this ranking, the most preferred birds are indigenous turkeys and ducks (Intermediate Technology, 1996).

A diverse portfolio of activities based on the contributions of agricultural biodiversity (e.g. crop cultivation, harvest of wild plant species, herding, fishing, hunting) helps sustain rural livelihoods because it improves their long term resilience in the face of adverse trends or shocks. In general, increased diversity promotes more flexibility because it allows greater possibilities for substitution between opportunities that are in decline and those that are increasing.

Many rural people, regardless of whether their agroecosystems are predominantly pastoral, swidden or based on continuous cropping deliberately incorporate wild resources into their livelihood strategies (Table 1). Nor is livelihood diversification based on such wide use of agricultural biodiversity the exclusive preserve of rural households in developing countries. In Poland for example, wild bush and berry fruits are important for local consumption and for export, with *Vaccinium myrtillus* being the principal export species at present (over 30, 000 t/year) followed by *Rubus spp., Sorbus aucuparia, Sambucus nigra, Prunus spinosa* and *Rosa spp*. (Glowacki, 1988).

Different types of agricultural biodiversity ("cultivated", "reared" or "wild") are used by different people at different times and in different places, and so contribute to livelihood strategies in a complex fashion. Understanding how cultivation, herding, fishing, collection, use and marketing of different types of agricultural biodiversity are differentiated by wealth, gender, age and ecological situation is essential to evaluate their overall economic value. Understanding this differentiation within communities is essential because there is great variation in wealth, ability, age and power in every rural society. For example, wild resources are particularly important for the food and livelihood security of the rural poor, women and children, especially in times of stress such as drought, changing land and water availability or ecological change. These groups generally have less access to land, labour and capital and thus need to rely more on the wild diversity available. In India, the poor obtain 15-23% of their total income from common property resources, as compared with 1-3% for wealthier households (Jodha, 1986). In Zimbabwe, some poor households rely on wild fruit species as an alternative to cultivated grain for a quarter of all dry season meals (Wilson, 1990). Whilst wild food species supply vital nutritional supplements to all diets based largely on carbohydrate rich staples, they are crucial sources of vitamins and minerals for children. Children are often the most frequent collectors and consumers of wild fruit (Scoones et al, 1992).

The degree to which the resources of agricultural biodiversity are important for local people's livelihoods affects the appropriateness of policies on resource management and on incentives for conservation and sustainable use. Comparing the economics of agricultural biodiversity use with other livelihood options can help assess people's willingness to sustain biodiversity as part of a livelihood strategy. There is however no single valid economic approach for doing this. Combining economic concepts with participatory research does nevertheless allow for a more comprehensive valuation of agrobiodiversity, recognising not only the financial value, but also the indirect and non use values. The insights thus gained into the relative and changing seasonal importance of different types of agricultural biodiversity for livelihood security can be quite startling. For example, "wild" agrobiodiversity may provide a significant proportion of total household incomes, particularly where farming or herding is marginal. In parts of Botswana, where unpredictable rains make farming a risky business, basket making from the wild palm *Hyphaene petersiana*, and beer brewing from the wild fruit *Grewia bicolor* provide a more secure income source,

especially for women (Bishop and Scoones, 1994). Other local level valuation studies of agricultural biodiversity conducted in a total livelihood context show that many wild resources have significant economic value by preventing the need for cash expenditure and providing ready sources of income to cash poor households, often yielding a better income than local wage labour (IIED, 1995).

Table 1. Use of wild plants and animals for food and medicine by farming communities

Location	Importance of Wild Resources
Botswana (1)	The agropastortal Tswana use 126 plant species and 100 animal species as sources of food
Brazil (2)	Kernels of babbasu palm provide 25% of household income for 300,000 families in Maranhâo State
China, West Sichuan (3)	1320 tonnes of wild pepper production; 2000 t fungi collected and sold; 500 t ferns collected and sold
Ghana (4)	16-20% of food supply from wild animals and plants
India, Madya Pradesh (5)	52 wild plants collected for food
Kenya, Bungoma (6)	100 species wild plants collected; 47% of households collected plants from the wild and 49% maintained wild species within their farms to domesticate certain species
Kenya, Machakos (7)	120 medicinal plants used, plus many wild foods
Nigeria, near Oban National Park (8)	150 species of wild food plants
South Africa, Natal/KwaZulu (9)	400 indigenous medicinal plants are sold the area
Sub-saharan Africa (10)	60 wild grass species in desert, savanna and swamp lands utilized as food
Swaziland (11)	200 species collected for food
Thailand, NE (12)	50% of all foods consumed are wild foods from paddy fields, including fish, snakes, insects, mushrooms, fruit and vegetables
South west of USA (13)	375 plant species used by Native Indians
Zaire (14)	20 tonnes chanterelle mushrooms collected and consumed people of Upper Shaba
Zimbabwe (15)	20 wild vegetables, 42 wild fruits, 29 insects, 4 edible grasses and one wild finger millet; tree fruits in dry season provide 25% of poor people's diet

Sources: (1) Grivetti, 1979 (2) Hecht et al, 1988; (3) Zhaoqung and Ning, 1992; (4) Dei, 1989; (5) Oommacha and Masih, 1988; (6) Juma, 1989; (7) Wanjohi, 1987; (8) Okafor, 1989; (9) Cunningham, 1990a, b; (10) Harlan, 1989; (11) Ogle and Grivetti, 1985; (12) Somnasung et al, 1988; (13) Fowler and Mooney, 1990; (14) Scoones et al, 1992; (15) Wilson, 1990.

The cultural and spititual values of some parts of agricultural biodiversity can sometimes be considered as more important than monetary values. Many rural communities designate certain biodiversity-rich areas of land or water as sacred. Sacred groves, for example, are clusters of forest vegetation that are preserved for religious reasons. They may honour a deity, provide a sanctuary for spirits, or protect a sanctified place from exploitation; some derive their sacred character from the springs of water they protect, from the medicinal and ritual properties of their plants, or from the wild animals they support (Chandrakanth and Romm, 1991). Such sacred groves are common throughout southern and south eastern Asia, Africa, the Pacific islands and Latin America (Shengji, 1991; Ntiamoa-Baidu et al, 1992). The spiritual values of sacred places on land or water are often inextricably tied with the functions that their associated agrobiodiversity may provide in maintaining the health of the ecosystem. For instance, in a ranking exercise conducted to show the relative importance of different values derived from savanna woodlands in Zimbabwe, villagers explained that one of the most important aspects of their woodland was the sacred areas it contained. Honouring and preserving these sacred areas according to the wishes of the ancestral spirits is essential for good rainfall. The wide range of consumption benefits derived from the woodland were ranked lower than these spiritual ecosystem functions, as they could not exist without the rains, which in turn depend on the sacredness of the woodland (Hot Springs Working Group, 1995).

The rich tapestry of locally unique agrobiodiversities represents, at the global level, a huge amount of *between* species diversity. Out of the 250, 000 plant species that have been identified and described, some 30, 000 are edible and about 7,000 have been cultivated or collected for food at one time or another (Wilson, 1992). World-wide, several hundred animal species including mammals, fish, reptiles, molluscs and arthropods also contribute to food and livelihood security.

Diversity *within* species is also remarkable among those plant and animal species that have been domesticated for crop and livestock production by innovative rural people. The inherent variation within farmers' crop varieties (landraces) is immense for cross-pollinated species such as millet or maize. For self-pollinated crops such as rice and barley, and for vegetatively propagated crops like potatoes and bananas, individual varieties are less variable, but the number of landraces developed may be very high. Estimates of the distinct number of varieties of asian rice (*Oryza sativa*) range from tens of thousands to more than 100,000 (FAO, 1998) while some communities in the Andes grow as many as 178 locally named potato varieties (Brush, 1991). A review of the immense genetic variation in plant crops,- and its contribution to food and livelihood security-, has recently been compiled by the FAO (FAO,1998).

Livestock keepers have also generated and safeguarded considerable intra-specific diversity through their animal husbandry. In India alone, 26 different breeds of cattle and 8 breeds of buffalo, 42 breeds of sheep and 20 breeds of goat have been identified along with 8 breeds of camel, 6 breeds of horses, 17 breeds of domestic fowl,- in addition to native pigs, mithum and yak. World wide, it is believed that the total number of mammalian and avian livestock breeds is between 4,000 and 5,000 (FAO, 1995). Important contributions of animal diversity to food and livelihood security are summarised in box 3.

Box 3. Livestock diversity's contributions to food and livelihood security

Domestic animals' contributions to livelihood security are highly site specific and seasonal, and their importance differs from one social group to another. Each contribution of livestock diversity to livelihoods is governed by many interacting institutional factors and social relations. For each economic and ecological setting, a differentiated analysis of livelihoods is therefore essential to understand what a particular contribution of livestock is worth, to whom, when and in what way. Some of the products of animal diversity include:

- *Food*. Domestic animals provide a considerable part of the food requirements of pastoralists. For small scale mixed farmers they can be especially important during the seasons of grain scarcity.

- *Nutrients.* Domestic animals are important sources of essential amino and fatty acids. Ruminants through their symbionts also convert cellulose into products that are digestible to humans.

- *Clothing.* Wool, hair and leather are used for making garments, blankets, shoes, bags etc.. These may be for subsistence or income generation.

- *Utensils*. Bone is used to make a variety of utensils, leather for making bags to carry water, food etc.

