Use and cultivation of plants that yield products other than timber from South Asian tropical forests, and their potential in forest restoration

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ABSTRACT

Rural communities have traditionally valued forests for a diversity of products and services, with timber serving a minor role. No-where has this diversity been greater than in tropical South Asia, and in particular south India and Sri Lanka. As economies advance towards full development and populations become increasingly urbanized, forests become increasingly valued for their services. National development generally occurs at differing rates in different regions, with rural forest dependent communities falling behind and pockets of poverty long remaining. The demand for ‘non-timber forest products’ (NTFPs) therefore changes from subsistence to monetary based values. Overall, though, forests have suffered an unprecedented decline with development in the tropics, especially in Asia. This necessitates restoration which takes account of the enrichment of economy, wellbeing and culture which forest products provide. Methods for such restoration, and the fundamental principles upon which these must rest, are presented for species yielding NTFP’s. In this paper we first review the history of NTFP species use within south India and Sri Lanka. Second we provide a description of the broad regional characterizations of the forest formations within this region in relation to their affiliated patterns of NTFP use and exploitation. We consider seven guilds as a way to categorize NTFP’s into autecological groups for application in restoration silviculture, and use it as a framework to suggest restoration protocols for South Asian forests. We use examples of scenarios based on experimental studies of NTFP’s in reforestation trials which take account of different social values and land tenures. We conclude with a call for further research.

1. Introduction

Beyond the deserts, it is considered on ecological grounds that tropical Asia, like South America, was continuously covered with closed forest before the advent of humankind (Cerling et al., 1997; Bond et al., 2005). Unlike Africa, these two tropical regions lack the rich browsing fauna which reduces so much of the deciduous woodlands of seasonal Africa to orchard savanna or even grasslands (Bond et al., 2003, 2005). In tropical Asia, only where great rivers push out of the Himalaya to extensive floodplains do grasslands exist. But the use of fire by Asia’s human ancestors has been dated to 1.8 million years ago, and hominid-induced fire must surely have modified tropical Asia’s deciduous forests at least since then (Bond et al., 2003, 2005).

Tropical south Asia has had the good fortune to retain traditions of forest use of unique diversity and complexity. These traditions survived remarkably intact through the many invasions of peoples from the temperate north. Such invasions have in fact enriched forest use and tree agriculture. While the Dravidian cultures of South India retained sophisticated traditions of plant use, the Indo-Arians, the Mughals and the European colonists brought fruit species (Kosambi, 1975). These introductions became incorporated into ‘tree gardens’, diverse mixtures of trees that provide fruit, medicines and spices, which now characterize the more humid parts of the region (Diamond, 2002).

Tree gardens have always remained a separate entity from the natural forest whose uses also achieve an unequalled complexity. Minority peoples in India and the rural poor in Sri Lanka are now mostly confined to the un-irrigable lands of the hills, where the remaining natural forest exists. These peoples conserve in their traditions the specific knowledge of local conditions and habitats, as a continuum of accretion since people first colonized these
forests. The introduction of irrigation technology, perhaps through the dry warm temperate period of the Indus culture 4-2000 YBP, provided the agricultural wealth and an ease of communication that led to the first urban civilizations (Kosambi, 1975; Maloney, 1992). These in turn fostered the great indigenous religions, Hinduism, Jainism and Buddhism, and a documented pharmacopoeia, Ayurveda, that remains the foundation of medical tradition today, in complement to the western ‘scientific’ tradition (Kosambi, 1975). The increased communication also led to homogenization of knowledge and the spread of a more uniform tradition fostered by lively regional trade in medicinals. Most of these species continued to be harvested from their indigenous forest habitats (Fox, 1995; Mahapatra and Mitchell, 1997).

But the last century has brought challenges to this progress. Although minorities and other poor rural communities have continued to depend largely on their individual place-specific, and more general Ayurvedic knowledge and resources, increases of both rural and urban populations continues to foster increasing demand of NTFP’s (Chomnitz and Kumari, 1998; Bhakat and Pandit, 2003). Few current studies have critically examined whether and to what extent demand can be met by natural populations. At the same time, exploitative harvesting of some species for wider markets is leading to threatened extinctions. This has been increasingly reported in the case of herbs from Himalayan alpine grasslands (Olsen, 1998; Adhikari et al., 2004); but even some commoner tree species such as eaglowood (Aquilaria species notably A. krasnou) in East Asia are being threatened (Chakrabarty et al., 1994; Soehartono and Newton, 2001). It is both surprising and worrying how few useful indigenous forest species have been brought into cultivation; and how little experimental work has been done on their silviculture. Research on restoration of degraded forests and wastelands has started to include species that yield products other than timber. The principles and optimal methodologies for such restoration will be presented.

In this paper we first provide a review of history of NTFP species use within the tropical region of southern India and Sri Lanka. Second we provide a description of the broad regional characterizations of the forest formations within the region in relation to their affiliated patterns of NTFP use and exploitation. Third we describe the seven main functional and ecological categories (guilds) of NTFP’s and provide ten economically important examples. We consider the seven guilds as a way to categorize NTFP’s into autecological groups for application in restoration silviculture. We use it here as a framework in our proposed restoration protocols for South Asian tropical forests for different social and economic objectives. We conclude with recommendations for further research and summarize present challenges of NTFP use.

2. A rich and complex history

People cannot survive without a ready supply of carbohydrates. Plant sources in the tropics, doubtlessly also present in ancient time as indicated by surviving nomadic cultures, include palm trunk cores, yams (Dioscorea, Ipomaea and Colocasia), grass and other seeds (Morrison, 2007; Zohari et al., 2012). Although the starch yielding Metroxylon and Eugiessona palms yield important sources of starch in the wet tropics of East Asia, neither exists now in tropical South Asia (Ruddle, 1979), while cereal grasses and the prevailing yam genus there, Dioscorea, are most abundant in dry regions (Mahapatra and Tewari, 2005; Zohari et al., 2012).

