# Chapter 4
# Ecological Approaches to Forest Restoration: Lessons Learned from Tropical Wet Asia

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**Summary and Key Lessons**
In this chapter, we present examples of restoration methods that have successfully returned forest cover to a selected set of study sites in biodiversity hotspots of south and southeast Asia. These examples, which focus on ecological restoration of tropical lowland and lower montane rainforests, hold the promise of better-advised and more widespread application for similar landscapes in need of restoration.

In the mixed dipterocarp forest regions of the lowlands and hills of southwest Sri Lanka, we planted rainforest tree species across a range of site and shade conditions. This planting was beneath the canopy of a *Pinus caribaea* plantation, a non-native tree used widely for reforestation in the wet zone of Sri Lanka. Our results

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demonstrated that many native tree, shrub, liana, and herbaceous species of economic and conservation value performed better both in survival and growth under intermediate shade conditions than beneath a closed canopy pine plantation or in fully open habitats. We also demonstrated that, in the absence of fire, many rainforest pioneer and site generalist species can naturally recruit beneath pine plantations.

In both the lower montane forest of Western Ghats in India and the Knuckles region of Sri Lanka, we also demonstrated that planting mixtures of native tree species and actively controlling invasive species is a more effective approach to restoring forest cover than reliance on natural recruitment and release mechanisms in open areas. This result presumably reflects the fact that many rainforest trees of this forest type are dispersal-limited and sensitive to fire and grazing, which means that, for successful restoration, they must be planted and protected during their establishment.

The "Rainforestation" method, originally practiced in Leyte and now widespread throughout the mixed dipterocarp forest regions of the lowland and hills of the Philippines, also reveals the importance of planting as compared to natural regeneration. Here, the planting of eclectic mixtures of native trees on community and small private lands, based on owner preferences, has shown high survival rates combined with utility value to the landowners.

Lastly, in East Kalimantan, Borneo, within the same mixed dipterocarp forest type, the Samboja Lestari restoration project demonstrated that reforestation on *Imperata* grassland can succeed through mixed methods by (i) assisting natural regeneration where and when appropriate; (ii) using successional agroforestry, where crops are initially cultivated then relinquish their growing space to planted trees, and (iii) direct planting, at the same time, of both native and non-native trees.

All these approaches have demonstrated that successful restoration can be achieved across an assortment of differing socio-economic and ecological environments. These attempts range from specific site-based restoration treatments facilitating similar composition and structure to the original rainforest, such as in Sri Lanka and Western Ghats, to more general strategies which establish tree cover to support more general economic and conservation values as seen in the Philippines and east Kalimantan.

## Statement of Implications

Our studies across wet environments in tropical Asia indicate that, in most cases, tree planting is necessary to overcome dispersal limitation and that high diversity mixed-native species plantings can lead to significant forest recovery. Late successional tree species of the original rainforest with conservation value typically need to be planted on appropriate sites and need some degree of partial shade and protection from fire and herbivory for their successful establishment. This can be achieved by planting both native site generalist and restricted tree species beneath a thinned canopy of native or naturalized non-native trees that are tolerant of fire, high light, and low nutrient soil conditions, acting as nurse tree stands. The plantings of non-native species of economic value mixed with native species can also be a viable reforestation option for enhancing local livelihoods. Finally, in some circumstances, rudimentary second growth forest can be established without active planting when fire and other disturbances such as herbivory are excluded.

## General Introduction

The United Nations' Decade on Ecosystem Restoration (2021–2030) is emerging as a unified global strategy toward conserving threatened biological diversity, mitigating climate change, and curbing desertification. Enabled by the three international conventions, namely the Convention on Biological Diversity [UNCBD], the UN Framework Convention on Climate Change [UNFCCC], and the UN Convention to Combat Desertification [UNCCD], and enacted in conjunction with other multilateral agreements such as the Bonn Challenge and the New York Declaration on Forests (which aims to restore 350 million hectares of degraded landscapes by 2030), these calls to action have mobilized a level of political commitment and are acting as a potential accelerator of ecosystem restoration efforts around the world (https://wedocs.unep.org/bitstream/handle/20.500.11822/30919/UNDecade.pdf). Forest Landscape Restoration (FLR) has emerged as a key approach to fulfilling these formidable restoration goals, with the overall objective of achieving a more optimal balance between economic and ecological criteria for reversing deforestation and land degradation.

Of particular relevance to this chapter is the notion that concentrating restoration initiatives in regions that are biodiversity hotspots appears to provide an opportunity to make significant contributions toward the goals of the UN Decade on Ecosystem Restoration (https://forestdeclaration.org/goals/goal-5) whilst, at the same time, conserving native biological diversity. Today's 36 terrestrial biodiversity hotspots represent only 2.4% of earth's surface area (15.4% of its land area), yet they collectively harbor no less than 50% of the world's vascular plant species and nearly 43% of terrestrial vertebrate species, which are amphibians, birds, mammals, and reptiles (Hrdina & Romportl, 2017; Mittermeier et al., 2011). Hotspots by definition have lost at least 70% of their original habitat and many are threatened by continued deforestation and land conversion, making them some of the most endangered terrestrial ecoregions of the world (Brancalion et al., 2019; Cunningham & Beazley, 2018; Mittermeier et al., 2004).

The south and southeastern tropical Asian region is an important area for restoration because it is home to five global biodiversity hotspots, these being in Western Ghats and Sri Lanka, Indo-Burma, Sundaland, the Philippines, and Wallacea. A common feature across this broad region is an endemic-rich, hyper-diverse tropical rainforest flora that displays a degree of habitat specialization through niche partitioning and habitat filtering (Smith et al., 2018). Such spatial patterning of tree species at landscape level results from variations in topography and site conditions, such as hydrology, and soil conditions and external disturbances, which include drought, windfall, landslides, and temporary forest clearance for agriculture. These spatial patterning processes can play a significant role in shaping forest structure, species composition, and diversity as is evident from studies involving large-scale Forest Dynamics Plots. Such work has been done in Sinharaja (Sri Lanka), Lambir (Sarawak), and the Danum Valley (Sabah), Malaysian Borneo, Gunung Palung National Park (west Kalimantan in Indonesian Borneo), and, to a limited extent in Palanan, the Philippines, and Mudumalai in the Western Ghats, India (Co et al., 2006; Davies, 2001; Gunatilleke et al., 2006; Paoli et al., 2006; Pulla et al., 2017; Punchi-Manage et al., 2013; Russo et al., 2008; Smith et al., 2018; Webb & Peart, 2000; Yamada et al., 2007). It has also been noticed that habitat preferences are reinforced by species' differential demographic responses to supra-annual variations in climate such as droughts during El Niño events, which affects seedling recruitment, growth, and mortality of plant species (Yamada et al., 2007).

