Agroforestry in the Western Ghats of peninsular India and the Satoyama landscapes of Japan: a comparison of two sustainable land use systems

B.M. Kumar[1]* and K. Takeuchi[2]

[1]Department of Silviculture and Agroforestry, College of Forestry, Kerala Agricultural University, KAU P.O., Thrissur, Kerala 680 656, India; [2]Graduate School of Agricultural and Life Sciences, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8654, Japan

*Author for correspondence: Fax +91 4872371040; Phone +91 4872370050; Email <bmkumar.kau@gmail.com>.

Abstract

Agroforestry in the Western Ghats (WG) of peninsular India and satoyama in rural Japan are traditional land use systems with similar evolutionary trajectories. Some of their relevance was lost by the middle of the twentieth century, when modern agricultural technologies and urbanization engineered shifts in emphasis towards maximizing crop production. There has been, however, a resurgence of interest in traditional land use systems recently, in view of their ability to provide ecosystem services. Both agroforestry and satoyama are thought to be harbingers of biological diversity and have the potential to serve as “carbon forests.” Carbon (C) stock estimates of the sampled homegardens in WG ranged from 16 to 36 Mg ha^{-1}. Satoyama woodlands owing to variations in tree stocking and management conditions indicated widely varying C stocks (2 to 279 Mg ha^{-1}). Agroforestry and satoyama also differ in nature, complexity, and objectives. While agroforestry involves key productive and protective functions, and adopts ‘intensive management’, the satoyama woodlands are extensively managed; understorey production is seldom a consideration. Differences in canopy architecture (multi-tiered structure of agroforestry vs. the more or less unitary canopy of satoayama) and land ownership pattern (privately owned/managed agroforestry holdings vs. community- or local government- or privately- owned and mostly abandoned satoyamas) pose other challenges in the transfer and application of knowledge gained in one system to the other. Nonetheless, lessons learnt from satoyama conservation may be suitable for common pool resource management elsewhere in Asia and aspects relating to understorey production in agroforestry may be relevant for satoyama under certain scenarios.

Keywords: Agrobiodiversity, Carbon Sequestration, Common Pool Resources, Ecosystem Services, Hill and Valley Cultivation.

Introduction

The Western Ghats of peninsular India (WG) and the Satoyama landscapes in Japan are geographically diverse regions (Table 1). Yet there are remarkable similarities in the traditional land use practices and physiographic features of these territories (Figs 1 and 2). A series of rolling hills and plateaus intersected by deep valleys characterize both. The hill and valley farming system of the high ranges of WG and the Satoyama system of Japan also have resemblances. Rice (*Oryza sativa*) forms the predominant crop in the lowlands and often terraced plateaus of both, bordered by homesteads and various forms of managed woodlands. Forests occur on the upper reaches of these land use patterns and provide many goods and services. Managed ecosystems existed in apparent equilibrium with the natural landscape at both locations for long.

The traditional land use systems in WG and Japan, however, have changed over time – as a function of the interplay of socioeconomic and technological factors (e.g., Kumar 2005; Ichikawa et al. 2006). Figures 3 and 4 illustrate the paradigm shifts in this respect. Such traditional landscapes and production systems, however, have been receiving attention recently, especially after the adoption of the Convention on Biological Diversity (CBD) in June 1992. It is now recognized that the traditional farmers have not only conserved biodiversity of great economic, cultural, and social value, but have also enhanced it through selection and value addition (Kumar and Nair 2004). The potential of traditional land use systems to serve as sinks (soil and biomass) of atmospheric CO_2, a theme highlighted in the Kyoto Protocol of 1997, is also getting attention of late (Nair et al. 2009). Nevertheless, only limited information is available on the potentials of agroforestry in WG and the Japanese satoyama for carbon sequestration and biodiversity conservation.

Although the CAB abstracts (Web of Knowledge: http://apps.isiknowledge.com; accessed 5 January 2009) lists 1142 studies for 'Western Ghats' and 33 for 'satoyama' (some of the Japanese language literature is seemingly excluded in this database), only a few of them deal with aspects such as 'carbon (C) sequestration' (just three for WG and none for satoyama). Regarding 'biodiversity', although certain aspects have been explored (126 studies for WG and 10 for satoyama), more information is needed on the impact of land-use changes on species losses vis a vis conservation. An attempt is made here to synthesize the available information on salient attributes of agroforestry in WG and satoyama in Japan with particular reference to C sequestration and biodiversity conservation and inter alia compare these land-use systems to facilitate transfer and application of knowledge gained at one location to another, and to other similar systems elsewhere. System description and paradigm shifts in land use with implications for sustainable management and conservation planning relevant to all tropical and temperate regions, where the traditional farmers have been practicing woody perennial based land use systems, are the principal focus of this paper.

System description

The Western Ghats: An Overview

The biogeographic region, WG, is the mountain range running along the western margin of the Deccan Plateau in peninsular India (Fig. 1). 'Ghats' implies the terraced appearance of the mountains and the steps of the terrace are indicative of successive lava flows (Krishna 1968). Steep-sided valleys, narrow gorges, and waterfalls are distinctive features of this landscape. The steep seaward slopes are deeply dissected by rivers and streams and there are numerous canyon-like valleys (Pichamuthu and Radhakrishna 1968). The landward side slopes are, however, more gentle, with wide valleys and rolling topography. Rich natural resource endowments in terms of vegetation, fish, animal, and soil make WG a mega-biodiverse region. Over-exploitation of the natural resources including the timber and non-timber forest products (NTFPs) and agricultural intensification, however, have led to severe biotic and abiotic pressures on the biodiversity of this region (Vencatesan and Daniels 2008). The high rates of biodiversity losses coupled with inherently high species richness, make WG one of the 'biodiversity hot spots' of the world (Myers et al. 2000).

Managed ecosystems of WG, as elsewhere in the tropics, present a complex pattern with a great diversity of trees and field crops. Agroforestry systems where trees are grown with crops, and/or sometimes animals, in interacting combinations in space or time dimensions, abound in WG (Kumar 1999; 2005). In particular, plantation agriculture involving coffee (*Coffea* spp.), tea (*Camellia sinensis)*, and spices in association with a wide spectrum of trees, and para rubber (*Hevea brasiliensis*), rice-based cropping systems, coconut (*Cocos nucifera*)-based cropping systems, and the all pervasive homestead farming systems dominate the region (Kumar 1999; Kumar 2005). Historically, plough agriculture was prevalent in Wayanad, one of the high altitude locations in WG, as early as in the Megalithic Age (between 400 BCE and 400 CE) and spices like pepper (*Piper nigrum*), ginger (*Zingiber officinale*), and cardamom (*Elettaria cardamomum*) were grown there since the early Middle Ages (500 to 1400 CE; Warriar 1995).

Natural history studies during the two previous centuries (Mateer 1883; Logan 1906) suggest that the people in the WG region traditionally used their 'homesteads' (a small garden surrounding the house—housegarden or homegarden) for a variety of needs such as food, energy, shelter, medicines, and the like. A steady supply of fruits and vegetables from the homesteads presumably provided nutritional security to the homegardeners (Kumar 2008a). Although homegardens are widespread around the tropics, the state of Kerala in southern WG is one of the 'Meccas'of tropical homegardens (Nair and Kumar, 2006). This constitutes the rationale for selecting homegardens for this analysis. There are also similarities among the homegarden systems across the tropics (Kumar and Nair, 2006) and the selected homegardens are representative of this category.

Satoyama, the satoyama landscape, and shifting land use paradigms

Geomorphologically, the Japanese archipelago also consists of valleys and basins developed for paddy cultivation, much like WG (Fig. 2). Human settlements, juxtaposed between agricultural woodlands and lowland paddy fields, subsisted along the foothills of mountains in Japan (*sensu*. Brown and Yokohari 2003). *Satoyama* (a Japanese term originally used to refer to agricultural woodlands; Shidei 2000), was ubiquitous in rural Japan until mid-twentieth century. Korea and Eastern Russia are other geographical regions where similar systems existed (Senior 2005). The word satoyama was originally used in a concrete sense to mean coppice woodlands. However, of late, it is used in a wider abstract sense, signifying all remaining natural environments, or the entire landscape used for agricultural activity—the *Satoyama landscape* (Takeuchi 2003; Kobori and Primack 2003). Yamamoto (2001) described satoyama landscape as a sequence of intimately linked agricultural land use systems such as woodlands, farmlands, settlements, and reservoirs, bordered on the upper reaches by forests (man-made or natural). Upland terraces, lowland rice-paddies, ponds, grasslands, and wildlife habitats—often situated midway between mountains and flatlands— are integrated in this mosaic, which constitute about 40% of the national lands of Japan (Takeuchi 2003). In this paper, the term satoyama is used both in a concrete sense (satoyama woodlands) and in an abstract sense (satoyama landscape). Regarding geographical focus, aspects such as carbon stocks and diversity indexes are based on reports from the Kanto region. However, other features are based on studies scattered throughout the Japanese archipelago.