Humans arrived in sufficient numbers in South Asia perhaps 100 thousand years ago as the last north temperate ice age was beginning to increase in intensity. During this cooling period, the southwest Indian monsoon abated, probably for prolonged periods (e.g. Wang et al., 2001). Much of the land was likely desert, but there would also have been significant seasonal precipitation to support deciduous forest, well provided with game and sufficiently rich in carbohydrate sources to support nomadic tribes. Lowland evergreen forests would have retreated to those foothill valleys which continued to receive orographic rainfall. Evidence is accumulating, nevertheless, that humans were surviving in such forest refuges both in the Western Ghats and in SW Sri Lanka, where rock shelters provided escape from rain and predators (Perera et al., 2011). Remains of carbohydrate sources have not survived, but a Sri Lankan site yielded shells of Canarium nuts, sure evidence that the surrounding forest was rain forest (Coronel, 1996). Dioscrea, the major carbohydrate source for Peninsular Malaysian forest negritos, would surely also have been important to South Asian forest dwellers, while the possibility of an early discovery of flour production would have permitted storage of carbohydrate from seasonal tree seeds such as Vateria, and even the supra-annually yielding beraliya (Shorea section Doona) in SW Sri Lanka (Guntilleke et al., 1993). Such plant foods require cooking, so fuelwood, along with hafts for cutting implements, digging sticks and other tools would have been among early harvested NTFPs, as well as medicinals which would surely have been gathered by ancestral hominids (Morrison, 2007).

The date of arrival of cereal cultivation is unclear. The cereals were, likely rice and millet varieties that would have been introduced from the north and east more than 10 thousand years BP (Zohari et al., 2012). The main practice of cultivation would have been swidden; that is to say by slashing forest patches, burning the dried slash which releases nutrients, and cultivation until weeds overtake the capacity to control, then abandonment to natural regeneration (Dove, 1983; Rangarajan, 1999). This would have resulted in the first major change in human dependency on the forest. Here artificial canopy gaps would have been made for the first time, increasing the relative area of successional stages in the forest. These gaps would have been small, having little effect on seed dispersal for regeneration; and occupied for short enough periods in wet climates to have limited impact on soil surface conditions. The most abundant, and therefore many of the most used, NTFPs are successional light demanders, and would have increased as a consequence of swidden. The initiation of cultivation would also have fundamentally changed the role of men and women in food gathering. Whereas mixed bands, or men alone, would have foraged over the long distances formerly necessary to gather sufficient harvests of carbohydrate and many other NTFPs, Swidden, following initial preparation by men, permitted cultivation which women came to dominate. Women, who may always, as now, have been responsible for woody litter fuel collection, also came to dominate the collection of many other accessible NTFPs growing in nearby successional stands (Dove, 1983).

The arrival of irrigation, perhaps 3000 year BP, led for the first time to permanent forest clearance (Kosambi, 1975; Maloney, 1992). This resulted in the retreat of NTFP species to non-irrigable upland forest, much of which continued under swidden as populations expanded; to the fertile riparian fringes where woodland has traditionally been retained as food defense; and to the deciduous forests of regions too dry for all but local irrigation, and where many NTFP’s continued in intensive use and in abundance. Irrigation also produced the excess of food, notably cereals, and facilitation of communication and trade through road building, which provided the means for the first cities, city states, and regional ruling hierarchies. Land tenure became settled and enshrined in tradition or law (Rangarajan, 1999; Sarker, 2011). That resulted, at some time following the loss of the fertile lowlands to irrigation, and the need for ready access to uncommon or long-lived NTFPs, to the origin of the woody ‘tree gardens’ for which the moister regions of South Asia are so celebrated (Hochegger, 1998; Illukpitiya and Yanagida, 2010).
Evidence from current plant distributions and the stone relics in Borubudor, Java, and elsewhere, suggest that south Asians migrating eastward during classical times accomplished the astonishing feat of transporting living seedlings, of NTFP-yielding indigenous forest tree species lacking seed dormancy, to East Asian communities who still cultivate them: Syzygium, Artocarpus heterophyllus and Mangifera indica fruit trees, Cassia fistula with elegant blossoms, Terminalia arjuna for feeding the Tussar silkmoth caterpillar (Hutterer, 1983; Ashton, 1999). And bananas, rambutans (Nephelium spp.), mangoosest (Garcinia mangostana) and durian (Durio zibethinus) came the other way (Hui-Lin, 1970; Hutterer, 1983). Whereas major trade in NTFP's in the East Asian tropics has developed with China over somewhat more than a millennium (Lauffer, 1919; Kosambi, 1975), international trade with South Asian nations, which included forest yielding spices (cinnamon, pepper) has also been long established with Europe and the Middle East (Crone, 2004). During the Roman Empire c. 2 millenia ago, and growing thereafter with the Middle East, trade in spices again grew with the arrival of European colonial powers; in South Asia, the Portuguese, then Dutch and British (Kosambi, 1975). The Portuguese brought species that yield NTFP's from tropical American forests for domestic use, and these uses have become incorporated into S. Asian culture: Many, including papaya (Carica papaya), soursop (Annona spp.) and caimito (Chrysophyllum caimito) have become intrinsic members of South Asian tree gardens; and what must food have been like there without chili? But the Dutch and British have established botanical gardens throughout the tropics for the purpose of exchanging commercially useful plants, including those yielding NTFP, worldwide, with the ultimate objective of large scale plantation of those that proved profitable in international markets (Brockway, 1979; McCracken, 1997). The introduction of tea (Camellia sinensis), coffee (Coffea arabica, Coffea canephora), and Hevea rubber, trees indigenous to evergreen forests in their places of origin, has changed the evergreen forest landscapes of tropical South Asia on a massive scale (Brockway, 1979). It may seem extraordinary that not one of these commercial introductions, even in its original form unimproved by selection, has invaded native forests; this reflects the fine level of their niche specificity to their source communities. Their large scale commercial plantations have weaned populations from traditional forest products in favor of products in international markets, and have doubtless resulted in extinctions (Dove and Kammen, 1997). Now, no South Asian community is independent of wider markets.

The Dravidian cultures of the south retained sophisticated traditions of plant use, such as of the sugar palm Borassus flabellifer for which an ancient sutra describes eight hundred uses (Fox, 1977; Cassou and Depommier, 2002), and groves of useful forest plants such as the Soppina Betta betel palm groves which originally served as a source of fuelwood, fodder and leaf litter for manure and agriculture cultivation (Mani, 1985; Nayak et al., 2000). But the tree garden has always remained a separate entity from the natural forest whose uses also achieved an unequally complex. Minorities, now mostly confined to the more remote lands of the hills, conserve in their traditions the specific knowledge of local conditions and habitats (Bhat et al., 2001; Davidar et al., 2008).