The forests of the south and southeast Asia region have suffered from widespread deforestation and forest degradation, making it a major target for forest landscape restoration. This chapter focuses on restoration approaches employed in five landscapes spread across three biodiversity hotspots of the region: two study sites in Sri Lanka, and one each in the Western Ghats of India, the Philippines, and Indonesia. The case studies include small-scale experimental plot trials in Sinharaja and the Knuckles regions in Sri Lanka, and landscape-level trials in Anamalai Hills in Western Ghats, Leyte Province in the Philippines, and the Samboja Lestari restoration project in East Kalimantan, Indonesia (Table 4.1). These case studies demonstrate that there are a variety of different approaches that can be undertaken to restore the forests, and these reflect the differing social and ecological contexts of the sites and management objectives of the restoration proponents. These restoration strategies can help such countries to achieve the significant restoration targets that they have set for themselves for the 2021–2030 period (Table 4.1).

## Case Studies

### *Study 1: Sinharaja (Sri Lanka)*

#### Background

Our forest restoration research in Sri Lanka was undertaken in the ever-wet Mixed Dipterocarp Forest (MDF) formation of the southwestern part of the island. The MDF formation is biologically the richest forest type in this region and has a strong biogeographic affinity with MDFs in Sundaland and the Philippines (Ashton, 2014). The MDF-dominated landscape in SW Sri Lanka exhibits a series of parallel hill ranges running in SE–NW direction with steep-sided V-shaped valleys (Erb, 1984, Annex 1a).

**Table 4.1** Salient features of the selected case study regions in south and SE Asia

| **Restoration case study sites/region** | **Sinharaja World Heritage Site (WHS), Sri Lanka** | **Knuckles Forest (Central Highlands WHS), Sri Lanka** | **Valparai Plateau/ Anamalai Hills, Western Ghats, India** | **Leyte Province, Philippines** | **Samboja Lestari study site/ Balikpapan, Indonesia** |
|---|---|---|---|---|---|
| Climate of the case study region | Perhumid/Everwet tropical | Perhumid/Everwet tropical | Humid/wet tropical | Perhumid/ Everwet tropical | Perhumid/ Everwet tropical |
| Reference forest type | Lowland Mixed Dipterocarp Forest | Lower Montane Mixed Species Evergreen Forest | Mid-elevation Tropical Wet Evergreen Forest | Lowland Mixed Dipterocarp Forest | Lowland Mixed Dipterocarp Forest |
| Elevational range at study sites (m) | 400–500 | 1058–1157 | 800–1350 | 80–140 | 10–100 |
| Mean annual rainfall (mm) | 5016 | 4830 | 2400 | 2400 | 2250 |
| Major soil type | Ultisols/Red Yellow Podzols | Ultisols and Mountain Regosols | Alfisols | Andisols | Acrisols |
| Land extent of the case study | 03 ha demonstration site, later replicated in two other sites | 2.5 ha Demonstration site, Later extended to 5 ha | 100 ha (actively restored)<br>1075 ha (passively restored) | Initially a 2.4 ha site, later extended to 28 small demonstration sites | 1850 ha |
| Year of initiation of the project | 1991 | 2003 | 2001 | 1992 | 1999 |
| Forest restoration/rehabilitation method/s used | Relay Floristic Successional Method using *Pinus caribaea* as nurse trees | Succession-based mixed species planting using native and naturalized species as nurse trees | Maximum diversity mixed native species planting protocol with weed removal/passive natural regeneration | Rainforestation Farming – Native species with food crop species | Assisted natural regeneration/ Agroforestry/ Buffer zone restoration |
| **National restoration targets/ pledges** | **Sri Lanka** | | **India** | **Philippines** | **Indonesia** |
| Nationally determined contribution/ Bonn challenge pledges for 2021–2030[a] | 200,000 ha | | 58,433,270 ha | 7,250,000 ha | 12,000,000 ha |
| **Population Density (persons/km$^2$)** | **341** | | **464** | **368** | **151** |

[a]https://www.pbl.nl/en/publications/goals-and-commitments-for-the-restoration-decade

Large areas of the forest have been lost to small landholder cultivation, with tea and other plantation crops that have subsequently been abandoned. These areas have been colonized by shade-intolerant and fast-growing grasses, shrubs, vines, and ferns. Seed sources are available within the surrounding forest landscape, but natural regeneration of late successional tree species has been slow (Ashton et al., 2001a).

As elsewhere in the humid tropics, efforts by the Forest Department of Sri Lanka since the mid-twentieth century to establish native forest plantations on degraded areas have met with little success (Vivekanandan, 1989). The primary reason for the low success of reforestation is that the species selected for planting were late successional canopy species, which are ecologically ill-adapted to establishment on open, eroded, nutrient-poor, and fire-prone sites. In the 1960–1990s, the forest department switched to large-scale planting of introduced trees such as *Pinus caribaea* as single species plantations that performed better under these conditions. The Forest Department was successful in establishing around 15,000–18,000 ha of mature *P. caribaea* plantations in the lowland districts of southwest Sri Lanka by the turn of the twentieth century (Bandaratilake, 1989). However, these monoculture plantations which clothe the hill crests and upper slopes came under frequent criticisms from the environmentalists and local village communities for (i) supporting frequent anthropogenic fires during dry periods, followed by (ii) heavy soil erosion and landslides during monsoonal rains, leading to (iii) poor regeneration of native species, (iv) reduced groundwater recharge and rapid drying up of water courses during the dry seasons, particularly during *El Nino* years, and (v) lack of tangible benefits to local communities who have been traditionally dependent on a range of timber and non-timber products and other ecosystem services from natural forests (Perera, 1989).

## Rationale and Goals

We made use of basic socio-ecological findings gathered since the 1970s from the natural reference forest of Sinharaja, a UNESCO World Heritage Site (WHS) and International Biosphere Reserve (IBR), to experimentally manipulate the canopy of a *Pinus caribaea* nurse tree plantation in its buffer zone (Ashton et al. 2001a, b, 2014). The primary goal was to facilitate transformation of the buffer zone to a mixture of trees aimed at meeting both conservation goals and the livelihood needs of the local people, particularly in respect of their traditional artisanal and dietary use of forest products for basketry, health food, medicines, and beverages.

To achieve this goal, our study had two objectives: (i) to identify the optimal environmental conditions within *Pinus* plantations which would encourage establishment of native rainforest tree species based on their known functional traits and habitat affinities (Figs. 4.1 and 4.2) and (ii) to evaluate growth and yield of species producing timber and non-timber forest products of rural economic value.