As in the tropics, the satoyama woodlands were traditionally managed by local communities for collecting green leaves and litter for manuring wetland rice fields, timber for construction, and nontimber forest products such as bamboo shoots and mushrooms for food, as well as for firewood gathering. Although the total size of satoyama per village was variable depending on the number of inhabitants and the area of rice fields, it was a general custom until the Edo era (1603 to 1867 CE) to maintain several hectares of early successional forests per hectare of rice paddy cultivated, and a family of 7 to 8 persons typically needed 1.0 to 1.5 ha of satoyama woodlands (Kobori and Primack 2003). During the Edo period (Fig. 3), however, overexploitation caused large-scale degradation of the *Satochi* (a broader term signifying all the intermediate areas between mountains and flatlands: Takeuchi 2001)-satoyama (secondary forests and terraced paddy fields) systems throughout the Japanese archipelago (Chiba 1973). The rulers of Edo/Tokugawa period therefore initiated "regenerative forestry" in early modern Japan, around 1600 CE (Totman 1989).

During the Edo period, one family utilized around 5 ha of the satoyama landscape (Kikuchi 1986). Late in the Edo and Meiji (1868 to 1912) eras, however, the satoyama areas became further smaller in extent and have particularly shrunk after the 'fuel revolution' (1960-) as a result of urban development. Consistent with this notion, Ichikawa et al. (2006) demonstrated drastic landscape-level changes in the urban fringe of Tokyo Metropolitan Area —from agricultural to urban areas, with unique land use and transition patterns—between 1880 and 2001.

The post-World War II economic boom of Japan and in particular the availability of chemical fertilizers made the farmers less dependent on green leaves and litter for nourishing the crop fields (Fig. 3). The traditional use of satoyama woodlands further ceased around 1950–1960 as the use of coal as an energy resource diminished and the use of plant residues as fertilizers of the paddy fields came to an end and uplands became available for modern forestry (Iwamoto 2002) or urbanization (Ichikawa et al. 2006). Moreover, the 'Basic Agricultural Law' of 1961targeted on modernizing/industrializing farming in Japan (Totman 1989) and it focussed on economies of scale, division of labour, and standardization, besides encouraging the farmers toward mechanization, heavy use of chemicals (fertilizers, pesticides and herbicides), and single-crop farming (Fujimoto 1998; Berglund 2008). This led to a general lack of appreciation of the goods and services derived from satoyama woodlands. In view of this, Fukamachi (2002) observed that since the 1970's, such woodlands were primarily used as local resources for economic purposes and were mostly decimated.

The Japanese archipelago also has a great deal of topographic diversity and different climatic regions and the satoyama landscapes are quite diverse in their history, vegetation, and current conditions (Tsunekawa, 2003; Ichikawa et al. 2006). Some of these differences may be local and the effects of land-use changes have primarily been examined at or below the regional scale; therefore, it remains unclear whether such effects scale up to the macroecological scale (i.e. nationwide). The paradigm shifts in Japanese land use explained in the preceding paragraph, however, parallel the developments elsewhere, where input intensive agricultural systems replaced the traditional farming systems (Fig. 4). In this single-commodity paradigm especially in the WG where agroforestry was the predominant land use activity, these age-old practices of growing crops and trees together were ignored or bypassed (Nair 2008).

Climatic and physiographic exigencies of Western Ghats and Japan

From an evolutionary perspective, the generally steep terrains and the moderate to heavy rainfall intensity of WG and Japan presumably necessitated a rational land use and watershed management system that alleviates the ill effects of swift overland flows. The indigenous people responded to this challenge by evolving satoyama in Japan, and a profoundly similar hill and valley cultivation system (predominantly agroforestry) in the WG. We can find such “relict” farming landscapes and the people still practicing such land-use in the so-called marginal areas in the uplands or mountains of Japan (Berglund, 2008), as well as in WG. Although there are other places around the world with comparable physiographic, climatic, and land use features, the focal areas are unique in having historically important sustainable multifunctional production systems (see the ensuring section).

In both cases, the hill slopes were largely covered by natural or managed woodlands and terraced paddy fields—serving as sources of food, fuel, and timber, besides providing an array of ecosystem service benefits. To illustrate this point further: the traditional farmers of southern WG typically maintained three land parcels, situated at different altitudinal zones within a micro watershed— the low-lying paddy fields providing a significant part of the food and feed requirements, the 'garden land homestead' situated close to the paddy fields and sustaining a mixed plant/tree crop system, and the upland plot with mixed tree cover including forest trees for meeting the grazing, organic manure, and soil conservation needs. The multistrata 'garden land homesteads' and the upland plots are thought to be 'relics' of forests left behind during the process of land clearing, but evolved subsequently under variable planting and/or extraction regimes.

The concepts of multifunctionality and sustainability

Multifunctionality is a characteristic feature of both satoyama and WG agroforestry, as in many other traditional land use systems. It is also closely interrelated with sustainability (Otte et al. 2007). Figure 4 illustrates the concept of multifunctionality and the remarkable linkages between woodlands and croplands in satoyama and WG agroforestry. Both these systems are also managed with locally available resources. The "nutrient subsidies" from woodlands, presumably common to all forest-margin areas, helped the traditional WG and Japanese farmers to maintain soil fertility and productivity. In particular, the unidirectional flow of materials such as leaves/litter for manure and mulch, fruits and nuts for food, green fodder and wood for fuel, poles, timber, and various other non-timber products, with essentially no reverse flows (Kumar 2005), helped the small farmers with limited access to chemical fertilizers. Kambu (2008), following the framework for ecosystem services outlined in the Millennium Ecosystem Assessment (2005), illustrated the provisioning, regulating, supporting, and cultural functions of satoyamas, and highlighted its sustainable nature.

The indigenous farmers also used `traditional ecological knowledge' to manoeuvre crop plants and trees, which endowed sustainability to them (Berkes et al. 2000). For example, the WG farmers integrated the shade tolerant crop species in the understorey; a case in point is the tropical homegardens. Maximization of productivity was never targeted or attained and hence industrial crop production techniques were seldom employed in the homegardens, justifying the soubriquet ‘epitome of sustainability’ (Kumar and Nair 2004).

According to Moriyama (1998), these traditional rural landscapes were important culturally too and provided social and ecological networking to the village community. Modern societies especially those in Japan have appreciated the recreational and aesthetic values of traditional landscapes, and there have been private and communal initiatives to restore such landscapes that are adjacent to cities (Takeuchi et al. 2003). Although farm tourism and ecotourism have emerged as recent concepts in WG, much of this is still rudimentary.

The sacred groves and sacred landscapes of WG, however, are a prominent feature of the mythological landscape there. Apart from being repositories of rare and endemic species, these are remnants of primary forests left untouched by the local inhabitants and protected by religious beliefs and customs (Ramakrishnan et al. 1998). Likewise, the cultural landscapes of Japanese satoyama have been shaped by the interrelationship between humans and nature. Iwatsuki (2003) observed that the lifestyle in satoyama is consistent with the traditional Japanese faith of paying respects to eight million Gods. Implicit in this is that the indigenous traditional societies have spiritual relationships with the existing physical environment, which presumably helped to sustain them. There has been, however, historic transition from multifunctional, largely subsistence-oriented pre-industrial land use, to post-industrial multifunctional land use throughout the world (Mander et al. 2007). Such transformations probably impinged the intrinsic sustainability features of these traditional land use systems.

Recent paradigm shifts

Resurgence of interest in the traditional land use systems

Recognizing the importance of satoyama landscapes for harmonious existence of human beings and other entities of the abiotic and biotic environments, the Japanese Basic Environment Plan (Environmental Agency, 1994) emphasized the need for its preservation (Fig. 3). Since then, several satoyama conservation initiatives were launched in various parts of Japan (Takeuchi et al. 2003). In particular, a programme on 'Sub-global Assessment of Satoyama and Satoumi' (marine and coastal ecosystems with human interaction) is underway at the United Nations University (UNU undated), since late 2006. It adopts the UN's Millennium Ecosystem Assessment (MEA) framework and focuses on scientific information development to evolve policies and strategies at the local, regional, and national levels to enhance conservation and sustainable use of ecosystems within satoyama and satoumi and their contribution for human well-being.