3. Characterization of forest formations, patterns of NTFP use and forest exploitation

The tropical forests in south India (comprising the states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh) and Sri Lanka are broadly correlated with the nature and degree of seasonality in rainfall, ranging from mixed dipterocarp forests of the southwest region and much of the Central mountain range of Sri Lanka, which lack a dry season, to the thorn woodland of the dry east and central on the Deccan and northwest and southeast of Sri Lanka, where there are at least eight dry months (Fig. 1). A secondary axis of forest differentiation is correlated with elevation, in which there are gradual changes in mean annual and seasonal temperatures along with rainfall and, most specifically zones of cloud and fog, up the mountains within the region, many of which ascend above 2000 m. The forests can be conveniently categorized, in relation to their prevailing NTFP's into seven regional formations modified after Champion and Seth (1968); Gunatilleke and Ashton (1987) and Ashton (1995, 2003). The seven categories are: 1. mixed dipterocarp forest; 2. seasonal evergreen dipterocarp forest; 3. semi-evergreen forest; 4. moist deciduous forest; 5. dry deciduous forest; 6. thorn woodland; and 7. tropical lower montane (some upper montane) forest. The species yielding the most important commercial non-timber forest products within each of these forest formations and their regions have been summarized (Table 1) and described in more detail by their distribution, ecology, use and cultivation (see Appendix 1).

The lowland, including lower hill forests are confined below 750 m. There is then a gradual ecotone to 1200 m, above which the montane forests are confined. The mixed dipterocarp forest exists as a refuge, of c.10,000 km² in southwest Sri Lanka, and is an appendage to the main part of the forest formation which dominates the lowlands of Sunda Land, 2000 km to the east. Mean annual rainfall may reach 5000 mm and is never below 2500 mm. This kind of forest comprises both lowland and hill dipterocarp associations and is species diverse, well stratified, and dominated by high statured trees (30–45 m) in the genera Dipterocarpus, Meura, Callicoma and Shorea.

Seasonal evergreen dipterocarp forest (both lowland and hill) dominates the western foothills of the Western Ghats from Cape Comorin north to Shimoga (Fig. 1). Receiving the brunt of the rains as the southwest monsoon is forced up the slopes of the Ghats, annual rainfall can exceed 8 m, though there is also an annual dry season of 2–4 months, increasing from the south. They are shorter and less clearly stratified than the mixed-dipterocarp forest formation, except in sheltered coves (Subramanyam and Nayar, 1974). Though generically similar, their communities lack some important endemic tree genera, differ substantially at species level and are one quarter less rich. Both forest formations are now restricted to government forest timber reserves and parks since most has been converted to rubber, tea, coffee, rain-fed rice, coconut and small holder tree gardens. Many of these lands outside of forest reserves and government lands are held privately by small-holders or commercial estates. Much of the private land as well as some government land has been abandoned and reverted to grass and fern (see Ashton et al., 2014). The most commercialized non-timber forest products (NTFP's) exploitied from the remaining native forest in these two forest formations comprise medicinals (such as Coscinium fenestratum), cane (Calamus spp.) for artisanal work, resins for incense and fragrance (e.g. Gyrinops walla), and sugar from forest palms (Caryota urens) (Narendran, 2001; Senaratne et al., 2003; Gopalakrishnan et al., 2005; Murthy et al., 2005) (Fig. 2). In India, tribal peoples and farmers are much poorer than the rural small-holders in Sri Lanka, and more heavily depend on a host of subsistence NTFP crops that include litter for manure and fuel wood for cooking (Mani, 1985; Jacob and Alles, 1987).

The moist deciduous and semi-evergreen forest formations differ in the obvious character of evergreenness that indicates rarity of crown fires. Fire promotes the moist deciduous characteristic, because all but a few evergreen species are fire sensitive even to ground fires as seedlings, whereas most deciduous species even recover from crown fires by epicormic shoots. However, the two formations are often intimately integrated within the same landscape with semi-evergreen occupying soils and landforms that are more fire resistant (e.g. riparian areas, flood plains), and lands with lower
frequency and intensity of human-induced fire. The moist deciduous forests primarily occur along the lowland western coastal plain of Kerala, before and adjacent to the slopes of Ghats that promote higher rainfall and the seasonal evergreen-diptercarp forest. Moist deciduous formations (with some semi-evergreen) are also extensively found on the eastern foothills of the Western Ghats in Karnataka, and in the north-east peninsula mostly comprising Andhra Pradesh and Orissa. In these regions dry seasons can extend up to six months of the year; annual rainfall is generally less than 2000 mm. The moist deciduous forest that does remain includes teak (Tectona grandis) down the western coastal plain (Kerala) and Sal (Shorea robusta) in the north-east (Andhra Pradesh, Karnataka). Sal is managed both as plantations and as native forests for timber (Champion and Seth 1968). The native forests of Sal are also characterized by Terminalia and Lagerstroemia species and are the forests richest in bamboo, especially Bambusa and Dendrocalamus, which play a diverse and important part in rural economies. Other NTFPPs include fruit trees (Mangifera spp., - Mango; Aegle marmelos - wood apple), plants of medicinal value including gingers and amla (Phyllanthus emblica), food plants for tussar silk moth (T. arjuna), a host of plants for the lac insect, and trees of importance to both Bhuddist and Hindu religions (Ficus religiosa, Butea monosperma) (Sequiera and Bezkorowajnyj, 1998; Hegde and Enters, 2000; Sharma et al. 2006).

A distinct semi-evergreen forest is also represented along the south-east coastal hills of Tamil Nadu and most of northeastern Tropical South Asia and Sri Lanka.
Sri Lanka, that Champion called dry evergreen forest. This forest, dominated by evergreen species, is notophyllous. These regions receive some dry season rain from the north-east monsoon. In Sri Lanka much of this forest remains as ancient second growth post land abandonment from civilization collapse in the 1314th centuries (De Silva, 1981). Several such forests there are now wildlife parks and reserves. This forest formation is characterized by *Chloroxylon swietenia*, *Drypetes sepiaria*, and the genera *Diospyros*, *Ficus*, *Lagerstroemia*, and *Terminalia*. The NTFP’s utilized in this forest are largely the same as those listed for the moist deciduous formation (Shankar et al., 1998; Narendran, 2001). In India very little of this forest remains but that which does has been degraded, sometimes to grassland savanna by livestock owned by local communities.

The tropical dry deciduous forest formation occurs from the foot of the Western Ghats on the eastern (leeward) side where and rainfall is very seasonal, only amounting to between 900 and 1300 mm per year and with 6–9 month dry season. Most are subject to frequent ground fires, which can develop into crown fires in moister climates, particularly where the exotic shrub *Lantana camara* dominates the understorey. This forest formation is widely reduced to waste land by overgrazing and lopping in northern peninsular India but is still widespread in the south; in many regions what forest remains comprise small relics that resemble savanna woodland or are protected as sacred groves around Hindu temples (Shankar et al., 1998; Narendran, 2001). In India very little of this forest remains but that which does has been degraded, sometimes to grassland savanna by livestock owned by local communities.