- *Construction.* Hides, wool and other fibres are used to make shelters.

- *Transport.* In some countries animals still provide the most affordable form of transport.

- *Traction.* Domestic animals reduce the amount of human labour needed for farm operations

- *Fuel.* In some places, animal dung is the only fuel available.

- *Fertiliser.* Animal manure is an important component of many mixed farming and aquaculture systems

- *Income.* Animals convert low value scattered feedstuffs into high value commodities. Since ownership is not a prerequisite for keeping animals, income derived from animal products can be especially important for the poor. Revenue from small animals may be the only income controlled by poor women.

- *Insurance*. Animals are a readily convertible source of cash and provide a safety net against unforseen events, such as adverse climatic conditions, temporary food shortages, changes in family circumstances, and unstable comodity prices.

- *Spiritual functions.* Animals often play important roles in religious ceremonies and rituals.

Modified from: Intermediate Technology Development Group, 1996. Livestock keepers safeguarding domestic animal diversity through their animal husbandry.

Domesticated plant varieties, animal breeds and diverse agroecosystems are largely sustained through local peoples' crop husbandry, livestock management practices and fishing techniques. Conservation of diversity is through active use in different ecological and economic settings.

ii) Agricultural biodiversity's contributions to production and environmental sustainability

Each species in an agroecosystem is part of a web of ecological relationships connected by flows of energy and materials. Whilst each species may occupy a

specific ecological niche (e.g. primary producer, specialist or generalist consumer, decomposer) it is involved in sustaining many different agroecosystem functions and environmental processes, either directly or indirectly. In this sense the different components of agrobiodiversity are inherently multifunctional and contribute to the resilience of production systems whilst providing environmental services at the larger landscape level. However, it is important to note that some species may play a key driving role in forming the structure and overall behaviour of agroecosystems and landscapes at different scales. There is indeed growing evidence that the diversity and functional complexity of all ecosystems can be traced to a small number of critical structuring processes, some of which are mediated by critical "keystone species" (Holling et al, 1995). An example is the suite of 35 species of insectivorous birds that mediate budworm outbreak dynamics in the eastern boreal forest of North America (Holling, et al, 1995).

Farmers, herders and fishermen have often enhanced the multifunctional character of agricultural biodiversity through choice of genetic material, design of cropping patterns, development of crop and livestock production systems, land and water management practices as well as institutional arrangements. Local knowledge about the properties and dynamic roles of agricultural biodiversity is crucial in this connection. For example, the *mal monte* (bad weeds) and *buen monte* (good weeds) of Mexican farmers recognises that the vegetation community as a whole must be managed to promote those aspects that are beneficial (Chacon and Gliessman, 1982).

In low external input farming, different components of agricultural biodiversity are usually combined to give practices finely tuned to the local biophysical and socio-economic conditions of individual farmers, herders and fish culturists. Natural processes mediated by agricultural biodiversity are favoured over external inputs and by products or wastes from one component of the agroecosystem become inputs to another. An example is the mulberry grove-fishpond system in the Pearl River Delta of China. In this multifunctional system, the white mulberry (*Morus alba*) tree produces organic substances (mulberry leaves etc). These are used to feed silkworms that, in turn, produce their silk and chrysalides. The fallen parts of the mulberry tree and the excrement of the silkworm are applied to the fishpond where they are converted into fish biomass. The excrement of the fish, as well as other unused organic matter and bottom mud are returned to the mulberry grove as fertiliser, after being broken by a diverse suite of benthic microorganisms. The agricultural biodiversity harnessed by the fish culturalists allows for the closing of nutrient cycles and efficient production in time and space. Fish polycultures are thus made up of species that dwell in the upper, medium and lower layers of the pond, as well a fish species with different feeding habits (e.g. plankton feeders, herbivorous fish, benthic mollusc feeders, and onmnivorous fish) (Ma, 1985; Zhong, 1982).

In more specialised, high input farming based on the use of high yielding varieties, agricultural biodiversity helps sustain many production functions such as soil organic matter decomposition, pollination and pest control. In the USA or Australia for example, farmers may manage cover crops primarily to save soil and water in intensive orchard production systems. However, the species chosen will usually perform other functions in the agroecosystem. In addition to protecting against soil erosion, cover crops usually enhance soil structure, improve soil fertility and nutrient cycling as well as play a role in pest management by providing habitat heterogeneity and preserving a favourable balance between pests and predators. Depending on the species, trees can also provide fodder for animals, so increasing the number of internal linkages within the agroecosystem. These examples highlight

the multifunctional character of agricultural biodiversity and are a reminder that functions are discussed one by one only for convenience sake here.

Decomposition and nutrient cycling functions. The crop plants, trees, livestock and fish deliberately chosen by farmers are the main determinants of the diversity of the flora and fauna that makes up the decomposer subsystem (Swift and Anderson, 1993). Available evidence shows that decomposer communities are highly diverse and are centrally involved in nutrient cycling, organic matter dynamics and other ecosystem functions. Detailed knowledge on the extent and functions of this diversity is limited; there is relatively more information on the functions of soil biodiversity than on the dynamics of decomposer communities in aquatic environments. Some functional groups in soils are widespread in distribution (e.g. nitrogen fixing bacteria, mycorrhizal fungi and predators of soil borne pests) whilst other like earthworms and termites are more restricted in their distribution. A gradually emerging picture structures soil biodiversity into a series of more or less spatially independent guilds (Swift, 1976; Lavelle et al, 1998). The spatial separation between distinct guilds (surface litter, root litter, rhizosphere guilds…) allows decomposer organisms to co-exist whilst containing communities of organisms that are functionally equivalent. For instance, several ecological guilds of earthworms can be recognised in humid tropical soils with different roles in litter transformation and as "ecosystem engineers" (Lavelle et al 1998). Through their activities of feeding, burrowing and casting, they modify the physical, chemical and biological properties of soil and thus its ability to support above ground vegetation. Together with termites, different species of earthworms are among the key functional groups in humid tropical soils. At least 42 native and exotic earthworm species common in tropical agroecosystems have been identified as able to resist disturbances linked to agriculture and agroforestry practices and build up sizable populations in these environments. Conservation of species richness is generally better achieved when a natural ecosystem is converted into a managed system that has kept the original structure, such as a pasture in a savanna ecosystem or an agroforestry system in a forest.

The sensitivity of decomposer functions to farm management practices is also evident in the mechanised agriculture of developed countries. Comparisons of the soil biodiversity in biodynamic, organic and conventional farms in Switzerland show higher species diversity and functional levels in biodynamic and organic plots than in conventional systems. The significantly higher biomass, diversity and functional activity of soil microorganisms, earthworms, ground beetles, staphilinids and spiders found in biological systems are largely due to the organic amendments and more selective plant protection measures used in the biological systems (Mader et al, 1996).

In high input-high output agriculture, microbial diversity is also a central component of integrated plant nutrition systems (IPNS) that aim to maximise the efficiency of plant nutrient supplies to crops by complementing the use of on-and off-farm sources of plant nutrients. Nitrogen fixation through bacteria (notably *Rhizobia spp*) and algae (*Azolla spp*) as well as phosphorus cycling *via* mycorrhizal fungi species are particularly noteworthy in this connection (Alexandratos, 1995; Gray and Williams, 1971).

Microbial diversity is generally known to mediate nutrient cycling. However, there are few detailed studies of the dynamic role of micro-organisms in structuring landscapes and agroecosystems at different spatial and temporal scales. A long term study of African savannas has shown that the productivity of large mammalian herbivores, -upon which the human economy of the savanna is based-, is

dependent on water availability acting as an "on-off" switch for the mineralisation of nitrogen, phosphorus and sulphur. Some 80% of the mineralisation is performed by the diversity soil micro-organisms which respond dramatically to the presence of water or rain. Where the immediate limiting resource in broad leafed savannas is nitrogen, the key effect of water is to control the availability of inorganic nitrogen by modulating the functions of soil microbial diversity rather than control photosynthesis. The interaction between water and micro-organism activity thus sustains soil fertility. In turn, soil fertility has a profound effect on savanna ecology by determining not only plant production but also what fraction of it is edible and what species of plants and animals will be present (Scholes, R.J. and Walker, 1993). Livestock production is thus closely dependent on the dynamic interactions between water availability and the activity of a diverse suite of soil micro-organisms in these semi-arid landscapes.

Biomass production and yield efficiency functions. Low external input production systems usually incorporate a wide range of species and genotypes that serve a variety of production goals and are used for their resistance to diseases and pests as well as for the differential exploitation of microhabitats. The relative productivity and efficiency of these diverse agroecosystems (fish polycultures, mixed herds, intercrops, integrated agro-sylvo-pastoral systems) have been quantified in terms of relative yield or energy efficiency of diverse units as compared with sole crops (Trenbath, 1974; Vandermeer, 1988; Leach, 1976). Results indicate that diversity rich agriculture is generally highly productive in terms of its use of energy and unit land area (or unit water volume). For example, the land equivalent ratio (LER) of intercrops in which mixtures include a legume species is usually significantly greater than unity, -unequivocal evidence that intercrops outyield sole crops (Vandermeer, 1990). The energy efficiency (ratio of energy output to energy input) of pig or poultry production in internally diverse agroecosystems can be up to 10 times higher than that of intensive pig and poultry farms based on genetically uniform single species reared with enormous subsidies of fossil fuels (Leach, 1976). Whilst the yield output per labour hour of the more intensive and uniform systems is extremely high (in the absence of adequate internalisation of social and environmental costs), the more agricultural biodiversity rich systems are generally efficient producers of significant amounts of biomass. This efficiency is largely a product of the systems' biological and structural complexity that increases the variety of functional linkages and synergies between different components of agricultural biodiversity.

