Review/synthesis

Land use in Kerala: changing scenarios and shifting paradigms

B.M. Kumar*

Department of Silviculture and Agroforestry, College of Forestry, Kerala Agricultural University, KAU PO, Thrissur 680 656, Kerala

Received 7 March 2005; received in revised form 20 September 2005; accepted 30 September 2005

Abstract

Agricultural land-use changes in Kerala during the past half-century were marked by an initial increase in total cropped area (26% between 1960 and 1969), followed by dramatic shifts in the coverage of individual crops. For example, rice area dropped by 60% between 1975 and 2003, while the cultivation of coconut, rubber, arecanut and banana+plantains increased spectacularly (106, 627, 41 and 96% respectively between 1955 and 2000). Agricultural expansion coupled with over-exploitation of forests has affected the state's forest ecosystems, however. Primary forests dropped substantially between 1940 and 1970—average loss of publicly managed forests being 5000 ha per year. Satellite imageries show a further drop thereafter, with a concomitant loss of biodiversity. As monospecific cultivation methods became extensive and the live fences/scattered trees on farmlands were decimated, the capacity within the agricultural sector to meet its own demands (green manure, poles, fodder, firewood and timber) also reduced, which in turn, increased the dependence on forestlands.

In the light of environmental degradation and the need for climate change mitigation, a paradigm shift in the state's land management is imperative. Agroforestry, which aims at optimizing productivity and above all, sustainability, has the potential to provide many resources for which the people have traditionally depended on forests. Yet, as a modern land management strategy, agroforestry has not received adequate attention in Kerala. Agroforests if established on degraded lands will not only reduce the anthropogenic pressure on existing forest resources but also will enhance the sink potential of CO_2.

Keywords: Agricultural intensification, agrobiodiversity, agroforestry, carbon sequestration, forest cover, land-use changes

Introduction

The philosophy and methods of land use in Kerala have changed over the past half century or so. Historically, agroecosystems in the Western Ghats have depended on the forests in a myriad of ways. A unidirectional flow of materials from forests such as wood for fuel, poles and timber, leaves/litter for manure and mulch, fruits and nuts for food, green fodder and various other non-timber products, constitutes the core of this relationship. Forests also serve as repositories of genetic diversity and confer hydrological benefits; besides facilitating soil and water conservation, micro-climatic modification and CO_2 sequestration. Despite this, forests were cleared in the past for agricultural expansion, plantation development and for various other developmental activities (Menon and Bawa, 1997; Jha et al., 2000). Despite the promotion of ecodevelopment and sustainability, forest destruction for agricultural and other uses continues unabated. In this paper, I summarise how the land use pattern of Kerala have changed over years and what are its principal impacts on the agroecosystems. Development of sustainable land use systems, which optimises the combined production of trees and field crops, and mitigate climate change are also addressed.

*Author for correspondence: Phone +91 487 237 0050; Fax +91 487 237 1040; E-mail <bmkumar53@yahoo.co.uk>

Agricultural land use changes in Kerala during the past five decades-an overview

Data presented in Fig. 1 clearly show that the area under cultivation increased from 2.3 million ha in 1960 to 2.9 million ha during 1969. This, in turn, was associated with a dramatic rise in the coverage of rice (*Oryza sativa*), i.e., between 1955 and 1970 rice area increased by *c.* 150,000 ha. Since then, however, the total cropped area remained more or less stagnant, while the area under rice cultivation plummeted by about 526,000 ha—indeed a 60% drop between 1975 and 2003. Concomitantly, there has been a pronounced "coconut (*Cocos nucifera*) and rubber (*Hevea brasiliensis*) boom". That is, coconut area increased by 106% between 1955 and 2000; thereafter it, however, stabilized. Likewise, rubber area expansion in the state for the 1955 to 2000 period was 627%. Other crops that gained substantial coverage over the same period include arecanut (*Areca catechu*: 41%), banana and plantains (*Musa* spp: 96%). Cassava (*Manihot esculenta*), however, lost much of the area that it occupied in the mid-1970s. Overall, the land-use changes represent an intricate pattern especially in view of the wide variations in physical settings and the complex development patterns adopted in the past. Yet, a clear shift away from food crops, mainly rice and cassava, in favour of tree crops such as rubber and coconut (Fig. 2)

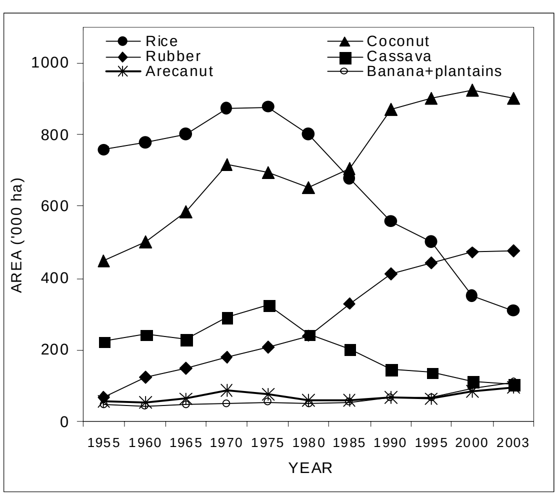

Fig. 1. Quinquennial changes in area under major crops of Kerala (source: KSLUB, 1995 and Farm Guide, 1995 to 2005)

and some of the export-oriented cash crops such as pepper (*Piper nigrum*), ginger (*Zingiber officinale*), coffee (*Coffea* spp.) and cashew (*Anacardium occidentale*) was discernible.

