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Ecology In Developing Countries: The Emerging Paradigms

P S RAMAKRISHNAN
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067

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In recent times the research emphasis in ecology has gradually shifted towards the human dimension as an integral component of ecosystem functioning and understanding ecological processes. "Global Change" related research efforts have brought the need for working at the interphase between natural and social sciences. Building bridges between ecological and social processes has become critical for coping with issues such as climate change, biological invasion, biodiversity depletion, land degradation and desertification. The author discusses the emerging new ecological paradigms in the context of researches initiated by him, starting with early 1970s, in the biodiversity/natural resource rich upland regions of India where traditional societies live. In the ultimate analysis natural resource management in the developing tropics in linked with sustainable livelihood of these traditional rural societies as a short-term strategy, and sustainable development of the rural landscape as a long-term plan.

Key Words : Ecology, Human dimensions, Nutrient dynamics, Biodiversity Agroecosystems, Integrated forest management

Introduction

At the turn of this century, ecology was largely a descriptive science, biogeographical in nature and with strong taxanomical overtones. Lindeman's concept of the hierarchical trophic structure of ecosystems, of the 1940s led to studies based on trophic dynamism. The ecosystem was considered to be producer-controlled, both structurally and functionally, and hence predictable. The research emphasis was on well protected pristine ecosystems. During the 1970s, the emphasis shifted somewhat with the conceptualization of predator-controlled or consumer controlled ecosystems. Still the emphasis remained on undisturbed study sites. With greater realization and emphasis placed on evolution as an ongoing active process, in more recent times, disturbance was seen as a driving force in the evolution of ecological systems. The research emphasis shifted from pristine to human impacted ecosystems, and a desire to emphasize upon the human dimension of ecological processes.

Human Ecology as a discipline, until recent times, has largely been the concern of social scientists and geographers. Though ecology (biological) and human ecology are closely linked conceptually, ecologists who have developed their paradigms largely based upon biological concepts have traditionally kept the humans out of the ecosystem concept; the humans if at all were recognized as impacting agents from outside. Further, the biological models of ecosystem function cannot be extended to handle more complex social systems. Earlier studies in human ecology were largely focussed on isolated traditional societies ,with a large natural resource base; therefore, ecological-social linkages were not critical issues for analysis. More over, concerns related to environmental degradation were not crucial issues in dealing with these systems. The independently evolved paradigms in social

sciences differed significantly from that of the biologically oriented ecologists. With a shift in human ecology towards an understanding of rural and urban societies that exert greater pressure on a limited natural resource base, we are now faced with a situation where building bridges between ecological and social science paradigms is crucial for environment and development.

Building Bridges - A Communication Problem between Natural and Social Sciences

In 1974, when I initiated a multi-disciplinary study on the shifting agricultural (jhum) system in north-eastern hill region of India, except for some very highly restricted studies under the 'Man and the Biosphere'(MAB) programme of the UNESCO, there was very little to fall back upon, in dealing with the human dimension of the problem. Though MAB studies helped in creating awareness and some interaction between ecologists and social scientists, no serious efforts were made by ecologists working in the field to link ecological processes with social processes. In fact, ecologists and social scientists often worked independent of each other and efforts for integration of the two diverse set of paradigms were missing.

An integrative approach was the most obvious choice for me when I initiated the studies in the north-east Indian jhum system. This system had a variety of ecological ramifications - agroecosystem function under varied land uses by different communities; ecological impact analysis under different land use systems as related to soil fertility, hydrology and forest ecosystem level alterations; agroecosystem-forest ecosystem interactions and the consequent forest management issues; and indeed the human dimension - social, economic and cultural - that impinges upon all these aspects; and the implications of all these for sustainable development of tribal societies. With a biological ecology training, while I was able to handle the ecological issues, the human dimension related studies were initially entrusted to the social scientists, as part of a team effort. It did not take me too long to realize the communication gap between ecological science and social science paradigms; in the absence of an integrating set of paradigms , this effort for interaction had to be abandoned very soon. The human dimension component of the north-eastern case study was then taken on board directly by me and looked at with a view to find solutions to ecological issues.

Looking back now, on the basis of extensive experience in dealing with ecological issues that lie in the interphase with social sciences, I realize that the usage of social science methodology and paradigm may bring out very broad features of the system under study, provided the ecologist is able to address the right kind of question, as the team leader. Ecology is the discipline that can integrate different disciplines in the area of environmental studies and therefore the initiative is with the ecologist. Biologically trained ecologists are not suitably equipped for this. If ecological process studies have to be effectively integrated with social processes operating within a given ecological system, then we need to go beyond the generalities. Ecological or social science methodologies, by themselves and independent of each other, are not equipped to handle the finer details. While working in the north-east, I soon realized that this could be achieved only by a participatory mode of research. Ecologists with a biological background but with the aptitude to work in a participatory mode were encouraged to look at the ecological and the related social component of the system simultaneously. The results were very rewarding. Having learned from this experience, then it becomes easier to do a team work with involvement of social scientists.

Human Dimensions in Landscape Ecology

North-East Indian Landscape

The entire discussion in this section and in others related to the north-east Indian mountain landscape is based on the synthesis of a series of studies done over the last 25 years (Ramakrishnan 1992a) and which is continuing up to the present.

Agricultural Land Use

The north-east Indian hill areas form a highly complex landscape mosaic (Ramakrishnan 1992a). The region is inhabited by over 100 tribes with their own linguistic and cultural characteristics. All the tribes are involved in shifting agriculture (locally called jhum), a major landuse system in the region. The jhum procedures involve slashing and burning of the natural vegetation on a 2-3 ha plot at a given forest successional stage, mixed cropping done usually for a year (seldom cropping is done for the subsequent few years; if at all done it is usually perennial cropping such as banana plantations), and allowing the fallow regrowth to occur subsequently for a few years. Therefore, the jhum plots exist in the landscape at various cropping and fallow phases. At present, the average length of the jhum cycle is about 5 years, but longer cycles up to 30 years are often available in the region. In more remote areas, rarely, cycle lengths up to 60 years or so could occur.

In sites under intense human pressure such as in and around Shillong, one could find further shortening of the jhum cycle to 2 to 3 years but with elimination of the slash and burn, because of the reduced slash material available. In this fallow system of agriculture (FAO/SIDA 1974), two croppings may be done in a year, one a mixed cropping and another a monocrop of potato.

Further shortening of the cycle has resulted in sedentary systems of agriculture, where the weed biomass coming up during winter months, in between two successive cropping periods, alone are slashed and mulched. Mixed cropping is the usual practice with a rotational pure legume, such as Flemingia vestita cropping being done once in 3 to 4 years.

Other land use systems available in the region are valleyland wet rice cultivation and home gardens (a mixture of perennial trees and shrubs along with annual herbs and climbers to form a tightly packed system imitating a forest). The former is restricted by topography and restricted to the valleys. Each one of these land use systems show large variation in their structure, organization and functions, arising out of cropping patterns and procedures. This in turn may lead to wide differences in economic yield and ecological efficiencies. All these differences could be related to the ecological and social setting under which a given system operates.

Secondary Successional Forests

When the forest is converted to cultivable land, as under jhum, not only is its original vegetation destroyed, but the site is subject to continuing perturbations due to fire, the introduction of crop species, weeding, hoeing and other disturbances to the soil when the crops are harvested. These result in a progressive reduction in species diversity and so the early successional stages contain few species, with the number increasing gradually as the secondary community develops. With increase in species diversity dominance decreases sharply with fallow age.

The early successional stages up to about 10 years of fallow regrowth is dominated by native and exotic weedy species. These species at lower elevations (around 100m) have native weeds such as *Imperata cylindrica, Thysanolaena maxima, Saccharum spontaneum,* and *Panicum* spp.; the exotics here are *Eupatorium odoratum* and *Mikania micrantha.* At higher elevations (900 m and above), apart from

Imperata cylindrica, other grasses are *Arundinella* spp., *Ischaemum goeblii,* and *Eragrostiella leioptera;* pteridophytic, *Dichranopteris linearis* and *Pteridium aquilinum* also come in. *Ageratum conyzoides* and *Borreria hispida* are other native forbs at this elevation. The exotic weeds that dominate here are two other species of *Eupatorium,* namely, *E. adenophorum* and *E. riparium.*

Between 10 to 30 years of fallow regrowth, at lower elevations many species of bamboos dominate, often forming pure formations. Among the more important species are *Dendrocalamus hamiltonii, Bambusa tulda* and *B. khasiana.* Beyond 30 years of fallow regrowth, broad-leaved tree species increase in their numbers at all elevations. These mixed early successional forests at lower elevations that replace the bamboo forests have trees such as *Anthocephalus kadamba, Duabanga sonneratioides,* and *Lagerstroemia parviflora. Alnus nepalensis* occurs at a range of altitudes (300m to 1700m). Late successional forests at lower elevations have a variety of species such as *Castanopsis indica, Shorea robusta, Englehardtia spicata, Actinodaphne angustifolia, Myristica latifolia, Cinnamomum* sp., *Mesua ferrea, Millusa roxburghiana,* etc., forming a mixed broad-leaved forest. At elevations of around 1300m, the mixed broad-leaved forest have an equally diverse species mixture, with species such as *Englehardtia spicata, Sysigium communii, Echynocarpus dasycarpus, Drymycarpus racemosus* and *Elaeocarpus lanceaefolius.* At higher elevations, however, Khasi pine (*Pinus kesiya*) is the dominant tree species along with a few early successional broad-leaved tree species such as *Schima wallichii, S. khasiana* and *Alnus nepalensis,* during this phase of succession. They may continue up to about 60 years of fallow regrowth. At high elevations (1500 m and above), the dominant late successional species are *Quercus dealbata, Q. griffithii,* and *Machilus kingii.* Forest ecosystem degradation in north-eastern India has resulted in arrested succession of weeds over large areas, under the influence of large-scale deforestation due to timber extraction in the past, rapid shortening of the jhum cycle from a longer 20-30 years to 4-5 years in recent times, and the subsequent impact of shortened jhum cycle of 4-5 years imposed again and again on the same site. Under longer jhum cycles of 10-20 years, large tracts of land have been taken over by bamboo forests. In extreme cases, desertification has occurred over large tracts of land as in the west Khasi hills of Meghalaya including the Cherrapunji region, which has resulted in balded landscape with arrested and degraded grasslands.

Village Ecosystems

Interspersed within these varied land use systems are a large number of village ecosystem types where the number of households may vary from less than 10 on the lower side in more remote locations, to over 400 or more in areas with better infrastructural facilities. Within these village ecosystem boundaries, animal husbandry and domestic subsystems form part of the village ecosystem, apart from the variety of land use systems described above. It is also not uncommon to find different communities coexisting in the same area but organized into small villages of their own forming a village cluster.

Thus the rainforest landscape has a variety of ecological systems, natural and man-made, interacting at biophysical and socio-economic planes.

Nutrient Dynamics in the Landscape

Nutrient Depletion

After clear-cutting and burning of the forest, the ecosystem loses its ability to hold nutrients (Ramakrishnan 1992a). Much ash is blown away by strong winds during the dry months of

March and April. Large losses also occur through volatilization of carbon and nitrogen during the burn so that there is a reduction in the quantity of these elements in the surface soil layers. These losses continue during the early cropping phase. In contrast, available phosphorus and cations are added to the soil during the burn (Ramakrishnan & Toky 1981).