Soil and water conservation functions. Soil, water and nutrient conservation have been improved with the use windbreaks, contour farming with appropriate border crops and cover crops in a wide range of agroecosystems. In France over 150 species of trees and shrubs are used for soil and moisture conservation, with different species mixtures planted as hedges and taller windbreaks in gardens, orchards, whole farms and the larger rural landscape (Soltner, 1984). In Sahelian countries of Africa windbreaks made up of *Euphorbia tirucali*, *Parkinsonia aculeata, Opuntia tuna* and *Prosopis africana* trees and shrubs help to conserve soil and moisture, raising the yields of cereals grown between. In Mexico, contour lines are often planted with *Agave americana* to conserve soils and retain moisture whilst in southern Italy and Greece *Opuntia tuna* performs similar functions. Many of these plants are multiple purpose species yielding wood, edible fruit and nuts, fodder, refuges for natural enemies of pests, nitrogen biofixation and medicines in addition to their soil and water conservation functions.

Cover crops consist of plant species that are deliberately established after or intercropped with a main crop to serve various regenerative and conservation functions including soil and water conservation. Annual bluegrass, lana vetch,

crimson clover, black medic, purple vetch and barley are some of the species recommended as cover crops for orchards and vineyards in California , USA (Finch and Sharp, 1976). The wide variety of management systems in high input-high output orchards and vineyards creates a demand for a diversity of cover crops. Grass species have fibrous root systems that make them particularly useful in building soil structure, providing erosion control, and improving water penetration. Legumes are not as effective as grasses in improving water penetration but they contribute nitrogen to the soil. Many cover crop options can be selected for soil and water conservation from a diversity of annually seeded winter growing grasses and legumes, summer annuals, perennial grasses and legumes and reseeding winter annual grasses and legumes.

In North America and Europe, living mulch systems can be an economic way for commercial soybean, corn and vegetable growers to reduce soil erosion and water loss, increase soil organic matter and keep yields constant in high input-high output agroecosystems (Miller and Bell, 1982). Legume species commonly used as living mulches include alfalfa, short white clover, hairy vetch and red clover.

Pest control functions. Agricultural biodiversity in the form of predators, parasitic wasps, micro-organisms plays a key role in controlling agricultural pests and diseases. For example, more than 90% of potential crop insect pests are controlled by natural enemies that live in natural and seminatural areas adjacent to farmlands. The substitution of pesticides for natural pest control services is estimated to cost $54 billion per year (CAST, 1999).

Many methods of pest control, -both traditional and modern-, rely on biodiversity. The development of crop varieties and animal breeds that are resistant to specific pests and diseases selectively draws on the genetic diversity available *in situ* and in *ex situ* collections of germplasm (Browning, 1980). Genetic mixtures deployed in temperate and tropical agroecosystems can be effective in containing diseases in small grain crops (Browning and Frey, 1981; Leonard, 1969; Wolfe,1985) as well as insect outbreaks in cassava (Gold, 1987), corn (Power, 1988) and potato (Cantelo and Stanford; 1984) for example. There are also many documented experiences showing that insect pests tend to be less abundant and damaging in agroecosystems with higher plant diversity e.g. intercrops, polycultures, crop rotations, cover crops, mixed tree stands, mixtures of annual and perennial plants (Andow, 1991; Altieri, 1994). Depending on the pest species and the context, the plant diversity acts to reduce pest damage by interfering with the host seeking and reproductive behaviour of the pest, by enhancing the pests' natural enemy populations or by a combination of these processes. Judicious vegetation management within and around agroecosystems can thus enhance biological control or confer an overall resistance to pests and disease outbreaks.

Understanding how agricultural biodiversity directly or indirectly affects pest and disease dynamics is critical for the design of pest management at different scales. For instance, recent work in Javanese rice fields shows that there is an enormous diversity of arthropods, even in high input-high output agriculture. The arthropod communities are structured such that the dynamics of seasonal succession consistently lead to high levels of pest suppression, with little chance of outbreak. From the time that water first floods a farmer's field in preparation for planting, organic matter, -derived from residues from the previous crop cycle, organic waste in irrigation water, and algal growth-, provides the energy for an array of micro-organisms (bacteria and phytoplankton) and detritus-eating insects. The adults of the plankton-feeders (midges and mosquitoes) together with the detritus-feeders, provide a consistent and abundant source of alternative food for generalist predators

very early in the season. As a result, pest mortality due to predation is high from the very earliest part of the season; hence, minimising the chance of damaging pest outbreaks (Settle et al, 1996). However, this intrinsic strength and stability of the rice agroecosystem is influenced by two main, large scale, external factors: 1) local and regional patterns of pesticide use, and 2) landscape effects—specifically, the spatial scale at which fields are synchronously planted, the duration and nature of fallow periods, degree of surrounding weedy or natural vegetation and existence of nearby ponds or other sanctuaries for natural enemies. This type of information on the functions of agrobiodiversity in rice paddies provides the ecological basis for integrated pest control through careful management of the wider landscape and decisions on pesticide use.

Pollination and dispersal functions. There are more than 100,000 known pollinators (bees, butterflies, beetles, birds, flies, and bats). Pollination mediated by components of agricultural biodiversity is an important function in a variety of terrestrial agroecosystems (biotic pollination *per se* is poorly represented in aquatic ones). About half of all plant species, including food-producing crop species, are pollinated by animals. For example, the pollination of various fruit crops by bees and other insects is critical in mountain areas of Asia. In Nepal *Apis cerana* begins foraging at temperatures 5-7ºC lower than those that initiate *Apis mellifera* foraging. Managed crop pollination with a variety of bee species in different zones plays an important role in overall agricultural development (Partap and Partap, 1997). The benefits of pollination are also considerable in high input-high output agriculture: the economic value of pollination services in the United States is estimated in billions of dollars per year. Management practices that reduce the species or abundance of pollinators can result in less genetic variation in crops dependent on pollinator visits for reproduction, both in temperate and tropical agriculture. With a loss in pollinators, seed production declines and the vulnerability to pests and climatic change increases with the resulting loss of genetic diversity.

"Mobile link" species (i.e. animals necessary for the persistence of plant species that in turn support otherwise separate food webs) such as pollinators and seed dispersal agents may be critical to the maintenance of the species richness of tropical forest based agroecosystems and complex homegardens imitating the natural forests' architecture. Many species in tropical forests managed for food and agriculture depend on a small suite of frugivores for dispersing their seeds. Loss of these species of fruit eaters may adversely affect the long- term viability of many tree species important for food security. Reductions in genetic variability are likely to be high for plant species that are highly dependent on frugivory for seed dispersal.

Biodiversity conservation functions. There is no strict divide between "wild" and "domesticated" species important for food and livelihoods. Many wild plant species and populations that have been considered to be wild are in fact carefully nurtured by people (Gomez-Pompa and Kaus, 1992; Posey, 1999). A similar continuum exists for animal species that use agroecosystems as habitat, nesting grounds and food. Whilst not necessarily the subject of conscious management by herders or farmers, many wild species thrive in, or are dependent on, agroecosystems. In general the more structurally and biologically complex the agroecosystems, the more diverse the forms of wildlife. For example:

- The systems of shifting cultivation common in Asia have long been considered to be damaging to biodiversity in particular. However, given the opportunity, shifting cultivators preserve wild resources. Studies in Asia have concluded that most of the mature forests in this region are not virgin forests, but merely old forests that have reached a relatively stable dynamic state after some earlier clearing by human or

natural means (Spencer, 1966; Wharton, 1968; Michon and de Foresta, 1995). Under traditional systems of shifting cultivation, wildlife flourishes, with elephants, wild cattle, deer, and wild pigs all feeding in the abandoned fields. Tigers, leopards and other predators are in turn attracted by the herbivores. Older fields contain a high proportion of fruit trees that attract primates, hornbills, squirrels and a variety of other animals.

- Long term research in the Lowland of west Poland shows that a mosaic of landscape structure of small cultivated fields, shelterbelts, meadows and small ponds helps maintain biological diversity (and many other functions such as enhanced water storage). Mammal, amphibian, reptile, insect diversity are enhanced and the number of bird species is positively correlated with the diversity index of the landscape (Ryszkowski, 1995).

Climate functions. Given the large area of land and water used for food and fibre production, agricultural biodiversity interacts with the atmosphere in various ways. As a source of atmospheric constituents agricultural biodiversity contributes significantly to the chemical composition and properties of the atmosphere and thus has a marked influence on climate. In turn changes in climate have a strong feedback on agricultural biodiversity and its multiple functions, and thereby influences biogenic emissions. Since agricultural biodiversity is also an important sink for numerous atmospheric constituents, the flux of toxic compounds from the atmosphere (e.g. pesticides, acids, photochemical oxidants) into the web of agricultural biodiversity may impair essential functions in time and space.