Significantly, the paradigm shifts in tropical agroecosystem management were (Fig. 4) similar to that of satoyama (Fig. 3), although ahead of time. For instance, during the late 1970s, international efforts were initiated to bring the traditional woody perennial-based practices into the realm of modern agricultural science (Bene et al. 1977). Escalating tropical deforestation rates, fuel-wood shortage, and soil degradation as well as increased awareness about the relevance of the age-old tree-and-crop integrated farming practices were the principal drivers of this (Nair 2008). Today, however, environmental concerns such as global warming, land degradation, erosion of biodiversity, loss of wildlife habitats, and increased non-point source pollution of ground and surface water provide additional impetus for the development and adoption of agroforestry around the world (Fig. 4).

Major sinks of atmospheric CO_2

It is now widely recognized that most traditional tree based land use systems have a considerable potential for storing carbon in soil and biomass and occupies a prominent place in the climate change mitigation strategies (IPCC 2007). The climate change mitigation strategies through agroforestry and satoyama would also ensure greater synergy with the CBD in view of their ability to maintain high biodiversity (FAO 2004; Takeuchi et al. 2003). Basically there are three mechanisms which help reduce atmospheric CO_2 levels (Montagnini and Nair 2004; Kumar 2006a): *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). While all these are relevant for agroforestry and for satoyama, aspects such as carbon sequestration and substitution are focused here, as quantitative data on avoided deforestation on account of agroforestry/satoyama are not readily available.

C sequestration: As can be seen from Table 2, the mixed species tropical homegardens in the WG can sequester on an average 17 to 36 Mg C ha^{-1}. Variations in C sequestration potential, however, abound and this is probably because of differences in tree age, site, and management factors. Nair et al. (2009) reported that vegetation C stock values (above and belowground) range from 2.2 to 107 Mg ha^{-1} for a range of agroforestry systems. Although it is difficult to compare the figures reported in the literature in view of the differences in stand characteristics and sampling strategies adopted by different researchers (Kumar 2006a; Nair et al. 2009), the present values (Table 2) are apparently greater than the C stocks in agroforestry systems such as fodder banks, parklands and live fences of Ségou, Mali in West African Sahel (Takimoto et al. 2008), tree-based intercropping in Canada (Peichl et al. (2006), agrisilviculture in Chattisgarh, Central India (Swamy and Puri 2005) and silvopasture in Western Oregon, USA (Sharrow and

Ismail 2004); but lower than the values for the Indonesian homegardens (Roshetko et al. 2002) and the Panamanian agroforests (Kirby and Potvin 2007). Such variations in C stocks can be explained based on tree stocking levels and management, as mentioned. In general, the high species-diversity of homegardens and other multistrata systems promotes more efficient use of site resources leading to greater net primary production (Vandermeer 1989) and therefore higher C sequestration potential.

Aside from the aboveground C stocks, “species-rich” land-use systems also have a greater chance of maintaining soil organic matter relations than “species-poor” agricultural systems (Russell 2002; Kumar 2005). Consistent with this, Saha et al. (2009) reported that for species rich homegardens in WG, soil organic carbon content (SOC) within the 1 m soil profile was 119.3 Mg ha^{-1}. Gardens with medium and low species densities had 7% and 14% lower SOC, respectively.

Biomass and C stock estimations from satoyama systems are few. Just to indicate the potential of these systems for C sequestration, however, certain reports available on Japanese forest stands are summarized in Table 3, which indicates a wide range of values. This is presumably because of the variable tree stocking in the woodlands and plantations considered in these estimates, besides the management regimes followed. A comparison of these values with homegardens (Table 2) is difficult in view of the fact that trees in the homegarden systems are scattered and intensively managed to facilitate understorey crop production (e.g., pruning, lopping, pollarding, or thinning). By extension, the typical satoyama woodlands, which are also subject to some degree of lopping and other forms of tree management, may have lower C stocks than natural forests and forest plantations. Despite such differences, the data presented in Tables 2 and 3 indicate that both agroforestry systems (e.g., homegardens, multipurpose trees and plantation agriculture systems, particularly important in southern WG) and satoyama have considerable potential for sequestering atmospheric CO_2.

Carbon substitution (*biomass utilization as carbon neutral energy*): This constitutes yet another dimension in the rationale for reviving the management of agroforestry and satoyama woodlands. The traditional homegardens constitute a principal source of biofuels for rural households – contributing 51 % to 90 % of the fuelwood collected in various geographical regions in South and Southeast Asia (Kumar and Nair 2004). Shanavas and Kumar (2003), however, noted profound variations in the combustion characteristics *vis à vis* tissue-types of woody perennials grown in the Kerala homesteads. Regarding satoyama, despite being a time-honored tradition, only few studies have attempted to characterize the fuelwood production potential of these systems. In an attempt to evaluate the potential of coppiced woods to contribute to the reduction of CO_2 emission, Terada et al. (2007) estimated that satoyama lands in Tsukuba city (Japan) may produce 3000 to 26,000 tonnes of biomass annually and it has the potential to achieve 30 to 530% reduction in the CO_2 emission targets. The role of agroforestry in carbon conservation and substitution is also implicit in the emerging new mechanisms that support interventions for reducing deforestation and forest degradation (e.g., “Reduced Emissions from Deforestation and Degradation” or REDD; IPCC, 2007; Kanninen et al. 2007).

Biodiversity losses from WG and satoyama: a cause of concern

Erosion of farmland biodiversity is one of the most serious problems today (Benton 2007). Advances in agriculture and forestry usually entail single-species stands, characterized as “biological deserts” of low species diversity (Kumar and Nair 2004). Agricultural intensification in WG has resulted in a large proportion of the homegardens and other traditional agroforestry systems, which traditionally preserved several landraces and cultivars, and rare and endangered species, being converted into small-scale plantations of rubber or cropping systems consisting of fewer crops (Kumar and Nair 2004; Kumar 2005). Data on species and cultivar losses from such land use changes are not available. The IUCN (2008), however, reported that a total of 659

Indian species are threatened (246 plants, 96 mammals, 76 birds, 25 reptiles, 65 amphibians, 40 fishes, 2 molluscs, and 109 other invertebrates)—a significant part of this is presumably from WG. The *Atlas of Endemics of the Western Ghats, India* (Ramesh and Pascal 1997), which lists 352 tree and shrub species, subspecies, and varieties with a girth at breast height greater than 10 cm (63% of the tree species of the evergreen rainforest and semi-evergreen forests), also indicates that 14% of all trees (~50 species) are threatened (Puyravaud et al. 2003). Habitat fragmentation, which leads to loss of native habitat limiting the species' potential for dispersal, colonization, and foraging ability, besides altered demographic structure and genetic make-up, is the principal cause of this. Apart from the managed ecosystems in WG, about 60 % of the rainforests (15,000 km^2) are also severely fragmented (<10 to 2000 ha in extent; Collins et al. 2000), further aggravating the problem of habitat loss.

After chemical fertilizers and fossil fuels came into common use, and as cities grew due to rapid economic growth since the 1960s, a similar sequence of events unfolded in Japan too. That is, a large proportion of woodlands and agricultural lands has been either abandoned or converted into urban land uses, adversely impacting the structural diversity of the landscape (e.g., Nakajima 1996; Ichikawa et al. 2006). With changing agricultural practices, many plants and animals characteristic of *satoyama* are now in danger of extinction. For example, 79 of 200 native

Japanese freshwater aquatic plants, terrestrial plants, and fish species are facing extinction (Kobori and Primack 2003).

Traditional agroecosystems of WG and Japan: as harbingers of agrobiodiversity

Integrated, dynamic, mosaic landscapes with traditional land use and management, that includes various successional stages have the potential to create habitat mosaics and thereby conserve biodiversity (Sutherland et al. 2006). Although substantial parts of such systems have been lost during the “development phase” (Figs 2 and 3), the remaining agroforestry in WG and the satoyama landscapes are excellent examples of agrobiodiversity conservation. Experimental studies from WG clearly highlight that mean Simpson and Shannon-Wiener diversity indexes[i] of certain agroforestry practices (tropical homegardens) were comparable to that of the adjacent natural forest areas (Kumar et al. 1994; Saha 2008). Furthermore, floristic diversity was higher in the smaller homesteads (Table 4), signifying the role of smallholder land use systems in WG for biodiversity conservation.

Regarding the satoyama system, robust accounts on floristic attributes are lacking; however, a few authors have studied the landscape diversity following land use changes (e.g., Fukamachi et al. 2001; Amano et al. 2008). From the available information summarized in Table 5, it can be surmised that the traditional satoyama ecosystem is inherently capable of maintaining high plant diversity. Most of the over 500 species of flora and fauna in the secondary forests of Japan (Natuhara et al. 1999; Trisnawati and Nakamura 2008; Kuramoto and Sonoda 2003) presumably occur in the satoyamas. Although the data presented in Tables 4 and 5 are not strictly comparable, because of the differential sampling strategies adopted in these studies, species richness and diversity were clearly higher in the WG homegardens. This is not surprising as WG is one of the 'mega-biodiversity areas' and has over 4000 species of flora and fauna (Gunawardene et al. 2007) compared to approximately 500 species in the Japanese archipelago.