The driest climate with woody vegetation cover supports tropical thorn woodland formation, extensive on the Deccan Plateau and south-western Rajasthan and adjacent Andhra (Champion and Seth 1968), and in the northwestern and southeastern corners of Sri Lanka. These comprise low statured open trees such as *Acacia* spp., *Capparis* spp., and *Euphorbia* spp. with sparse grass appearing during the rainy season. This forest formation experiences a long dry season, exceeding 9 months, with variable rainfall averaging 400–900 mm per annum. In Sri Lanka such forests comprise mostly wildlife refuges. In India much of the land is tribal and community owned and degraded because of poor control, weak regulation and absence of consistent management practices. Some of the NTFP’s exploited from the remaining forest comprise trees that produce fragrant woods with medicinal properties and resins (*Santalum album*, *Pterocarpus santalinus*) (Ambasta, 1986; Anon., undated).

Lower (and upper) montane forests are evergreen notophyll or microphyll forests that are restricted to elevations over 900 m: on both slopes of the Western Ghats, a few valleys in the north of the Eastern Ghats, and the Central, Rakwana and Knuckles Ranges of Sri Lanka. Rainfall typically exceeds 3000 mm per year, with short dry seasons lasting from January–March though dry periods may intervene more of the year towards the north of the Ghats. Again, much of this forest in Sri Lanka has been converted to tea, and extensive forest remaining is now in parks. In India conversion has been to coffee and livestock pastures towards the north and on the drier eastern slopes of the Western Ghats. In addition Sri Lanka has extensive areas of dark histosols, rich in organic matter, which have been converted within the last thirty years to vegetable production for consumption in nearby cities.
Much of the forest that has not been cleared has been cut for fuel-wood for heat and cooking by these market garden farmers, and by tea estate workers. Extensive areas of forest that remain have been cleared of the understorey to cultivate the spice cardamom (Elettaria cardamomum). This is particularly the case for the Knuckles and Rakanwa ranges of Sri Lanka, and primarily in Kerala and Karnataka in the Western Ghats (Anon., undated; Ambasta, 1986; Dhakal et al., 2012).

4. Functional and ecological categories of NTFP's

To develop silvicultural guidelines for species that yield non-timber forest products, it is first important to develop a system of identifying and then categorizing autecological traits that species have in common. This provides a systematic protocol for identifying the most promising species or species groups for a given silvicultural treatment (Smith et al., 1997). It has been well defined for trees where differences in their shade and drought tolerance, their successional status, together with their mode of dispersal and germination provide a framework for regeneration methods and post-establishment treatments. As far as we are aware this has yet to be done for NTFP's, probably because they comprise an eclectic mix of growth habits ranging from ground-story herbs, to vines to canopy trees (Ticktin, 2004). We present a simple framework here restricted to both woody dicots and monocots (mostly woody). Firstly, we have identified three phases of stand development that we think important for characterizing an NTFP's successional status: (1) Stand initiation; (2). Stem exclusion; and (3). Understorey re-initiation/old growth (after Oliver and Larson, 1996). Secondly we divide species that yield non-timber forest products into seven functional groups (guilds) based upon their growth habit, and stage of reproductive maturity (successional status) in relation to phase of stand development (Table 2; Fig. 3). By characterizing plants that yield NTFP's by these two major attributes, there is enough of a structural framework to identify some common ecological themes among NTFP species that can provide the basis for devising silvicultural methods of regeneration and treatment (see Section 5). Within these guilds we describe their mode of dispersal and germination (see Table 2). We believe our framework to be general enough for use across all tropical forest regions, but it is most applicable to tropical South Asia. Toward that end we provide some well recognized (native and exotic) South Asian NTFP species for easier understanding as guild examples in this section (see Table 3 for natives).

4.1. The seven guilds

Those plant species that yield NTFP's that establish very early after a disturbance and flourish in the open before canopy closure from the next young stand of regenerating trees would be considered “pioneers of stand initiation” (e.g. gap phase; Whitmore, 1990). We identify two NTFP guilds within this stage of stand development: 1. Pioneers that are shade-intolerant, fast-growing herbaceous monocots, woody shrubs or herbaceous vines that spread quickly through vegetative means but originally regenerated either from the soil seed bank (e.g. Clidemia hirta; Rubus spp., blackberries) or from their dispersal as seed rain by small birds and bats (e.g. Malpighia spp., acerola; Piper spp., pepper) (Guild 1); and 2. those that are fast growing, shade-intolerant pioneer trees, that form a spreading crown (Guild 2). In the more ever wet forest formations (mixed dipterocarp, seasonal evergreen dipterocarp and montane) Guild 2 species are generally large-leaved with umbrella-shaped crowns, that are superficial-rooted and weak in structure (e.g. Erythrina spp; Macaranga spp., Trema spp.,); but are very effective at usurping canopy growing space and nutrients that would be leached post disturbance if such species were not present (Whitmore, 1990). In the more seasonal and dry deciduous forest formations the species in this guild dramatically reduce their leaf size and arrangement to produce a more diffuse leaf canopy that is often deciduous (e.g. Gliricidia sepium, Albizia spp.). Some species in Guild 2 also fix nitrogen – a nutrient that is usually deficient after a severe soil disturbance.

In terms of categorizing their uses based upon their ecology, NTFP’s in Guild 1 often produce multitudes of small fruits that are high in sugar, and/or large roots and fruits that are important sources of carbohydrate (Solanum spp., potatoes; Manihot spp., cassava; Manihot esculenta).
esculenta, manioc). Species in Guild 2, because of their growth morphology, comprise almost all the nurse and shade trees used in agroforestry systems. Many are now widely planted in the wetter regions (Ashton and Ducey, 1999).

The second phase of stand development is defined by canopy closure of the new regenerating stand, with intense competition and self-thinning among competing trees (stem exclusion phase of Oliver and Larson, 1996; the building-phase of Whitmore, 1990). The understorey is deeply shaded, and the crowns of the stand are tightly packed and seemingly growing together. Species that dominate the canopy of this stage of succession are “pioneers of stem exclusion”. Two NTFP guilds can be identified with species that mature at this stage of stand development: (1) the trees that embody the stem exclusion process – fast-growing, tall, columnar-stemmed, with tightly-packed crowns that are predominantly shade-intolerant and if over-topped are quick to die (Guild 3); and (2) the vines that depend on stem exclusion for support (Guild 4). The pioneer trees of stem exclusion are some of the world’s most productive timber trees for the construction industry given the nature of their growth and stature, but they are also trees that can efficiently produce abundant amounts of sap, latex and resin (e.g. Alstonia spp.; Eucalyptus spp.; Castilla elastica, Panama rubber tree; Hevea brasiliensis Brazil rubber; Pinus spp. pine); and, given space through thinning and cultivation, some are important producers of nuts and fruits (Spondias spp. – jobo; Syzygium spp. – rose apple).