Fig. 2. Shift in land-use pattern of Kerala - conversion of paddy lands to coconut groves

George and Chattopadhyay (2001) observed that such shifts in land-use may have profound implications for the food security of the state, which already depends on 'outside supplies' to meet more than half the its food grain requirements. In addition to the conversion to upland crops owing to socio-economic and/or technological/commercial reasons, population growth and urbanisation have led to a marked increase in clay mining (for brick making) and other non-agricultural uses of land (Fig. 3), which further exacerbated the situation.

Impact on forest ecosystems

Agricultural land-use changes have impacted the forest ecosystems of Kerala in two major ways; first, a conspicuous shrinkage of the state's forest cover and, second, the loss of structural integrity of the remaining forests.

Declining forest cover

Over the 30-year period from 1940 to 1970, there was

Fig. 3. Changing land-use in Kerala – paddy lands appropriated by the brick-kiln industry

a steep drop in the state's forest area (Fig. 4) with the cumulative loss of publicly managed forests (*c.* 154,000 ha) averaging 5,000 ha annually. This declining trend is also reflected in the comparisons involving topographical maps of 1905 and the LANDSAT images of 1973 and 1983 (Chattopadhyay, 1985). The forest cover of Kerala dropped from 44.4% in 1905 to 27.7, 17.1 and 14.7% respectively in 1965, 1973 and 1983—indeed a 0.27% annual forest loss from 1905 to 1965 and average 1% drop thereafter (1965 to 1973). A study by the National Remote Sensing Agency for the period from 1972 to 1982 also demonstrated an annul deforestation rate of 1.4% of the total forest cover in Kerala (Nair, 1991)

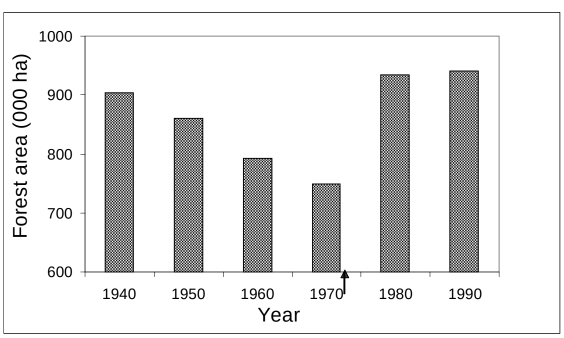

Fig. 4. Decennial changes in forest area under public ownership (effective) in Kerala, 1940-1990 (source: Kerala Forest Statistics, 1956 to 1992, arrow refers to vesting of private forests). Forest plantations account for 16.36% of the total area (http://www.prd.kerala.gov.in/prd2/forest/forestinner.htm)

signifying that the 1970s were a period of most intense deforestation.

George and Chattopadhyay (2001) highlighted four distinct phases of deforestation in Kerala; *viz.*, (1) extensive conversion of forestlands to plantations following a Royal Proclamation in the late nineteenth century, (2) the "Grow More Food" campaign of the mid-1940s when substantial areas of forests were opened up for the cultivation of food crops, (3) colonization during the 1950s and 60s which created new settlements in the deforested areas, and (4) infrastructure development of the post-independence era during which projects in power, irrigation and transportation sectors were set up on forestlands. Shifting cultivation also was widespread in several parts of Kerala during and after the late nineteenth century (Pouchepadass, 1995).

In view of the unprecedented rates of deforestation, and the rapidly rising human population pressure, the per capita forestland availability in the state declined from 0.060 in 1961 to 0.034 ha in 2001 (Fig. 5). Despite a substantial clearing of forestlands for agriculture, the cultivated land per capita also dropped from 0.14 to 0.077 ha between 1961 and 2001 mainly because of population growth during that period. However, from 1980 onwards, the official statistics show that the effective forest cover (under public management) in Kerala has stabilised at ~940,000 ha (Fig. 4). The increment of approximately 200,000 ha between 1970 and 1980 is due to the annexation of private forests under the 'Kerala Private Forests (Vesting and Assignment) Act' of 1971.

Although the official estimates do not reflect any decline of forest area in the recent past because of the reporting system used, the post-1980 studies based on satellite imagery clearly show that the primary forests of Kerala have declined. For example, Prasad et al. (1998) indicated that the annual decline in natural forest cover of Kerala for the period from 1961 to 1988 was ~0.90%. Likewise, Jha et al. (2000) showed that forest cover in the southern part of the Western Ghats (~4,000,000 ha) declined by 25.6% over the 22 years from 1973 to 1995. There has been, however, a great deal of temporal and spatial variability in this respect. According to Jha et al. (2000),

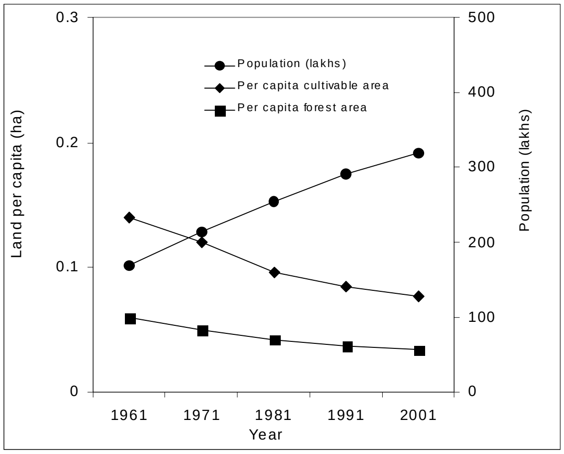

Fig. 5. Changes in population (lakhs), cultivable land per capita (ha) and forest land per capita (ha) in Kerala from 1961-2001 (source: KSLUB, 1995; Farm Guide, 2005)

Palghat district experienced an annual rate of 2.1% loss of dense forests between 1973 and 1995, while Ernakulum and Kozhikode experienced relatively lower loss rates (0.1% and 0.6% respectively). Deforestation rates have also accelerated in recent times. For instance, Ramesh et al. (1997) reported a five-fold increase in deforestation between 1920 to 1960 and 1960 to 1990 for the Agastyamalai region in southern Western Ghats.