There is however a paucity of knowledge on biodiversity/atmosphere exchange processes and their interactions with agroecosystem functions. It is generally accepted that enlargement of the net area of agricultural land results in higher carbon dioxide, methane and nitrogen dioxide emissions when the primary productivity of the subsequent cropping system is lower than that of the vegetation it replaces. Increases in the area of permanently or quasi-permanently flooded rice cultivation are believed to account for a significant proportion of the increase in net methane emissions (Schutz et al, 1990). The increased specialisation of ruminant production based on high yielding breeds has also significantly contributed to global methane emissions (methane is produced by anaerobic digestion in animal guts). The increasing cultivation of high sulphur crops such as rape may be linked with enhanced biogenic emissions of carbonylsulphide (Hofman, 1990). Oxidation of carbonylsulphide in the stratosphere leads to the production of sulphate aerosols that influence the intensity of ultra violet radiation reaching the earth's surface (Charlson et al, 1987), potentially affecting the dynamic functions of agrobiodiversity. Volatile organic compounds such as terpenes and isoprenes are produced and released into the atmosphere by many plant species (Tingy et al, 1991), especially in agroecosystems dominated by Mediterranean shrubs, eucalyptus and conifers. By influencing the oxidation capacity of the troposphere, these volatile compounds influence the abundance and distribution of trace gases such as ozone (Rennenberg, 1991).

Functions in the water cycle. There are few experimental studies exploring the links between agricultural biodiversity and water. However, available evidence shows that agricultural biodiversity plays a crucial role in cycling water from the soil to the atmosphere and back. It also has measurable impacts on water quality. Agroecosystems with different species assemblages and plant architectures result in differences in the amount of precipitation intercepted, the proportion of precipitation converted to stem flow, and the proportion of precipitation that infiltrates the soil rather than running off. At the landscape level, the types, relative

abundances and relative spatial locations of agroecosystem types affect the amount of water moving from one point to another. For example, conversion of vegetation within a watershed from forest or shrub land to less structurally and biologically complex grassland is known to influence stream flow out of the watershed, in both temperate and tropical systems.

At the functional group level, the root structure, phenology and physiology of different plant species important for food and agriculture have direct implications for the quantity and timing of water transfer to the atmosphere *via* evapotranspiration. Individual plant species differ in their resistance to water stress, their efficiency of water uptake from the soil, and so on. Genetic variations among crop varieties (differences in water use efficiency, stomatal resistance…) also influence these processes. At the landscape level, evapotranspiration from agroecosystems can have an effect on relative humidity and microclimate downwind.

In both terrestrial and aquatic environments, the plant and animal components of agricultural biodiversity also function to alter water quality by performing various filtration, uptake and excretory processes. These functions all affect the composition and concentration of dissolved gases, solutes and particulates. Biodiversity in aquatic systems affects water quality more than distribution. Species level differences in physiology can positively or negatively affect water quality. However, in most cases a greater diversity of biological organisms (from microbes to fish and macrophytes) leads to a higher quality of water for human consumption and use.

The influence of agricultural biodiversity on landscape structure. A landscape is a heterogeneous area made up of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron, 1986). The spatial layout between landscape elements together with the interactions and linkages between them determine the landscape's structure and functions. The many different species found in a landscape are essential components of that landscape. By providing environmental services and functions (described above) agricultural biodiversity can have a profound influence on landscape structure. Through its positive or negative effects on agricultural biodiversity, human activity can transform whole landscapes over large areas. For example, many rural communities enrich their agricultural plots and forest fallows with valued perennial plants. Through such enrichment practices, successional vegetation can become a site for economic production as well as for ecological rehabilitation (Dubois, 1990). Each of the major tropical forest regions has many economic woody plants that have been managed, probably for millenia, in enriched fallows (Wood, 1993). In Vanuata the natural composition of forests has been dramatically altered by centuries of itinerant gardening, favouring tree species that bear edible fruits and nuts (Weightman, 1989). Fallows have been (and still are) enriched with rattan in East Asia, rubber in Sumatra, *Casuarina* in Papua new Guinea, *Gliricidia* and peach palm in Central America, oil palm in West Africa, and edible fruits and nuts universally. Locally adapted enrichments have altered species composition and also directly influenced the structure of landscapes at different spatial scales.

The influence of agricultural biodiversity on landscape structure is partly determined by the social institutions that mediate the relationships between rural people and the environment, and partly by climate and edaphic factors. For example in the semi-arid landscapes used by patoralists of Africa, there are high levels of spatial and temporal variability in fodder biomass production, highly variable rainfall and episodic chance events such as drought. In these non-equilibrium systems pastoralists have developed opportunistic management schemes to exploit the patchiness of the vegetation, learnt to avoid risks by moving herds and flocks to

make best use of heterogeneous landscapes and diversified their livelihood activities. Pastoralists have rules and regulations which govern the use of water, pasture, animal movement and control of vegetation and trees. Management of agricultural biodiversity and the larger landscape is mediated by these local institutions. The local adaptive management of agricultural biodiversity enables people to cope with uncertainty and sustain the dynamic environmental processes that define and shape those landscapes. This is in stark contrast with the degradation that occurs under the centrally planned, standardised rangeland and livestock management schemes often based on erroneous concepts of carrying capacity and equilibrium ecology (Behnke et al, 1993; Scoones, 1994). New perspectives in ecology have indeed challenged conventional views of drylands in Africa as stable ecosystems subject to decline and desertification once carrying capacity is exceeded. Rangelands and pastoral landscapes are resilient and less prone to degradation and desertification than once thought. The new findings concord with the knowledge of many local livestock herders and emphasise how rangelands are subject to high degrees of uncertainty and ecological dynamics characterised by sudden transitions rather than slow and predictable change.

Specific components of agricultural biodiversity are often directly implicated in the processes that structure agroecosystems at different temporal and geographical scales (from small farm plots to whole water/landscapes). Even highly complex landscapes like tropical irrigated rice or forests in the savannah transition zone of West Africa, are apparently structured by a very few key variables (cf. Settle et al, 1996; Fairhead and Leach, 1996). Research over the past 20 years in applied ecology of managed systems shows that ecosystem and landscape dynamics tend to be organised around a small number of nested cycles, each driven by a few dominant variables (Gunderson et al, 1995; Holling, 1993; Holling et al, 1995).

"A small number of plant, animal, and abiotic processes structure biomes over scales from days and centimeters to millennia and thousands of kilometers. Individual plant and biogeochemical processes dominate at fine, fast scales; animal and abiotic processes of mesoscale disturbance dominate at intermediate scales; and geomorphological ones dominate at coarse, slow scales….the physical architecture and the speed of variables are organised into distinct clusters, each of which is controlled by one small set of structuring processes. These processes organize behavior as a nested hierarchy of cycles of slow production and growth alternating with fast disturbance and renewal" (Gunderson et al, 1995).

Identifying and understanding the dynamics these "structuring variables" provides a practical basis for sustainable agriculture and landscape management.

iii) Agricultural biodiversity's contributions to rural development

In addition to its direct contributions to rural livelihoods (see section (i)), agricultural biodiversity may generate other rural development opportunities through eco-tourism and a variety of income generating schemes. Many humanised landscapes in Europe, South America, Australia and the Asia-Pacific regions are increasingly valued for aesthetic and historical reasons. For example, throughout the Asia-Pacific region mountainous terrain has, over the centuries, been shaped into landscapes of terraced pond fields for the cultivation principally of rice, but also of taro and other crops. In Europe, low input, extensive farming systems such as the Dehesas in the Iberian peninsula of Spain cover some two million hectares. Dehesa systems are open savanna like woodlands used as pastures, with sclerophyllous trees, mainly *Quercus rotundifolia* Lam., and a therophytic herb layer (MAB, 1989). Dehesas are home to many endangered species of wildlife such as the Iberian lynx,

the golden eagle, the little bustard and the Egyptian vulture (Pineda and Montalvo, 1995).

These landscapes exist both as archaelogical sites and as living landscapes, which continue to be used and maintained by the people who created them. The conservation of these cultural landscapes is considered important by a growing number of stakeholders. For example, many low external input agroecosystems in Europe are valued by urban populations ready to pay for the experience of a holliday in rural areas (IEEP and WWF, 1994). At a global level, the intrinsic value of cultural landscapes, and what they can teach about enduring systems of human-nature interaction, has led to a strategy within which the identification, evaluation and conservation of specific regional landscape types are to be considered within the framework of the World Heritage Convention (UNESCO, 1996). The ecotourism potential of these cultural landscapes is viewed as potentially important for rural development and local employment creation, both in the developed and developing countries.

However, recent evidence suggests that the potential of eco-tourism can only be realised under certain conditions. As is often the case for classical tourism, eco-tourism schemes tend not to be integrated with other sectors of the national or regional economy; and only a fraction of earnings generated actually reach or remain in the rural areas (Honey, 1999; Koch, 1997; Speelman 1991). More importantly, the majority of the rural population is frequently bypassed economically even where some earnings remain in the tourist location, as they are used up by the related administration or appropriated by local élites and business people. At the same time, local livelihood sources and cultures are negatively affected in nearly all cases. Generating economic benefits and fostering equitable rural development is only feasible when many wide-ranging reforms,- such as restoration of land and water rights to local communities, support for new forms of tenure and rights of usufruct, strengthening of local groups and institutions, investment in technical and managerial skills and mandatory impact assessments of all ecotourism schemes-, are carried out (Koch, 1997). The necessary structural political and economic changes along these lines are difficult in many developing and developed countries.