The other NTFP guild that dominates this stage of stand development are vines. Vines can easily usurp this growing space post-disturbance if the stem exclusion process is not uniform but broken by edge and shaded by larger, older trees of the original forest (e.g. selective logging). The vines vary in their shade tolerance, either waiting for the disturbance as advance regeneration in the forest understorey (e.g. Calamus, cane) or originate from seed rain (wind or small birds) after the disturbance (e.g. Vitis, grape) (Schnitzer and Bongers, 2002). Many of these species yield cordage and fiber (Calamus spp., Desmoncus spp.), while some species produce medicines from either the stem or from leaves and fruits (Passiflora edulis, Ziziphus oenoplia) (Ashton et al., 1997a; Parrotta, 2001). And the root tuber of Dioscorea spp. vines (yams), still valued medicinally, were the original mainstay of hunter-gatherer sustenance prior to agriculture within the South Asian region.

The third and last phases of stand development have been combined (“understorey re-initiation” and “old growth” (mature phase of Whitmore 1990) primarily because differences in their development do not clearly differentiate the autecology of NTFP’s. These phases of development are later successional, where mid-successional tree species that come to dominate stem exclusion are over-topped by much taller-statured, longer-lived late-successional species. Here, shading in the understorey becomes less homogenous as forest structure and foliage stratification becomes the most complex, and new canopy gaps begin to form; persisting regeneration (e.g. advance regeneration) of the shade-tolerant late successional species re-establishes in the understory, whose seed is from the reproducitively mature trees that have now ascended into the sub-canopy and canopy. Species that mature and produce NTFP’s at this stage of succession can be categorized into three guilds: (1) understorey shrubs and small understory trees that are shade-tolerant, can often recover from damage by sprouting, with planar branches maximizing light capture, produce small flowers and fruits, and synthesize nasty tasting chemicals in their leaves for protection (Guild 5); (2) taller subcanopy trees that usually have deep columnar crowns, are shade-tolerant, and produce larger and more nutritious fruit than those in the understory (Guild 6); and (3) canopy trees that are long-lived, developing first with columnar crowns which, once they attain the canopy, spread to become conical or dome-shaped (Guild 7) (Ashton and Hall, 2011).

Understorey shrubs and small trees produce NTFP’s that comprise many medicines, beverages and spices because of the chemicals that they harbor (e.g. C. sinensis, tea; Coffea spp., coffee; Elettaria spp., cardamom; Gymnopus spp.; Theobroma cacao, cacao). Similarly, late-successional sub-canopy trees produce the same kinds of products but, because of access to more light, produce fruits that are larger and more nutritious (e.g. A. heterophyllus, Canarium spp., Garcinia indica (kokum), Pouteria spp.). The large canopy trees often produce the most nutritious or carbohydrate rich fruits because of their crown position’s access to the most light, but many also produce incense and resins. These trees also

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comprise species that produce the durable luxury timbers used for furniture, veneers, flooring and heavy construction (e.g. *Diospyros* spp., ebony; *Durio zibethinus*, durians; *Mangifera* spp., mangos) (Whitmore, 1990; Ashton and Hall, 2011). These seven guilds can be considered as a way to categorize NTFP’s for purposes of restoration of South Asian forests (Table 3).

### 5. Silvicultural treatments for restoration and reforestation

Silvicultural systems for NTFP cultivation in tropical South Asia can be broadly categorized as those that rely upon natural regeneration and low intensity manipulations to secure natural regeneration for the desired species composition and structure without planting; and those systems that rely upon intensive site preparation, planting and post-establishment treatment that more closely control species composition and structure (Ashton et al., 2001a). For use of NTFP’s in restoration and reforestation, this dichotomy of intensive control (planting) and less intensive control (natural regeneration) provides a means of categorizing management approaches for a given circumstance.

#### 5.1. Working with second growth forests

Second growth forests in tropical South Asia arise from two kinds of human disturbance: (1) those that originate as early successional regrowth resulting from overharvesting timber; and (2) those that were originally old pastures used for livestock or were formerly agricultural. Those lands that were overharvested for timber are usually state or community lands (e.g. Forest Reserves). Lands that were originally pastures are tribal or community lands within the drier forest formations (dry and moist deciduous forest; thorn woodland). Former agricultural lands that have reverted to second growth are small-holder and commercial estates that originally cultivated plantation crops such as tea, rubber and coffee within the wet forest formations (mixed dipterocarp; evergreen dipterocarp; montane forests). In all these circumstances, when there is already some forest structure and composition present half the effort in NTFP species restoration has been avoided because of either the presence of a nearby seed source within the regrowth or because the regrowth structure provides the environmental protection needed for NTFP species establishment (see Ashton et al., 2014; Gunaratne et al., this issue). If appropriate the most

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Guild categorization for some important native non-timber forest products in South Asia by evergreen and seasonal deciduous forest types.</th>
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</thead>
<tbody>
<tr>
<td><strong>1. Wet mixed-dipterocarp and seasonal evergreen dipterocarp forests</strong></td>
<td><strong>NTF species</strong></td>
</tr>
<tr>
<td>Initiation</td>
<td>1. Shrub-like herbs, vines and shrubs</td>
</tr>
<tr>
<td>Stem exclusion</td>
<td>2. Small trees</td>
</tr>
<tr>
<td>2. Semi-evergreen, moist and dry deciduous, and thorn scrub forests</td>
<td><strong>NTF species</strong></td>
</tr>
<tr>
<td>Initiation</td>
<td>1. Shrub-like herbs, vines and shrubs</td>
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<td>Stem exclusion</td>
<td>2. Small trees</td>
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<tr>
<td>Understorey initiation</td>
<td>3. Fast-growing trees</td>
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</tbody>
</table>
economic approach is to work with what NTFPs have already established through natural regeneration. But where the forest structure and composition is either absent or not desirable, then the only alternative is to plant.