Over-exploitation of the remaining forests

The declining ratio of forests-to-agricultural lands and the increased intensity of land-use increased the pressure on remaining forests due to illicit cutting of trees (for firewood, charcoal and for making agricultural implements), overgrazing and collection of fodder, green leaf manure, litter and non-wood forest products (Jayanarayanan, 2001; Amruth, 2004; KFRI, 2005). In addition, the local people frequently set fires in the forests for promoting grass growth that benefits the grazers by enriching soil fertility of the crop fields in the fringe areas through post-fire ash transport in rains, facilitating easier extraction of non-timber forest products and so on (Kodandapani et al., 2004; Muraleedharan et al., 2005).

Little quantitative information, however, is available on many of these anthropogenic activities, so that it is impossible to assess the precise impacts. Nonetheless, it is reasonable to assume that increasing levels of disturbance are accompanied by a reduction in forest biomass, impaired vegetation structure, altered regeneration spectrum, floristic changes and an opening of the forest canopy. Consistent with this, field-level observations indicate that about 19% of the state's actual forest cover is 'open' (i.e., crown density below 40%; Table 1). Narayanan (1988) reported that pole stage crop was poorly represented in the natural forests of Thrissur division (Fig. 6). Altered light and soil moisture availability is yet another consequence of such structural changes in vegetation. This, in turn, may favour regeneration of deciduous species often at the cost of shade tolerant and moisture-loving evergreen species (Pascal, 1988; Rajesh et al., 1996). Likewise, the recurring fires may lead to the predominance of fire-hardy species (Hegde et al., 1998).

As forests have declined at an unprecedented rate, especially in the highlands of Kerala with its rolling topography and heavy rainfall, soil erosion continued unabated leading to reduced soil quality and low productivity (Vinod et al., 2003; KFRI, 2005). According to the Kerala State Planning Board (2003), there are about 1,476,000 ha of degraded lands in Kerala, of which about 950,000 ha experience moderate-to-severe erosion intensities. Diminished infiltration rates and greater run-off from catchment areas (Meunier, 1996), flash floods and high rates of sediment production in mountain streams are also seemingly widespread. For example, sediment production rates in various hydro-electrical reservoirs of Kerala have been estimated to range from 4.43 to 71.05 m^3 ha^{-1} yr^{-1} (Kerala State Planning Board, 2003), signifying a considerable drop in the reservoir

Table 1. Actual forest cover of Kerala by density classes

Density classes	Area (000 ha)
Dense forest (crown density above 40%)	842.9
Open forest (crown density 10-40%)	189.4
Scrub area (tree lands with <10% crown density)	9.1
Non-forest	2844.9
Total	3886.3

Source: FSI (1999)

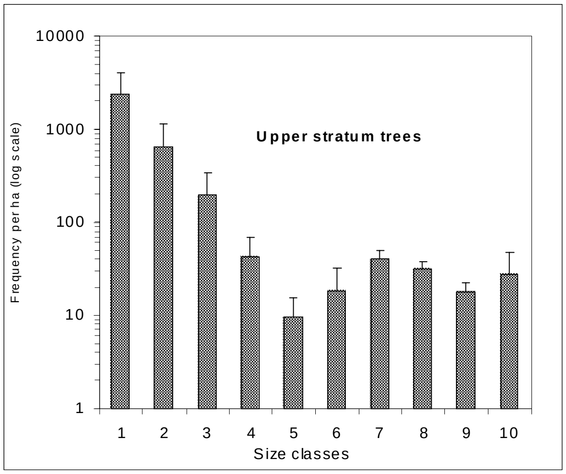

Fig. 6. Size class distribution (total number of individuals) of upper stratum species in a moist deciduous forest of Thrissur, Kerala [Size classes: 1) height ≤50 cm, 2) height >50 and ≤100 cm, 3) height >100 cm and diameter at breast height (dbh) <1 cm, 4) dbh ≥1 and ≤10 cm, 5) dbh >10 and ≤20 cm, 6) dbh >20 and ≤30 cm, 7) dbh >30 and ≤40 cm, 8) dbh >40 and ≤50 cm, 9) dbh >50 and ≤60 cm and 10) dbh >60 cm; Source: Narayanan (1988)]. Error bars indicate standard deviation.

capacities (4.18% in Pamba to 30.9% for Anayirankal). The recent landslides in Idukki and Wayanad districts also have been linked to forest destruction and the changing cropping patterns especially in the upland watersheds.

Yet another consequence of the over-exploitation of the natural ecosystems is the reduced supply and availability of poles, small timber, fuelwood and charcoal, and leaves/ litter for manure and fodder (Pandurangan and Nair, 1996; Jayanarayanan, 2001; Muraleedharan et al., 2005), besides loss of wildlife habitats (Venkataraman et al., 2002). The latter, in particular, has led to increased conflicts between humans and wildlife, especially in areas such as Wayanad and Idukki, where crop-raiding by wild elephants is a recurring phenomenon (KFRI, 2005).