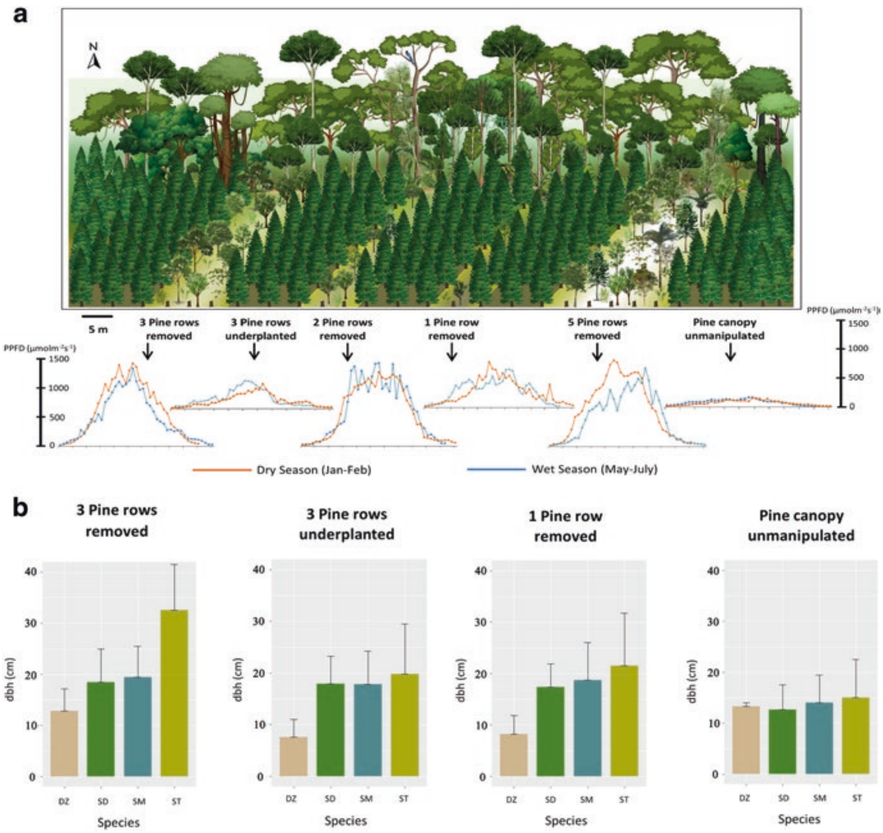


**Fig. 4.1** (**a**) Experimental design for introducing site generalist and restricted native and naturalized species of utility value under the manipulated nurse canopy of a *Pinus caribaea* plantation creating different diurnal light regimes, in the buffer zone of the Sinharaja MAB reserve, Sri Lanka. The daily average Photosynthetic Photon Flux Density (PPFD) measured from 09:00 to 15:00 above the canopy of the planted saplings (12 years after establishment) during wet and dry seasons is plotted beneath each pine canopy removal treatment. (**b**) Diameter growth performance of four late successional native tree species under different pine canopy manipulated treatments, after 31 years (1991–2022). *DZ Dipterocarpus zeylanicus, SD Shorea disticha, SM Shorea megistophylla, ST* Shorea *trapezifolia* (all of the family Dipterocarpaceae and endemic to Sri Lanka.)

## Key Strategies Used

First, we conducted comparative floristic surveys of the (i) reference natural forest, (ii) selectively logged forests, and (iii) *Pinus* plantations and fernlands of the buffer zone of the Sinharaja WHS/IBR to select candidate species for restoration (De Zoysa et al., 1991; Gunatilleke & Gunatilleke, 1985; Shibayama et al., 2006; Tomimura et al., 2012).


**Fig. 4.2** Three pine-row removal treatments creating canopy gaps (width 10 m) along a N-S direction and planting of native species of utility value. This photographic sequence shows the growth performance of site generalist- and restricted species planted in pine canopy gaps over a period of 31 years

Second, seedling ecophysiology of over 50 tree species was studied using shade house experiments and plantings in natural forest canopy gaps to determine their survival, growth, and site adaptations (Ashton & Gunatilleke 1995; Ashton et al. 2001a, 2006, 2011, 2014; Ediriweeera et al., 2008; Goodale et al., 2012; Gunatilleke et al., 1998).

Third, species distributional patterns in the 25 ha Sinharaja CTFS ForestGEO Plot, together with another set of 100 plots (totaling 25 ha) yielded information on tree community structure and habitat affinities of about 140 species across the ridge-slope-valley landscapes that are typical of lowland MDF forests of SW Sri Lanka (Annex 1a). These patterns were indicative of 'site–species matching' (Gunatilleke and Gunatilleke 1985; Gunatilleke et al. 2004, 2005a, 2006; Ashton et al. 2011, 2014; Punchi-Manage et al. 2013).

Fourth, we conducted a series of genetic diversity studies in the reference forest (The Sinharaja Rainforest Complex) which estimated the rates of gene flow and the degree of genetic differentiation among populations of selected canopy tree species (Gunatilleke & Gunatilleke, 2013).

Fifth, a series of socio-economic studies were carried out on the use of non-timber forest resources by villagers living around the Sinharaja WHS with a view to incorporate these species in restoration programs (De Zoysa, 1992; Everett, 1995; McDermott et al., 1990).

## Project Management

Using the data thus generated from previous studies, researchers from the Universities of Peradeniya and Sri Jayewardenepura (Sri Lanka), and Yale University (USA), with logistic support from the Forest Department of Sri Lanka, started an initial experiment in 1991 to transform an 11-year-old *P. caribaea* plantation in a sloping landscape typical of this region into a native forest. Treatments included canopy openings that varied in size arranged along a slope in order to reflect a range of light conditions found in the rainforest (Fig. 4.1a).

Transplanted species included the natural forest canopy dominant species *Dipterocarpus zeylanicus*, *Shorea megistophylla*, *S. trapezifolia* and *S. disticha* (all of Dipterocarpaceae), and *Mesua ferrea* (now *M. thwaitesii* of Calophyllaceae). These species associated with valleys, slopes, and ridges were selected as framework native species for this landscape investigation (Gunatilleke et al., 2005b). In addition, the native utility tree species *S. stipularis* (Dipterocarpaceae), *Diospyros quaesita* (Ebenaceae), *Pericopsis mooniana* (Fabaceae), and *Caryota urens* (Arecaceae) each having a strong affinity to a site along the valley-mid slope-ridge continuum were also selected for planting (Ashton et al., 1997). The naturalized non-native site generalist species *Swietenia macrophylla* (Meliaceae), a much sought-after timber species among small landholders in this region, was also included for comparison.

Moreover included in this experiment were *Coscinium fenestratum* (Menispermaceae) a medicinal vine, *Arundina graminifolia* (Orchidaceae) an ornamental ground orchid, *Calamus ovoideus* (Arecaceae) rattan, and *Elettaria cardamomum* var. *majo*r (Zingiberaceae) which is wild cardamom. These non-timber forest species are of significant local economic value. The experiment was established as a two-factor (light, species) factorial design comprising three replicates for each treatment (Ashton et al. 1997, 1998, 2001a, b, 2014). All planting materials, whether raised in local nurseries and as wildlings (non-timber species), were sourced from local provenances giving due consideration to their spatial genetic structuring (Murawski et al., 1994a, b; Stacy, 2001). Growth rates of tree species were monitored over 12 years and that of non-timber species over 9 years (Gunatilleke et al., 2005b; Kathriarachchi et al., 2004) (Fig. 4.2) and statistically analyzed to estimate the effects of opening size and slope (Ashton et al., 1997; Gunatilleke et al., 2005b). Diameter growth of four canopy-dominant species after 31 years (using the most recent census data collected in 2022) is given in Fig. 4.1b.