During the latter phases of the cropping period, carbon and nitrogen recovery occurs in the soil, partly because of the addition of organic matter through crop and weed biomass and rapid nitrogen fixation by soil microbes. The depletion of organic carbon depends on the intensity of the cropping and the ratio of the cropping to the fallow period. Under long agricultural cycles (a cycle is the length of the fallow phase between two successive croppings on the same site), adequate humus can be maintained in the soil even after many years of shifting agriculture. Recovery of the available nitrogen lost during the burn occurs because of accelerated microbial activity following a rise in the *p*H and temperature of the surface soil (Moore & Jaiyebo 1963, Ahlgren & Ahlgren 1965). The increase in nitrification may be due to the removal of chemical inhibitors or to clear-cutting of intact vegetation and subsequent burning (Smith et al. 1968, Rice 1974). The activity of nitrifiers may also be closely linked to competitive interference by litter-decomposing heterotrophs in the humid tropics (Saxena & Ramakrishnan 1986).

After the slash and burn operation, the mixture of crop species is sown on plots of 2-2.5 ha on slopes of 30-40°. Nutrient losses occur through runoff and leaching during the early monsoon, particularly before the crop cover is established. A large proportion of the losses occurs. The total losses through runoff and leaching can be considerable during one cropping season, particularly under a short agricultural cycle. The losses are even more impressive when totaled over 30 years. They are much greater for six croppings under 5-year cycles compared with three croppings under 10-year cycles; these in turn, have much greater losses than those which occur for one 30-year cycle.

Nutrient Budget in Agroecosystems

During nitrogen budget analyses of a slash and burn system under cycles of 15, 10 and 5 years at higher elevations, showed that a shortening of the cycle lowers the nitrogen content of the soil before burning as well as at the end of the 1- or 2-year cropping period (Mishra & Ramakrishnan 1984). Nitrogen loss under a 15-year agricultural cycle may be high because of the large quatities built up in soil and vegetation after a longer fallow regrowth phase. Although the loss of nitrogen from a 5-year-cycle plot is lower after one cropping phase than that from a 15-year-cycle plot, the total loss is higher if the 5-year-cycle plot values are put on a time-scale of 15 years and multiplied by a factor of three.

We showed in this study that during one cropping phase, the agroecosystem loses about 600 kg ha-1 of nitrogen (the difference between the soil nitrogen capital before and after one cropping) (table 1). If the plot under a 5-year cycle at the time of this study and during the previous 20 years (for which period land-use history was known) had longer cycles preceding the 20-year period, then the sytem had lost 1.28x103 kg ha^{-1} of nitrogen from its initial capital of 7.68-6.40 x 103 kg ha^{-1}. While 10-or 15-year agricultural cycles are long enough to restore the original nitrogen status in the soil before the next cropping, it seems unlikely that the 600 kg ha^{-1} of nitrogen lost during one cropping could be restored under a 5-year cycle. Traditional societies cope up with such shortened agricultural cycles using socially selected species such a the Nepalese Alder (*Alnus nepalensis*) as part of their cropping and fallow phases, a technology that is traditional knowledge based. Otherwise, one of the

Table 1 *Net change of soil nitrogen and available phosphorus (kg ha^{-1}) under jhum at Lailad in Meghalaya (from Swamy & Ramakrishnan 1988c)*

	20-yr jhum cycle		5-yr jhum cycle	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Soil pool before burning (x 10^3)	10.9	0.02	10.45	0.0073
Soil pool at the end of cropping (x 10^3)	9.78	0.032	9.91	0.012
Net change	1.12	0.012	0.54	0.0047

important disadvantages of a 5-year cycle lies in the reduced nitrogen capital; increased frequency of fire and cropping with too short a fallow phase thus results in rapid site degradation (Ramakrishnan 1992a).

A comparative analysis of three weeding regimes showed that traditional weeding, where about 20% of the weed biomass is left behind by the forest farmer, has an important nutrient conservation role (Swamy & Ramakrishnan 1988). Thus the loss of sediment and labile elements such as potassium through runoff is reduced by 20% when compared with total weeding. Traditional weeding has little effect on the yeild potential of the crop mixture compared with total weeding. The harvested weed biomass traditionally put back into the system ensures efficient recycling of this resource. This weed management concept of the traditional farmer does not adversely affect the economic efficiency of the agroecosystem and suggests that the agriculture of the future should also have integrated weed management, rather than weed control (Gliessman et al. 1981, Ramakrishnan 1992a).

Nutrient Cycling in Forest Fallows

With the rapid transfer of nutrients from the soil to the vegetation during the early phase of the fallow, rapid depletion of nutrients occurs in the soil even though losses by leaching and runoff are greatly reduced. It is only after about 10 years of fallow that net transfer of nutrients back to the soil through litterfall becomes important and soil fertility recovers. This is one of the reasons why a 10-year cycle for slash and burn agriculture is considered to be the shortest possible for the stability for the system (Ramakrishnan 1992a), unless the fallow has an accelerated regrowth with species such as the introduced *Alnus nepalensis* and other fast-growing early successional trees which improve soil fertility by rapid recycling of nutrients with a fast turnover of leaves (Ramakrishnan et al. 1982). Traditional knowledge of local communities on native species have much to offer in soil fertility management (Ramakrishnan 1994). Larger transfers of all nutrients from the soil to the tree biomass in older fallows conserve nutrients in the biomass, at the same time enriching the soil through gradual release through litterfall (Ramakrishnan 1992a).

With an early successional warm temperate pine (*Pinus kesiya*) forest (Ramakrishnan & Das 1983) and climax mixed higher soil acidity and resinous pine litter all contribute to lower nutrient cycling rates during the forest fallow. For this reason the forest farmers merely cut off the lower branches of the sparse pine trees for agriculture rather than clear-felling as done at lower altitudes.

Nutrient Conservation through Bamboos

Bamboos which are abundant in the north-eastern region are another group of species, socially and culturally valued by local communities; they are used for a variety of village based needs - utensils, pipes for transport

of water, construction material, etc. They being an important component of the secondary successional forests of north-eastern India, play an important role in nutrient cycling. Many of these species decline beyond 25-30 years of fallow regrowth. In studies on the role of bamboos (Ramakrishnan 1992a), we have shown that they have much more nitrogen, phosphorous and potassium than the other species in the community. We have already discussed the role of *Dendrocalamus hamiltonii* in accumulating potassium in the forest fallows. Nitrogen and potassium are highly labile and lost through runoff and leaching; nitrogen is also lost through volatilization, whilst phosphorus is fixed by insoluble sesquioxides in the clay of soils rich in aluminium and iron (Gebhardt & Coleman 1974, Tinker 1977). The bamboos, a set of socially selected species play a critical role in conserving these major nutrients in shifting agriculture (Ramakrishnan 1992a).

Biological Invasion and Nutrient Cycling Properties

With the shortening of agricultural cycles, weeds become more abundant as seen by us (Ramakrishnan 1992a) and by (Nye & Greenland 1960, Zinke et al. 1978); we have quantified weeds under slash and burn agriculture. The weeds increase under short fallow cycles is due to the continuous presence of the same weed species in the cultivated plots and in the 4-6-year-long fallow plots. This allows a build-up of the soil banks of propagules.

Exotic weeds are important pioneers. In north-eastern India, there are species such as *Eupatorium odoratum* L.(lower altitudes), *E. adenophorum* and *E. riparium* (higher altitudes) and *Mikania micrantha* (lower altitudes); all are native to the Latin American tropics. These were introduced to india about 100 years ago.

A series of perturbations occur during slash and burn resulting in the release of nutrients in a flush, followed by heavy losses during the agricultural operations. Under these conditions, when the high seasonal rainfall of over 2000 mm flows down the hill slopes of 30-40°, the resultant soil is heterogeneous (Ramakrishnan 1992a). The availability of labile nitrogen in particular is uncertain. The pattern of C_3 and C_4 plants early in succession helps in the exploitation of nutrients from heterogeneous soils. C_4 species have a higher nitrogen-use efficiency and are restricted largely to nutrient-poor microsites, whilst the less efficient C_3 species occur in nutrient-rich microsites. It is also interesting that the C_3 species such as *Eupatorium* spp. and *Mikania micrantha* and grasses such as *Imperata cylindrica., Saccharum* spp., *Panicum* spp. and *Thysanolaena maxima* are all C_4 species. Native C_3 species do occur but they have a low biomass (Saxena & Ramakrishnan 1984).

The consequences at the ecosystem level of biological invasion are considered in detail by Ramakrishnan and Vitousek (1989) and Ramakrishnan (1991). Since exotics colonize disturbed habitats, especially sites altered by the humans (Chandrashekara & Ramakrishnan 1993, 1994), it can be difficult to separate the ecosystem level effects of biological invasions from those of the disturbance that created theinvaded habitat. However, the north-east Indian case study (Ramakrishnan 1992a) suggests the following impacts on ecosystem structure and functioning: (a) arrested succession predominated by exotic weeds drastically alter the ability of the system to recover into a forest; with human intervention, the cost could be exorbitant; (b) high reproductive potential of these exotics combined with specialized ecological characteristics for multiplication and growth at the expense of natives only compound rehabilitation of these unproductive landscape; (c) an exotic weed like *Mikenia micrantha* play a significant role in conserving a labile element like potassium in the system under short agricultural cycles, a role that a bamboo species like *Dendrocalamus hamiltonii* plays under longer

cycles; (d) in the rural landscape in general and institutions where traditional societies are more closely integrated within ecosystem/ landscape functions, livelihood of local communities could adversely affected.

Linkage between Cropping and Fallow Phases

Soon after the slash and burn operation, the soil nutrients differ, both quantatively and qualitatively, between the short and long agricultural cycles. The quantitative differences are directly related to the biomass build-up during the fallow phase and the consequent slash load and ash release during the burn (Ramakrishnan & Toky 1981, Ramakrishnan 1992a). Herbaceous communities of up to about 5 years of age generally have more phosphorous, and *Dendrocalamus hamilitonii* of 10-25 years of age has more potassium, so that different quantities of these elements are released in ash under short and long agricultural cycles. We have seen how fallows dominated by *Mikania micrantha* also conserve potassium under short cycles (Ramakrishnan 1992a). Thus qualitative differences in the nutrients after slash and burn are related to the vegetation structure of the fallow phase. We have also shown that there is an increased propotional release of calcium and magnesium when agricultural cycles are long (60 years or clearing of virgin forest) as in the Arunachal Pradesh in north-eastern India.