Declining biodiversity

In general, species adapted to forest ecosystems typified by local, small-scale disturbance and gradual changes may be unable to persist in landscapes where human land-use intensified the disturbance regimes. Excessive clearing of forests and the loss of structural integrity, thus, may lead to a severe erosion of biological diversity (Hermy et al., 1999). Western Ghats, one of the "biodiversity hotspots" in the world (Myers, 1988) is particularly vulnerable in this respect (Menon and Bawa, 1997). There are about 1272 known species of endemic angiosperms (out of the 3800 species) occurring in the Kerala part of the Western Ghats (http://www. keralaforest.org/html/flora/endemic.htm). Furthermore, of the 300 rare, endangered or threatened plant species in the entire Western Ghats, 159 occur in Kerala (http://www.keralaforest.org/html/flora/rareplants.htm). The uncertainties that still surround our knowledge of tropical biota (including the extant species) and the difficulty of recording the extinctions, however, complicate the matter. Suffice to say that considerable damage has already been done to some of the unique forest types of Western Ghats. In particular, substantial portions of the fresh water swamp forests and mangroves were already converted to crop fields/aquaculture areas, leading to local extinction of many endemics (Varghese and Kumar, 1997). One of the challenges of biodiversity conservation in Kerala, therefore, is to locate areas of high concentration of endemic species so that critical endemic plant sites can get priority for conservation.

Effects on agrobiodiversity and ecosystem services

Land-use changes, and in particular agricultural intensification, affect the biodiversity of managed landscapes. Indeed, a large proportion of the Kerala homegardens has been converted into small-scale plantations of coconut and rubber or cropping systems consisting of fewer crops due to commercialization and fragmentation of land holdings (Kumar and Nair, 2004). Coincidentally, many local varieties of mango (*Mangifera indica*), jackfruit (*Artocapus heterophyllus*) and other traditional fruit/vegetable crops, which were once abundant in the Kerala homegardens, are now thought to be extinct (Santhakumar, 1996; Kumar and Nair, 2004). With the advent of the high-yielding variety (HYV) programme in Kerala, most of the paddy lands (81% coverage according to the Kerala State Planning Board, 2003) were also dedicated to modern varieties;

consequently, cultivation of a vast majority of the distinctive landraces have vanished. Quantitative data on such species/landrace losses, however, are not available; yet it seems reasonable to surmise that genetic diversity of the agricultural lands in most parts of the state has declined.

Such biodiversity losses, however, have resulted in a reduced capacity of agro-ecosystems to perform many ecosystem services that underpin agricultural productivity (FAO, 1999; Kremen et al., 2002). Examples include pollination services, maintenance of natural enemy complex of plant pathogens/parasites, soil organic matter relations, and so on. In certain cases, maintaining these services provides a powerful argument for conserving biodiversity *in situ*. It is well known that different species or genotypes when present perform slightly different functions, and this built-in redundancy makes "biodiverse" systems more resilient. That is, those components, which are redundant at one point in time, become important when some environmental change occurs (Vandermeer et al., 1998).

Yet, most advances in agriculture and forestry entail single-species stands, usually described as "biological deserts" of low diversity. Specifically, agricultural intensification in many areas (e.g., large-scale use of agricultural chemicals) reduced the diversity and abundance of native bees such that pollination services to crop plants were affected (Kremen et al., 2002). It also substantially diminished the natural enemy complex of crop pests/pathogens (FAO, 1999). Consequently, monocultures are widely believed to be vulnerable and susceptible to pest outbreaks, while the diversity and abundance of biota, typical of the traditional agro-ecosystems, may lower the pest/pathogen infestation/load. Jactel et al. (2005) found three probable factors that predispose single-species forest plantations, and by extension monospecific agroecosystems, to insect attack. Firstly, the lack of physical or chemical barriers provided by other associated plant species that could reduce access of herbivores to the large concentration of food resources, i.e., the high density of host plants in monoculture. Secondly, the low abundance or diversity of natural enemies often observed in monospecific plantations can result in limited biological control of pest insects. Thirdly, the potential absence of a diversion process, *i.e.*, the disruption effect on pest insects resulting from the presence in the same stand of another more palatable host species.

Soil organic matter (SOM) is a keystone component of the ecosystem (Swift et al., 2004), which is related to the quantity and variability of plant litter inputs. Higher floristic diversity generally ensures greater litter heterogeneity and, therefore, faster decay rates (Hättenschwiler et al., 2005). Although the imminent global warming may have profound impact on this (Kumar et al., 2005a), "species-rich" land-use systems generally have a greater chance of maintaining soil organic matter relations than the "species-poor" ones (Russell, 2002). Organic matter flows, also regulate water infiltration and retention processes. However, crops in intensive systems are generally selected for high harvest indices, and there may be uses for crop residues other than soil fertility maintenance (e.g. fodder or fuel). A key feature of agroecosystem management is thus the trade-off between the gains in production from 'mining' the SOM versus the potential negative impact on other ecosystem services and in particular on system resilience (Swift et al., 2004).

Reduced capacity within the agricultural sector to meet the demands for green manure, poles, fodder and firewood

Consistent with the high biodiversity inherent in traditional agroecosystems, the farmers used to meet part of the requirements for green manure, fodder and other demands from trees and bushes in the live fences and homegardens (Kumar et al., 1994; Kumar and Nair, 2004). However, a decline in landscape diversity and the replacement of live fences with cement walls have resulted in a notable decline in 'on-farm' availability of green manure, fodder and firewood resources (Russell et al., 1997; Mahesh, 1999). Likewise, substitution of paddy with cash crops represents the loss of an "internal" fodder supply source too.

Overall, the reduced capacity within agricultural sector to meet its own demands for organic manure, fodder and poles has increased the dependence on adjacent forests. It is equally possible that the agroecosystems are dependent on "nutrient subsidies" from forested areas. Small farmers with limited access to chemical fertilisers are obligated to remove green leaves/litter from forest floor for use in the fields, or otherwise aid in the growth of subsistence crops and/or for fuel purposes (Byard et al., 1996). Such increased outflows of organic matter and nutrients, signifies a major nutrient export from the forest ecosystems, *albeit* little quantitative data are available on this. Thus, forest destruction over vast tracts of Western Ghats and the associated loss of agrobiodiversity has a detrimental effect on the flow of organic matter and nutrients, in turn, adversely affecting the maintenance of soil fertility of forest-dependent agricultural systems.