The complex micro-zonal pattern of WG land use systems with well-defined vertical/horizontal stratification with each structural ensemble occupying a specific niche such that they cannot be easily dissociated from one another may explain the high species richness and diversity (Kumar and Nair 2004). Likewise, the mosaic-like arrangement of ponds, reservoirs, and streams of the satoyama ecosystem are important to the survival of an array of species including many water dependent species (e.g., dragonflies and fireflies; Primack et al. 2000; Kobori and Primack 2003). The land and tree management practices traditionally adopted in the satoyama woodlands are particularly responsible for maintaining high structural heterogeneity, and providing diverse microhabitats (Hatase et al. 2005). Prominent examples of land management practices in satoyama and how they impact biodiversity are summarized below:

- Frequent cutting and thinning of woodlands may lead to the domination of dwarf pines and coppices, providing niches for diverse organisms (Ogura 1992). Indeed, shrub cutting decreased the occurrence of invasive species, and increased forest floor species diversity (Iida and Nakashizuka 1995; Kameyama 1996).
- Harvesting mixed Japanese oak (*Quercus serrata*) and Japanese chestnut oak (*Quercus acutissima*) deciduous broadleaf forests for fuelwood and charcoal prevented their transition (succession) in to dense laurel forest dominated by *Castanopis sieboldii*, *Machilus thungbergii,* and *Aucuba japonica* (potential climax type for western Japan), ensuring greater diversity (Kobori and Primack 2003).
- Collection of forest floor litter and regular cutting of deciduous forest trees encouraged the regeneration of spring and summer wildflowers (Moriyama 1998). Lack of disturbances and successional changes associated with the decline of satoyamas, however, have threatened "Seven Autumn Wildflowers," a Japanese symbol of nature's beauty (MOE 2000). Undisturbed situations also favour native rhododendrons (*Rhododendron* spp.), which may suppress the regeneration of other species (Morimoto and Yoshida 2005).

- Agricultural water management and growing of rice preserved the wetlands, providing a veritable habitat for wildlife. Abandonment of rice cultivation due to farm labour shortage (Tsunekawa 2003), however, has caused a decline of aquatic plants (e.g., *Sparganium japonicum*, Kato 2001), birds (Fujioka and Yoshida 2001; Amano et al. 2008), insects such as the endemic Genji-firefly (*Luciola cruciata*; Takeda et al. 2006), *Japonica saepestriata, Antigius attilia* (Kato 2001), *Oligoaeschna pryeri*, and *Rhyothemis fuliginosa* (Washitani 2001), paddy field weeds (Yamada et al. 2007), and some freshwater fish species (e.g., the native Japanese killifish or *Oryzias latipes*; Kobori and Primack 2003).

The evidences presented above clearly suggest that disturbances such as cultivation, trampling, and mowing of the traditional satoyama systems augment habitat diversity, thereby promoting species packing. This is consistent with Connell's (1978) intermediate disturbance hypothesis which states that biodiversity is highest when disturbance is neither too rare nor too frequent. With low disturbance, competitive exclusion by the dominant species increases and with high disturbance, only species tolerant of stresses can persist. There is, however, only limited experimental data available comparing the suite of species in 'disturbed' and 'abandoned' satoyama systems (e.g., Yamasaki et al. 2000; Hatase et al. 2005).

Other ecosystem services

'Biodiverse' agro-ecosystems generally have great capacity to perform many ecosystem services that underpin agricultural productivity in the tropics (*sensu.* Kremen et al. 2002). Examples include pollination services, maintenance of natural enemy complex of plant pathogens/parasites, soil organic matter relations, and the like. Land use changes especially those affecting species diversity, however, may have disrupted these. Habitat fragmentation, in particular, upsets the intricate relationship between pollinators and food plants. A case study of the mid-elevation wet forest site at Kakachi in southern WG showed that approximately 75% of the 86 arborescent species were specialized to a single pollinator group such as bee, beetle, or moth (Devy and Davidar, 2003); and disturbances could lead to cascading local extinction of the food plants and their pollinators. Decline in landscape diversity also may result in reduced 'on-farm' availability of green manure, fodder, and firewood resources and increased dependence on adjacent forests in the WG for organic manure, fodder, and poles (Kumar 2006b).

Non-point source pollution owing to agricultural intensification constitutes yet another major environmental problem in several parts of WG. For instance, Pawar and Shaikh (1995) reported anomalously high NO_3 levels (2.2 ppm to 64 ppm) in ground and surface water samples from a small watershed in the Deccan Trap Hydrologic Province. In another study of the Krishna basin in Belgaum district of Karnataka, Purandara et al. (2004) also observed high post-monsoon loads of major anions and cations in the Malaprabha river (kg day^{-1}): Na (1557 to 4276), K (1145 to 6480), Ca (6594 to 25401), Mg (1786 to 12960), Cl (6493 to 68915), SO_4 (11448 to 53784), and HCO_3 (48603 to 229262)—more than 90% of which was derived from non-point sources.

Research data on non-point source pollution from the satoyama landscapes are scarce. Nevertheless, the satoyama landscape is now recognized as a source of public goods – e.g., biodiversity conservation and recreational uses (Fukamachi et al. 2001; Takeuchi et al. 2003; Fujimoto et al. 2006). Similarly, environmental sustainability to meet the exigencies of loss of wildlife habitat and ecological degradation is globally emerging as a driver of agroforestry (Kumar 2006b). It is generally recommended that agroforestry is a strategy to overcome non-point source pollution of ground and surface water and site degradation through accumulation of salts and other contaminants (e.g., phytoremediation; Nair 2008).

Distinctions between satoyama and agroforestry in the WG

Despite the similarities outlined above, there are notable variations among the land use systems in WG and satoyama (Table 6). A fundamental difference lies in land tenure and ownership pattern. While most agroforestry systems in the WG are private-owned and managed individually, the satoyama woodlands belong to either the local communities, local governments (common pool resources), or private owners (Nakajima and Furuya 2004). Following the dissolution of common lands during the Meiji period and again after WW II, bulk of the satoyama woodlands have become privately owned; some are also owned or leased by local governments and managed as parks, but most are simply abandoned. This may be both a challenge as well as an opportunity in the transfer and application of knowledge gained at one location to another (see the section on transferability of the concepts).

There are also structural and functional differences (nature, complexity, and objectives) between agroforestry and satoyama. While agroforesty involves more than one life-forms on the same land management unit with key productive and protective functions, and adopts intensive management, the satoyama woodlands are extensively managed; understorey production is seldom an objective. Multi-tiered canopy architecture constitutes yet another distinctive attribute of WG agroforestry (e.g., homegardens; Kumar and Nair 2004). But the satoyamas are generally characterized by a simpler canopy structure. The product range of agroforestry also involves an array of items such food, fuelwood, fodder, timber, and green manure (Fig. 5). Production, however, is not major objective of the current satoyama conservation initiatives that focus on ecosystem services.

Implications for management and policy

Commercialization and urbanization are major banes of both agroforestry and satoyama, and it has resulted in considerable loss of tree cover and cultivable areas (Figs 2 and 3). Urgent steps are therefore necessary to revitalize these traditional land use systems. While significant efforts to conserve the Japanese satoyama lands are being made (e.g., Nakagawa 2003), little or no such efforts in this direction are visible in the WG context. The former may be attributable to the realization that satoyamas, although do not seem to provide several of the utilities they provided earlier, is a 'dying heritage' that needs to be preserved. As a result, the significance of satoyama landscape in terms of species conservation as well as its social, cultural, recreational and educational functions are now well recognized (Takeuchi et al. 2003). Conservation measures based on cultural value (Fukamachi et al. 2001) to satisfy the rather strong demands for recreation and nature observation are on the anvil (Okada 1999). Examples include habitat preservation through the "Totoro Hometown Fund Campaign" to save areas of satoyama located in the Sayama Hills on the outskirts of Tokyo in Saitama Prefecture (Kobori and Primack 2003) and the proposed Japan Sub-global Assessment on satoyama and satoumi (UNU undated).