It was found that all tree species performed better in canopy openings than either in the closed canopy or fully open conditions outside of the pine plantation. By year 12, the best performing mid-slope specialist, *S. trapezifolia,* which is a relatively shade-intolerant species, had grown to 14 m in height in the three pine rows removed canopy opening treatment providing 50% of the full sunlight environment (Ashton et al., 2014; Fig. 4.2). This was almost the same height as the *P. caribaea* trees in the surrounding stand. *Mesua thwaitesii,* a shade-tolerant and stream-associated species, showed about half the growth rate (both height and diameter) of the best-performing Dipterocarps across all canopy opening treatments (Ashton et al., 1997, 1998, 2014; Gunatilleke et al. 2005b). The 2022 census data provided further evidence of nuanced diameter growth performance (Fig. 4.1b). Among the NTFP species, the shade-intolerant rattan, the orchid, and the medicinal vine, all of which are forest fringe specialists, grew better within openings than beneath the canopy of the *Pinus*. However, wild cardamom, a shade-loving understory herb, grew better in both partial and full shade conditions (Gunatilleke et al., 2005b; Kathriarachchi et al., 2004).

Integration of population genetic parameters of species is an important element in the design and implementation of restoration projects (Nef et al., 2021). Studies involving species in different geographical ranges and disturbance regimes in the Sinharaja rainforest complex have indicated a strong potential for biparental inbreeding depression within forest tree populations and for partial reproductive isolation. These conditions have led to outbreeding depression among fragmented populations across the landscape. The optimal outcrossing for two canopy species of MDFs examined occurred over a range between one to several kilometers (Stacy, 2001; Stacy et al., 2001). Selective logging resulted in elevated levels of inbreeding in canopy dipterocarp species (Murawski et al., 1994a, b). Furthermore, genetic diversity studies carried out in 10 subpopulations of the canopy species *Shorea trapezifolia* along the altitudinal range from west to eastern Sinharaja rainforest complex has shown that small forest fragments have already begun to show genetic differentiation due to limited gene flow as a result of long-term isolation leading to genetic drift (Dayanandan, 1996; Gunatilleke & Gunatilleke, 2013). These findings underscore the importance of integrating intraspecific genetic information in restoration planning, including provenance-based seed sourcing for rainforest restoration projects and setting benchmarks in genetic differentiation over time (Gunatilleke & Gunatilleke, 2013).

### Challenges

A major challenge was communicating the message to forestry officials and policy makers that there are socio-ecological benefits in establishing mixed-species plantations comprising mostly native trees as opposed to plantations of *P. caribaea* in critical watersheds and sites close to protected forests. Foresters are generally trained in plantation silviculture, and therefore convincing them how a mixed species native forest plantation could be established as an alternative in this degraded landscape is a problem that needs to be addressed (Gunasena et al., 1989).

Indeed, there is a dearth of sound ecological and silvicultural knowledge on the native tree species for purposeful reforestation, and this information had to be obtained before wider communication could be achieved with potential partners. In addition, invasion of exotic weeds, fire, and damage from wild animals to planted seedlings, particularly wild cardamom and sugar palm, had to be successfully controlled during the initial period with harmonious assistance from local communities.

### Major Outcomes

This native species planting trial for conservation and utility value at Sinharaja now serves as a demonstration site to promote its replication and upscaling. The ecological, ecophysiological, and population genetic information on tree species made available from prior studies has been successfully incorporated into site-species guides for propagation and planting using *P. caribaea* plantations as a facilitatory successional mechanism (Ashton et al., 2011, 2014; Gunatilleke et al., 2006; Gunatilleke & Gunatilleke, 2013; Punchi-Manage et al., 2013).

Incorporating the lessons learnt from this site, two other restoration trails have been established in the lowland rainforest region of Sri Lanka (Geekiyanage et al., 2021; Jayawardhane & Gunaratne, 2020). In one of these trials, a biological corridor linking two rainforest fragments in the Greater Sinharaja Rainforest complex is being established in partnership with Dilmah Ceylon Tea Company PLC, a leading private sector company (https://www.dilmahconservation.org/initiatives/sustainability/biodiversity-corridor-endana.html). Of great assistance here was that a grant from the Fondation Franklinia to improve the conservation status of globally threatened rainforest tree species listed on the IUCN Red List was awarded to continue our ongoing studies (https://fondationfranklinia.org/en/conservation-rainforest-southwest-sri-lanka/).

## Key Learnings

Establishment of fast-growing generalist species, such as *P. caribaea* in degraded landscapes, can catalyze active forest landscape restoration across the variable topography which is so typical of SW Sri Lanka through appropriate light manipulation of nurse stands. The Forest Department of Sri Lanka is now working with relevant stakeholders to convert *P. caribaea* plantations into broadleaf mixed-species stands in critical watersheds elsewhere in this climatic region.

We note that most of the late successional species are site-specific in the ridge-slope-valley landscape which is typical of SW Sri Lanka (Annex 1a), necessitating an understanding of their ecology to ensure site–species matching for planting and tending.

Successful introduction of several non-timber forest species of socio-economic value into the mixed species tree plantings in the buffer zone restoration project has laid the foundation to replicate this protocol through community participation in both buffer and transition zones of protected areas. At least two such studies using lessons learned have been applied elsewhere in SW Sri Lanka (Geekiyanage et al., 2021; Jayawardhane & Gunaratne, 2020).

*Alstonia macrophylla* (Apocynaceae), another non-native and naturalized tree species with invasive tendencies and, at the same time, of considerable timber value to rural communities has the potential to be used in a similar manner. Some native species have already established under their shade and judicious manipulation of the canopy of these *A. macrophylla* trees with community participation (taking a cue from the present *P. caribaea* study) could lead to the scaling up of the establishment of mixed native species forest stands.

## *Study 2: Knuckles (Sri Lanka)*

### Background

The lower montane rainforests of the Knuckles region are a northern extension of the Central Highland massif (Annex 1b). Constituting less than 1% of Sri Lanka's forests (Premakantha et al., 2021), these forests are critical for safeguarding biodiversity and ecosystem services such as soil conservation, carbon sequestration, and the provision of water for hydro-electricity generation and downstream agriculture. Presently, lower montane forests in the Knuckles Conservation Forest (KCF) are located as patches in a mosaic of other land uses that include tea and non-native tree plantations, grasslands, and scrublands (Fig. 4.3a). Annual burns that are frequent in the grasslands during the dry season have led to reduced carbon stocks, increased soil erosion, and downstream flash-flooding in response to extreme weather events. The region has similar landscape heterogeneity, physiognomy, and associated socio-ecological issues to those of Anamalai forests of the Western Ghats, India (Gunaratne et al., 2014; Muthuramkumar et al., 2006).

### Rationale and Goals

The project aimed to identify ecologically and socially acceptable restoration prescriptions to accelerate natural forest recovery in the degraded grasslands of the Knuckles Conservation Forest.