It may be concluded that: (a) compared with the cropping phase, the nutrient losses from the system are greatly reduced in the early fallow phase of the weedy herbaceous community; (b) in the initial 15 years or so of fallow regrowth, there can be rapid shifts in the nutrient pool between the soil and the vegetation compartments when the community structure changes from herbaceous to bamboo/pine dominated and , finally and more slowly, to a mixed broadleaved forest; (c) from a nutrient cycling viewpoint, a 10-year cyclre for agriculture is the minimum for cropping because, among other reasons, soil fertility recovery is adequate at this stage; (d) a few species such as *Mikania micrantha* or *Dendrocalamus hamiltonii* may have a dominant role in nutrient cycling; (e) biological invasion by exotics need not always be viewed as undesirable as they may have useful attributes, e.g. *Mikania micrantha* helps to conserve potassium. (e) Species that are socially/culturally valued often have a key role in the ecosystem; eg. the Nepalese Alder for soil fertility improvement under shortened agricultural cycles or the role of bamboos in nutrient conservation during succession.

Biodiversity Science - Integration of the Humans: A New Dimension in Ecosystem Complexity

Though biodiversity versus ecosystem stability and resilience has been a matter of academic concern among ecologists for some time now (Odum 1971), it is only recently that attempts have been made to clearly delimit the biophysical role of biodiversity in ecosystem function (Mooney et al. 1994). The recent interest on the role of biodiversity on ecosystem function arises out of a concern for utilization of natural resources in a sustainable manner that satisfies current needs without compromising the needs or options of future generations. In recent times, activities initiated in pursuit of an improved quality of life, through the production of food, fibre, shelter and consumer goods, recreation, etc. have led to unintended results (figure 1). Since humans of industrial societies play a key role in altering ecosystem level processes, they have traditionally been considered by ecologists as being outside the ecosystem boundary and inpacting upon ecosystem in a variety of different ways. However, in the tropical world, biodiversity concentrations are largely tied up with regions where traditional societies live. These traditional societies by the very nature

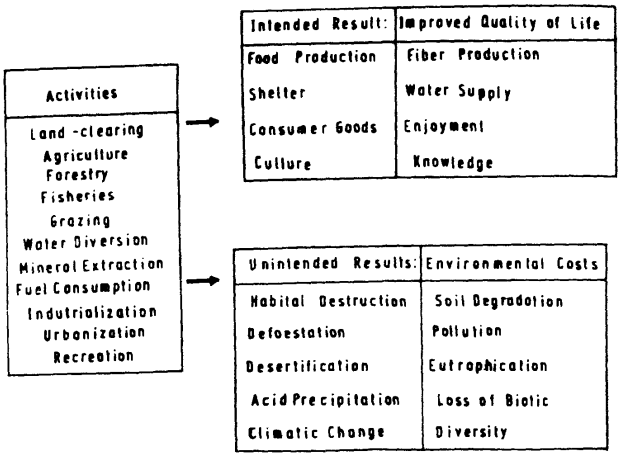

Figure 1 Human activities affecting the sustainability of the biosphere (from Lubchenco et al. 1991).

of their livelihood activities are part of the ecosystem/landscape functions, rather than being external players (Ramakrishnan 1992a,b). If at all, they act differently, it is due to external pressures exerted by the industrialized human, leading to resource degradation and societal disruptions arising there from. Otherwise, traditionally, biodiversity has always been the driving force for their sustainable livelihood concerns. Therefore, integrating the humans as part of the ecosystem rather than keeping them outside its boundary is important. Biodiversity is not only an important regulator of ecosystem functioning in a biological sense, but is also crucial for satisfying a variety of societal needs and functions. Such an approach will provide us with a totally different perspective on the role of biodiversity in ecosystem functioning, in determining its values for the humans who are dependent upon this biodiversity for their livelihood needs, strategies for sustainable management of natural resources and conservation of biodiversity and indeed sustainable development of human societies in these biodiversity rich 'hot spots'. The following discussion, therefore, explores the human dimensions of biodiversity in the context of the role played by traditional societies of the developing tropical world in natural ecosystem function, an evolving paradigm shift in biodiversity science.

Humans Integrated within Ecosystem Boundaries

The concept of village as an ecosystem amongst traditional tribal societies, with all its ramifications involving agriculture, animal husbandry and the domestic sector enmeshed with the forest and forest-related activities such as hunting and gathering of food, fodder, fuelwood and medicine and forest farming as done under shifting agriculture , is an example of integrating humans within the ecosystem boundaries and for evaluating the role of biodiversity in ecosystem function in a broader context (Ramakrishnan 1992a,b). Thus, for example, a total of 171 plant species, and over a dozen animal species are used by four tribes, the Nishis, the Hill Miris, the Sulungs and the Apatanis living in a cluster of villages, in the Lower Subansiri District of Arunachal Pradesh of north-eastern India (Gangwar & Ramakrishnan 1990). The plant species belong to a wide variety of categories - for leafy vegetables, edible fruits, a variety of other food items, cereals, tubers, liquor, medicine household goods, traditional dresses, dyes, tattoos, fish, animal poisons, or salt extraction. The Sulungs use the starch extracted from the pith of *Metroxylon sagu* as their staple food. Such an extensive use of biodiversity suggests that the tribes of north-eastern India, and traditional farmers elsewhere (Brookfield & Padoch 1994), rely heavily on forest ecosystem to meet their varied needs. This implies that conserving this biodiversity is crucial for their survival, as a component of the rainforest ecosystem.

It is not only the mere presence of biodiversity and the functional role it has for the tribal humans that is significant here. The manner in which the tribals manipulate this biodiversity for ecosystem functional integrity,

and through that for their own function within the landscape is interesting. Under a 60-year shifting agriculture cycle, the number of crop species are over 40. Here the emphasis is on cereals which are largely placed towards the base of the slope as they are less nutrient-use efficient, whilst the more nutrient use-efficient tuber crops are placed towards the top of the slope where soil fertility levels are low. Under shorter 10- or 5-year cycles, the cropping pattern shifts with emphasis on tuber crops (Ramakrishnan 1992a). This indeed is an elegant example of adaptation towards optimization of resource use and risk coverage, through manipulation of biodiversity, by the humans within the ecosystem. Through mixed cropping involving a large number of species, and traditional weed management strategies, shifting agricultural farmer of north-east India ensures effective check on nutrient loss during the cropping phase.

Within a given landscape, the tribal farmer of north-east India also has a variety of land use systems contributing towards biodiversity at all levels ranging from the sub-specific, through the species, population, and the ecosystem (Ramakrishnan 1992a,b). Thus, apart from the diversity of species at the sub-specific and species levels, he may have a variety in cropping patterns within the shifting agriculture systems, a whole variety of natural fallow forests and human managed systems such as valley rice cultivation systems and home gardens occur. These mosaic of ecosystem types of the landscape perform a variety of functions towards the integrity of the system as a whole, whilst having a variety of service functions for the humans. The valley lands capture water and nutrients washed out from the hill slopes useful for rice production. The home gardens imitating a natural forest is self-sustaining through tight recycling of nutrients within and is of value to the humans as a source of food supplement, medicines, fodder, fuelwood, fibre, spices and condiments, for their use and for cash income (Gliessman 1990, Ramakrishnan 1992a). These and the secondary successional vegetation on the hill slopes effectively capture the nutrients which could otherwise be lost through hydrology (Ramakrishnan 1992a). Indeed, evidence now suggests that the diversity and adaptability of indigenous farming practices have much to offer in explaining why some are successful at conserving resources and others are not.

The linkages that exist between the various sub-systems (agriculture with further sub-divisions within, animal husbandry and the domestic) of the village ecosystem and its further linkages with the forest ecosystem at the landscape level (figure 2) illustrates how the humans form part of the ecosystem function at the village level, and indeed form part of the landscape functional unit itself.

Linkages between Ecological and Social Processes

Linking ecological and social processes is crucial for appreciating the relationship between biodiversity and ecosystem function and to utilize this relationship for human welfare through sustainable management of resources. The linkages could be at two levels: at the process level or at the ecosystem/landscape level.

Process Level Linkages

The whole variety of patterns of crop organization as adopted by the shifting agriculture farmer of northeast India in response to soil fertility gradient on the hill slope or in response to shortening of the shifting agricultural cycle illustrate synchrony of nutrient availability with nutrient use by crop species, both in space and time (Ramakrishnan 1993). Further, sequential harvesting of crops in the multi-species cropping system is an elegant way in which the shifting agriculture farmer achieves synchrony between nutrient release and uptake at different phases of the cropping season. Depending upon differences in litter quality and micro-environmental conditions

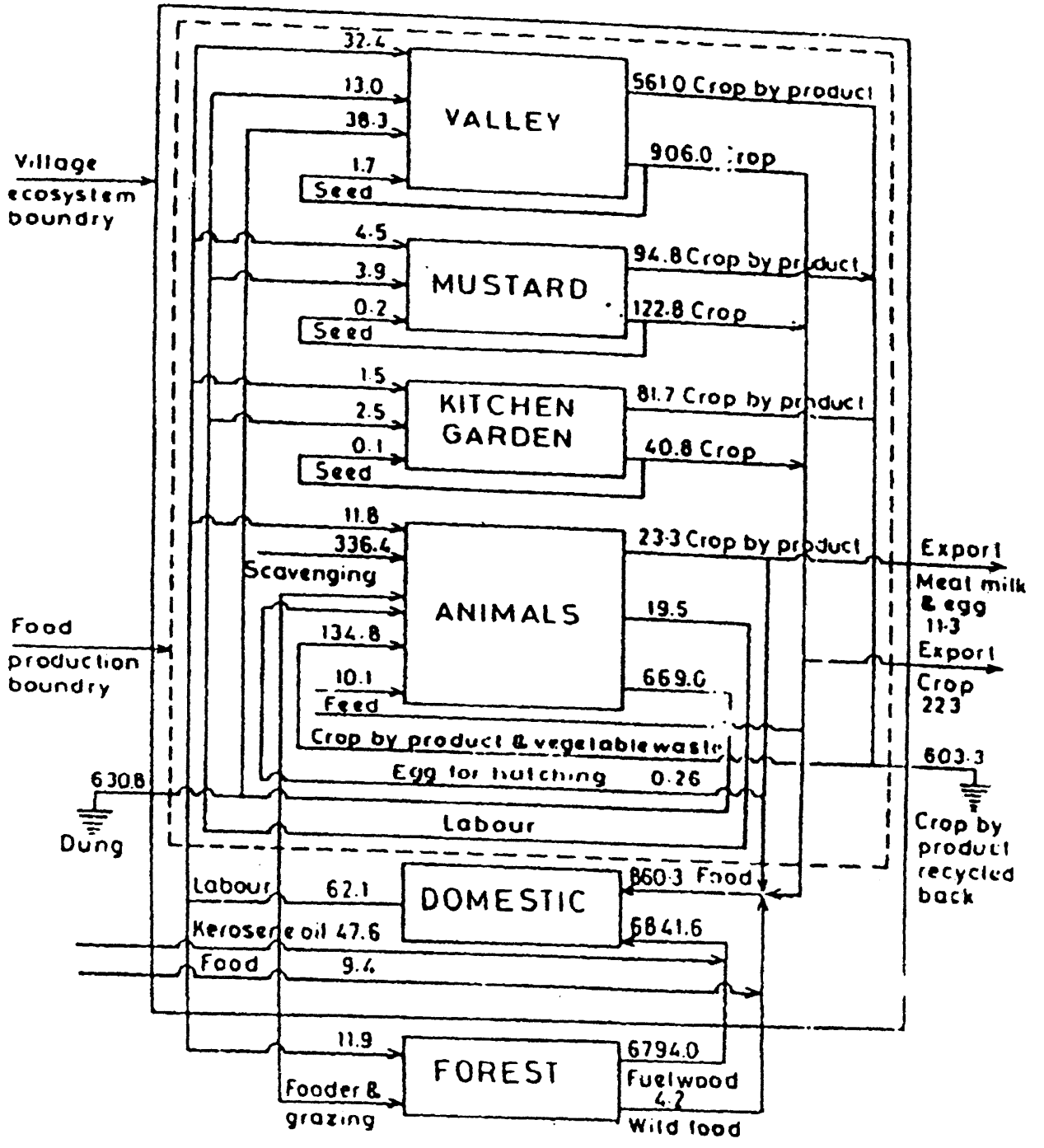

Figure 2 Energy flow diagram for the Nishi village ecosystem at Balijan in Arunachal Pradesh in north-eastern India. unit = MJ X 10^3 (from Maikhuri & Ramakrishnan 1990).

prevailing at the time, nutrient release gets regulated.