In the WG context, however, land is still a predominant source of livelihood and it is fundamental to ensure that intensive agriculture does not impair the resilience of the ecosystems. Targeting the multifunctional nature of these land-use systems and the creation of incentives such as niche markets for products from such ecosystems could assist, to some degree, in realistically addressing the situation. In the light of continuing environmental degradation, there is, however, consensus that integrated tree-crop production systems such as agroforestry is the way to manage tropical agroecosystems in general (Nair 2008), and the fragile ecosystems of WG in particular (Kumar 2006b). As mentioned earlier, agroforestry is a key provider of ecosystem services (Fig. 5) and it offers additional opportunities through carbon financial markets for trading carbon offsets (e.g., CER or Certified Emission Reduction). Despite this, policies for sustainable agriculture, i.e. to promote integrative practices that focus on the conservation of resources (including genetic diversity) as well as productivity have proved elusive in the WG context. Agricultural policy in the forest fringes of WG should shift its orientation from production of consumables to integrated management of all aspects of farm and the adjacent forestlands. The social challenge of delivering sustainable agricultural landscapes by adjusting the land use practices at the individual farm-level, however, is daunting.

Transferability of the concepts

Although there are many similarities between satoyama woodlands and WG agroforestry (section titled 'System description'), the land use systems in WG are structurally, functionally, and managerially different from the satoyama woodlands (Table 6). They perhaps bear only minor structural and functional resemblance, and, thus, it seems difficult to apply the conservation strategies developed for satoyama to the tropical landscapes. Moreover, climate, land use pattern, vegetation, and the social system of the WG and satoyama are different. Yet another major difference between the two regions is that WG involved both subsistence agriculture and plantation production systems, and this resulted in intensive resource utilization. In Japan, however, satoyama has been declining due to socioeconomic and technological factors and the conservation activities are primarily oriented towards environmental and biodiversity conservation (Takecuchi et al., 2003).

Despite the differences of the two systems, the prospect of extending the ideas of harmonious man-nature relationships that existed in Japanese satoyama to other parts Asia including WG looks promising. In particular, the techniques for conservation and sustainable use of the commons in satoyama are relevant to the management of common pool resources in the tropics. Management of NTFPs, community grazing lands, and sacred groves in the WG are potential loci for this. Incidentally, over exploitation of NTFPs and the associated threats for biological diversity are widespread in WG (Muraleedharan et al. 2005). Likewise, overgrazing, destruction of natural habitats and site degradation are major concerns of the community grazing lands in certain parts of the peninsular India (Gadgil 1983-'84).

The sacred groves (part of a landscape, often a forested ecosystem, with well-defined geographical features, delimited and protected by traditional societies through traditional institutional arrangements, often not codified, utilizing a whole set of myths and beliefs; Ramakrishnan et al. 1998) of WG have been losing their traditional veneration, as most of these are decimated under the garb of increasing productivity. It is possible to apply the lessons of social engineering and participatory management learnt from Japanese satoyama conservation strategies to the conservation and management of these common property resources. The forthcoming 10^{th} Conference of the Parties to the Convention on Biological Diversity (CoP CBD) in October 2010 at Nagoya in Japan is likely to discuss this idea of sustainable human-nature interactions in *satochi-satoyama* and its relevance to the modern society.

On the reverse side, production currently is not a significant function of the satoyamas; however, it may become important should the economic situation change and the prices of commodities such as food and wood in the international markets increase (Takeuchi et al. 2003). Under such a scenario, the system management concepts evolved for agroforestry would probably be relevant for satoyamas too. Research partnerships between agroforestrers and satoyama researchers, if established, may facilitate the transfer of lessons learnt in one to the other.

Conclusions

Agroforestry in the tropics and the satoyama landscape of Japan are important examples of sustainable land use practices. We have an exceptional window of opportunity in these traditional land use systems for sequestering atmospheric CO_2, in a manner that ensures greater synergy with CBD and for providing ecosystem services. Although conservation of the satoyama landscape for harmonious existence of human beings and other entities of the abiotic and biotic environments are being emphasized currently, their role in climate change mitigation has been seldom focussed. Likewise for agroforestry, although several potentially promising opportunities of reducing deforestation exist under international treaties like Kyoto Protocol, through increased investments through avoided deforestation to mitigate global climate change, much of these have not yet been explored adequately. This calls for renewed efforts to revitalize these traditional systems and a new approach to natural resource management so that these management systems can be tailored and adapted to meet the requirements of ecosystem services. Transfer and application of knowledge between satoyama and agroforestry may be valuable to promote environmental services, and to safeguard global public goods, and hence should be promoted.

Acknowledgements

This paper, written during the tenure a visiting professorship awarded to BMK by the Integrated Research System for Sustainability Science, University of Tokyo, Japan, was presented at the Ecosystem Service Assessment Series seminar of the United Nations University-Institute of Advanced Studies at Yokohama, Japan on 19 January 2009. Dr. Kaoru Ichikawa assisted in translating the Japanese language literature referenced in this article.

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Figure captions

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Table 1. A comparison of the climatic and physiographic features of Western Ghats and the Satoyama landscapes of Japan.

Parameter	Western Ghats	Satoyama landscapes
Climate	Tropical	temperate
Latitude (^{o}N)	8 – 21	23 – 45
Longitude (^{o}E)	73 – 75	125 – 142
Annual precipitation (mm)	1100 – 6000	1000 – 2000
Terrain	rugged and mountainous	mostly rugged and mountainous
Total cultivated area (km^2)	32,000[a]	60,000 – 90,000[b]

[a]It is assumed that the hill and valley system of cultivation is followed in about 20% of the total area of Western Ghats, which is 160,000 km^2 (Vencatesan and Daniels 2008)

[b]Tsunekawa (2003)

Table 2. Aboveground carbon stocks of homegardens in six administrative divisions (*panchayaths*) of southern Western Ghats (Thrissur, Palakkad, and Malappuram districts of Kerala), India (source: Kumar, unpublished data).

Panchayaths	Mean	Minimum	Maximum	Standard error (n=30)
			$Mg\ C\ ha^{-1}$	
Athirappilly	16.91	6.63	37.77	1.26
Edarikode	35.76	24.27	50.41	1.31
Edavanna	32.29	19.97	60.76	1.72
Mundur	26.62	7.76	45.08	1.59
Sreekrishnapuram	23.40	14.49	32.81	0.94
Thiruvilwamala	20.68	11.43	36.87	1.29

Notes

1. Though reported as carbon sequestration potential, the values are based on biomass stock estimates: 50% total biomass stock is taken as C stock.
2. Aboveground carbons stocks of trees above 30 cm girth at breast height were computed on total homegarden area basis: that is inclusive of the land area used for herbaceous crop production within the homegarden (often in association with trees) and the portions used for residential purposes. 50% of tree biomass was taken as carbon stock.
3. The six panchayaths form a subset of the 31 panchayaths where a homegarden survey was conducted (Kumar et al. 2005; Kumar 2008b). The methodology involved a two-stage stratified random sampling scheme in which about 10% of the *panchayaths* in each district was sampled and a detailed household survey of 30 randomly selected households per *panchayath* was conducted. All dicot trees except rubber (*Hevea brasiliensis*) was enumerated by measuring tree the height and girth at breast height, GBH of all scatterd trees and shrubs (>15 cm girth at breast height on the homestead and border except palms and rubber. For palms, except coconut palms the mean height corresponding to 10 trees (wherever available) and frequency were recorded. For coconut palms the tree age as reported by the garden owner and the number of trees was recorded. For rubber trees also, only the average girth at breast height of 10 trees and the number of trees were noted. Girth at breast height (GBH) of all bamboo clumps [*Bambusa bambos*] in the selected homegardens was carefully measured after removing the overhanging thorns.
4. For estimating tree biomass, the following equations were used:

- All dicot trees: $Y = \exp\{-2.134+2.530*\ln(D)\}$ where Y= biomass per tree in kg, D = diameter at breast height in cm (FAO 2004).
- Coconut palms: $y = 5.5209x + 89.355$ ($R^2 = 0.89$ y= dry weight, kg; x= tree age, years; Kumar and Russell, unpublished data).

- All other palm trees (areca palm, palmyra palm etc.): Y (biomass, kg) = 4.5 + 7.7 * stem height (m) (Brown 1997).
- Bamboo, $\ln y = 4.437 + 2.576 \ln (\text{DBH})$ where y is the total dry weight (kg) and DBH is clump diameter at breast height (m); Kumar et al. 2005).