5.1.1. Restoration of NTFP’s in degraded forests

In circumstances where the existing forest has been degraded through chronic (e.g. repetitive) exploitation of products (timber and non-timber), the most important objective is to prevent the chronic impact, and then either do nothing and let natural processes of stand development sort out; or facilitate these processes through release treatments that control vines, and thin and select trees that are undergoing stem exclusion for the future forest canopy. If degradation processes are top-down, from the extraction of canopy trees through activities like selective logging, the focus should be on restoration of the advance regeneration of late successional canopy species in the understorey (Guild 7) (see Ashton et al., 2001a). If degradation processes from exploitation are bottom-up, from the removal of sub-canopy trees and shrubs through activities such as the cultivation of shade coffee, cacao or cardamom (mixed dipterocarp, seasonal evergreen dipterocarp, and lower montane forest formations), or from over-grazing the understorey with livestock (semi-evergreen, moist and dry deciduous forest formations) then the focus of the restoration activities should be on regenerating and facilitating the species composition and structure of the forest understorey (Guilds 5 and 6) (see Ashton et al., 2001a).

Non-timber forest products in South Asian second growth forests that have originated after human disturbance (particularly top down impacts) to primary or old growth rain forests can be prolific and diverse (De Zoya et al., 1991). There are several reasons for this: (1) there is an existing seed source within the residual forest itself that can easily be dispersed far and wide; (2), four of the seven NTFP species guilds (Guilds 1–4; see Tables 2 and 3) are pioneers of either stand initiation or stem exclusion – making many species suited to high light and open conditions; and (3) top down impacts in particular open up the canopy and create openings sufficient to liberate the multiple resources of light, soil moisture and nutrition for new forest establishment (Goode et al., 2012). Little attention needs to be paid to planting in these circumstances, at least for those NTFP’s that are pioneers; but to insure their full stocking release treatments may need to be done to remove competing vegetation (Chandrahasheka and Sankar, 1998). Many studies have shown that NTFPs can be higher in second growth forests that have been disturbed or logged as compared to late successional or primary forests (Ticktin, 2004). Examples can be seen throughout the tropics. This is particularly true for the guild comprising NTFP’s yielding vine’s of the stem exclusion stage (Guild 4). Examples are Calamus spp. (rattan) in Indonesia post-swidden (Siebert, 1993), and Desmoncus after land clearance in the floodplain forests of the Amazon (Troy et al., 1997). In South Asia Calamus spp., Dioscorea spp., and Cocosium fenestratum have been shown to flourish in logged forests (Ashton et al., 2001b; Mumhumperumal and Parthasarathy, 2013). The pioneer NTFP guild comprising shrubs (Barleria trianis, Carissa carandas, Justicia adhatoda) (Guild 1) and trees (Macaranga spp., Alstonia spp., Cocospurum religiosum, P. emblica) (Guilds 2 and 3) of all forest formations can be planted beneath the canopy; but timing is critical. Planting during stand initiation (before canopy closure) or after understorey re-initiation (canopy break-up) is best (Pelissier et al., 1998). This needs to be followed by release treatments that maintain the immediate growing space around and immediately above the planted seedlings until plants are well established (Smith et al., 1997). Planting beneath regenerating stem exclusion stage forest will likely fail because of high understory shade and competition for resources with a well-established, vigorous canopy. Because these species are shade-tolerant creating large canopy openings should not be necessary (Gunatileke et al., 2006). Deciduous forest formations that are devastated (i.e. moist and dry deciduous and thorn woodland) on the contrary, may need planting and establishment of nurse trees, especially small-leaved light shade producing legumes, to establish the eventual late successional canopy species, although these are universally light demanders (e.g. D. melanoxylon, Santium album, A. marmelos, A. latifolius).

Some additional caveats to planting late-successional NTFP species in evergreen forests include the fact that: (1) many are site restricted, and are found on particular sites and topographic positions, meaning that species site-specific guidelines need to be developed (e.g. A. coccaea, E. cardamomum, Semecarpus spp., Wright, 2002; Gunatileke et al., 2006); and (2), many of the large-fruited species dispersed by large mammals and birds exhibit density dependence, meaning that seedlings of the same species should not be planted together or near their parent trees because of susceptibility to species-specific insects, disease and seed predators (e.g. C. uren’s, Gyropnos walla) (Ashton et al., 2001b; Wright, 2002; Ashton and Hall, 2011).

5.1.2. Restoration of NTFPs in second growth forests originating after agriculture abandonment

Lands in the mixed dipterocarp, seasonal evergreen dipterocarp, and lower montane forest formations that have been long cleared for agriculture such as for tea, rubber, and coffee, and that were subsequently abandoned and subject to periodic burning, revert back to grasses and ferns maintained by use of fire (see next section). However, where fires are prevented and/or sites are wet...
enough that the forest vegetation comes back with vigor (often riparian areas) then a species depauperate second growth forest can develop (Kodandapani et al., 2004). Such second growth is often low-statured, and dominated by one or two large-leaved pioneers of stand initiation that have strong abilities to vegetatively sprout and spread (Dillenia spp., Clerodendron spp., Hibiscus furcatus) to form dense thickets that excludes the recruitment and establishment of other species. Similar findings have been reported elsewhere in SE Asia for the mixed dipterocarp forest (Chua et al., 2013).

In deciduous forest and woodland formations, recruitment of the core suite of fire tolerant copropping tree species is usually more diverse (Champion and Seth, 1968; Sagar et al., 2003). Their understoreys are more suited to colonization by other late-successional tree species that are also fire tolerant, except where exotic invasive dense-canopies of Lantana, or the perennial Chromolaena and Parthenium (Asteraceae) have established and must be cleared before reforestation can begin (Sukumar et al., 1992; Hiremath and Sundaram, 2005).

There are several remedies that incorporate NTFP’s into these monodominant vegetation thickets. All need a heavy hand in removing existing vegetation (either manually or with a bull dozer), that then piling and burns the slash. This opens up the growing space to either allow natural regeneration to establish site generalist and opportunistic pioneers (Guilds 1–4); or to promote a planting and cleaning regime for late-successional understory, subcanopy and canopy NTFP trees (Guilds 5–7) similar to those suggested in the preceding section (Sagar et al., 2003).

5.2. Reforesting open lands

Open land generally means lands that were formerly forest, were cleared for plantation agriculture (tea, rubber, coffee), and because of poor markets, degraded soils, or insecure tenure the lands have subsequently been abandoned yet have not regenerated into secondary forest. Such lands, in the mixed dipterocarp and seasonal evergreen dipterocarp forest formation regions of South Asia usually revert to grasslands (Imperata cylindrica) or fernlands (Dicranopteris linearis) that are maintained by fire (Cohen et al., 1996). In the moist and dry deciduous forest formations the invasive shrubs L. camara, Chromolaena odorata and Parthenium hysterophorus can dominate particularly on the degraded soils of wastelands (Kodandapani et al., 2004; Kohli et al., 2006). In circumstances like these, where little to no residual forest cover exists, establishing NTFP species within a new forest can be approached in two ways. The first approach is to establish a fire-tolerant, fast-growing, often exotic, pioneer tree plantation (pioneer trees of stem exclusion – Guild 3), that can shade out the invasive grass, fern or shrub, facilitating natural regeneration of NTFP’s (Guilds 1–4) or allowing for NTFP species under plantings (Guilds 4–7) (see Ashton et al., 2014).