The role of keystone species in conserving and enhancing biodiversity, and indeed in manipulating ecosystem function is a critical area which has not been adequately explored. Keystone species play a crucial role in biodiversity conservation, through key functions that they perform in an ecosystem. Therefore, they could be used for not only managing pristine ecosystems (Ramakrishnan 1992a, b), but also for building up biodiversity in both natural and human-managed ecosystems, through appropriately conceived rehabilitation strategies (Ramakrishnan et al. 1994a). In many areas in north-east India where local population pressures are more intense, the shifting agricultural cycle has come down to less than 5 years, leading in extreme cases to continuous cropping year after year, through a rotational fallow system of agriculture. (Ramakrishnan 1992a).The fallow period could be a short 1 or 2 years, or it may even be just the fallow regrowth of the previous winter season. In these mixed cropping systems, the farmer uses a number of lesser known plants of food value, of which *Flemingia vestita* (Gangwar & Ramakrishnan 1989) is significant for this discussion. Selected by the farmer on the basis of experience, the tuber of this plant rich in protein and stored in gunny bags placed belowground serves as a food supplement during the lean season when traditional food supply is limited. Our studies suggest, though his mixed cropping system and by raising a pure crop of this species once in 3 to 4 years, the farmer is able to add as much as 250 kg of nitrogen per hectare per year into his plot. The farmer, on the basis of intuitive experience knows to adapt traditionally evolved technology to fit in with his present day requirements. This lesser known crop legume is a keystone species for his crop biodiversity and agroecosystem integrity, under condition of extreme pressure on the land and low soil fertility.

While working in the sacred grove forests of Cherrapunji in Meghalaya, we came across four dominant tree species, namely, *Englehardtia spicata, Echinocarpus dasycarpus, Sysygium cuminii* and *Drimycarpus racemosus* that contain a high level of nitrogen, phosphorus and potassium in the leaf tissue, inspite of the fact that these species grow in highly infertile soils (Khiewtam & Ramakrishnan 1993). These keystone species through their nutrient role in ecosystem function, they contribute towards supporting biodiversity in these relict forests, often protected by local people for religious and cultural reasons. Manipulating these keystone species is a simpler way of managing a whole variety of biodiversity in the ecosystem; they are significant species in rehabilitation ecology (Ramakrishnan et al. 1994a).

The examples of Nepalese alder *(Alnus nepalensis)* which conserves about 120 kg of nitrogen in a year through nitrogen fixation in the shifting agricultural system (Ramakrishnan 1992a,b)and bamboo species such as *Dendrocalamus hamiltoni, Bambusa tulda,* and *B. khasiana)* conserve niitrogen, phosphorus and potassium in the forest fallows also come in this category. Similarly, the Oaks in the Central Himalayan region could be viewed as keystone species, modifying ecosystem properties through their role in soil fertility, water retention within the soil profile and the consequent enhancement of associated biodiversity and indeed through their role in the economic life of the hill communities by providing fodder and fuelwood (Ramakrishnan et al. 1998). These keystone species not only determine ecosystem function in that particular seral stage of succession where it appears, but even determine the very process of succession itself due to their impact on nutrient cycling. Indeed, they modulate ecosystem function, both in space and time. Such species could be of value in rehabilitating ecosystems, following a successional pathway.

Systems Level Linkages

While linking ecological with social processes for the purpose of sustainable development with peoples' participation, one may end up with identifying one or two critical driving factors that would trigger the developmental process. To cite one such example, in the Himalayan region, the present author while working at the G B Pant Institute of Himalayan Environment and Development along with the scientists of this Institute, identified water as the key factor for landuse development in the entire Himalayan belt, right from north-west to the north-east. Water is a scarce commodity outside the monsoon season even in areas that may receive up to 24 meters of rainfall in an exceptional year, as at Cherrapunji. Leave alone water use for agricultural development, people often find it difficult to procure drinking water. Therefore it was not surprising when local communities right across a range of ecological and social situations in the Himalayas consistently identified water as the key resource in short supply. By harvesting surface run-off water of the rainy season and by diverting sub-surface seepage water through cheap rainwater harvesting tanks (Kothyari et al. 1991), we could link it with a variety of ecosystem rehabilitation efforts which elicited enthusiastic community participation. Agroecosystem redevelopment in the Garhwal and the Kumaon hills, mixed plantation forestry and Ringal bamboo related forestry activities in the Kumaon hills, whole watershed development in the Sikkim region and redevelopment of shifting agriculture in the north-east are some of the activities which had a strong community participation. Because, the critical factor was provided, namely water outside the monsoon season, rehabilitation costs were minimised and with distinct economic benefits accruing to the local communities rather quickly. Through such an approach biodiversity could be built up by strengthening of traditional agroecosystems, and by accelerating forest succession. This again works on the principle that in rural environments, it is appropriate to consider humans as an integral component of ecosystem function, for effectively managing biodiversity.

General Considerations

Sustainable development and effective rehabilitation/management of ecosystems with adequate concern for biodiversity represent two sides of the same coin (Ramakrishnan 1992b, 1993, Ramakrishnan et al. 1994a,b). To be effective, it is crucial to have a good appreciation of the role of biodiversity in ecosystem function, where in humans are well integrated within. In this view, ecological issues are tied up with social, economic, anthropological and cultural dimensions (Ramakrishnan 1992a,b, Ramakrishnan et al. 1996, 1998), since the guiding principles of sustainable development (table 2) cut across these very disciplinary realms, with obvious trade-offs.

Table 2 *The guiding principles of ecological sustainable resource management (adapted from Hare et al. 1990)*

o Inter-generational equity: providing for today while retaining resources and options for tomorrow.
o Conservation of cultural and biological diversity and ecological integrity.
o Constant natural capital and 'sustainable income'.
o Anticipatory and precautionary policy approach to resource use, erring on the side of caution.
o Resource use in a manner that contributes to equity and social justice while avoiding social disruptions.
o Limits on natural resource use within the capacity of the environment to supply renewable resources and assimilate wastes.
o Qualitative rather than quantitative development of human well-being.
o Pricing of environmental values and natural resources of cover full environmental and social costs.
o Global rather than regional or national perspective of environmental issues.
o Efficiency of resource use by all societies.
o Strong community participation in policy and practice in the process of transition to an ecologically sustainable society.

Complex Agricultural Systems and Globalization

Whilst dealing with agriculture in the contemporary context, one is faced, on the one hand, with globalization of agriculture based on high energy input, which is based on a monoculture production system using genetically engineered uniformity in organisms that could be manipulated under conditions that maximizes output. By controlling external subsidies such as water, nutrients and pesticides, under ecological situations that can easily be controlled, this market driven land use system has come to stay. On the other hand, are over 1.4 billion people (Wolf 1986) in the developing world involved in a whole variety of low input multi-species complex agroecosystems (Ramakrishnan 1992a, Swift et al. 1996) operating under difficult ecological and/or socio-economic circumstances. Essentially set upon traditional technologies developed on the basis of empirical knowledge accumulated over a long period of time, the traditional societies involved learnt to use crop and associated biodiversity in a variety of ways to strengthen the internal processes that determine stability and resilience of these systems. The emphasis here has been not so much on high production, but more towards coping with uncertainties in the environment, under not so favourable ecological situations in which these agroecosystems operate.

Globalization of agriculture so far has been towards fine-tuning high energy input systems for increasing productivity of a selected few of crop species. High energy input agriculture is the norm in the developed world, this transformation is currently occurring at a rapid pace in the developing world through 'green revolution'. This has had a number of consequences. 'Green revolution' in many parts of the developing world have led to benefits accruing to rich farmers who have access to costly inputs required to sustain them. This had led to marginalization of a greater number of small farmers who had no access to these inputs; this often has led to the small farmers concentrating on low-input systems which often operate at subsistence levels. This trend is further compounded by external subsidies becoming costlier under structural adjustment programmes initiated under the umbrella of globalization of economy. The net consequence is the increase in the land area under low-input subsistence agriculture.

Under the impact of 'global change' - large-scale deforestation for meeting industrial needs, over-exploitation of land for agriculture by ever increasing population, the associated decline in biodiversity, soil erosion and nutrient losses, and site desertification on a scale that is unprecedented - the traditional multi-species agroecosystems have often become unsustainable. This then raises a whole variety of issues on long-term sustainability of these agricultural systems. Redeveloping these traditional systems are important for the livlihood concerns of the rural poor. Further, these very agroecosystem types hold the key to the long-term sustainability of the now globalized high-input commodity oriented modern agriculture itself. The long term sustainability of modern agriculture is dependant upon the agricultural biodiversity embodied within these traditional agricultural systems.

Partly arising out of a concern for *in situ* conservation of biodiversity and partly due to adverse environmental impacts of modern agriculture, there is a renewed interest in traditional agroecosystems, as models on which new pathways for agricultural development could be designed, for long-term sustainability of agriculture (Swift et al. 1996). The concerns for sustainable agriculture is further exacerbated under increasing threat from 'global change', because the traditional agroecosystems have evolved for coping with uncertainties in the environment, though at the cost of production. The challenge then is to

build upon this traditional knowledge base, with a view to conserve the agroecosystem biodiversity, maintain resilience of agroecosystems on the face of 'global change' and at the same time to maximize economic productivity.

It is in this context we have to evaluate the impact of globalization of agriculture on these traditional agroecosystems and evaluate the options that are available to us for adapting them to meet with livelihood concerns of traditional societies in the short run and sustainable development of these communities.

Agriculture and Food Security

With over a billion people in third world countries going hungry or malnourished, by the turn of the century, the food security with equity considerations is becoming a major issue, in spite of all the advances that we have made during the last few decades through modern agriculture. Whilst some of this much needed food could be grown elsewhere and marketed to areas, where they are needed most, a substantial section of this world population will not have access to it for want of purchasing power. The worst affected are the traditional societies who have been the custodians of agricultural biodiversity which is being exploited to improve and depend upon a whole variety of multi-species complex agroecosystems (Swift et al. 1996).