Table 3. Carbon sequestration potential (aboveground) of different woodland vegetation types in Japan

Vegetation types	Carbon stock (Mg C ha^{-1})	Remarks/scenario	Source
Broad-leaved secondary woodlands, Kyoto (satoyama)	49	All stems ≥3 cm DBH	Goto et al. (2003)
Secondary woodlands: *Quercus serrata* and *Quercetum acutissimo*, Tsukuba (satoyama)	66	Rotational clear cutting, 15 year interval	Terada et al. (2007)
Plantations: *Cryptomeria japonica* and *Chamaecyparis obtusa*, Tsukuba	156	Rotational clear cutting, 60 year interval	Terada et al. (2007)
Plantation or secondary woodlands: *Pinus densiflora*, Tsukuba	180	Rotational clear cutting, 60 year interval	Terada et al. (2007)
Abies firma forests, Shikoku	242	Stem plus branch	Ando et al. (1977)
Tsuga sieboldii forests, Shikoku	279	As above	As above
Deciduous broadleaved forests *(Quercus serrata* and *Q. acutissima),* evergreen broadleaved forests *(Cryptomeria japonica* and *Chamaecyparis obtusa)* and plantation *(Pinus densiflora),* Tsukuba	1.87	Trunk, branches, and understorey plants	Yokohari et al. (2006)

Notes

1. Though reported as carbon sequestration potential, the values are based on biomass stock estimates: 50% total biomass stock is taken as C stock.
2. The systems described above were selected from the available reports concerning biomass estimations of Japanese forests. Some of these are, however, relatively small plots assessed during the period of the International Biological Programme (e.g., Ando et al. 1977).
3. For the Terada et al. (2007) study, carbon stocks were derived by multiplying the average annual C yield with rotation lengths, as stated in the remarks/scenario column. This article originally calculated the amount of carbon substitution by using woody biomass from satoyamas.

4. For the Yokohari et al. (2006) study, which reported biomass stocks for 12% of 284 km^2 area in Tsukuba city (12757 Mg), 50% of the biomass, is reported as C stocks.

Table 4. Floristic diversity indexes (woody perennials ≥ 15 cm girth at breast height or 4.8 cm diameter at breast height) of homegardens in the Western Ghats in Kerala (source: Kumar et al. 1994).

Holding size category	Area sampled (ha)	Number of		Simpson's diversity index	Shannon-Wiener functions		
		Species	Individuals		H'	H_{max}	$E=H'/H_{max}$
Small	1.111	21	269	0.61^{a}	2.30^{a}	4.24^{a}	0.54^{a}
Medium	1.908	26	1173	0.44^{b}	1.66^{b}	4.58^{b}	0.37^{b}
Large	4.916	20	561	0.46^{b}	1.64^{b}	4.00^{c}	0.43^{c}

Holding size categories small, medium, and large refer to <0.4, 0.4 to 2, and >2.0 ha respectively. Values with the same superscripts do not differ significantly.

Table 5. Simpson's diversity indexes for satoyama woodlands in Japan (values correspond to individuals above 4.8 cm diameter at breast height; computed from the sources mentioned in the footnote).

Vegetation type/Location	Area sampled (m^2)	Number of		Simpson's Diversity index	Shannon-Wiener functions		
		Species	Individuals		H'	H_{max}	E
Evergreen forests, Akabanedai and Hachiman Shrine, Kita Ward, Tokyo[1]	100	6	15	0.67	1.41	1.79	0.79
Deciduous forests, Akatsuka Park, Itabashi Ward, Tokyo[1]							
Belt transect along the slope	104	7	37	0.71	1.55	1.95	0.79
Old castle ruins	100	2	8	0.22	0.38	0.69	0.54
Quercus serrata secondary woodland (Kanagawa Niiharu citizens' woodland), Midori Ward, Yokohama[2]	250	4	29	0.56	0.94	1.39	0.68
Quercus serrata woodland, Noyama and Rokudouyama Park, Tokyo Prefecture[3]	3750	11	255	0.68	1.49	2.40	0.62
Castanopsis sieboldii woodland, Tonogayato teien (garden), Kokubunji, Tokyo[4]	200	8	27	0.76	1.69	2.08	0.82
Cyclobalanopsis myrsinaefolia woodland Sourousenen (garden), Koganei, Tokyo[4]	100	5	16	0.57	1.16	1.61	0.72
Carpinus tschonoskii woodland Inokashira Park, Musashino, Tokyo[4]	100	7	17	0.78	1.68	1.95	0.86
Yanokuchi, Inagicity, Tokyo [5]							
Abies firma community	300	10	56	0.72	1.61	2.30	0.70
Cryptomeria japonica and *Chamaecyparis obtusa* forest plantation	100	4	13	0.48	0.93	1.39	0.68
Carpinus tschonoskii and *Q. serrata* community	300	11	76	0.77	1.72	2.40	0.72

<u>Notes</u>

1. All data were based on 10 x 10 m quadrats except for Akatsuka Park (2x 52 m belt transect), and the *Quercus serrata* Secondary woodlands at Yokohama (5 x 50 m) and Noyama (six 25 x 25 m quadrats).
2. Source of data:

[1]Japanese Institute of Landscape Architecture and Tokyo Prefecture Northern Park Office (1996). Report of vegetation survey on terrace scarps in and around Akatsuka Park No. 2, 102p (Jp.)

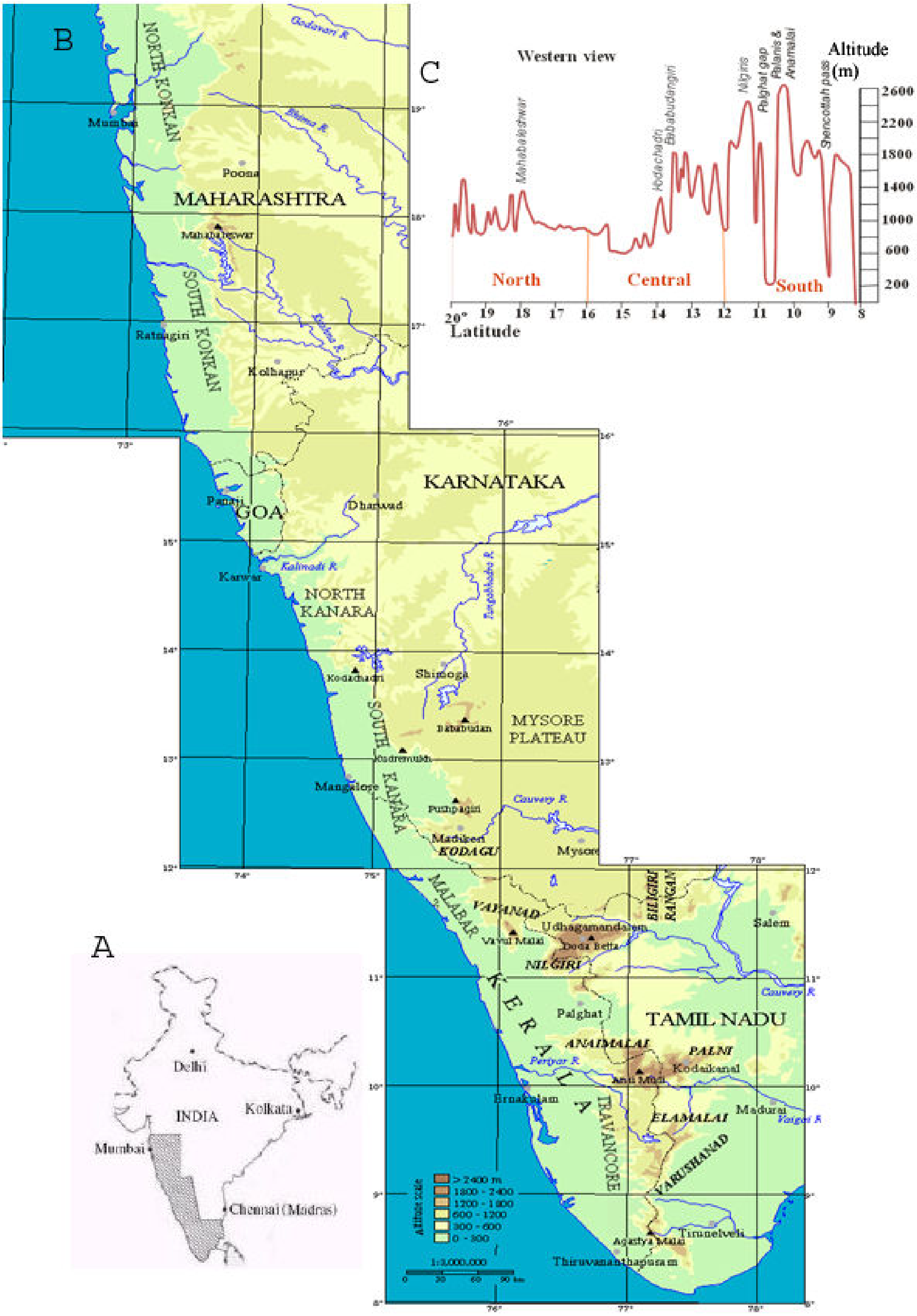
[2]Department Ecosystem Studies, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Japan (2007). Field practice on site, vegetation, and its management in coppice woodland in suburban area. (Jp.).

[3]Tokyo Prefecture Western Park Office, Ryokusei Research Institute, Inc. (1996). Report of woodland regeneration planning in Noyama-kita and Rokudouyama Park, 63p, (Jp.)