Implications for management and policy

As explained above, an integral feature of agricultural intensification in Kerala is the deliberate reduction of diversity especially at the plot level. The current management paradigm focuses on how humans can maximise economic wealth or productivity and does not often recognize the intrinsic worth of traditional land use systems, knowledge and/or natural vegetation. It is also unlikely that farmers maintain biodiversity for purposes other than those of direct use or '*utilitarian*' benefits. That is, the farming community may ignore the *serependic* (i.e. future) value of diversity, which is much more likely to be valued by national and global communities (Swift et al., 2004). Therefore, if further loss of biodiversity is to be avoided, a paradigm shift in the state's agricultural practices in which biodiversity and agriculture can be reconciled in the context of more sustainable land management systems, is imperative.

Policies for sustainable agriculture, i.e., to promote integrative practices that focus on the conservation of resources (including genetic diversity) as well as productivity, however, have proved elusive in Kerala. Overall, biodiversity may well increase, especially if the areas of land dedicated to intensive production of food and materials decline (Swift et al., 2004). Furthermore, production of organic manure and green manure crops within the farm and increased on-farm timber/fodder production through integrated tree and crop production system should receive greater focus. The social challenge of delivering sustainable agricultural landscapes by adjusting the land use practices at the individual farm-level is, however, daunting.

The recent Biodiversity Action Plan, implemented at national and, increasingly, at regional levels (e.g., KFRI, 2005) signifies that agricultural landscapes have far more functions than supporting agriculture; conservation of biodiversity, providing wider environmental services such as water and carbon management, cultural services, including management of cultural features and landscapes and economic services, including providing the landscapes for tourism and leisure are cardinal among them. It focuses on the need to document the existing diversity and recognizes its *serependic* values. Parallel to this, organic farming and eco-agricutlure (Peter et al., 2002; FAO, 2002; Padmanabhan, 2005) and farm tourism (http://www.earthfoot.org/in_keral.htm) are gaining greater attention.

Agroforestry- a 'new old' land use paradigm

In the light of continuing environmental degradation, there is growing consensus that integrated tree-crop production systems such as agroforestry is the way to manage tropical agroecosystems in general and the fragile ecosystems in particular (Nair, 1993). This approach to land management considers not only the productivity of commercial trees and field crops, but also focuses on the underlying web of complex interactions among the organisms that are critical to ecosystem structure and functioning (*sensu.* Zeide, 2001). Furthermore, agroforestry, which aims at optimizing productivity and above all, sustainability, has the potential to provide many resources for which the people have traditionally depended on forests (fuel, fodder, green manure and timber). It thus eases the pressure on natural forests, which are "our doomed warehouses of global biodiversity (Ewel, 1999). Despite such advantages, agroforestry as a land management strategy has not received adequate attention from the decision makers.

Fig. 7. A typical Kerala homegarden

Traditional tree-based production systems, however, abound in the state; homegardens (Fig. 7) are unique a unique example in this respect (Kumar and Nair, 2004). Many commercial timber species (*Tectona grandis*, *Acacia mangium* etc.) are also increasingly planted on farmlands (Fig. 8), in small woodlots, in homegardens or in mixtures with other trees and agricultural crops (Kumar et al., 1994; Kumar and Peter, 2003). Dicot trees are often included in the coconut gardens for green manure/fodder/timber purposes (Kumar et al., 1999) and/or as support trees for trailing pepper vines. Beverage crops such as tea (*Camellia sinensis*), coffee (*Coffea* spp.), cacao (*Theobroma cacao*) and spices like clove (*Syzigium aromaticum*), nutmeg (*Myristica fragrans*), vanilla (*Vanilla fragrans*), medicinal plants such as galangal (*Kaempferia galanga*) etc., which require shade

Fig. 8. Multipurpose trees as potential C sinks: *Acacia mangium*

for optimum growth and production (Depommier, 2003; Kumar et al., 2005b), also abound on the Kerala landscape. Trees and shrubs are also planted on farm borders to demarcate the boundaries or function as windbreaks/shelterbelts, live fences and/or as green manure sources (Table 2).

A wide spectrum of trees, eulogised as the 'multipurpose trees' (MPTs), has been involved in such programmes. Important attributes of MPTs include rapid juvenile growth, efficient dry matter production in terms of water and nutrient inputs, crown characteristics to maximise interception of solar radiation and ease of regeneration. Objectives of tree planting also vary widely, from multiple uses of perpetually 'natural looking forests', development of high yielding and sustainable industrial plantations for wood production and control of land degradation (Kumar et al., 1998). Trees in managed

Table 2 Frequency of important trees and shrubs on farm boundaries and scattered trees in the homegardens of Kerala

Species	Frequency (%)	
	Boundary	Scattered
Ailanthus triphysa	21.3	4.3
Artocarpus heterophyllus	10.8	12.6
Mangifera indica	9.4	15.5
Tectona grandis	5.9	6.7
Anacardium occidentale	5.0	6.0
Artocarpus hirsutus	5.0	5.9
Erythrina indica	4.2	2.6
Macaranga peltata	3.7	2.3
Tamarindus indica	3.4	4.4
Thespesia populnea	3.4	0.7
Psidium guajava	3.0	0.9
Bombax ceiba	1.8	2.3
Leucaena leucocephala	1.4	0.6
Swietenia macrophylla	1.3	1.5
Gliricidia sepium	1.1	2.1
Delonix regia	0.9	1.1
Phyllanthus emblica	0.7	1.3
Annona squamosa	0.6	0.7
Terminalia paniculata	0.5	1.1
Ceiba pentandra	0.4	0.9
Azadirachta indica	0.4	1.0
Paraserianthes falcataria	0.2	1.6
Others	13.9	23.6

Source: Kumar (1994)

species mixtures also have a great potential to bring about soil fertility improvement (George and Kumar, 1998; Kumar et al., 1998; 2001) and climate change mitigation through carbon sequestration (Montagnini and Nair, 2004).