Agriculture is an important economic activity for a large population of the developing world. In India,`green revolution' which is largely confined to a small section of our rural society, for instance, has had positive repercussions in terms of general self-sufficiency in food production. But, this has had its negative impacts too. Firstly this energy intensive activity is still confined to a small sector of a predominantly agricultural society. Vast sections of rural communities are left out leading to wide disparities in: (a) access to resources, and (b) income generation for want of effective and affordable appropriate technologies. More and more farmers (over 40%) have been marginalised in spite of overall self-sufficiency in food production. The worst affected are the entire tribal/traditional population occurring in different parts; much of India's biodiversity also occurs in these zones, eg., the hill people in the entire Himalayan region, the north-eastern hills, the Western Ghats, the Andaman and Nicobar islands, etc. Not only these communities have been adversely impacted by the activities of the industrial man having over-exploited the natural resources in their territories, their problems have been accentuated because of increasing population pressure and the consequent fragmentation of the land holdings, now impoverished by environmental degradation. This is apart from the difficulties faced at a national level by many developing countries including India to have access to non-renewable resources like petro-based chemical fertilizers and pesticides to sustain `green revolution' itself in the face of increasing population pressure and to cope up with the larger problems of environmental degradation caused by excessive and uncontrolled use of water and chemical subsidies. The story is the same in many countries of the developing world.

A special mention on gender and poverty would be appropriate at this stage. Traditionally, women have always played a key role in agricultural activities, in some form or the other. Even as agriculture employs 70% of the total working population, it employs 84% of all economically active women. Green revolution has had adverse impact on this vulnerable section of our society (Shiva 1988, Venkateswaran 1992). From a position of being a key player in the food production system, she has been marginalised more and more; from a cultivator to a labourer is the extreme in this marginalization process. Within a given

household, there is overwhelming evidence to suggest that women as a group are more vulnerable than men to extremes of poverty and its consequences (World Bank 1991).

Apart from equity considerations, many of the lesser-known food crops such as many legumes, coarse grains, Cassava, etc. on which many of these poorer sections of the society depend, are to be grown locally through these traditional agroecosystems. A more lasting solution obviously would be to have additional pathways for a more broad-based agricultural production system. These are the very concerns that prompted the Consultative Group on International Agricultural Research (CGIAR) to suggest that a text-book based conventional high-input agricultural technology which is tuned to the conditions of more fertile lands, has less relevance to the increasingly fragile circumstances, of drought, marginal soils, and steep slopes, under which these societies operate (Consultative Group on International Agricultural Research 1995). Indeed, as also recognized by this Group of agricultural experts, the technologies that can enable poor farmers to make sustainable livelihood under conditions of fragility of ecosystems, where soil fertility is often not sustainable through external inputs need to come from a combination of indigenous knowledge systems and modern agricultural research (Ramakrishnan 1992a, Woomer & Swift 1994).

What are Complex Agroecosystems?

Complex agroecosystems are ecosystems in which people have deliberately selected crop plants and livestock animals to replace natural flora and fauna of the site. There is a great diversity of agroecosystems, rich in biodiversity sometimes close to that found in natural ecosystems, which differ in the intensity of human intervention (Harwood 1979, Ramakrishnan 1992a) from those with only low intensity management through middle intensity management and getting on to high intensity management. Functions in agroecosystems are determined by the production goals of the farmer which include economic, cultural and often aesthetic values as well as those of biological production (Swift et al. 1994). Dependent on the circumstance of the farmer, preference may be given to short-term maximization of specialised productivity or to diversity, persistence and stability of production. These factors influence the complexity of agroecosystems and the way in which biodiversity is managed.

Classifying complex agricultural systems and relating them to agradient in management intensification is a difficult task. However, a grouping based loosely on the intensity of land use and management provides a useful framework of discussing the relationship between agroecosystem complexity and function. The following is a brief description of agroecosystem types in this gradient, starting with casually managed shifting agriculture and ending with intensely managed modern agriculture (figure 3). A whole variety of agricultural systems come under this category: *Shifting agriculture,* which is extensive in Asia, Africa and South America; *Rotational fallow* systems where the agricultural cycles get shortened; *Home gardens, consturcted* through incorporation of trees and other perennials with annuals as components of an elaborate kind; *Compound farms,* with subsystems ranging from the home garden through shifting agriculture to fully sedentary and relatively specialised fields, as found in West Africa and Asia; *Mixed arable-livestock farming,* sedentary cultivation of cereals and roots crops such as cassava done on a rotational or shifting basis in the drier savanna zones in many parts of Africa and centred around livestock production; *Traditional agroforestry systems,* in which trees are common components, either retained selectively from the natural vegetation or deliberately planted; *Agrisilviculture,* involving the use of crops and trees, including shrubs or vines on the same land, including fruit trees and

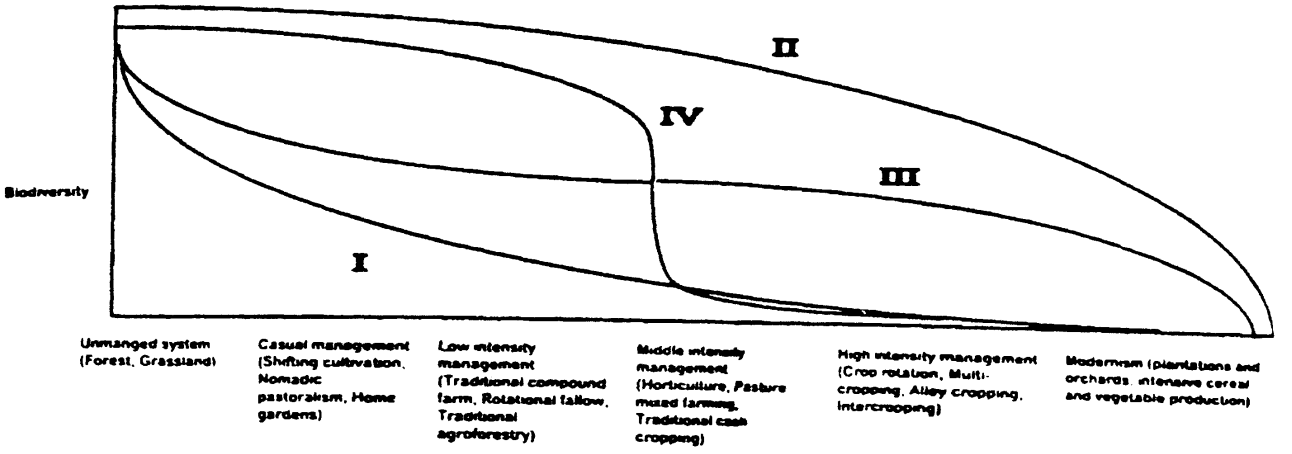

Figure 3 Biodiversity changes (four patterns) as related to agroecosystem types and intensity of management. Curve I and Curve II represent two extreme possibilities that seem to be unlikely. Curve III is a softer version the ecologists' expectations, whilst Curve IV seems to be more likely and is the most interesting from the point of view of biodiversity conservation (Swift et al. 1996)

shrubs mixed with arable crops on farmland, or trees used as windbreaks, contour barriers or boundary markers; *Silvopastoralism*, a combination of pastures and trees including grazing systems for livestock in the form of grass-legume mixtures; *Agrisilvopastoralism*, combining food crops, pastures for livestock and trees, often, with woody hedges for browse, mulch, green manure, erosion control and riverbank stablization; *Specialised cash crop systems*, of 'high value' crops, of traditional economies, handled internally, labour coming exclusively from within the family household, the products being bartered for others; *Intercropping and crop rotation*, a sedentary practice whereby more than one crop is cultivated in the same land area through space and time; *Alley cropping and farming*, where trees are planted closely in rows to form hedgerows and the crops are grown in the 'alleys' between them; and *Modern monocropping agriculture*; of high yielding varieties of a particular ideotype replacing biodiversity in agriculture, and intensely managed.

Sustainable Agriculture in the Context of Globalization

Modern high-input agriculture has come to stay. Using advanced biotechnological tools, modern agriculture will get further sharpened in the direction of better quality high production systems. However, wider inapplicability of modern agriculture, for a variety reasons that are both ecological and socio-economic (Ramakrishnan 1992a), has led to a renewed interest in traditional systems of agriculture which presumably offer the basis for ecological efficiency and sustainability, together with social justice. Sustainable agriculture not only demands efficient use of water and nutrients based on locally available resources, but also regulated cropping done in a manner that would contribute towards sustaining soil fertility (Woomer & Swift 1994).

Biodiversity in the context of agricultural intensification

It is generally acknowledged that ecosystem complexity decreases as habitats change from forest to traditional agriculture to modern agriculture. If we plot total biodiversity (not just that obviously associated with the production system itself) at each point along this gradient, it is highly probable that the resulting relationship will be monotonic and decreasing, the exact form of the curve being somewhat uncertain (figure 3).

Most ecologists concerned with biodiversity in natural systems have tacitly assumed that the pattern in Curve I is most likely to occur, hypothesising a substantial loss in biodiversity as soon as any human use and management is brought to bear on the ecosystem. Curve II representing the other extreme assumes that management has little effect until high intensity is reached; this too seems to be unlikely. Curve III is a softer version and suggests that after an initial dramatic loss in biodiversity, further losses in biodiversity are slight, until the extreme is reached in management, namely, modern agriculture. Curve IV is more probable and interesting from the point of view of managing agroecosystem complexity for stability with resilience. This suggests that biodiversity is little affected by initial stages of management and that the loss is gradual until some critical stage in management intensity is reached, followed by a rapid decline, perhaps, somewhere between low and middle intensities of management. It seems to follow from this that planning research activities should be focused on this critical gradient in management, for coping with issues relevant to biodiversity and sustainability of agriculture in the context of 'global change' (Swift et al. 1996).

Pathways for Agricultural Development

There could be three different pathways for sustainable agriculture: (a) evolution by incremental change, (b) restoration through the contour pathway, and (c) development through the auto-route (table 3) (Swift et al. 1996). Realizing that biodiversity does contribute in a variety of ways to ecosystem functions (Gliessman 1990, Ramakrishnan 1992a) and that agroecosystems do harbour a great deal of biodiversity valuable for sustaining modern agriculture and human welfare, it is reasonable that we go in for a mosaic of natural ecosystems coexisting with a wide variety of agroecosystem models derived through all the three pathways. Such a highly diversified landscape unit is likely to have a wide range of ecological niches conducive to enhancing biodiversity and at the same time ensure sustainability of the managed landscape.

Application of wrong technology and/or over-exploitation of natural resources may give short-term gains but could often lead to ecological degradation no longer sustainable by man. It is in this context that we looked at the whole question of sustainable development of the tribal communities of the north-eastern hill region in a holistic way (table 4), by building upon traditional technology as the starting point (Ramakrishnan 1992a).

General Considerations

We need to conserve and redevelop the multi-species complex agroecosystems of traditional societies for a variety of reasons. The biodiversity contained therein is crucial for continually updating modern agriculture itself through development of high-yielding varieties of traditional crop species under constant threat from pests and diseases. We owe a greater responsibility to ensure a better quality of life to these traditional societies for having conserved the agricultural biodiversity, up to the present. From the point of view of coping up with the problem of 'global change', which has already assumed serious proportions, what we do in these biodiversity rich area will to some extent determine our ability to cope up with this problem. Carbon sequestration through agroforestry.