[4]Japan landscape Contractors Association (1985). Report of planting technology survey of Showa Kinen Park. Planting Division, Road Department, Public Works Research Institute, Ministry of Construction, Tokyo (Jp.)
[5]Taisei Corporation, Yomiuri Land Co. Ltd. and Ryokusei Research Institute, Inc. (1992). Environmental Survey Report, Keio Yomiuri Land Station Development Project, Tokyo (Jp.)

Table 6. Key differences between traditional agroforestry and satoyama

Parameter	Agroforestry	Satoyama
Geographical focus	Predominantly tropical	Temperate East Asia
Philosophy and approach to land management	Individualistic	Collective, community, or private
Objectives	A tool for landscape restoration, improve human welfare by reducing poverty, increase cash income and improve food and nutritional security	Co-existence of nature and humans with high natural and social quality on national lands.
Intrinsic features	Intentional, Intensive, Interactive, and integrated	Integrated, dynamic, mosaic landscapes with traditional land use and management
Structural aspects	Mimics the natural forests in certain cases, possesses multi-tiered canopy architecture, and provides niches for different species groups.	Includes various stages of arrested succession, less complex architectural pattern, have the potential to create habitat mosaics
Functional aspects	Multiplicity of products as well as ecosystem services	Principal focus is on ecosystem services and conservation of natural resources (production focus lacking)
Land tenure	Predominantly private ownership	Mostly common pool resources; conservation entails processes of social engineering and participatory management involving various stakeholders



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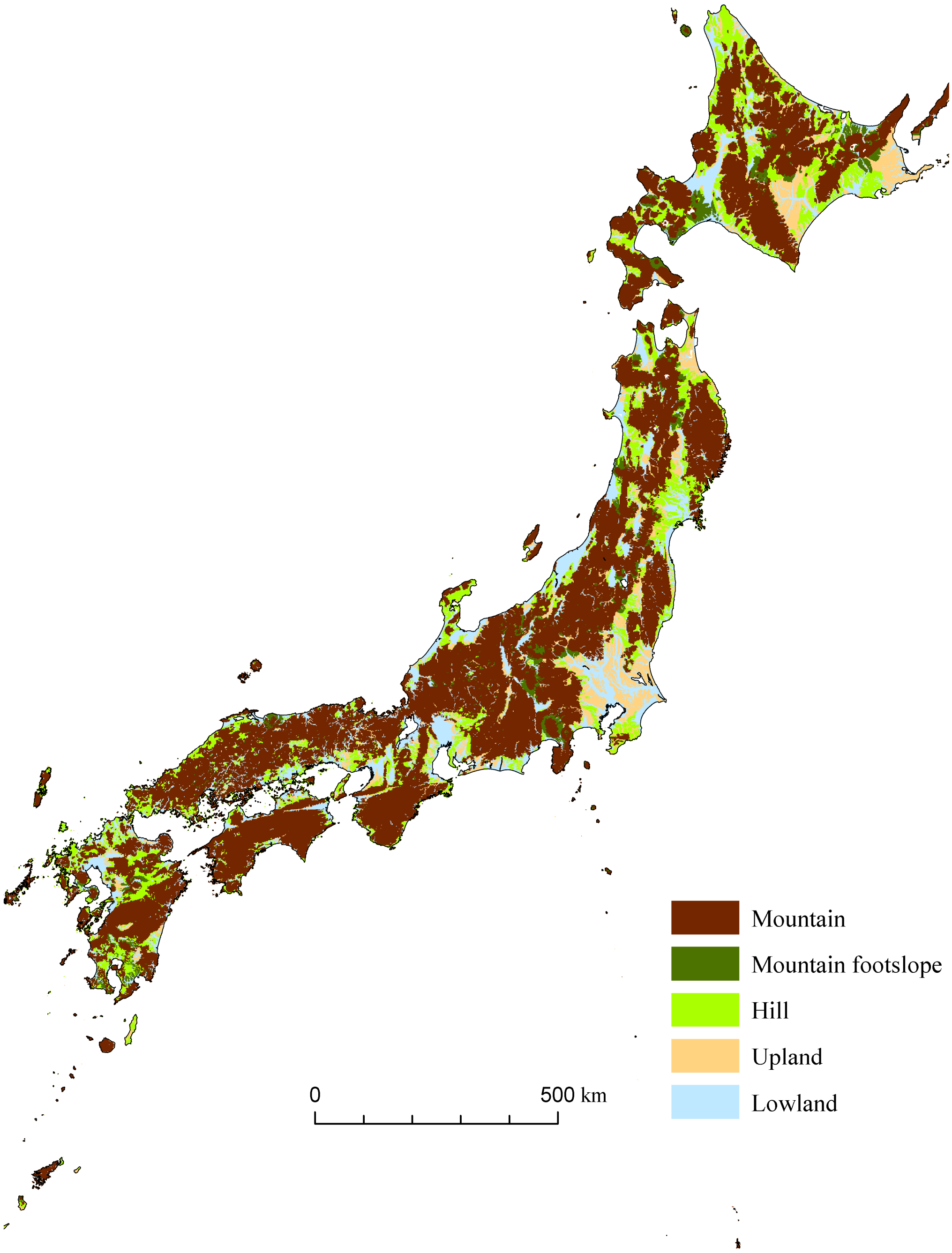

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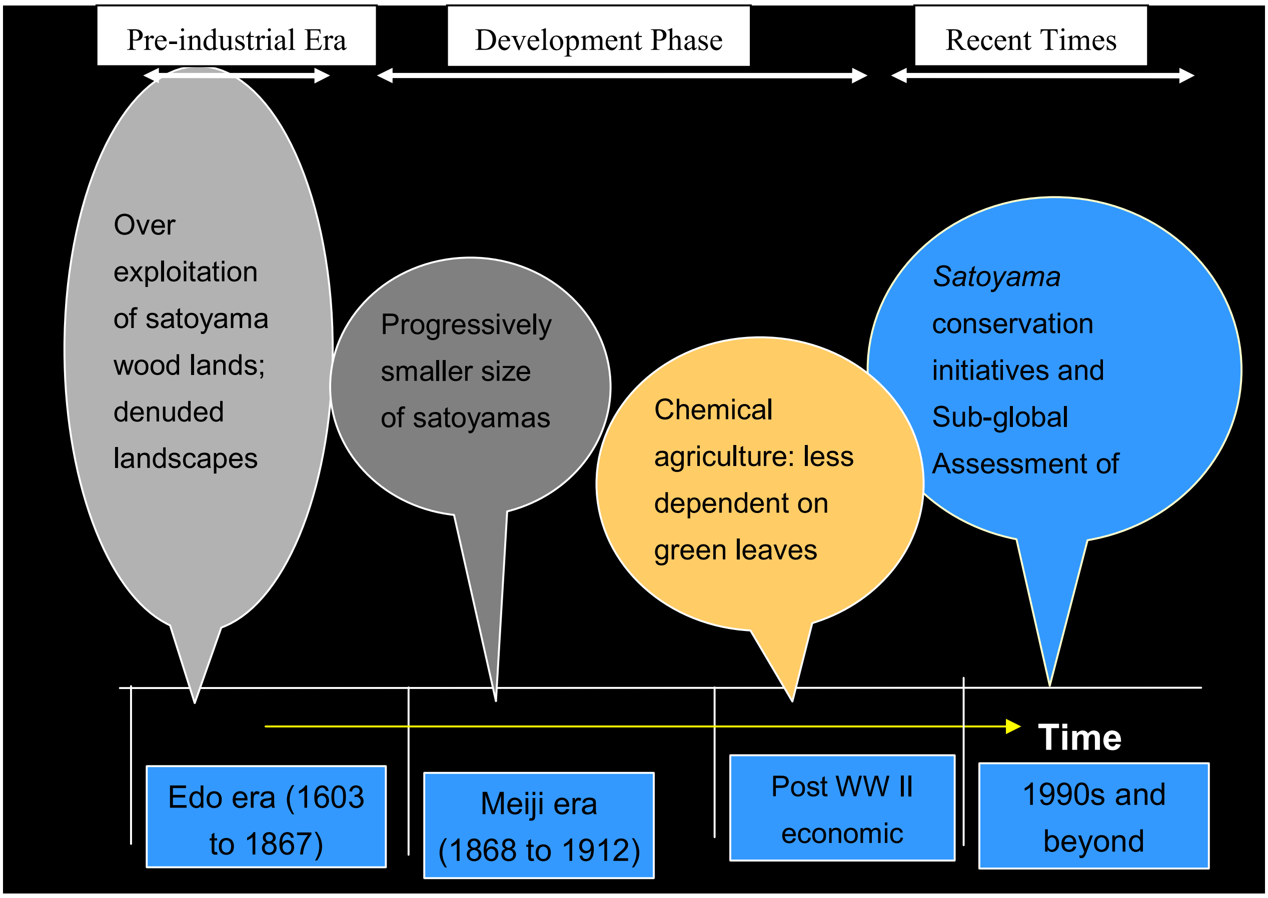