Carbon sequestration in agroforestry

Climate change is one of the most serious environmental threats facing the world today. Forest destruction is a major cause of rising atmospheric CO_2 levels (Watson et al., 2000). The terrestrial ecosystems, however, can serve as sinks of atmospheric CO_2—a major theme highlighted in the Kyoto Protocol of 1997 that came into force on 16 February 2005. The tropical forests have a special role in this respect; yet in recent years, a significant portion of this C sink has been returned through deforestation and forest fires. The IPCC special report on land use, land-use change and forestry (LULUCF), suggests that with the continuation of forest conversion rates in the 1980s and 1990s, the annual carbon uptake in the first commitment period (2008-2012), resulting from afforestation and reforestation, would be between 190 and 538 Tg C per year (Watson et al., 2000).

Agroforestry plays a cardinal role in this remarkable C sequestration process. Basically there are three mechanisms involved through which agroforestry can help reduce atmospheric CO_2 levels (Montagnini and Nair, 2004): *carbon sequestration* (creating new stocks in growing trees and soil), *carbon conservation* (eases anthropogenic pressure on existing stocks of C in forests through conservation and management efforts) and *carbon substitution* (substitution of energy demand materials by renewable natural resources, fuelwood production, increased conversion of biomass into durable wood products for use in place of energy-intensive materials). Most agroforestry systems (e.g., multipurpose trees, silvopasture, energy plantations and the like) sequester C both in biomass and soil, reduce fossil-fuel burning by promoting wood fuel production, help in the conservation of C stocks in existing forests by alleviating the pressure on natural forests and ensure greater synergy with the Convention on Biodiversity Conservation (FAO, 2004).

International efforts to mitigate human-caused changes in the earth's climate are also considering a system of incentives (debits and credits) that can help to reduce the atmospheric concentration of CO_2. In view of the relatively lower cost of such sink enhancement activities under the Kyoto Protocol (average cost of up to US$ 15 per MgC; Missfeldt and Haites, 2001), the developing countries such as India have a special role in global C sequestration programmes. According to recent land-use/ land cover statistics, there are about 129.58 million ha of degraded lands in India and about 1.28 lakh ha in Kerala (ICFRE, 2000; Fig. 9), which could be potentially used for C sink enhancement activities and biofuel production. Biomass energy incidentally is the single largest category of renewable energy, with both traditional (fuelwood) and modern (e.g. ethanol and co-generation) applications (Hall and Scrase, 1998).

Fig. 9. The degraded and terraced landscape of Attappady

Conclusions

Land use changes in Kerala were unprecedented during the past half century. A substantial decline in the area under rice and cassava, besides increases in coconut and rubber cultivation are paramount in this respect. The consequences of deforestation, which also has been widespread in the state, include frequent flash floods and landslides, soil erosion, and silting of reservoirs, causing serious ecological and environmental problems and complex feedback effects on agricultural production. In the light of massive environmental degradation and need for climate change mitigation and the rising demands for fuel wood, fodder and timber, agroforestry holds promise. However, very little extension work has been done on integrated tree-crop production systems in the state. Further effort is, therefore, required to develop management practices in participation with farmers that will maximise complementary interactions and resolve the location-specific constraints to spread the adoption of agroforestry technologies.

Acknowledgements

An earlier version of this paper was presented at the "Consultation Meeting on Natural Resources of Kerala" at the Kerala Agricultural University, Vellanikkara on 7 September 2004. I appreciate the cooperation of Dr. Luckins C. Babu, Dr. M. Achuthan Nair and Mr. T.K. Kunhamu in reviewing this manuscript. Dr. Ann Russell of Iowa State University, USA, provided useful comments on a previous draft.

References

Amruth, M. 2004. Forest-agriculture linkage and its implications on forest management: A study of Delampady panchayath, Kasaragod district, Kerala. Discussion Paper. Kerala Research Programme on Local Level Development, Centre for Development Studies, Thiruvananthapuram, 88p.

Byard, R., Lewis, K.C. and Montagnini, F. 1996. Leaf litter decomposition and mulch performance from mixed and monospecific plantations of native tree species in Costa Rica. Agric. Ecosyst. Environm., 58: 145-155.

Chattopadhyay, S. 1985. Deforestation in parts of Western Ghats region (Kerala), India. Intern. J. Environm. Manage., 20: 219–230.

Depommier, D. 2003. The tree behind the forest: ecological and economic importance of traditional agroforestry systems and multiple uses of trees in India. Trop. Ecol., 44: 63–71

Ewel, J.J. 1999. Natural systems as models for the design of sustainable systems of land use. Agroforest. Syst., 45: 1-21.

FAO 1999. Agricultural biodiversity. Background paper 1. FAO/Netherlands Conference on Multifunctional Character of Agricultural Lands. FAO, Rome, 42p.

FAO 2002. *Organic Agriculture, Environment and Food Security*. El-Hage S.N. and Hattam C. (eds.). Environment and Natural Resources Series 4. FAO, Rome, 258p.