The second approach is to establish NTFP species plantings together with planted or seeded pioneers of initiation and stem exclusion (Guilds 1–4). This approach simulates a successional agricultural system such as an indigenous swidden system. It requires intensive maintenance and careful control at the early stages of development to weed out and maintain the growing space for the planted NTFP seedlings within the pioneers, which given their nature can be very effective at crowding out competition. Selecting the right pioneers is therefore critical. As the successional processes of the new forest progress the intensity of maintenance and control treatments declines to almost nothing.

5.2.1. Sequential reforestation

In some circumstances it would make sense to plant surrogate, usually exotic species, categorized as pioneers of stem exclusion, as an initial nurse crop on waste lands (Guild 3). These trees often have the ability to usurp the growing space away from grasses, shrubs and ferns (which are themselves often exotic), after which, given some period of time, the plantation understory becomes conducive to the establishment of other native tree species. However, it was never consciously considered until foresters and researchers observed the recruitment of second growth rain forest in plantation understoreys of certain species (Parrotta et al., 1997).

Studies conducted within the mixed-dipterocarp forest formation at the Sinharaja Man and the Biosphere (MAB) Reserve in southwest Sri Lanka have demonstrated that reforestation with fast-growing fire tolerant Pinus caribaea is a useful way for controlling and extirpating crown fire and invasive species in wet climates, and facilitating the recruitment of native species through natural regeneration after plantation canopy closure (Shibayama et al., 2006; Tomimura et al., 2012; see Ashton et al., 2014); and through enrichment planting (Ashton et al., 1997b; Ashton et al., 1998). This work is supported elsewhere by other studies where similar understory recruitment of native species was reported for Acacia mangium (Otsamo, 2000; Norisada et al., 2005); Eucalyptus (Parrotta et al., 1997; Kanowski et al., 2005); and T. grandis (Koonkhunthod et al., 2007). However, studies have also suggested that rain forest regeneration can fail beneath plantations because of inability to prevent fire (Kanowski et al., 2005; Shibayama et al., 2008); allelopathy from the exudates of the plantation trees themselves (e.g. teak – Healey and Gara, 2003; Eucalyptus – Lamb, 1998); and deep shade created by the plantation canopy (e.g. A. mangium – Otsamo, 2000). It therefore means that careful selection of the plantation tree species for the circumstance at hand is critical for NTFP restoration.

Research at Sinharaja, in a wet aseasonal climate, demonstrated that P. caribaea, a tree that shows no ability to naturalize in this forest, has the capacity to increase surface soil organic matter and water-holding capacity in the absence of ground fire, and promote diffuse understory light of high quality and partial shade; both environmental phenomena conducive to regeneration recruitment (Ashton et al., 1997b). Our studies there recorded the spontaneous establishment of a number of important NTFP’s of all seven guilds (though mostly the pioneer Guilds 1–4) beneath pine including the vine Calamus thwaitesi, the understory late-successional trees Cinnamomum zeylanicum and Chaetocarpus castanocarpus; the subcanopy palm C. urens; and the canopy tree Canarium zeylanicum (Shibayama et al., 2006; Tomimura et al., 2012). To secure higher stocking and control of NTFP’s supplemental plantings can be done. This may be the only alternative if there is no nearby seed source from adjacent rain forest (Tomimura et al., 2012). NTFP vine’s C. thwaitesi and C. fenestratum (Guild 4) establish well along the edges of canopy openings created within the pine (Ashton et al., 2014). Planted seedlings of C. urens (Guild 6) do best within the center of canopy openings of pine; and understory trees and shrubs like E. cardamomum (Guild 5) do well beneath the pine canopy and along the edges of openings (see Ashton et al., 2014). Plantings of most late-successional canopy tree species (e.g. Vateria spp., Guild 7) showed greatest increment growth in both diameter and height within those moderate sized canopy openings where three rows of pine had been removed (Ashton et al., 1997b; Ashton et al., 1998). As with planting regimes within second growth forest (see preceding section) consideration must be given to whether the species of choice is site restricted or exhibits negative density dependence.

All of the results to date on facilitating natural and planted regeneration that yield NTFP’s have been in the wetter forest formations. For the semi-evergreen and the seasonally moist and dry deciduous forest formations, the idea of incorporating plant species that produce NTFP into plantations needs to be tested. As far as we are aware no trials have been conducted as of yet but...
obvious plantation tree species to test are teak (*T. grandis*), *Eucalyptus* spp. and sal (*S. robusta*). Both teak and *Eucalyptus* spp. have been shown to both facilitate and suppress natural regeneration establishment elsewhere, so clearly, this needs further examination.

5.2.2. *Simultaneous reforestation through successional agriculture*

The use of tree plantations to facilitate NTFP's is a novel idea that can be used on lands that require low investments and relatively low monetary rewards. However, there are plenty of open lands where people are willing to invest labor and money for higher rewards. In such investments direct reforestation and restoration toward the use of successional agroforestry systems (e.g. swidden systems) whereby agricultural food and commercial annuals can be inter-planted with NTFP trees and shrubs that over a period of years usurp the growing space first to pioneer shrubs and trees of stand initiation (Guilds 1 and 2), then to pioneers of stem exclusion (Guilds 3 and 4) and subsequently to understory, subcanopy and canopy late-successional NTFP trees (Guilds 5–7). This plantation design would resemble a traditional stratified indigenous tree garden, so familiar within the region (see Ashton and Ducey, 1999 for details) (Fig. 4). Conceptually, such a system may be a modern day swidden but, instead of a focus on subsistence crops, focus should be on commercial NTFP’s for today’s global and regional economies. NTFP’s are sequentially yielded over successional time, eventually ending in a simplified but stratified, second growth rain forest. The finances of similar systems have been evaluated in comparison to the intensive commercial production of tea and income calculated is equivalent or higher (Ashton et al., 2001b). The problems lie in the degree of sophistication needed to practice such plantings successfully.