Another potential engine for rural development is the exploration, extraction and screening of biological diversity and indigenous knowledge for commercially valuable genetic and biochemical resources (biodiversity prospecting or bioprospecting) (Reid et al, 1993). A detailed treatment of the economics of bioprospecting is beyond the scope of this paper. However, it may be noted here that despite frequent mention of benefit sharing agreements in commercial contracts between bioprospecting agents and sovereign states, the specific terms of benefit sharing are strictly confidential. Available evidence indicates that benefits shared with countries in which collections took place represent a small fraction of the annual R&D budget of the corporations involved (RAFI, 1994; Pimbert, 1997; UNDP, 1994). Moreover, indigenous and local people receive only a minuscule proportion of the profits generated from sales of products that embody their knowledge and resources. For example, it is estimated that less than 0.001 per cent of the market value of plant based medicines have been returned to local and indigenous peoples from whom much of the original knowledge came (Posey and Dutfield, 1996). And while various codes of conduct and guidelines have been developed to ensure greater equity, compensation and fair sharing of benefits between bioprospecting companies and local communities (e.g., FAO, 1993; WWF, UNESCO and Kew Gardens in Cunningham, 1993b; Shelton, 1995), none are internationally legally binding.

Further opportunities for rural development hinge on creating local businesses and products that sustainably use agricultural biodiversity and add value to it in the context of more localised economies. In a growing number of rural areas in Europe, North America, Australia, Japan and New Zealand the diversity of local plants and animals is being harnessed for sustainable economic development. In south east France, the regional genetic heritage program of the Provence-Alpes-Cotes d'Azur involves a wide range of actors spread across six administrative departments,- about 31,500 square kilometres of very diverse ecosystems. Ways and means of reintegrating locally adapted, traditional animal breeds (sheep, goats, cattle and bees) and crop varieties (fruit trees, fodder plants and cereals) are being explored to generate local products, jobs, income and environmental care (PAGE PACA, 1990). Similar initiatives are reinvigorating local economies and employment in the Willapa watershed of the Pacific North West (USA). The Willapa watershed includes 275 000 hectares on the coast of Washington state and is rich in agricultural biodiversity: oysters, clams, sturgeon, crabs, salmon and dense forests. With the support of the Ford Foundation and a Chicago based community bank a range of local businesses have been set up to add value to this local agricultural biodiversity. For example, Willapa oysters are now marketed locally rather than shipped out wholesale, alder is harvested from secondary forests for high quality wood products, fish and crab are marketed with the north-west image of wholesome foods, cranberry growers produce a wide range of products retaining more of the value added from food processing within the watershed (Maughan, 1995).

These forms of endogenous rural development seek to create viable and locally controlled economic activities based on locally adapted agricultural biodiversity, knowledge, skills and negotiated partnerships between civil society, government and the private sector. Initiatives to reclaim diversity for rural development often focus on regenerating local food systems and economies based on comprehensive definitions of well being and wealth, both in developed (CES, 1999 ; Pretty, 1997) and developing countries (Women Sanghams et al, 1999).

These examples together with the recent "discovery" of the potential of cultural landscapes and the creativity of their inhabitants illustrate a more fundamental point. Agricultural biodiversity, together with the local knowledge, institutions and management practices associated with it, may provide a robust foundation for development in many different economic and ecological settings. Understanding the forces that have neglected or undermined the values and functions of agricultural biodiversity can help identify ways forward.

Underlying causes of agricultural biodiversity losses

The neglect of indigenous knowledge, local institutions and management systems

In relatively recent times, local and indigenous ways of knowing, valuing and organising the world have been brushed aside by so called "modern" technical knowledge which claims superior cognitive powers. Colonial administrations in Africa, Asia and the Americas, as well as governments of newly emerging nation states in Europe, have neglected or actively undermined many local management systems. These systems were generally tuned to the needs of local people and often enhanced their capacity to adapt to dynamic social and ecological circumstances. In addition to ignoring local knowledge and skills, many modernising interventions have superseded existing formal and informal institutions that were central for the sustainable management of agricultural biodiversity. In both terrestrial and aquatic landscapes, these local groups enforce rules, incentives and penalties for eliciting

behaviour conducive to rational and effective resource conservation and use. For as long as people have engaged in livelihoods pursuits, they have worked together on resource management, labour sharing, marketing and many other activities that would be too costly, or impossible, if done alone. Local groups and indigenous institutions have always been important in facilitating collective action and co-ordinated management of agricultural biodiversity at different spatial scales. Indigenous peoples resource management institutions probably offer the most striking evidence of active conservation and sustainable use. These institutions include rules about use of biological resources and acceptable distribution of benefits, definitions of rights and responsibilities, means by which tenure is determined, conflict resolution mechanisms and methods of enforcing rules, cultural sanctions and beliefs (Alcorn, 1994).

This neglect of human ingenuity and diversity continues today and ultimately reinforces the dominant model of development based on uniformity, centralisation and control (Scott, 1998).

The dominance of blueprint paradigms and policies

One of the most fundamental causes of agricultural biodiversity loss, both past and present, is the active promotion and spread of the blueprint approach to development. Typical expressions of this are industrial agriculture and the closely related Green Revolution. The blueprint paradigm also informs much contemporary forest, fishery and rangeland development. This approach to food and fibre production focuses on maximising commercially important yields and productivity through the use of monoculture systems and uniform technologies, including high yielding seeds and animal breeds, agrochemicals, irrigation, mechanised equipment and large infrastructure developments. The methods and means deployed for production largely originated in the affluent West where money and trained personnel ensure that technologies work and that laws are enforced to secure management objectives. During and after the colonial period, these technologies, and the values associated with them, were extended from the North to the South,- often in a classical top down manner. Positivist science and the modernisation ethic hang together with this top down, transfer of technology model. They are mutually constitutive elements of the industrial blueprint paradigm (Table 2).

Table 2. Agricultural biodiversity management paradigms: the contrast between blueprint and learning-process approaches

	Blueprint	**Process**
point of departure	nature's diversity and its potential commercial values	the diversity of both people and nature's values
keyword	strategic planning	participation
locus of decision making	centralised, ideas originate in capital city	decentralised, ideas originate in village
first steps	data collection and plan	awareness and action
design	static, by experts	evolving, people involved
main resources	central funds and technicians	local people and their assets
methods, rules	standardised, universal, fixed package	diverse, local, varied basket of choices

analytical assumptions	reductionist (natural science bias)	systems, holistic
management focus	spending budgets, completing projects on time	sustained improvement and performance
communication	vertical: orders down, reports up	lateral: mutual learning and sharing experience
evaluation	external, intermittent	internal, continuous
error	buried	embraced
relationship with people	controlling, policing, inducing, motivating, dependency creating. People seen as beneficiaries	enabling, supporting, empowering. People seen as actors
associated with	normal professionalism	new professionalism
outputs	1. diversity in conservation, and uniformity in production (agriculture, forestry,...) 2. the empowerment of professionals	1. diversity as a principle of production and conservation 2. the empowerment of rural people

(adapted from David Korten and Pimbert and Pretty, 1995)

Managerially, the blueprint approach fits the type of organisations with clear and fixed definitions of roles, procedures and methods, hierarchical authority, punitive management style and inhibited lateral communications. Such organisations are better suited to routine activities and do not cope well with fast changing circumstances. The main actors in these organisations are normal professionals who are concerned not just with research, but also with action. Normal professionals are found in research institutes and universities as well as in international and national organisations where most of them work in specialised departments of government (forestry, fisheries, agriculture, health, wildlife conservation, pastoral administration...). Despite some notable exceptions, the thinking, values, methods and behaviour dominant in their profession or discipline tends to be stable and conservative. Lastly, normal professionalism generally "values and rewards "first" biases which are urban, industrial, high technology, male, quantifying, and concerned with things and with the needs and interests of the rich" (Chambers, 1993).

This blueprint approach to the management of agricultural biodiversity is supported, subsidised and defended by an elaborate institutional structure,- including many international donors and development agencies, international and national research institutions and national governments. Numerous policies, -ranging from general agricultural development policies to pricing and credit schemes-, directly or indirectly influence biodiversity in livestock production, agriculture, forestry and fisheries. The most influential are incentive policies (e.g. subsidies for agrochemical inputs, extension programs, credit policies and marketing standards) that support the adoption of capital and energy intensive industrial inputs and technologies. For example, extension programs in many countries have mandated the adoption of uniform varieties and the elimination of diversity. Policy incentives for people to clear forested land and establish farms in order to gain tenure in Brazil, Costa Rica and Indonesia have contributed to

increases in food production but they have also induced biodiversity losses and unsustainable land use.

Corporate interests

Private companies, particularly transnational corporations that market agricultural inputs and process food and fibers, exert a strong influence on the type of agricultural biodiversity used in production. During the 1940s and 50s R&D capabilities started to move out of public institutions into the hands of the private sector. By the late 1990's, the pace of corporate concentration in the food, agrochemicals, pharmaceuticals, seeds and animal veterinary products accelerated. In 1998, the top ten seed companies controlled approximately 32% of the US $23 billion seed trade world-wide whilst the top ten animal health firms control about 60% of the US $17 billion animal health industry. A staggering 85% of the US$ 31 billion agrochemical market is controlled by less than eight corporations. With the help of the new biotechnologies (e.g. gene splicing, enzyme technology) traditional boundaries between pharmaceuticals, agribusiness, biotechnology, food, chemicals, cosmetics and the energy sector are becoming blurred. Biology and the use of the diversity offered by plant, animal and microbial genetic resources is the common denominator of all the new life industries (Baumann et al, 1996; RAFI, 1999). In many countries, including in the OECD countries, the R&D budget of these corporations dwarfs that of public sector research. As a result, corporate priorities and industrial strategies are increasingly reflected in research, development and distribution of seeds, livestock and other technologies that directly affect agricultural biodiversity. To date the evidence suggests that the corporate quest for commercial profits and control over production has promoted more, rather than less, genetic and ecological uniformity in agroecosystems. In particular, new biotechnologies such as pesticide resistant crops and seeds engineered to terminate germination after one growing season are potentially serious threats for agricultural biodiversity, at different temporal and spatial scales (Ho, 1997; UNEP-CBD-SBSTTA, 1999).