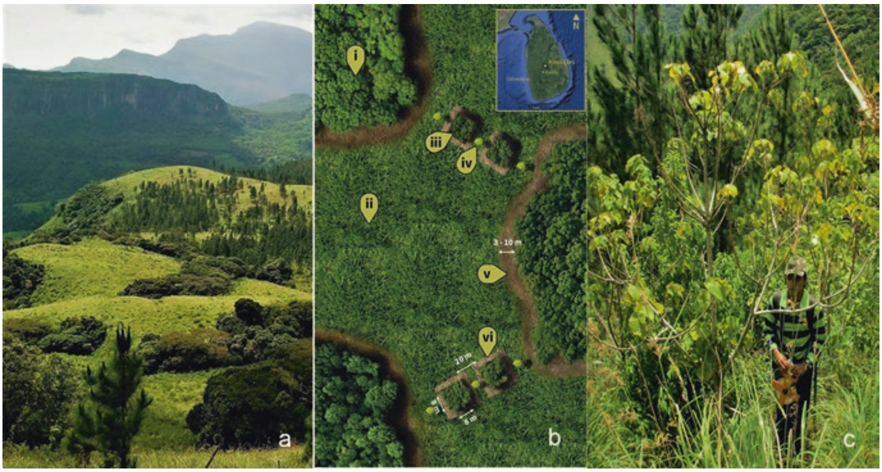


**Fig. 4.3** (**a**) Landscape mosaic on eastern slopes of KCF; (**b**) Restoration model for KCF (i): Protection of remnant forest fragments (ii): Degraded grasslands (iii): Establishment of tree islands with *Gliricidia sepium* as a nurse plant and early successional native tree species with application of biofilmed biofertilizer (iv): Early successional tree/shrub species (v) Grass removal and tilled up to 10 cm at forest edges (vi): Fire belts (2 m) (Designed by Risiru Hemage); and (**c**) Well-grown *Macaranga indica* tree in a tree island (8 × 8 m) established in grasslands 4 years after establishment

### Key Strategies Used

The project was conducted in four phases. Phase 1 (2003–2006) determined the site-specific biotic factors that could be impediments to tree colonization in the grasslands. The biotic constraints to colonization addressed by this research were limitations induced by seed dispersal into grassland, persistence of an antagonistic soil seed bank, and effects of herbivory and competition with the existing sward on native seedling emergence and survival. Abiotic factors that prevent tree colonization, including fire, micro-climatic conditions, soil nutrients, water availability, and disturbance, were also examined. In this phase, two early successional species, *Macaranga indica* and *Symplocos cochinchinensis*, and mid-late successional species *Dimocarpus longan* and *Syzygium spathulatum* were planted inside the forest and degraded grasslands to determine their potential use for restoration. Phase 2 (2006–2009) investigated the performance of the two native tree species (*M. indica* and *S. cochinchinensis' mis-spelt*) with *G. sepium* as a nurse plant along with the addition of cow dung as an organic fertiliser. Phase 3 (2011–2015) included the introduction of *Gliricidia sepium* as a nurse plant and application of biofilmed biofertilizer to test the performance of two early successional (*M. indica* and *S. cochinchinensis*) and mid-late successional (*Bhesa ceylanica* and *Eugenia bracteata*) tree species established in different sized tree islands (2 × 2 m, 4 × 4 m, and 8 × 8 m). These were carried out under four treatments in combination with and without *G. sepium* and with and without biofilmed biofertilizer. The attitudes of local villagers toward our restoration goals were also recorded. In Phase 4 (2017–2021), 20 native species (across nearly 5 ha) were transplanted between forest fragments. These sites are used to train undergraduates, civil society members, and forestry practitioners in the key aspects of restoration ecology.

### Project Management

An initial dialogue was held with private landowners in the KCF and the forest officers administering the area. Local communities were encouraged to participate in the project through a series of awareness-building meetings. Native tree species for planting in degraded sites were selected, these being based on their known successional status and the availability of seeds and seedlings. The local community supported the planning, field establishment, and construction of the nursery and shade houses located at the field site. An outreach program was initiated to disseminate research findings in partnership with the Forest Department of Sri Lanka, Noritake Lanka Porcelain (Pvt) Ltd., and the local community to restore degraded lands in the KCF (https://www.noritake.lk/csr.php).

Seeds and seedlings of native trees from forest edges or along roadsides were collected from the KCF (ensuring that <10% of seeds/seedlings were collected from a single mother plant). Seedlings were raised in polythene bags in forest topsoil and kept in fenced nurseries to protect them from predators, with no special seed treatment or chemical application during the first phase. In the third phase, biofilmed biofertilizer (produced using bacterial and fungal strains isolated from the rhizosphere of native species) was tested for enhancement of the growth and survival of native tree species in the nursery (Gunasekera, 2022).

Fire belts were established around all plots to protect them from dry season fires (May to September). Invasive plant species (*Austroeupatorium inulifolium*) were removed by cutting at ground level, while the weedy grass species *Cymbopogon nardus* was manually excavated. All removed plant material was piled along contour lines of the plots to reduce erosion and care was taken to retain all naturally regenerating forest species within the site during the removal of invasive species. Plots were fenced using barbed wire and mesh to protect plots from domestic cattle and wild herbivores such as sambar deer and elephants. Seedlings were introduced to the site during the main rainy season of the region (October to December) at a planting density of 4 seedlings/m$^2$. Plots were maintained by weeding (wet season) and clearing fire belts around plots (dry season) for 2 years after planting. The restoration plots were monitored for seedling performance for 18 months in Phase 1, for 12 months in Phase 2, and for 24 months in Phase 3. An outreach program initiated in 2017 will continue until 2026 under Phase 4.

### Challenges

The main challenges of the project were associated with conflicts over land tenure. Even though degraded grasslands are located within the KCF, some lands are still privately owned. Additional problems included a high incidence of herbivory on transplants and limited fund allocation by local funding agencies for long-term monitoring of restoration programs.

### Major Outcomes

The research findings were used to develop an instruction guide for linking lower montane forest fragments (Gunaratne et al., 2010, 2011, 2014) (Fig. 4.3b). During the project period (2003–2015), the frequency of anthropogenic fires in the dry seasons declined drastically due to awareness among the local community of the restoration work. An outreach program organized by the University of Peradeniya in partnership with the stakeholders was used to train a generation of students in ecological restoration.

### Key Learnings

Natural regeneration on degraded grassland is constrained by limited dispersal of woody plants from residual forest fragments. Competition from non-native grasses reduces the growth and survival of planted seedlings, which can be offset by use of *Gliricidia sepium* as a nurse plant and the addition of biofilmed biofertilizer

(Gunasekera, 2022). Large tree islands of native tree species can be established in grasslands to link lower montane forests (Fig. 4.3).

## *Study 3: Western Ghats (India)*

### Background

The Western Ghats range running along India's west coast (8–21°N; 73–77°E; 160,000 km$^2$) is recognized as a global biodiversity hotspot together with Sri Lanka (Mittermeier et al., 2004; Annex 1c). Deforestation since the early nineteenth century which was carried out in order to establish commodity plantations of coffee, tea, cinchona, spices, and timber has resulted in loss of natural ecosystems and biodiversity. This land use change also led to land degradation. Records show that by the early 1900s, large tracts of Valparai Plateau in the Anamalai Hills were under intensive tea or coffee plantations after deforestation of the natural forests (Mudappa et al., 2014; Mudappa & Raman, 2007). Furthermore, between 1985 and 2018, the Western Ghats region suffered a decrease in evergreen forest cover from 16.2% to 11.3%, along with loss of 12% of interior (contiguous) forest cover, primarily due to increase in built-up area and destructive developmental activities such as mining, and land conversion to agriculture and plantations (Ramachandra & Bharath, 2019).