Integrated Approach to Forest Management and Global Change

Agroforestry and Social Forestry for Carbon Sequestration

In the context of 'global change', a problem which is likely to be accentuated due to large-scale economic liberalization going on in many parts of the developing world and the consequent globalization of economy, carbon sequestration through all possible means

Table 3 *Pathways of agricultural development (after Swift et al. 1994)*

The 'autoroute' to maximal productivity:

Modern agriculture as a production system is based upon heavy external energy subsidies and in that sense is different from natural ecosystems that are regulated by internal controls. An appropriate metaphor would be the engineer who plans an autoroute by drawing a straight line from place to place on a map and proceeds to build a straight and level road regardless of the physical impediments. Such an agroecosystem type would stand apart as an artificial entity from the rest of the landscape - an attempt to convert the natural ecosystem into one that contains only those biological and chemical elements that the planner desires, almost irrespective of the background ecological conditions. eg., the 'Green Revolution' model.

Restoration: the 'contour pathway' to sustainability:

The 'contour pathway' seeks to acknowledge and work with the ecological forces that provide the base on which the system must be built, while acknowledging the social, economic and cultural requirements of the farming communities. Working with nature, rather than dominating it, this approach would involve active planning with the nature of the background ecosystem fully in mind. eg., the Sloping Agricultural Land Technology (SALT) developed in Philippines is one such system that ap proaches closer to this approach, though the initial reaction to the extension of SALT has not been very encouraging for reasons related to: (a) land tenure difficulties and (b) heavy labour investment. Many agroecosystem types in the 'low' and 'middle' intensity management categories (cf. figure 3) will come under this pathway.

Evolution by 'incremental change':

Many traditional agricultural systems need to be redeveloped through incremental, rather than quantum change; anything drastic may not find acceptance by the local communities. In this incremental change towards sustainable development, one may have to consider a short-term strategy that may be constrained because of ecological, economic, social or cultural reasons, apart from a more ideal and perhaps desirable long-term strategy. The possible ways in which a forest farmer practising shifting agriculture and other landuses such as valley wet rice cultivation or home gardens could pick up an appropriate variant from the local types that may be available or incremental change that could be brought about by strengthening the agroforestry component of the distorted shifting agriculture under a short cycle of 5 years or less through introduction of the Nepalese alder (Alnus nepalensis are illustrative of this pathway for sustainable development.

Landscape mosaic:

Compared with a landscape model that is often seen now, where pristine unmanaged ecosystems are set in a sea of intensive large-scale agroecosystems, it may be desirable to have a mosaic of agroecosystem types derived through all the three pathways coexisting with natural ecosystem types, managed or unmanaged. Maintenance of the overall sustainability of the system requires the patchwork mosaic that would, albeit inadvertently, be the best plan for biodiversity conservation in general.

has become critical. Among the many options that are available to sequester carbon and there by cope up with the adverse effects of 'global change', large-scale agroforestry for the rural poor seems to be one. This option is attractive in that it combines food production and carbon sequestration through the forestry component, within the same system.

Many of the multi-species complex agroecosystems being agroforestry systems of one form or the other, having fallen to disrepute on the face of onslaught from modern agriculture, there is a growing realization for redeveloping these systems on the lines discussed above. Such an option is becoming more and more popular in Asia and Africa, as a means for agricultural and rural development. In conjunction with social forestry activities, it forms a powerful tool for meeting a variety of rural needs such as food, fodder, fuelwood, timber and other forest products. Although, agroforestry in western nations have different labels such as silvipasture as in southern and western United States or landuse zoning and planning with involvement of general citizenry for management decisions on forest lands owned by U.S. farmers, the specifics are different from that of the developing countries (Bentley 1993). In any case, the shift is from simpler to more complex management systems. In a landscape mosaic, they form one of the components of a wide variety of ecosystem types: natural systems such as forest, grassland and fresh water pond or lake, interspersed with man-made agricultural monocropping systems such as rice, wheat or maize fields, village woodlots, etc.

Establishment and management of fuelwood and fiber plantations, intercopping systems (mixture of tree, agronomic and horticultural crops), and shelterbelts/ windbreaks are considered to be viable options to sequester and conserve carbon in terrestrial systems (Garrett 1991). Implementation of technical options are, of course determined by land availability and influenced by social, economic and political factors. Establishment of low-intensity agroforestry systems can store up to 50 t C/ha in boreal, temperate and tropical eco-regions (Dixon & Andrasko 1992).

We have no clear picture of the land availability or the suitability of the land for agroforestry development in the absence of reliable data, which gets further complicated by social and economic issues related to landuse options. However, opportunities do exist for strengthening existing agroforestry practices through science and technology input.

Integrated Forest Management

Forests are managed for a variety of purposes: timber for industrial use, forest products for rural communities, watershed of multipurpose use, and land use alterations based on land capability for carbon sequestration and/or conservation of biodiversity. Depending upon the objectives, the approach to management could differ. However, a few generalizations could be made. Traditional forestry has largely emphasized upon sylvicultural practices alone. Ecological inputs are important for determining management decisions (Ramakrishnan 1992b); this is well illustrated through the north-east Indian case study (table 4). Ecological knowledge from such areas tree biology and architechture, patch dynamics, ecophysiology of developing forest communities, reproductive biology and nutrient cycling processes could all be integrated into the current management process and future management options. In such an integrated approach to management, the socio-economic and socio-cultural issues and traditional knowledge coming from local communities need to be reconciled (Ramakrishnan et al. 1996, 1998). Deforestation and forestry in the tropics is essentially a human problem; a narrow based forestry initiative alone cannot tackle it. A broader based multi-disciplinary approach will facilitate the sharing

Table 4 *Shifting agriculture (jhum) and sustainable development for north-eastern India (from Ramakrishnan 1992a)*

For improving the system of land use and resource management in north-eastern India, the following strategies suggested by Ramakrishnan and his coworkers are based on a multidisciplinary analysis. Many of these proposals have already been put into practice.

* With wide variations in cropping and yield patterns under jhum practised by over a hundred tribes under diverse ecological situations, where transfer of technology from one tribe/area to another alone could improve the jhum, valley land and home garden ecosystems. Thus, for example, emphasis on potato at higher elevations compared to rice at lower elevations has led to a manifold increase in economic yield despite low fertility of the more acid soils at higher elevations.

* Maintain a jhum cycle of minimum 10 years (this cycle length was found critical for sustainability), when jhum was evaluated using money, energy, soil fertility biomass productivity, biodiversity, and water quality, as currencies) by greater emphasis on other landuse systems such as the traditional valley cultivation or home gardens.

* Where Jhum cycle length cannot be increased beyond the five- year period that is prevalent in the region, redesign and strengthen this agroforestry system incorporating ecological insights on tree architecture (e.g. the canopy form of tree should be compatible with crop species at ground level so as to permit sufficient light penetration and provide fast recycling of nutrients through fast leaf turnover rates). Local perceptions are extremely important in tree selection, for introduction into the cropping and fallow phases of Jhum, as is being done in a major initiative in the state of Nagaland in north-east India.

* Improve the nitrogen economy of jhum at the cropping and fallow phases by introduction of nitrogen-fixing legumes and non-legumes. A species such as the Nepalese alder *(Alnus nepalensis)* is readily taken in because it is based on the principle of adaptation of traditional knowledge to meet modern needs. Another such example is the lesser known food crop legume Flemingia vestita, traditionally used by tribals as an important species when jhum cycles decline below 5 years.

* Some of the important bamboo species, highly valued by the tribals, can concentrate and conserve important nutrient elements such as N, P and K. They could also be used as windbreaks to check wind-blow loss of ash and nutrient losses in water.

* Speed up fallow regeneration after jhum by introducing fast growing native shrubs an and trees.

* Condense the time-span of forest succession and accelerate restoration of degraded lands based on an understanding of tree growth strategies and architecture, by adjusting the species mix in time and space.

* Improve animal husbandry through improved breeds of swine and poultry.

* Redevelop village ecosystems through the introduction of appropriate technology to relieve drudgery and improve energy efficiency (cooking stoves, agricultural implements, biogas generation, small hydroelectric projects, etc.). Promote crafts such as smithying and products based on leather, bamboo and other woods.

* Strengthen conservation measures based upon the traditional knowledge and value systemtem with which the tribal communities could identify, e.g., the revival of the sacred grove concept based on cultural tradition which enabled each village to have a protected forest once upon a time although few are now left.

* In the ultimate analysis, have an integrated approach for land use development in a given ecological/cultural landscape; base short-term sustainable livelihood strategy on building upon traditional knowledge and technology; long-term sustainable development plan should based on larger ecologic/economic considerations should gradually built up to av avoid social disruptions.

of knowledge arising out of the three major components of the management strategy (figure 4).

Linking up forestry with sustainable development of rural communities by making adequate provision for food, fodder and fuelwood and timber to meet daily needs is critical (Ramakrishnan et al. 1994a) . In this effort and in providing cash income for a better quality of life, multipurpose species for agroforestry, social forestry and mixed plantations could play a useful role. Such an approach could also markedly reduce pressure on the remaining natural forests. Such a holistic approach to forest management should be linked up with agriculture redevelopment discussed above, with emphasis on landscape management.

Environmental Decision Making

Environmental decision-making has to be based on participatory research that recognizes traditional value system. With a variety of natural and traditionally managed interacting ecosystem types, traditional societies have often ensured application of a management strategy,

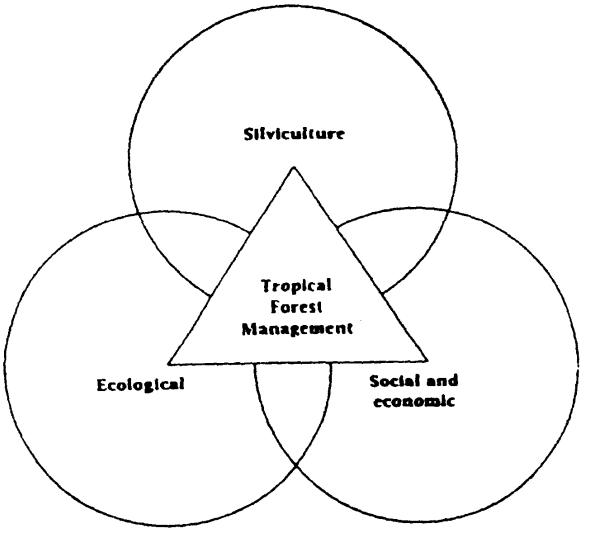

Figure 4. Interdisciplinary interactions called for in tropical forest management and conservation (from Ramakrishnan 1992b).

that is now being rediscovered in the context of a decentralized network of protected patches of biodiversity in a heterogeneous landscape (table 5). In the ultimate analysis, both at a local, national and more importantly at a global scale, we need to reconcile between ecology, economics and ethics.

General Considerations

There is an emerging view point which suggests that the pressure on forests and forest based natural resources is going to get further accentuated in the context of the ongoing liberalization and the globalization of economies currently occurring in many Third World countries. The reluctance on the part of the developed world to compensate the Third World nations to cope up with environemnet related 'global change' which to a large measure is the product of heavy resource use by the industrialized world will only aggravate the problem of biological natural resource depletion in the tropics.