Currently, we write this based on only a few experimental studies done by us (Ashton et al., unpublished data). We are not aware of any work that has demonstrated this through planting trials and careful experimentation and publication; though clearly such ideas have been descriptively recorded by researchers observing some of the original indigenous swidden systems of the region such as chena (Sri Lanka) and jum systems (western Himalaya) (Spenser, 1966; Ramakrishnan, 1992; Arunachalam and Arunachalam, 2002); and we suspect many current day reforestation/restoration plantings may have developed similar plantings but without publishable records. The only well documented adoption of swidden cultivation techniques in modern day tree plantation systems is the taungya system of Burma (Nair, 1984), adopted over 100 years ago!

5.3. *Social and economic goals*

Different socio-economic circumstances in forest ecological and socio-economic conditions dictate which of a number of approaches in forest restoration with NTFP’s can be taken. When the degraded forest or wasteland is owned by the government, the planting of NTFP species is a reforestation incentive toward promoting the co-management of land with a local community. The ultimate government goal may be for park restoration, buffer zone protection of nature reserves, watershed stabilization, or continued commercial timber production; but the use of NTFP’s is a method of involving the community in forest restoration for protection. Approaches to achieve these goals are likely low input, and low-intensity, utilizing nearby native forests as a seed source for open lands and working with degraded native forests wherever possible (as suggested above).

Approaches and opportunities for private landowners and commercial estates would be different, with incentives to more clearly control forest structure and composition, with the expectation of increasing income and species yield from NTFP’s as well as timber for households (small private landowners) or the regional market (large private landowners and estates). Options here are to plant either through enrichment within second growth forests or to reforest open land through plantation systems. Much of the extensive open land is either state or municipal owned. The opportunity exists for lease arrangements with the state to incentivize private investment in reforestation.

Clearly, there are many other variations in social goals and tenure regimes but we provide two general examples for government and private approaches that can utilize the different restoration models that we have described above.

![Fig. 4. A series of photographs depicting the successional and growth habit changes of a mixed species plantation over a ten year period.](http://dx.doi.org/10.1016/j.foreco.2014.02.030)
6. Management implications

6.1. Further research

In anticipation of a more prosperous future, and of a resurgent rural economy with a renaissance of rural quality of life, researchers have been experimenting with different approaches to restore value to degraded forests for rural communities, and to the plantations of exotic timber species that had, in effect, deprived them of their traditional forest heritage. In particular, much more research is needed to further examine and test techniques of cultivating NTFPs in both native forests and their plantation analogs. Some areas of focus should be:

1. Rigorous controlled experimental trials in South Asia’s semi-evergreen, moist and dry deciduous forests, currently so degraded by overexploitation especially by domestic cattle, must be the future priority. So far, this work has focused on the mixed dipterocarp and seasonal evergreen dipterocarp forest formations. Restriction of cattle to fenced pastures during the wet monsoon will be essential if hay production and thereby increased cattle health and carrying capacity, but also tree regeneration, is to be achieved. As has been the experience in the temperate west, and also in Rajasthan and elsewhere in India, this may only be achieved by establishing land tenure rights to individuals and families.

2. The development of growth and product yield estimates for a range of NTFPs in relation to variations in soil and climate.

3. The testing and development of enrichment planting guidelines for late-successional NTFP’s in second growth forests of all formations.

4. Documentation of recruitment of NTFP’s beneath tree plantations within all forest regions; and subsequent under planting and canopy opening trials of late-successional NTFP’s within such plantations.

6.2. Concluding remarks: The present challenge

The ideal economic transition from traditional to market economies is expressed in a Kuznets Curve (Fig. 5). It is the poorest communities now that depend most on NTFP’s (Chomnitz and Kumar, 1998; Baghel and Gupta, 2002; Adhikari et al., 2004; Belcher and Kusters, 2004). Chronic poverty ensues when these communities grow beyond the carrying capacity of their environment and methods of cultivation known to them, while NTFP’s become exploited beyond their capacity to yield (Tacconi, 2007); and when family holdings become divided below food sufficiency. Such poverty can be overcome, either by the appearance of alternative sources of income such as work in the city or for government; or in part by reinvesting the profits derived from trade in the traditional resource – forest products in the present case – with the aim of increasing its productivity (Chopra, 1993; Nair, 1984; Mohd Shawahid and Awang Noor, 1999; Saxena, 2003). In either case, development, manifested in the opening of the traditional forest resource to the wider market, initially draws its value down as it is exploited. But reinvestment can, by wise management actually raise the value of the resource – the forest as well as crop species – beyond former levels, thereby increasing the prosperity of those dependent on it. If this returning profit is invested in the people themselves, in their health and in particular their education (Saxena, 2003), they come, as in ancient times, to revalue the forest resource more for other qualities, notably services including the forest’s capacity to moderate water supply and local weather, later through its enhancement of the quality of life through its beauty, tranquility, and later still its conservation of our local and global natural heritage reflected in spiritual values, over products more valued in the past. But demand for those traditionally valued products – protein as game, medicinals, cordage – may still persist albeit in a different way, for recreation, heritage, or in a persisting niche market, spurred by the continuing respect, reliance on – and proven success – of the Ayurvedic medical and philosophical tradition (Saxena, 2003; Olsen and Helles, 2009). The forest, in part because it is now so much smaller in area and has therefore itself become a sort of rarity, gains a value in the successfully developed economy vastly greater than it ever had. Such is the case of forest resources and their value in Germany and in Japan, among the leading developed economies.

Overexploitation eventually decreases supply. This should lead to increased value and prices in an undistorted economy. But many of those rural populations that endure persisting poverty will then be less able to afford forest goods upon which they continue to depend. Often, suppliers to the market among the rural poor lose what profit they can make to middle-men, who may keep them in debt slavery by loans with unrealistic repayment rates. Meanwhile, overharvesting sustains undervaluation until extinction approaches.

These problems are exacerbated by the fact that different regions and communities within every country are at different stages in the development curve. Urban regions especially, generally at a more advanced stage, exert unsustainable demands on the resources of communities as yet unable to protect their own interests, thereby increasing economic inequalities. Motivation can

Fig. 5. A graphic depiction of a Kuznets curve illustrating environmental degradation in relation to stage of economic development (Modified after Panayotou, 1993).

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only be reinvigorated by restoring a sense of ownership. Legislation is essential to ensure that all communities have the opportunity to follow the Kuznets curve (Fig. 5) to a satisfactory modern economy. When the forest has become most degraded, and is often least valued, those products and services that remain are exploited to extinction unless the motivation is reversed, protection afforded, and restoration achieved. Lest we forget, species extinction is irreversible.

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Appendix A Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foreco.2014.02.030.

References