### Rationale and Goals

Our work in the Anamalai Hills of the Western Ghats aimed to restore the ecology and native biodiversity in degraded tropical rainforests. We focused on large tracts of mature rainforests protected within the 958 km$^2$ Anamalai Tiger Reserve and over 45 rainforest fragments (having areas of 0.3 to over 300 ha) embedded within the tea and coffee plantations on the adjoining 220 km$^2$ Valparai Plateau. Since 2001, our work has continued to study and conserve the larger rainforest tracts, ecologically restore degraded areas, and extend conservation efforts into the surrounding landscape which has been modified for human use (Mudappa et al., 2014, Mudappa & Raman, 2007).

Over the last 25 years, research in the Anamalai Hills (Raman et al., 2018) has addressed the impacts of forest fragmentation and degradation on plants (Muthuramkumar et al., 2006) and many animal taxa such as spiders (Kapoor, 2008), amphibians (Karthick, 2019), reptiles (Harikrishnan et al., 2018), birds (Sidhu et al., 2010), and mammals (Mudappa et al., 2007; Sridhar et al., 2008; Wordley et al., 2018). A large fraction of rainforest biodiversity persists in fragments, with patches between 1 and 10 ha having conservation value as biodiversity refuges and animal corridors (Kumar et al., 2010; Sridhar et al., 2008). While the area of the fragment exerts a small influence, rainforest animal communities are more strongly influenced by the degree to which the extant habitat structure and native plant diversity resemble relatively undisturbed mature rainforests. Degraded sites inevitably have greater prevalence of secondary successional or deciduous plant species and animal taxa typical of more open country or drier forests. These studies suggested that if such degradation could be reversed and fragments brought to resemble mature forests, it is likely to benefit conservation of native rainforest plant and animal species. Furthermore, rainforest bird species also benefit if surrounding tea and coffee plantations use native tree species as shade trees for their crop (Raman, 2006; Raman et al., 2021). By fostering the use of native rainforest tree species as plantation shade trees, the conservation value of production landscapes can be significantly enhanced.

## Challenges

Factors responsible for degradation of rainforest fragments that needed to be addressed include (i) past logging; (ii) conversion to coffee, cardamom, or vanilla plantations followed by abandonment; (iii) hard, exposed edges created along boundaries with tea plantations and hydroelectric reservoirs; (iv) chronic disturbances due to local firewood collection; and (v) effects of linear intrusions such as roads and power lines. Compared to mature rainforests, degraded fragments are characterized by open canopies, fewer large trees, lower plant density, reduced species richness, and basal area of trees and woody plants, especially those of mature rainforest tree species. Natural regeneration was limited or affected by invasive alien plant species, particularly *Lantana camara*, *Chromolaena odorata*, *Mikania micrantha*, *Sphagneticola trilobata,* and the African shade tree *Maesopsis eminii* (Joshi et al., 2015; Muthuramkumar et al., 2006). Robusta coffee (*Coffea canephora*), a shade-tolerant crop species, was seen to invade from adjoining plantations while the invading plants extended over 200 m into rainforests. This is likely to affect the regeneration (Joshi et al., 2009). In fragments, recruitment of seedlings through seed dispersal was reduced compared to recruitment in contiguous forests and appeared to depend more on the diversity of remnant overhead trees (Osuri et al., 2017), canopy cover, and restoration with mixed native species plantings (Osuri et al., 2021). Most rainforest fragments on the Valparai Plateau are on private land belonging to plantation companies, who are primarily concerned with their areas under tea or coffee production. The fragments, therefore, receive little attention or protection and were at risk of being cleared or converted to commercial plantations, especially where they are recorded as plantation lands rather than forests in government revenue records.

In the light of the above comments, to proceed with ecological restoration, the main concerns and barriers that needed to be addressed were (i) establishment of partnership with private landowners to recognize, protect, and restore the rainforests within their estates; (ii) removal of invasive alien weeds and maintenance of cleared sites; (iii) overcoming regeneration barriers through targeted planting of native rainforest species; and (iv) engage and involve local people in the protection of restored sites and to reduce tree cutting for firewood and other purposes.

**Project Management**

Our organization, the Nature Conservation Foundation (NCF), a non-profit conservation research organization, had established a Rainforest Research Station in the Anamalais and built a rapport with local plantation companies through a series of regular dialogues. As a first step, to establish partnerships with plantation companies within whose estates rainforest fragments remained, NCF signed memoranda of understanding (MoUs) between 2002 and 2005 with Hindustan Unilever Limited (now Tea Estates India Ltd), Parry Agro Industries Limited, and Tata Coffee Limited. The companies were motivated by their own corporate social responsibility and environment policies, sustainability certification for their crop and the innate interest of top managers in nature conservation. The MoUs recognized about 1075 ha of rainforest in 35 rainforest fragments in their estates for rainforest research, restoration, and wildlife conservation. The MoUs with the latter two companies were then periodically renewed at 3–5-year intervals and are still ongoing.

NCF established a local rainforest plant nursery currently located at Varattuparai on land generously provided by Tata Coffee (Fig. 4.4a). On a year-round basis, our team collects seeds of native trees and lianas from the edges of fragments or from roadsides through the forests, ensuring that no disturbance to forest interiors is caused. Seeds are raised in black polybags in locally collected soil mixed with organic compost, fenced from seed predators if required, with no special seed treatment or chemical application. Over the years, around 170 native species have been raised in the fully organic nursery, which presently stocks around 40,000 seedlings and has saplings of about 90 species.

The most degraded parts within the identified rainforest fragments were chosen for restoration on the basis of careful preliminary vegetation surveys. Multiple restoration plots of 0.25–1 ha area were demarcated in each site, totaling to a maximum of about 1–5 ha of land restored per year. The restored area is dependent on logistics, funding, and the number of saplings available. Restoration plantings were established in a range of site conditions ranging from dense shade to open grassy meadow. The sites included densely weed-infested areas with a disturbed canopy dominated by native trees or sites under non-native trees such as *Eucalyptus* sp., silver oak, *Grevillea robusta*, *Spathodea campanulata*, and *Maesopsis eminii*. Our restoration protocol involved the following steps (Mudappa & Raman, 2007, 2010; Osuri et al., 2019; Raman et al., 2009):

(i) Demarcation of the site and erection of temporary fencing (if livestock grazing was an issue).

(ii) Careful removal of invasive alien plant species, especially *Lantana camara. Lantana* and shrubby invasive alien plants were cut with a billhook, the rootstock removed with a mattock, and the woody material placed outside the site to be used as fuelwood by local people.

(iii) Retention of all naturally regenerating native plants, especially pioneers, such as *Clerodendrum infortunatum*, during weed removal.