What Then is Sustainable Development?

Conclusions Relevant to Sustainable Development from the North-East Indian Case Study

The Problem:

In this shifting agricultural region, during the last 20-30 years, the shifting agricultural cycle (the length of the fallow period between two successive croppings on the same site) has drastically come down from a more favourable 20 years or more to about 5 years or even less. This is partly because of large-scale timber extraction from the region leading to invasion of the landscape by exotic and native weeds, resulting in replacement of forest by an arrested succession of weeds or large-scale desertification resulting in totally balded landscape. Increasing population pressure on the land has also contributed to the shortened

shifting agriculture cycle. A shortened 5-year cycle obviously is not tenable because it exacerbates environmental problems in a variety of ways, apart from low crop productivity and social disruptions (table 6).

Governmental agencies, over the past 50 years or more, have tried in vain to replace shifting agriculture by sedentary terrace farming, which demands high energy inputs in the form of fertilizers, weedicides and pesticides. As the soil cover is thin and infertile and the nutrient losses from the system are very heavy, more and more fertilizer is often required to sustain the system over a time period, but with very low efficiencies. As weed problem gets exaggerated under

Table 5 *Loosely coupled landscape management strategy (from Ehrenfeld, 1991)*

Management plan should stimulate loose coupling within the system, rather than maximize tight coupling. Such a strategy would reduce the system's vulnerability to accidents.
Avoid manipulative management plan based on large, prioritized, single-protocol, single theory, generalized scheme. Instead for large protected areas have only a low key management plan, if required. Have individualized management for fragmented landscapes to accommodate singularities and uniqueness of each piece and ensure loose coupling.
In the ultimate analysis, management strategy should be flexible, capable of small-scale operations, information-sensitive, and composed of elements that are integrated and yet independent.

Table 6 *Shifting agriculture (Jhum) in north-eastern India and social disruption (from Ramakrishnan 1992a)*

North-eastern India has over 100 different tribals, linguistically and culturally distinct from one another; the tribes often change over very short distances, a few kilometers in some cases. Shifting agriculture of jhum as the tribals call it, is the major economic activity. This highly organized agroecosystem was based on empirical knowledge accumulated through centuries and was in harmony with the environment as long as the jhum cycle (the fallow length intervening between two successive croppings) was long enough to allow the forest and the soil fertility lost during the cropping phase to recover.
Supplementing the jhum system is the valley system of wet rice cultivation and home gardens. The valley system is sustainable on a regular basis year after year because the wash-out from the hill slopes provides the needed soil fertility for rice cropping without any external inputs. Home gardens extensively found in the region have economically valuable trees, shrubs, herbs and vines and form a compact multi-storied system of fruit crops, vegetables, medicinal plants and many cash crops; the system in its structure and function imitate a natural forest ecosystem. The number of species in a small area of less than a hectare may be 30 or 40; it therefore represents a highly intensive system of farming in harmony with the environment.
Linked on the this land-use are the animal husbandry systems centred traditionally around pigs and poultry. The advantage here is primarily that they are detritus-based or based on the recycling of food from the agroecosystem unfit for human consumption.
Increased human population pressure and decline in land area resulting from extensive deforestation for timber for use for industrial man and jhum has brought down the jhum cycle to 4- 5 year or less. Where population densities are high, as around urban centres, burning of slash is dispensed with, leading to rotational/sedentary systems of agriculture. These are often below subsistence level, though the attempt is to maximize output under rapidly deplete soil fertility. Inappropriate animal husbandry practices introduced into the area, such as goat or cattle husbandry, could lead to rapid site deterioration through indiscriminate grazing/browsing and fodder removal, as has happened elsewhere in the Himalayas. The serious social disruption caused demands an integrated approach to managing the forest-human interface.

sedentary farming, weed control assumes alarming proportion. For these ecological reasons and for a variety of social and cultural reasons related to land tenure and cultural and religious practices centred around shifting agriculture, the farmer rejected the alternates to shifting agriculture as a permanent solution to the problem. Meanwhile the highly distorted shifting agriculture now being practised under short cycles of 5 years or so has become less and less tenable in the region.

The Solution:

It is in this context that we stepped into the region to look at the whole issue of sustainable development, with people's participation. On the basis of extensive studies on agroecosystem and forest ecosystem function under a variety of situations and human ecology based analysis of village ecosystem function, short-term and long-term possibilities for sustainable development were recognized. A holistic approach for sustainable development that would link up agriculture, animal husbandry, and domestic sub-systems of the village ecosystem in the overall context of forest ecosystem function and management was identified (table 4).

The short-term (5-10 year) strategy considered transfer of technology from one tribe to another, as one of the path-ways. Strengthening agroforestry component of the shifting agriculture system using locally identified and acceptable species such as the Nepalese alder *(Alnus nepalensis)* and improvement of valleyland agriculture and home gardens with appropriately identified scientific inputs (linking traditional with modern technology) was considered as part of the short-term strategy. On the other hand, a shift towards plantation economy based upon the home garden concept and organization of families on a cooperative production/marketing system along with forestry based activities was considered to be a possible long-term (50 - 100 year) objective for sustainable development of the region.

The whole approach was to build upon traditional technology and knowledge base through modern scientific inputs, based upon a value system with which the people can identify themselves and therefore participate effectively in the developmental process.

Specially designed packages have to be developed for each cluster of villages, taking into account micro-climatic conditions, socio-economic levels, and socio-cultural background of the people. The aspirations of tribal people are unique (Ramakrishnan 1992a) because of their close integration with the forest environment. This dependence on nature is reflected in the undisturbed "sacred forest" which was often maintained as part of the village system. These village ecosystem-rain-forest ecosystem linkage characteristics should be adequately protected when planning for development. Embedded within these interlinked economic-ecologic systems are traditional ways for enhancing and protecting biodiversity.

Scientists, planners and administrators have often tried to impose development plans that they consider are good for people in the region, without trying to understand the social processes that operate in traditional societies and the linkages with ecosystem level processes. Planning should try to link up ecological processes within a land-scape (a set of interacting ecosystem types), with social processes operating within the system. Such a planning philosophy would take care of the traditional value systems, and therefore, would not only find ready acceptance by the tribal societies but would also ensure their participation in the developmental process.

The village headman is the key person in each tribal settlement. Village level institutions linked with the District Council infrastructure could provide the necessary institutional framework for development planning. The planning approach should incorporate a

review period so that appropriate adjustments may be made based on experience. Village Development Boards (VDB) constituted by the Nagaland Government (Anonymous 1980) appropriately linking up the existing Village Councils, for the purpose of managing developmental funds allocated for rural development is a model that is initiated in the right direction, for ensuring peoples' initiatives and participation.

General Considerations and Indicators of Sustainability

Sustainable development of local communities, effective management of natural resources with concerns for conserving biodiversity, and indeed rehabilitation of degraded/altered ecosystems in the context of climate change phenomenon are all closely interlinked with one another. Ecological issues are tied up with social, economic, anthropological and cultural dimensions, since the guiding principles of sustainable development (table 2) cut across these very disciplinary realms, with obvious trade-offs.

This implies that we have to make a series of compromises to achieve sustainable development in such a way that we do not lose track of the ultimate objective, namely, rehabilitation and management of natural resources in a manner that satisfies current needs, at the same time allowing for a variety of options for the future. Though an ecosystem type (man-made ecosystems such as agriculture, a fish pond in a village or village itself visualized as an ecosystem; or natural ecosystems such as grazingland, forest or river) may be the appropriate unit for convenient handling of the issues involved in sustainable management of natural resources, a cluster of interacting ecosystem types (a 'landscape') may be the most effective for a holistic treatment (Ramakrishnan et al. 1994a). A watershed is one such landscape unit. Further, from a sustainable developmental point of view, while one may bear in mind a long-term ideal objective to be achieved, ecological, social economic or cultural constraints may necessitate designing short-term strategies, for enabling peoples' participation in the developmental process. To quote one example, while forest-based economic activities and cash-crop plantation programme may be the most appropriate as a long-term alternative to shifting agriculture in north-east India, there is no option except to have a redeveloped agroecosystem package for the region using traditional knowledge and technology as the starting point for a short-term strategy (Ramakrishnan 1992a). The long-term strategy has to be reconciled with short-term requirements. Thus, sustainable development has spatial and temporal dimensions that needs to be reconciled.

Indicators of sustainable development are varied; therefore, here again, compromises are called for. Monitoring and evaluation has to be done using a number of diverse currencies (Ramakrishnan, 1992a, 1993) that may be : (a) ecological (landuse changes, biomass quality and quantity, water quality and quantity, soil fertility, and energy efficiency), (b) economic (monetary output/input analysis, capital savings or asset accumulation, and dependency ratio), social (quality of life with more easily measurable indicators such as health and hygiene, nutrition, food security, morbidity symptoms; the difficult to quantify measures such as societal empowerment, and the less tangible ones in the area of social and cultural values). We have considered all these diverse currencies to arrive at a meaningful sustainable developmental strategy for north-eastern hill areas of India (Ramakrishnan 1992a). The assumptions (table 7) which form the basis for rehabilitation of degraded rural landscape are equally applicable whilst considering the diverse currencies for sustainable development.

Further, institutional arrangements have to ensure peoples' participation, through a

Table 7 *Assumptions forming the basis for rehabilitation of rural land scape in the Asian tropics (from Ramakrishnan et al. 1994)*

A.1.Rehabilitation ecology has to effectively integrate ecological, economic, social, cultural and political dimensions of the setting in which it is attempted. In this, ecological concepts and processes should tie up with social processes and perceptions.
A.2. In order to integrate these components, effective linkages between the people and their institutions, governmental agencies, non-governmental organizations, scientists and technologists are essential.
A.3. Since there are many interconnections between ecosystem types in a landscape,and since tinkering with one type may impact another, it becomes imperative to consider landscape as a networking unit for rehabilitation. The approaches for a given ecosystem type may differ,but within a given framework.
A.4. An understanding of the ownership and use patterns of natural resources (private, common, public or any combination of these three ownerships) are critical for strategies and will require different rehabilitation tactics.
A.5. Rehabilitation may have to operate under varied ecological/economic/social/ legal/political/cultural constraints. Further, the objectives of rehabilitation may differ. Therefore, one may have to consider different time frames: short (upto 10 years) or long term (upto 100 years) strategies.
A.6. Whilst rehabilitation work should provide a wide range of benefits to stake holders, the socio-economic needs of the local communities and user groups should be a major consideration.
A.7. Ecological and socio-cultural concerns should determine technological interventions in order to ensure that the outcome agrees with local perceptions and value system.
A.8. Appropriate policy decisions are important for effective implementation of rehabilitation programme; while doing so such decisions should take into consideration all the ramifications (ecological, social, cultural and economic) that may act as an incentive/disincentive for rehabilitation.
A.9. Soil and water conservation and management is crucial for ecosystem rehabilitation.
A.10. Understanding the history and the causes for the present status of ecosystem degradation is crucial for designing strategies for rehabilitation and management.
A.11. Ecosystem rehabilitation and management is a dynamic process and therefore should be monitored continuously, and should be flexible and responsive to modifications.
A.12. Ecosystem rehabilitation and management is site specific.

bottom-up approach for their organization, ensuring that each household takes part in the decision making process at the lowest level in the hierarchy, and with special dispensation for the weaker and vulnerable sections of the society. Village development Boards (VDB) of Nagaland, in India is a case relevant to this discussion (Anonymous 1980). Village based Institutions such as the VDBs of Nagaland are formed with due representation given to each family, taking into consideration gender sensitivities, and more importantly by allowing the formation of the local Boards based on the local value system that they have always cherished and conserved. Such village level Institutions could be successfully broadened with inputs from scientists, non-governmental players (NGOs), and governmental agencies, as has happened with joint forest management committees that have become so successful in many regions of the Asian tropics (Ramakrishnan 1992b, Ramakrishnan et al. 1994a,b).