A more insidious, long-term threat lies with the disproportionate influence corporations have in determining which areas of scientific knowledge are developed, and for whom. Over time, reductionist science and techniques have been selectively favoured over whole ecosystem science, basic taxonomic work, population biology, landscape ecology and understandings of human-environment interactions based on plurial and interdisciplinary perspectives. This seriously undermines the long term ability of society to design sustainable agroecosystems based on a functional agricultural biodiversity that reduces dependence on suppliers of off farm inputs. Moreover, market dominance combined with monopoly patents gives the life industry unprecedented control over the products and processes of agricultural biodiversity,- the biological basis of food and livelihood security.

Inequitable tenure and control over resources

A significant cause of agricultural biodiversity loss is linked with the inequitable access to, and control over, land, water, trees and genetic resources. Denying rights of access and resource use to local people severely reduces their incentive to conserve resources and undermines local livelihood security. Colonial powers, international conservation organisations and national governments have a long history of denying the rights of indigenous peoples and rural communities over their ancestral lands and the resources contained therein. This has been one of the most enduring sources of conflicts and violence, both in the developing world and in advanced industrialised nations such as Canada where aboriginal people seek greater self-determination by regaining control over territories now enclosed in the country's protected area network

(Morrison, 1997). Denial of access, insecure tenure and rights of usufruct over the agricultural biodiversity contained in protected areas is one of the major factors undermining both conservation and development objectives (Ghimire and Pimbert, 1997). The same is true for forests, wetlands, farms, rangelands and common property lands outside of protected area networks.

Recognition of anthropogenic landscapes and "wild" species moulded by human agency has important implications for ownership, and consequently rights over access and use of biological resources. However, Western concepts of private property do not recognise the intellectual contributions and informal innovations of indigenous and rural peoples who have modified, conserved and managed so called "wild" species and landscapes (Crucible, 1994).

Inequities in access and control over genetic resources of domesticated plant and animals have also contributed to the erosion of diversity and the exploitation or displacement of local knowledge. Although most genetic resources originate from developing countries, transnational companies and northern institutions have captured a larger share of the benefits from using such resources in breeding programs and new natural product development. Legal means such as industrial patents and other intellectual property rights allow companies and northern institutions to maintain disproportionate control over the knowledge, genetic resources and benefits associated with agricultural biodiversity (GRAIN, 1998,1999; Tansey, 1999). In contrast, the local communities and farmers who originally nurtured this genetic diversity have generally not been recognised nor compensated for their innovations.

Market pressures and the undervaluation of agricultural biodiversity

Even though agricultural biodiversity has many values and performs many functions, it is undervalued or even ignored in conventional economic assessments. This is partly because the multiple ecological functions of agricultural biodiversity are difficult to value in economic terms. Moreover, the few economic analyses of biological diversity conducted so far have essentially focused on global values and foreign exchange elements and very little on the household use values of, for example," wild" foods and medicines (Scoones et al, 1992; IIED, 1995). Simple economic valuations based on direct use values (for consumption or sale) (see Pearce et al, 1989) have often been misleading and too reductionist to provide a sound decision making basis for policy makers and land use planners. The economic and social values of much of the biodiversity that nurtures rural people have been ignored or underperceived by outside professionals. This has biased conventional resource planning in favour of major food crops and species of commercial importance for urban centres.

The expansion of global markets and recent patterns of trade liberalisation tend to have a homogenizing effect on agricultural biodiversity by standardising food production and consumption. Global markets usually demand uniform foods that are increasingly processed and sold by transnational corporations, and are geared to meet the food desires of relatively wealthy, urban based consumers- both in developing and developed countries. In turn, these market pressures often force farmers worldwide to comply with those demands for uniformity. The policies for harmonisation of standards that accompany the globalisation of markets are also powerful forces undermining efforts for the sustainable use of local agricultural biodiversity and local adaptations.

Demographic factors

The expansion of human populations and large migrations are often partly responsible for agricultural biodiversity losses in new "frontier" areas such as forests, coastal zones, mangroves and grasslands. Whilst in some contexts population growth *per se* is clearly responsible for agricultural biodiversity loss, there are many situations in which inequitable land tenure, forest concession policies, colonisation programs, land use and fishing policies are the root causes behind the biodiversity loss induced by growth in human numbers or migrations. Conversely, more people can mean more care for the environment and enhanced agricultural biodiversity under certain conditions, as shown by research in Sierra Leone (Richards, 1993) and Kenya (Tiffen et al, 1994).

Options for sustaining agricultural biodiversity and its multiple functions

A recent FAO-SCBD International Technical Workshop identified a series of actions needed to sustain agricultural biodiversity and agroecosystem functions (Box 4). Taken together, these recommendations and action points offer a comprehensive and robust policy framework for national governments and international organisations. This concluding section endorses and complements the FAO-SCBD action points. Additional recommendations presented here expand on the results of the FAO-SCBD workshop (Box 4) and flow from the analysis of the root causes of agrobiodiversity outlined above.

Box 4. Action plan of the joint FAO and SCBD International Technical Workshop on Sustaining Agricultural Biodiversity and Agro-Ecosystem Functions, 2-4 December 1998, Rome

The following four sets of actions for the conservation and sustainable use of all agricultural biodiversity, especially at agro-ecosystem levels, should be prioritized, bearing in mind that many of these actions have already been identified for particular sectors or types of agricultural biodiversity by other forums.

1. Information, assessment and indicators

Despite the work of many organizations on the development of assessment methodologies and indicators, the workshop identified deficiencies with respect to agricultural biodiversity at agro-ecosystem levels and prioritized the following needs:

- to facilitate the exchange of information between different actors and stakeholders;
- to identify agro-ecosystem-specific indicators and the use of these for assessment, monitoring and understanding the causes of changes in agricultural biodiversity;
- to focus on developing indicators particularly for changes at agro-ecosystem levels and for the economic forces that influence these changes;
- to link indicators and assessment with particular dimensions of agricultural biodiversity, such as for food security, biological support systems or agro-ecosystem functions.

2. Research and development

Although the research and development programmes of many international, national and local organizations already have focused on activities for the conservation and sustainable use of agricultural biodiversity, the workshop

prioritized the need for:

- emphasizing greater coordination and information sharing between research and development programmes and better formal and informal sector linkages;

- strengthening national agricultural research systems on agricultural biodiversity related issues and for increasing research to demonstrate the value and costs and benefits of agricultural biodiversity conservation and sustainable use, building on proven local practices wherever possible;

- furthering farmer-driven participatory research and technology development processes through farmer field schools, recognition of local knowledge systems, etc., with full participation of local communities;

- emphasizing three main issues considered essential for research and development: ecosystem approaches and ecosystem functions; specific research on classes of species such as soil biota, pollinators and predators that are essential for productive soils and plants; and threats and positive incentives for agricultural biodiversity.

- developing a set of guiding principles for the identification, development, evaluation and reproduction of ecologically sound production systems and agricultural practices which promote the conservation and sustainable use of agricultural biodiversity in agro-ecosystems;

- promoting communications and facilitating the exchange of information on relevant scientific, research and practical information among different actors and stakeholders, including practitioners, producers and their organizations, and to relevant institutions and decision-makers, especially through improved South-South exchanges of electronic information.

3. Awareness raising and capacity building

Despite the interventions and actions of FAO, CBD and many expert institutions at all levels, and increased attention to biodiversity and sustainable use issues since UNCED, and bearing in mind the ecosystem approach adopted by the COP, the workshop prioritized actions for:

- capacity building to improve knowledge and information on agricultural biodiversity - which remains a key issue that hinders greater commitment and support - especially by raising awareness of the value and importance of agricultural biodiversity at the agro-ecosystem level;

- capacity building to disseminate sustainable methods for agricultural biodiversity conservation by demonstrating through case studies, training and briefing materials and public media as well as field demonstrations the importance and value of agricultural biodiversity in diverse agro-ecosystems and landscapes for all types of production systems;

- capacity building for decision-making and planning and policy-making on agricultural biodiversity by increasing communication, training and information campaigns in order to raise awareness and dialogue among policy-makers, politicians, professionals, producers, consumers, the public and students.