FAO 2004. Assessing carbon stocks and modelling: win–win scenarios of carbon sequestration through land-use changes. FAO, Rome, 156p.

Farm Guide 1995-2005. Farm Information Bureau, Thiruvananthapuram, Kerala.

Forest Survey of India (FSI) 1999. *The State of Forest Report*. Forest Survey of India, Dehra Dun, 113p.

George, P.S. and Chattopadhyay, S. 2001. Population and Land Use in Kerala. In: *Growing Populations, Changing Landscapes: Studies from India, China and the United States*. National Academy of Sciences, Washington DC, pp 79-106.

George, S.J. and Kumar, B.M. 1998. Litter dynamics and soil fertility improvement in silvopastoral systems of the humid tropics of Southern India. Int. Tree Crops J., 9: 267-282.

Hall, D.O. and Scrase, J.I. 1998. Will biomass be the environmentally friendly fuel of the future? Biomass Bioenerg, 15: 357–367.

Hättenschwiler, S., Tiunov, A.V. and Scheu, S. 2005. Biodiversity and litter decomposition in terrestrial ecosystems. Ann. Rev. Ecol. Evol. Syst., 36: 191–218.

Hegde, V., Chandran, M.D.S. and Gadgil, M. 1998. Variation in bark thickness in a tropical forest community of Western Ghats in India. Funct. Ecol., 12: 313–318.

Hermy, M., Honnay, O., Firbank, K., Grashot-Bokdam, C. and Lawesson, J.E. 1999. An ecological comparison between ancient and other forest plant species of Europe and implications for forest conservation. Biol. Cons., 91: 9-22.

Indian Council of Forestry Research and Education (ICFRE) 2000. *Forestry Statistics—2000*. Directorate of Statistics, ICFRE, Dehra Dun, pp 55.

Jactel, H. Brockerhoff, E. and Duelli, P. 2005. A test of the biodiversity–stability theory: meta-analysis of tree species diversity effects on insect pest infestations, and re-examination of responsible factors. In: *Forest Diversity and Function: Temperate and Boreal Systems*. Ecological Studies, Vol. 176. M. Scherer-Lorenzen, Ch.Körner and E.-D. Schulze (eds.). Springer-Verlag, Berlin, Heidelberg, pp 235-262.

Jayanarayanan, T. 2001. Forest degradation in Kerala—causes and consequences: a case study of Peechi-Vazhani area. Discussion paper No. 27. Kerala Research Project on Local Level Development. Centre for Development Studies, Thiruvananthapuram, 116p.

Jha, C.S., Dutt, C.B.S. and Bawa, K.S. 2000. Deforestation and land use changes in Western Ghats, India. Curr. Sci., 79: 231-238

Kerala Forest Research Institute (KFRI) 2005. *State*

Biodiversity Strategy and Action Plan (SBSAP) for Kerala. Kerala Forest Research Institute, Peechi, 405p.

Kerala Forest Statistics 1956-1992. Kerala Forest Department, Thiruvananthapuram.

Kerala State Land Use Board (KSLUB) 1995. *Land Resources of Kerala State*. Vikas Bhavan, Thiruvananthapuram, 209p.

Kerala State Planning Board 2003. *The Economic Review.* Thiruvananthapuram pp 29-164.

Kodandapani, N. Cochrane, M.A. and Sukumar, R. 2004. Conservation threat of increasing fire frequencies in the Western Ghats, India. Conserv. Biol., 18(6): 1553-1739.

Kremen, C., Williams, N.M. and Thorp, R.W. 2002. Crop pollination from native bees at risk from agricultural intensification. Proc. Natl. Acad. Sci., 99: 16812–16816.

Kumar, B.M. 1994. Agroforestry principles and practices. In: *Trees and Tree Farming*. P.K. Thampan (ed.), Peekay Tree Research Foundation. Cochin. pp 25-64.

Kumar, B.M. and Nair, P.K.R. 2004. The enigma of tropical homegardens. Agroforest. Syst., 61: 135-152.

Kumar, B.M. and Peter, K.V. 2003. Woody perennials in the farmlands of Kerala- policy and legal aspects. *Proc. National Workshop on Policy and Legal Issues in Cultivation and Utilization of Bamboo, Rattan and Forest Trees in Private and Community Lands*. C. Mohanan, K.C. Chacko, K.K. Seethalakshmi, S. Sankar, C. Renuka, E.M. Muralidharan and J.K. Sharma (eds.), KFRI, Peechi, Kerala, pp 166-170.

Kumar, B.M., George, S.J. and Chinnamani, S. 1994. Diversity, structure and standing stock of trees in the homegardens of Kerala in peninsular India, Agroforest. Syst., 25: 243-262.

Kumar, B.M., George, S.J. and Suresh, T.K. 2001. Fodder grass productivity and soil fertility changes under four grass+tree associations in Kerala, India. Agroforest. Syst., 52: 91-106.

Kumar, B.M., George, S.J., Jamaludheen, V. and Suresh, T.K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown under two age-series in Kerala, India. For. Ecol. Manag., 112: 145-163.

Kumar, B.M., Haibara, K. and Toda, H. 2005a. Does Plant litter become more recalcitrant under elevated atmospheric CO_2 levels? Global Environ. Res., 9: 83-91.

Kumar, B.M., Kumar, S.S. and Fisher, R.F. 2005b. Galangal growth and productivity related to light transmission in single-strata, multistrata and 'no-over-canopy' systems. J. New Seeds, 7: 111-126.

Kumar, S.S., Kumar, B.M., Wahid, P.A., Kamalam, N.V. and Fisher, R.F. 1999. Root competition for phosphorus between coconut, multipurpose trees and kacholam (*Kaempferia galanga)* in Kerala, India. Agroforest. Syst., 46: 131-146.