(iv) Ensuring a maximum diversity of mixed native species during the planting protocol (27–82 native species per plot).

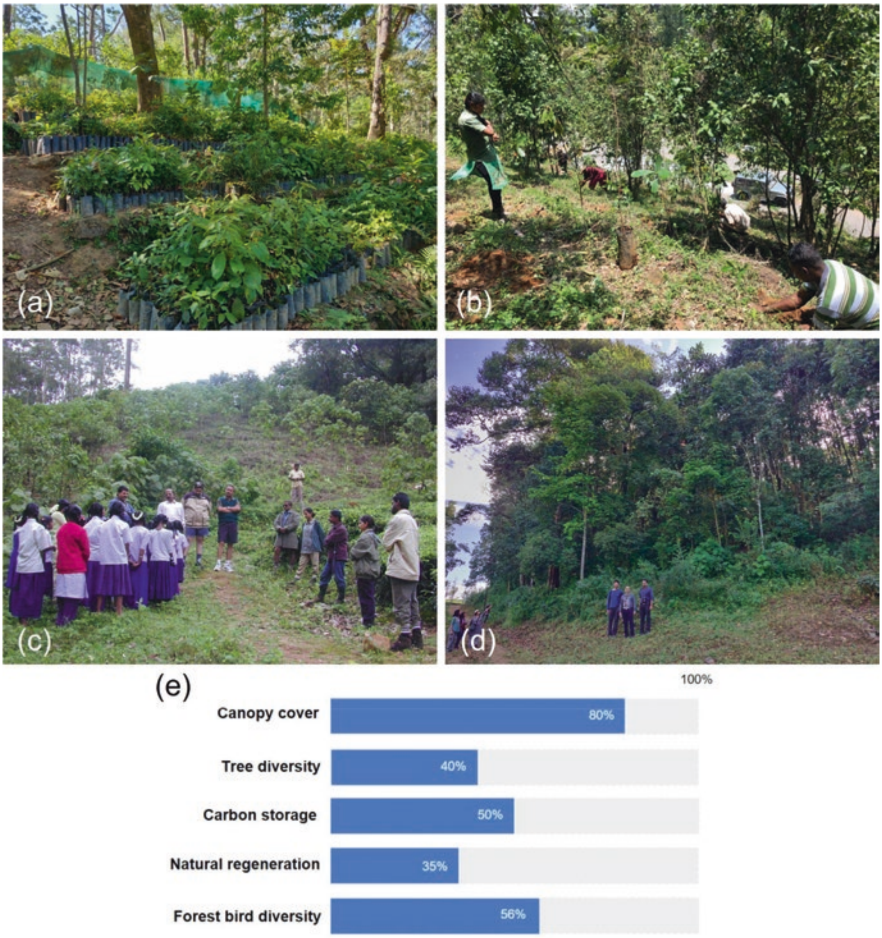


**Fig. 4.4** Rainforest restoration in the Anamalai Hills, India, showing: (**a**) The rainforest plant nursery in Varattuparai; (**b**) A field team planting rainforest saplings in a degraded rainforest fragment restoration site; (**c**) The Stanmore restoration site in 2002, prior to tree planting by volunteers from a nearby school; (**d**) The same restoration site in 2020 showing a taller, dense canopy of young rainforest trees.; and (**e**) Forest recovery (after 7–15 year) and bird community recovery (after 9–17 year) following rainforest restoration on the scale from baseline values in passively restored sites left as-is to target values in benchmark forests (0–100%)

(v) Planting 2- to 4-year-old saplings (after hardening) between late May and July, so as to receive rain from both the southwest monsoon (June to August) and northeast monsoon (October to December), at an average planting density of 1099 saplings/ha (1 SE = 154 saplings/ha).
(vi) Maintenance of plots through weeding for 1–2 years after planting.
(vii) Monitoring sapling survival (up to 6 years in some plots) followed by overall forest recovery and carbon storage monitoring after ~15 years, in 2017.

## Major Outcomes

Over the last two decades, besides overseeing passive restoration of the 1075 ha, we have actively restored around 100 ha through activities such as weed removal and mixed native species planting. Our monitoring (Raman et al., 2009) indicated that restoration with a high native plant diversity (>100 species) can be achieved in degraded sites with high sapling survival (>60%) after 2 years, including in open areas, *Lantana camara* infested sites (~75% survival), and under a canopy of non-native trees such as *Eucalyptus grandis* and *Maesopsis eminii* (67–76%).

When 7–15 years had elapsed after planting, comparisons with benchmark rainforests indicated that active restoration led to better recovery than passive restoration in comparable sites (Osuri et al., 2019), (Fig. 4.4). On the scale from baseline values in passively restored forests to target values in benchmark forests (0–100%), active restoration increased canopy cover (82%), tree (stems ≥10 cm girth at breast height) density (69%), species density (49%), late successional species density (42%), and compositional similarity to benchmark forests (14%). Likewise, among the saplings, stem density, species density, and late successional species density also recovered consistently by 51%, 52%, and 34%, respectively. Aboveground carbon storage recovered by 47% in actively restored forests (with a mean value of 143.9 Mg/ha C), relative to the difference between naturally regenerating sites (49.0 Mg/ha) and benchmark rainforests (287.6 Mg/ha). Recent research also indicates that actively restored sites support greater diversity of rainforest birds (and fewer open country bird species) and greater similarity in bird community composition to benchmark rainforests than comparable passive restoration sites (Hariharan & Raman, 2021).

In recent years, we have tried to share our findings and promote better ecological restoration protocols through dissemination of research findings, workshops and training events, direct outreach to visitors at our nursery and the Anamalai Nature Information Centre, and the creation of an informal network of restoration practitioners in India.

## Key Learnings

Our restoration efforts have had significant local success but, as yet, have had little wider impact, since conservation and biodiversity-friendly land use practices are yet to be adopted into mainstream activities by the plantation sector. Currently, only limited commercial benefits for private businesses exist through sustainability certification, and incentives for natural ecosystem protection and ecological restoration are non-existent. Consequently, private lands remain at risk of being ignored or converted to commercial uses. The model of ecological restoration using a high diversity of mixed native species suitable to local ecosystems has also not been significantly adopted by government agencies, which still carry out large-scale afforestation using monocultures or small numbers of mostly inappropriate species. This results in the planting of ecologically unsuitable species in ecosystems at risk.

Consequently, within the Western Ghats, state forest departments are yet to adopt better protocols to restore many degraded areas within their jurisdiction.

In comparison, our restoration efforts have led to substantial recovery in forest structure and carbon storage in previously degraded systems (Osuri et al., 2019), but we have not found ways to reduce on-going pressure on sensitive lands due to people's understandable dependence on forests for fuelwood and timber. Furthermore, as a result of a focus on trees, other plant life forms, including understorey plants, herbs, and epiphytes, remain poorly represented in restored sites. Whilst naturally regenerating seedling density and species density in benchmark and restored sites are significantly higher than in unrestored, naturally recovering sites (Osuri et al., 2021), limited regeneration of old growth plant species suggests that unresolved barriers to full rainforest recovery still remain.