4. Development of policies and instruments

Even though there are a number of separate decisions, instruments, policies and programmes that address aspects of the conservation and sustainable use of agricultural biodiversity in agro-ecosystems, the workshop prioritized the need for:

- integrating agricultural biodiversity in national biodiversity programmes and action plans as well as in national environmental action plans and agricultural strategies and plans;

- developing coordination and policy coherence at international, national and regional level between relevant organizations, ministries and sectoral bodies at all levels;

- mitigating the influences of (and reforming where possible) the market, market forces and the existing economic framework which have major impacts on agricultural biodiversity, exacerbated by economic disincentives through, for example, inequitable land tenure and negative or perverse incentives;

- introducing incentive measures as important instruments to counter the above, including: fees, charges and environmental taxes; certification and eco-labelling; market creation and property rights; and regulations;

- developing and implementing a Code of Conduct on Agricultural Biodiversity, based on existing agreements, which would assist private sector, government and civil society organizations to identify their rights and obligations and inform their policy-makers and programme developers.

Source: International Technical Workshop organized jointly by the Food and Agriculture Organization of the United Nations and the Secretariat of the Convention on Biological Diversity, with the support of the Government of the Netherlands 2-4 December 1998, FAO Headquarters, Rome, Italy. www.fao.org/sd/epdirect/EPre0063.htm

Broadly speaking, there are two alternative scenarios for the management of agrobiodiversity (Table 2). The dominant blueprint approach to development has been identified as a major underlying cause of agricultural biodiversity loss. Nevertheless, national governments, the private sector and civil society may choose to stay within this paradigm and reform some of its less acceptable elements in their quest for more sustainable agriculture and land use. In sharp contrast, the learning process approach focuses on reversals from the normal and structural change, rather than systemic adjustments within well defined and often narrow boundary conditions. Discussions around these alternative scenarios are inevitably emotionally charged. The issues at stake go beyond purely technical matters and include the fundamental human right to food, the right to a healthy environment as well as the political economy of who gains and who loses. These are difficult political questions that require contradictory debate within society and negotiated solutions involving all stakeholders. Answers are not the prerogative of experts and technical bodies alone. All the latter can do is to facilitate public debate by highlighting possible policy options and technical choices. Whilst some policy recommendations presented below may be relevant for both scenarios, many have been framed within the scenario that departs from dominant values and practices.

1. Expanding knowledge on the dynamics of agricultural biodiversity

Rationale

Knowledge about agricultural biodiversiy and the processes enhancing or eroding it is the basis of national and international policy making and determines which kinds of management regimes prevail However, much is uncertain and unknown about the structure and multiple functions of agricultural biodiversity.There are huge gaps in knowledge on the number of species living on Earth: estimates of total species numbers vary between 5 and 30 million and a mere 1.6 million species have been

described to date. Knowledge on the functions of biodiversity, -synergies and complementarities, interactions within agro-ecosystems, ecological processes within soils and interactions with the atmosphere and water-, are rudimentary. An emerging picture describes the structure and functions of agricultural biodiversity in terms of variability, sudden as well as slow change, complexity and indeterminancy at different spatial and temporal scales. But there are considerable uncertainties and on-going scientific debates on the actual functioning and dynamics of ecosystems and landscapes (e.g. equilibrium versus dis-equilibrium ecology, views on succession, stability-diversity relationships, carrying capacity…).

Major investments are therefore needed to improve and expand our knowledge about agricultural biodiversity and its functions. Historical analysis, the use of complementary methods from the social and natural sciences and the knowledge of local resource users are all clearly needed to identify and properly explain the structure and functions of agricultural biodiversity at different scales. There are, after all, differently situated forms of knowledge about agricultural biodiversity, and each is partial and incomplete. Participatory learning and action is needed to bring together these multiple and separate realities, combining the strengths of modern science with local knowledge. There is indeed a strong rationale for democratising science in an age of uncertainty by directly involving “extended peer communities” (Funtowicz and Ravetz, 1993) that include farmers, herders, forest dwellers, fisherfolk and other rural people in the production and sharing of knowledge on agricultural biodiversity and its many functions (Batterbury, et al, 1997; Irwin, 1995; Kloppenburg, 1991; MacRae et al, 1989; Pimbert, 1994).

Actions

Provide adequate fiscal and administrative support for basic taxonomic work and inventories within and among plant, animal, microbial species and varieties

Provide support for studies aimed at understanding the dynamic functions of agricultural biodiversity at different spatial and temporal scales, with a particular focus on the roles of soil biodiversity, pollinators, pest predators and the processes of landscape transformation

Develop and use methods and indicators to monitor the impacts of agricultural extensification and intensification on biological diversity and local livelihoods, and promote their application

Provide support and high rewards for studies on the functions of agricultural biodiversity that combine indigenous with scientific knowledge, using innovative participatory and complementary methodologies to do basic research in an applied way

Diversify the governance and the membership of budget allocation committees of public sector planning and research institutes to include representatives of farmer, pastoralist, forest and fishing communities, organisations and federations, at both local and national levels

Establish procedures to ensure transparency, equity and accountability in the allocation of research funds and dissemination of new knowledge

2. Increase effective use of agricultural biodiversity in food and fibre production

Rationale

Agricultural biodiversity performs vital functions in agriculture, land and water use. The diversity of plants, animals and microorganisms is essential for maintaining the productivity and sustainability of farm crops and animals, managed forests and rangelands, aquaculture and fisheries. Future global food security is dependent on harnessing and sustaining agricultural biodiversity and its many functions, from the farm plot to the landscape level.

In both low external input and high input agriculture, the goals of sustainability, productivity and equity may best be met through agroecosystem designs that enhance functional diversity at the genetic, species and landscape levels. A central challenge across the whole range of agroecosystems is to find alternatives to the input substitution approach and future dependence on costly biotechnology packages. This can be achieved through an agroecological approach that seeks to break the monoculture structure and dependence on suppliers of off farm inputs through the design of integrated agroecosystems. By assembling a functional biodiversity within and around agroecosystems, it is possible to encourage synergisms that subsidise agroecosystem processes by providing ecological services, the recycling of nutrients and the enhancement of natural enemies of pests as well as provide diverse, quality foods and other farm products.

The current overemphasis on genetic engineering must be balanced by higher level approaches that build on agroecology, landscape ecology as well as social and biological diversity. National sovereignty and food security ultimately depend on a wide choice of agricultural technologies and development options.

Actions

Establish and implement national policies to support agroecological approaches that enhance agricultural biodiversity in food and fiber production through integrated pest, crop, nutrient and soil management as well as land use planning. The policy framework should ensure political commitment, educational and institutional capacities as well as incentives for enhancing agricultural biodiversity and its functions in agriculture and land use

Provide fiscal and administrative support for studies that investigate ways to maintain and enhance the utilisation of agricultural biodiversity in crop and animal production and in different kinds of agroecosystems, particularly high yielding and intensive commercial production systems

Promote development on the basis of locally adapted genetic material. Strengthen in particular the capacity to develop new crop varieties and animal breeds that are specifically adapted to local environments. Increase the range of genetic diversity available to farmers

Broaden the use of genetic diversity to protect crops and animal breeds against pest and weather problems by introducing multiple genetic systems for coping with stresses and also by deploying functional genetic mixtures and multilines where appropriate

Broaden the use of species diversity into functional designs for agroecosystems that sponsor more of their own soil fertility, crop protection, pollination and water management (agroforestry systems, multiple cropping, fish polycultures…).

Plan and manage rural landscapes to sustain biodiversity and ecosystem services. Where appropriate, maintain hedgerows, windbreaks and mangrove strips, leave tracts of land in native habitat, plant a diversity of crops, encourage pastoral activities, mixed species forestry and aquaculture. Maximise the use of resources internal to the landscape whilst closing nutrient cycles by integrating production with local needs and markets situated within or near the managed landscape. Apply the same principles for urban landscapes where food and fibre are produced.

3. Promote local adaptive management of agricultural biodiversity

Rationale

Variation within and among agroecosystems is enormous. Daily, seasonal and longer term changes in the spatial structure of agricultural biodiversity are apparent at the broad landscape level right down to small plots of cultivated land (Box 5). These spatio-temporal dynamics have major implications for the way agrobiodiversity is managed, -how, by whom and for what purpose.

Uncertainty, spatial variability and complex non-equilibrium and non linear ecological dynamics emphasise the need for flexible responses, mobility and local level adaptive resource management in which local users of agricultural biodiversity are central actors in analysis, planning, negotiations and action (Gunderson et al, 1995; Pretty and Scoones, 1995; Swift, 1999). This calls for far greater appreciation of local farming practices and knowledge used by rural people to manage agrobiodiversity in forests, wetlands, fields, rangelands, coastal zones and freshwater systems. It frequently suggest new practical avenues for technical support in which land users' own priorities, knowledge, perspectives, institutions, practices and indicators gain validity (Leach and Mearns, 1996; Netting, 1993; Pimbert and Pretty, 1998; Posey, 1999; Richards, 1985).

Box 5. Spatial and temporal variation in agricultural biodiversity : some management implications

- Crop varieties planted out experience rapid changes in environmental conditions, both above and below ground. For example, the physico-chemical and biological characteristics of soils are rarely homogenous within a single plot, let alone between plots. The intense selective pressures associated with this kind of microgeographical variation calls for a fine grained approach to agricultural biodiversity management that hinges on participatory plant breeding and decentralised seed multiplication. This adaptive strategy is generally advocated for resource poor farming systems in marginal, risk prone environments. However, it may be increasingly relevant for high input situations where agricultural diversification is used to solve production problems induced by genetic uniformity (e.g. pest outbreaks) or to exploit new market opportunities (economic niche for local or regional products).