Mahesh, R. 1999. Causes and consequences of change in cropping pattern: A location-specific study. Discussion Paper No. 1. Kerala Research Programme on Local Level Development Centre for Development Studies, Thiru-vananthapuram, 56p.

Menon, S. and Bawa, K.S. 1997. Applications of geographic information systems, remote sensing and a landscape ecology approach to biodiversity conservation in the Western Ghats. Curr. Sci., 73: 134-145.

Meunier, M. 1996. Forest cover and floodwater in small mountain watersheds. Unasylva, 56 (185): 29-37.

Missfeldt, F. and Haites, E. 2001. The potential contribution of sinks to meeting Kyoto Protocol commitments. Env. Sci. Policy, 4: 269-292.

Montagnini, F. and Nair, P.K.R. 2004 Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforest. Syst., 61: 281–295.

Muraleedharan, P.K., Sasidharan, N., Kumar, B.M., Sreenivasan, M.A. and Seethalakshmi, K.K. 2005. Non-wood forest products in the Western Ghats of Kerala, India: Floristic attributes, extraction, regeneration and prospects for sustainable use. J. Trop. For. Sci., 17: 243-257.

Myers, N. 1988. Threatened biotas: 'hotspots' in tropical forests. The Environmentalist, 8: 187-208.

Nair, P.K.R. 1993. *An Introduction to Agroforestry.* Kluwer Academic Publishers, Dordrecht, The Netherlands, 499p.

Nair, S.C. 1991. *The Southern Western Ghats: A Biodiversity Conservation Plan*. INTACH, New Delhi, 92p.

Narayanan, I.V. 1988. Regeneration status of moist deciduous forests in Trichur Forest Division. MSc (For.) Thesis. Kerala Agricultural University, Thrissur, Kerala, 116p.

Padmanabhan, M.A. 2005. Institutional innovations towards gender equity in agrobiodiversity management: collective action in Kerala, South India. CAPRi Working Paper # 39. International Food Policy Research Institute, Washington, 56p.

Pandurangan, A.G. and Nair, V.J. 1996. Changing pattern of floristic composition in Idukki hydroelectric project area. J. Econ. Taxon. Bot., 21: 15-26

Pascal, J.P. 1988. *Wet Evergreen Forests of the Western Ghats of India*. French Institute, Pondicherry, 343p.

Peter, K.V., Sasikumar, B. and Kumar, B.M. 2004. Modern concepts in breeding of spices. In: Proc. PLACROSYM XV (November 2002), K. Sreedharan, P.K. Vinodkumar, Jayarama and B.M. Chulaki (eds.), Central Coffee Research Institute, Mysore, pp 1-5.

Pouchepadass, J. 1995. British attitudes towards shifting cultivation in colonial south India: Case study of South Canara district 1800-1920. In: *Nature, Culture and*

Imperialism: Essays on the Environmental History of South Asia. D. Arnold and R. Guha (eds.), Oxford University Press. New Delhi. pp 152-184.

Prasad, S.N., Vijayan, L., Balachandran, S., Ramachandran, V.S. and Verghesse, C.P.A. 1998. Conservation planning for the Western Ghats of Kerala: A GIS approach for location of biodiversity hot spots. Curr. Sci., 75: 211–219.

Rajesh, N., Kumar, B.M. and Vijayakumar, N.K. 1996. Regeneration characteristics of selection felled forest gaps of different ages in the evergreen forests of Sholayar, Kerala. J Trop. For. Sci., 8: 355-368.

Ramesh, B.R., Menon, S. and Bawa, K.S. 1997. A vegetation based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India. Ambio, 26: 529-536.

Russell, A.E. 2002. Relationships between crop-species diversity and soil characteristics in southwest Indian agroecosystems Agric. Ecosyst. Environ., 92: 235–249.

Russell, A.E., Kumar, B.M. and Devi, P.I. 1997. Impacts of changes in agricultural land use on forest ecosystems of the Western Ghats of Kerala. Seminar on "The Ecology of Moist forests in Southern India", USEFI and Madurai Kamaraj University, 23-26 April 1997, Tamil Nadu.

Santhakumar, V. 1996. On-farm biodiversity in Kerala. In: *Using Diversity*. L. Sperling and M. Loevinshon (eds), IDRC, New Delhi, pp. 22–34.

Swift, M.J., Izac, A.-M.N. and van Noordwijk, M. 2004. Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions? Agric. Ecosyst. Environ., 104: 113–134.

Vandermeer, J., van Noordwijk, M., Anderson, J., Ong, C. and Perfecto, I. 1998. Global change and multi-species agroecosystems: concepts and issues. Agric. Ecosyst. Environ., 67: 1–22.

Varghese, V. and Kumar, B.M. 1997. Ecological observations in the fresh water swamp forests of southern Kerala in the peninsular India. J. Trop. For. Sci., 9: 299-314.

Venkataraman, A.B., Kumar, N.V., Varma, S. and Sukumar, R. 2002. Conservation of a flagship species: prioritizing Asian elephant (*Elephas maximus*) conservation units in southern India. Curr. Sci., 82: 1022-1033.

Vinod, V.R., Syed Anwarulla, M. and Vishwanth, D.P. 2003. Run off and soil loss under different land use systems in the Western Ghats of Karnataka. Indian J. Soil Conserv., 31: 131-138.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds) 2000. Intergovernmental Panel on Climate Change (IPCC). *Land use, Land-use Change and Forestry*. A Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK. 377p.

Zeide, B. 2001. Resolving contradictions in forestry: back to science. Forest. Chron. 77:973-981.