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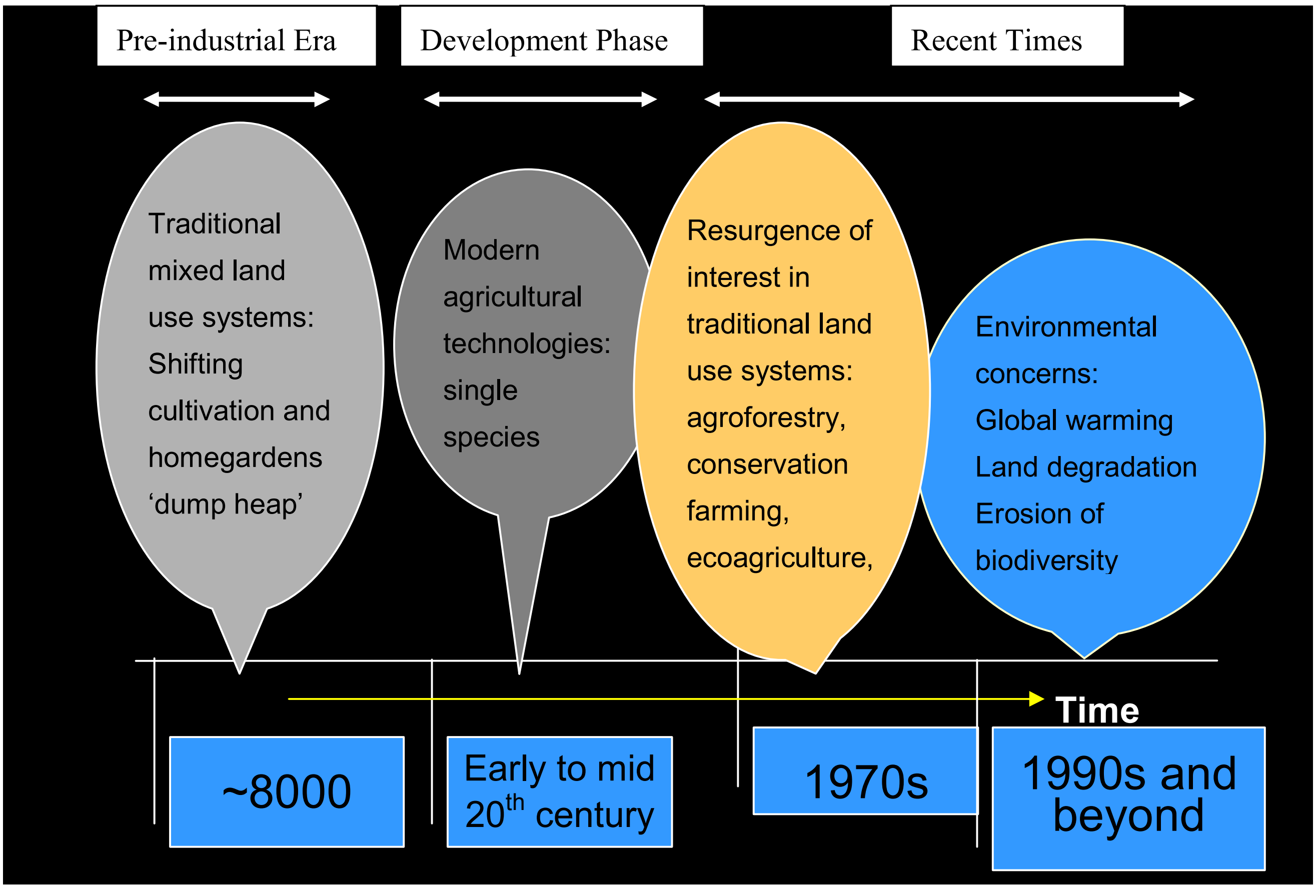

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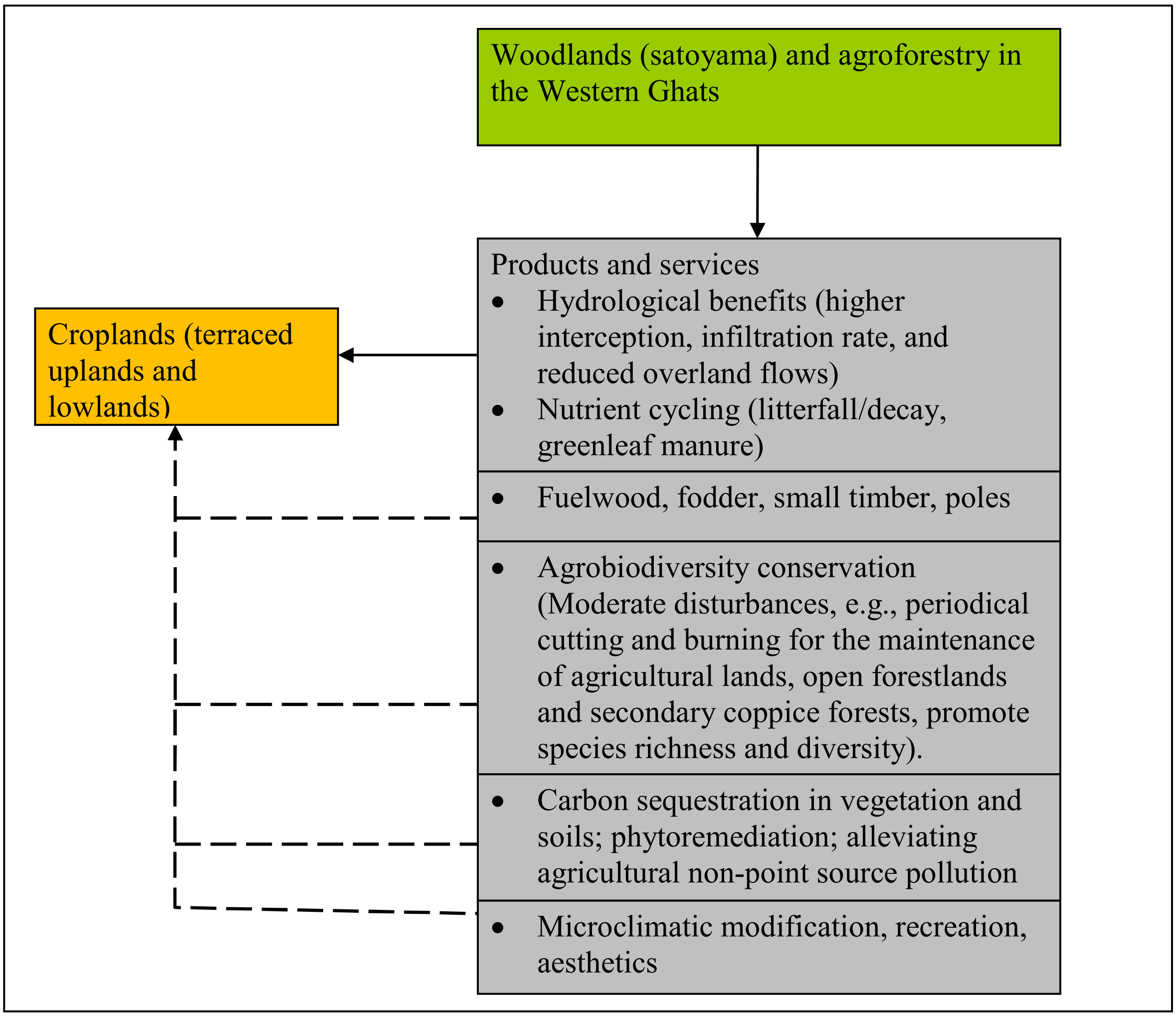

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Note

Millennium Ecosystem Assessment (2005) has categorized the ecosystem services into provisioning service (e.g., fuelwood, fodder, timber, poles etc.), regulating service (hydrological benefits, micrclimatic modifications), supporting service (nutrient cycling, agrobiodiversity conservation), and cultural service (recreation, aesthetics).

Endnotes

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[i] Simpson's Diversity Index measures the probability that two individuals randomly selected from a sample will belong to different species, and ranges between 0 and 1. Shannon-Wiener index (Shannon's index) accounts for abundance and evenness of the species present. The proportion of species i relative to the total number of species (pi) is calculated, and then multiplied by the natural logarithm of this proportion ($lnpi$). Shannon's equitability (E) can be calculated by dividing H' by $Hmax$ ($Hmax = lnS$ where S is the number of species). Equitability assumes a value between 0 and 1 with 1 being complete evenness.