- The abundance of insect pests and their predators is known to vary enormously within and between fields, -even in the more intensively managed systems. In high input irrigated rice farms, 100 fold differences in abundance of planthopper populations are commonly observed on rice plants grown a few metres apart. Huge variations in insect abundance also exist at larger spatial scales and all are marked by dynamic change over time. This implies that highly differentiated pest management approaches are needed to monitor and control pests effectively and economically. The FAO-Government program on IPM is a clear demonstration of the advantages of such local adaptive management of pests and their predators in irrigated rice in Asia (FAO, 1998). Farmer Field Schools have been a major innovation for the local adaptive management of agricultural biodiversity by developing farmers' own capacity to think

for themselves and develop their own site specific crop protection solutions.

Actions

Carry out administrative tasks, land use planning, agricultural research and development as near to the level of actual users of resources or beneficiaries of administration as is compatible with efficiency and accountability

Ensure flexibility and diversity in institutional and organisational design to enable government administration and services to track appropriately the dynamic changes which occur in agroecosystems and the functions of agricultural biodiversity at different time and spatial scales.

Educate policy makers, professionals and the public (including the bearers of local knowledge) about the value of local and indigenous knowledge and management systems in sustaining agricultural biodiversity and its many functions

Strengthen local groups and institutions by devolving resources and removing administrative or legal hurdles to local planning and action. Support the development of local institutions for common property resources and the equitable sharing of benefits from their utilisation

Identify and support a mediator for conflict resolution and an arbiter of last resort; guaranteeing a level legal playing field and equality of advocacy in disputes, both within and between local groups as well as between local groups and powerful external interests. Of particular importance in this connection are government policies and actions that explicitly prevent discrimination on the basis of differences in gender, ethnic origin and wealth.

4. Support local participation in planning, management and evaluation

Rationale

From the outset, the definition of *what* agricultural biodiversity is to be conserved, *how* it should be managed and *for whom* should be based on interactive dialogue to understand how local livelihoods are constructed and people's own definitions of well being. Most professionals have tended to project their own categories and priorities onto local people and landscape management. In particular, their views of the realities of the poor, and what should be done, have generally been constructed from a distance and mainly for professional convenience. Household livelihood strategies often involve different members in diverse activities and sources of support at different times of the year. Many of these, like collecting wild foods and medicine, home gardening, common property resources, share-rearing livestock and stinting are largely unseen by outside professionals.

Agricultural R&D and land use planning should not start with analysis by the powerful and dominant outsiders, but with enabling local people, especially the poor, to conduct their own analysis and define their own priorities. This methodological orientation is absolutely essential to meet the goals of equity, sustainability, productivity and accountability. In that context, dialogue, negotiation, bargaining, conflict resolution and joint management agreements are all integral parts of a long term participatory process which continues well after the initial appraisal and planning phases into monitoring and evaluation. This implies the adoption of a learning process approach in the management of agricultural biodiversity and its

functions (Table 2). It also calls for a new professionalism with new concepts, values, participatory methodologies and behaviour (Pretty and Chambers, 1993).

Actions

Ensure public participation of women and men (particularly farmer, herder, fisherfolk and forest dweller involvement) in the development of land use and agricultural policies and in the generation of technologies

Ensure inclusive equitable representation (gender, class, ethnic origin, age) in the participatory activities and process

Provide capacity building for technical and scientific personnel to foster those participatory skills, attitudes and behaviour needed to learn from farmers and rural people (mutual listening, respect, gender sensitivity as well as methods for participatory learning and action)

Provide institutional space and incentives for professionals to understand social and cultural complexity as well as agroecological diversity

Support joint problem-solving among local people, scientists and/or extension workers and the development of negotiated participatory research agendas and resource management agreements, using local criteria and indicators as well as those of outside professionals and their organisations

Support the participatory monitoring and evaluation of national policies, land use plans, food and fibre production technologies by building on the perspectives of all social actors. Encourage the use of gender disaggregated and socially differentiated local indicators and criteria in monitoring and evaluation as well as in guiding subsequent technical support, policy changes and allocation of scarce resources for agricultural biodiversity management.

5. Transform bureaucracies and professional practice

Rationale

Local adaptive management of agricultural biodiversity and large-scale participation do not mean that state bureaucracies and other external organisations have no role. But they do challenge bureaucracies to assume different roles and responsibilities. In particular, existing bureaucracies and professionals will often need to shift from being project implementers to new roles that facilitate local people's analysis, planning, action, monitoring and evaluation. The whole process should lead to local institution building or strengthening, so enhancing the capacity of people to take action on their own. Appropriate partnerships and co-management agreements between states, the private sector and rural communities are also required through new legislation, policies, institutional linkages and processes.

However, the adoption of a participatory culture and changes in professional attitudes and behaviour are unlikely to automatically follow when new methods are adopted. Training of agency personnel in participatory principles, concepts and methods must be viewed as part of a larger process of reorienting institutional policies, organisational cultures, procedures, financial management practices, reporting systems, supervisory methods, reward systems and norms (Absalom et al, 1995; IIED-IDS, 1999; Thompson, 1995). In both government departments and non governmental organisations, the challenge for top and middle management is to design appropriate institutional mechanisms and rewards to encourage the spread of participatory methods within the organisation. Without this support from the top, it is unlikely that participatory

approaches that enhance local capacities and innovation will become core professional activities.

Actions

Encourage shifts from hierarchical and rigidly bureaucratic structures to "flat", flexible and responsive organisations

Ensure that senior and middle management positions are occupied by competent facilitators of organisational change, with the vision, commitment and ability to reverse gender and other discriminatory biases in the ideologies, disciplines and practices animating an organisation.

Promote and reward management that is consultative and participatory rather than verticalist and efficiency led. Establish incentive and accountability systems that are equitable for women and men

Provide incentives and high rewards for staff to experiment, take initiatives and acknowledge errors as a way of learning by doing and engaging with the diverse local realities of farming, fishing and pastoral societies

Redesign practical arrangements, the use of space and time within the workplace to meet the diverse needs of women, men and older staff as well as their new professional obligations to work more closely with farmers and other stakeholders (time tables, career paths, working hours, provision of paternity and maternity leave, childcare provisions, mini sabbaticals, promotion criteria…)

6. Strengthen local rights and security of tenure

Rationale

There is a need to provide a legal framework within which a devolved management of agricultural biodiversity can operate effectively, especially in respect of resource tenure. The legitimacy of rural peoples' claims to tenure and rights to agricultural biodiversity are made more apparent as landscapes are re-interpreted as the product of social and ecological histories. If landscapes, species and genetically distinct populations have been moulded or modified by human presence and actions, local communities may claim special rights of access, decision, control and property over them. These findings support a rights based approach to the participatory management of biodiversity important for food, agriculture and livelihoods (Pimbert and Pretty, 1998; Posey, 1999). They also have major implications for national policies on the sharing of benefits derived from the use of landscapes, agricultural biodiversity and its end products. Guaranteeing the secular right of farmers' to save and re-use seeds and livestock progeny is crucial in this connection. Failure to enshrine these rights in national legislation and policy practice may lead to inequitable benefit sharing schemes and conflicts that could undermine the sustainable management of agricultural biodiversity and food security.

Actions

Reform policies and laws on rights of access, use and control over land, trees, water and genetic resources to ensure that farmer's and indigenous peoples' rights are protected as a basis for equitable benefit sharing arrangments

Ensure that intellectual property rights over genetic resources currently re-negociated within the TRIPs agreement of the World Trade Organisation do not undermine the objectives of conservation and sustainable use mandated by the Convention on Biological Diversity and the FAO negotiations on the International Undertaking on Plant Genetic Resources

7. Reform trade policies, markets and economic incentives

Rationale

Economic instruments are key to sustaining agricultural biodiversity and its multiple functions. Trade policies, markets, subsidies and economic incentives must reinforce the objectives of the International Convention on Biological Diversity rather than contradict or actively undermine them. A multilevel and systemic approach to economic transformation will often be needed to reform trade, taxation and public spending aimed at sustaining agricultural biodiversity and its multiple functions (Robertson, 1998; http://attac.org, 1999).

Actions

Reform international and national trade policies that contribute to the loss of agricultural biodiversity and develop trade rules that promote social and biological diversity by regenerating local economies and food systems

Eliminate policies and economic incentives that contribute to the erosion of agricultural biodiversity and its functions, particularly subsidies for High Yielding Varieties, pesticides and fertilisers; credit policies that require the use of such inputs and monocultures; variety release and seed certification legislation that hinder the utilisation of diverse genetic material through their requirements for distinctiveness, uniformity and stability; pricing and tax policies that favour genetically and ecologically uniform production systems

Assess the economic benefits of agricultural biodiversity (domesticated and managed wild diversity) in a more comprehensive manner to improve the decision making basis for policy makers, land use planners and agricultural R&D. Economic benefits based on the use of « wild » and domesticated agricultural biodiversity should be situated and evaluated in a total livelihood context

Establish flexibility in marketing standards to allow food distributors and retailers to diversify varieties of produce and reduce wasteful cosmetic standards for foods in markets

Implement anti-trust laws and other regulations that limit or prevent unfair market domination by corporations that sell seeds, animal embryos, agrochemicals, veterinary products and biotechnologies or/and process and distribute food and fibres

Restructure the tax system to encourage employment and enhance agricultural biodiversity in the entire food and fibre production-distribution chain. Ensure greater public sector spending and fairness within the food system by redistributing tax levies on speculative international financial flows (e.g. the Tobin tax)

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