Local level institutional framework, should consider the following aspects: (a) identification and strengthening of local level institutions that are already available such as those existing in the north-eastern region; (b) the

representative nature of these bodies and the extent to which individual family interests are taken care of; (c) their role in decision making right from the project formulation stage through different levels of implementation; (d) flexibility in function so as to take care of the interests of all sections of the society; (e) education and human resource development that these institutions have been able to trigger, particularly for weaker and vulnerable sections of the society; (f) ability of these institutions to stand on their own through empowerment in terms of capability building. These were the considerations that formed the basis for developing a set of general hypotheses (table 8) for rehabilitation of degraded ecosystems and sustainable livelihood for local communities in the Asian tropics. During recent times, there has been a variety of attempts to arrive at 'composite indicators' which may cut across ecological, social, economic and institutional dimensions. The question that arises is whether the indicators of sustainable development discussed above be linked to one 'composite indicator'. On the basis of my experience, the answer to this question has to be location and problem specific. I talked about conservation of water as a triggering agent for a variety of agricultural development activities and rehabilitation activities, under the monsoonic climate, that could be viewed as a composite indicator for sustainability of land use systems - this commodity then could be viewed as a 'composite indicator' of sustainability since this element helps in strengthening the internal processes within both natural and human- managed ecological systems, rather than demanding external

Table 8 *General hypotheses forming the basis for rehabilitation of the rural landscape in the Asian tropics (from Ramakrishnan et al. 1994a)*

G.1. Rehabilitation and management would only succeed if short-term economic benefits are assured to local communities, apart from long-term benefits envisaged.

G.2. If rehabilitation and management strategies are to be effective and successful, womens' participation is necessary.

G.3. Without a broad understanding of the complexities of the system (through rapid appraisal methodology), rehabilitation strategies may not succeed.

G.4. Unless ecosystem rehabilitation and management leads to a general improvement and maintenance of soil fertility and water quality, it is not sustainable.

G.5 Ecosystem rehabilitation will be sustainable only if: (a) internal control of processes (e.gresource recycling) within the ecosystem are strengthened, (b) inpendence on external subsidies (e.g., fertilizers) are minimised, and (c) self - regenerating capacities enhanced, to the extent feasible.

G.6 In order to succeed, ecosystem rehabilitation should have strong community participation in planning, management, implementation, and continuous monitoring of all these parameters.

G.7 Unless rights and responsibilities of ownership are clearly defined and understood by all the participants, ecosystem rehabilitation is not likely to succeed.

G.8 If community participation is to be effective, community / user group insitutions will have to be built to be built into the rehabilitation strategy.

G.9 Unless and capability analysis and classification, taking into consideration scientific/traditional knowledge is integrated, rehabilitation work will not be effective and sustainable.

G.10 Empowerment (training, institutional, access to facilities and resources) of local communities in general and vulnerable sections (landless and women) in particular is crucial for the success of any rehabilitaion programme.

G.11 In order that rehabilitation work is sustainable, surface and ground water resources and its exploitation is monitored and appropriately regulated through institutional mechanism.

subsidies which otherwise may be required for rehabilitation work (Ramakrishnan et al. 1994a). This 'composite indicator' impinges upon all the diverse indicators, bringing about ecological alterations to the system, social changes, economic well being to the communities and people's participation through appropriate institutional arrangements.

Earlier, I discussed the two keystone species, the role of *Alnus nepalensis* (the Nepalese alder) in north-eastern land use practices and the role of *Quercus* spp. (the Oak, locally called 'Bhanj') in the Central Himalayan region. Both are socially valued species. The former agroforestry tree species helps in stabilizing the shifting agriculture through improving soil fertility; being an early successional species in the shifting agriculture system, it determines the successional process itself, both in space and time, because of its role in improving the soil nitrogen within the fallow and thereby enhancing the associated biodiversity. The oaks in the Central Himalaya contribute towards soil fertility, water conservation and for meeting varied house-hold requirements of the local communities. No wonder that 'Bhanj' has been exalted to high level, through their incorporation into the traditional folklore. Indeed, the large-scale conversion of mixed oak forests to pine plantations, during the last hundred years, could be viewed as the real causative factor for the now famous' Chipko movement' which invoked intense local participation, leading to enactment of regulations to control forest conversion in this region. Because of their multipurpose value in the rural landscape, these two species qualify to be viewed as a 'composite indicator' for sustainability of the system. The extent to which these two species form part of the landscape functions, would reflect a whole variety of the ecological, social, economic and institutional indicators (figure 5), in the same manner water could be viewed, as discussed above.

In the ultimate analysis, we need such location-specific and issue-specific composite indications', apart from a whole set of individual

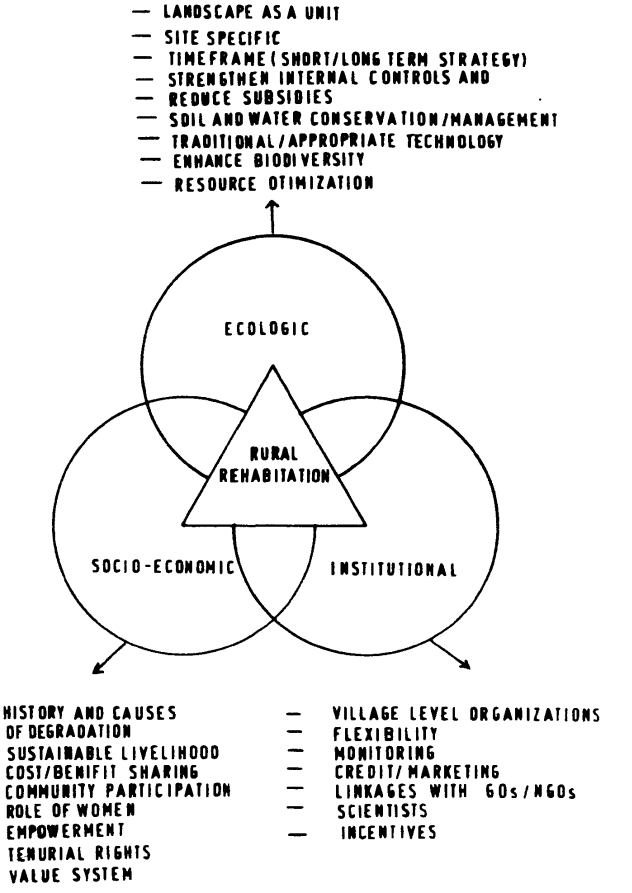

Figure 5 Integrative diagram linking the three major issues and many sub-issues crucial for rural rehabilitation

ones. This is still an emerging area, and offers a variety of opportunities for further refinement and development.

Biodiversity, Ecosystem Complexity, Landscape Dynamics Related to Golobal Change: the Emerging Paradigms

During this discussion, we have argued for integrating humans within the ecosystem boundary, since traditional societies in the biodiversity rich areas of the developing tropics indeed contribute towards determining the functional attributes of natural ecosystems, from within; this is unlike the modern human societies are divorced from natural ecosystems and impact upon them from outside. Such a paradigm shift tends to view ecosystem perturbations from a totally different perspective;

this in turn has implications for ecosystem/ landscape management, biodiversity conservation and their sustainable use. It is in this context the whole issue of sustainable management of natural resources and sustainable livlihood/development of traditional societies who are the custodian biodiversity need to be understood.

An ecological agenda which has started receiving considerable attention, not only from the scientific community at large, but also from natural resource manages, planners and administrators, environmental activist groups, governmental and non-governmental development agencies, is what may broadly be termed as 'global change'. Climate change related to global warming, biodiversity depletion due to over-exploitation of natural resources by the industrial society, rapidly increasing rates of biological invasion by exotics as a result of globalization and the concept of a global village leading increasingly rapid movement of biological materials from one part of the globe to another, land use and land cover changes occuring at rates that have never happened prior to industrial revolution leading in extreme situations to 'desertification' are the important elements of global change.

Of these, climate change is reversible, given the right technological innovations to combat pollution related impacts at local, regional and global levels, over the next 50 years or so, though climate change itself may impact upon the other components of 'global change' in a variety of different ways. Biodiversity, about which we have discussed a lot here, once lost cannot be retrieved at any cost; in other words biodiversity depetion is an irreversible component of 'global change' and therefore is much more disturbing. Biological invasion and land use related cover changes are reversible processes, though at a great economic cost and human effort; the problems related to rehabilitation of severely degraded ecological systems as a consequence of these two components are indeed very complex (Ramakrishnan et al. 1994).

It is in this context of differential impacts of the various components of global change that we have to view the issues concerning natural resource management and sustainable livelihood/development of traditional societies in the biodiversity rich areas of the tropical world, as is attemped here. To put the relevant issues in context, the much talked about climate change is a product coming from the industrialized world, though the developing world is also now moving in that direction; poverty and population only exaggerates the problem. In this context, any discussion on poverty. On the other hand, all land use based 'global change' issues directly impinge upon the quality of life in the developing world itself - land use changes leading to site desertification, biodiversity depletion and biological invasion have direct impacts on the quality of life in the developing world. Depletion of biodiversity arising out of land use changes, indeed, will also adversely impact upon the very developmental processes and quality of life promoted through currently available modern technology - agriculture, health care, energy conservation through carbon sequestration.

In the ultimate analysis, it is crucial that we conserve and manage our biodiversity 'hot spots', with adequate concerns for conservation and management of biodiversity and sustainable livelihood/development of the traditional societies living within the ecosystem/landscape as an integral component of its functioning. Traditional societies have always manipulated biodiversity in a variety of different ways in order to ensure resilience in natural and human-managed ecosystem functioning (Ramakrishnan 1992a, Ramakrishnan et al. 1996). Understanding this traditional knowledge is

important in managing biodiversity for ecosystem resilience in the context of 'global change', an area of current international interest, under a variety of initiatives such as the International Geosphere Biosphere Programme (IGBP) dealing with the biophysical issues and the International Human Dimensions Programme (IHDP) concerned with the human dimensions of 'global change', biodiversity indeed is an area of concern, as one of the important components of 'global change', the DIVERSITAS, concerned with the science of biodiversity, and the Global Invasive Species Programme, dealing with biological invasion. In all these initiatives, scientists are still trying to grapple with the problem of dealing with the human dimensions in ecology - and an emerging set of paradigms. As discussed here, we have a lead in this link-up of ecological processes with social processes, the key to sustainable natural resource management; this is an emerging area of research where the challenges involved in building new paradigms in ecology are indeed very exciting.

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