## *Study 4: Leyte, The Philippines*

### Background

The Philippines, which is an archipelago of over 6000 islands, is recognized to be one of the most megadiverse countries in the world. Endemism is so high on a hectare-for-hectare basis that the country has been referred to as "the Galapagos times ten" (Heaney & Regalado Jr, 1998). The country used to be almost entirely forested with 12 different forest formations but has suffered from widespread deforestation and forest degradation (Fernando et al., 2008). The first major episode of clearance to the Philippine forests came during the Spanish colonial period when large areas of the lowland forest were cleared for the establishment of large-scale plantations of sugar cane, tobacco, cotton, and other commodities. Some specific islands were heavily deforested, but forest cover, overall, remained at around 70%. The second major wave of deforestation came during the American colonial period when large-scale industrial logging was introduced. This was a major industry that continued into the post-colonial period, during which the Philippines became the largest global exporter of hardwood timber. Whilst the degraded forests might have been able to regenerate if left unattended, the logging road networks gave access to landless farmers who used the areas for destructive forms of slash-and-burn agriculture (*kaingin*). Other significant drivers of deforestation have been mining and infrastructure expansion such as road construction, hydropower dams, and tourism facilities construction (Rebugio et al., 2007). At present, only 3% of primary forest cover remains, making the Philippines one of the hottest of the biodiversity hotspots, and there is consequently a high probability of species extinction (Heaney & Mittermeier, 1997; Myers et al., 2000).

To address the loss of forest cover, the Philippines government has embarked on numerous reforestation programs over the last century (Chokkalingam et al., 2006). The conventional reforestation approach relies on the use of fast-growing non-native species, such as *Acacia mangium*, *Gmelina arborea,* and *Swietenia* *macrophylla*. These trees have been widely promoted by the Philippines Department of Environment and Natural Resources (DENR) for reforestation, because they can grow well in the prevailing harsh, open conditions. In some cases, these trees have succeeded in reestablishing tree cover, but they do not provide the same level of ecosystem services as do mixed stands of native trees. Indeed, in many cases, they do nothing to preserve traditional Philippine biodiversity or to meet the growing demand for native hardwoods. They have also been found to perform poorly when struck by typhoons, which enter the Philippines Area of Responsibility on an average of 20 times per year (Santos, 2021).

## Rationale and Goals

Dr. Paciencia Milan of Visayas State College of Agriculture, now the Visayas State University (VSU), and Dr. Josef Margraf of the German Technical Cooperation Agency, now the German Corporation for International Cooperation (GIZ), developed a closed canopy and high diversity forest farming system known as Rainforestation Farming, or RF, as an alternative to conventional reforestation (Margraf & Milan, 2006; Milan, 2020). Initiated in 1992, RF was designed to conserve biodiversity and enhance ecosystem services by planting native trees, while simultaneously meeting the economic needs of local community members.

## Key Strategies Used

RF was conceptualized as an agroforestry system that would provide multiple economic benefits by integrating ground crops, fruit trees, and native timber trees. RF was particularly introduced to replace the practice of slash-and-burn agriculture *(kaingin)*. RF also has the potential to be a system that could enhance or replace the small landholder coconut monocultures, which is a major land use on the island of Leyte where the Visayas State University is located (Göltenboth et al., 2003; Fig. 4.5; Annex 1d).

**Fig. 4.5** Cienda-San Vicente Farmer's Association's rainforestation site in 1996 (left) and 2022 (right). (Courtesy of VSU-ITEEM)

The key innovations underlying rainforestation were two-fold: ecological and social.

Ecologically, the proponents emphasized the use of native tree species, particularly, but not exclusively, dipterocarps. The conventional wisdom at the time was that dipterocarps could not be used for reforestation because seeds were frequently not available since Dipterocarp seeds are only available during infrequent masting events. In addition, they were considered to be slow growing. The use of dipterocarps in RF was made possible by (i) using wildings rather than seeds, (ii) employing the use of a recovery chamber to boost the survival of the wildings extracted from the forest from about 50% to nearly 100%, and (iii) learning which of the dipterocarps and other natives were truly late successional species, since there are fast-growing species that can be planted in more open conditions.

Socially, RF was designed to enhance rural livelihoods, a prerequisite for successful reforestation given the Philippines' dense, rural population. Conventional reforestation has been top-down and target-driven, where local communities were hired to plant the tree seedlings provided by the DENR. Typically, the tree species planted were chosen without input from local community members, so that they had little real interest in ensuring that the trees survived. Moreover, there was a perverse incentive that if the trees died, the community could benefit from the wage-labor stemming from a future reforestation project. The shift embodied by RF was to emphasize the importance of the trees in providing a broad array of ecosystem services and by working with the local land managers to choose the tree species that the community members wanted. With this shift, the community members could see value in the trees themselves, which they then helped plant and maintain without relying on direct payments. A lot of work was also done in establishing and promoting community organizations, introducing secure tenure, working out equitable distribution of benefits, and the development of a "community family" approach.

### Project Management

The first RF site was developed on a *kaingin* farm of 2.4 ha, which was later expanded to 6 ha. This was located within the VSU forest reserve (Annex 1d), and planting started in 1992, where much initial experimentation took place. From 1995 to 2000, VSU established 28 small-scale demonstration sites, ranging in size from 2.4 ha to 5.44 ha, across the Leyte province in conjunction with two local communities and 26 private landowners (Nguyen et al., 2014; Ota et al., 2018; Schneider & Pohnan, 2012). MoUs were signed between the landowners, VSU, and the local government units. Training, planting materials, and technical assistance were provided by VSU, while the landowners were responsible for maintaining the sites. Early prescriptions entailed planting 2500 seedlings per hectare of early successional trees, followed 2 years later by 2500 late successional trees (Göltenboth & Hutter, 2004; Milan et al., 1998). The system was enriched with food crops such as pineapple, okra, sweet potato, cassava, climbing yams, and fruit trees which included durian, lanzones, rambutan, and mangosteens. Approximately 100 tree species were used across the sites with each site having as many as 40 different species. Each site, however, had an individual mixture of tree species depending on what was available in the nursery at the time (Nguyen et al., 2014). Non-native species were also found in some of these plantations (Nguyen et al., 2014; Ota et al., 2018), but those trees generally preexisted in the sites before the establishment of RF.

### Challenges

Developing a new agroforestry approach that integrates native forest tree species inevitably faces numerous challenges and obstacles. These included convincing farmers to adopt a new system, strengthening people's organizations, overcoming tenurial problems, conducting research to strengthen the scientific basis of the system, and maintaining funding. With the DENR actively promoting these fast-growing exotics, finding the planting materials needed for RF was also a challenge until mother trees were identified and local community nurseries established.

One specific challenge that has to be faced in all rainforestation sites stems from the fact that a national logging ban was issued in 2011 outlawing the harvest of native timber from natural forest areas. This blanket prohibition clearly affects the harvest of planted native trees, so the DENR has instituted a process through which RF adopters can register their newly planted native trees, allowing them to be eventually harvested. However, this requires interactions with the DENR and therefore there is the possibility of increasing transaction costs. This is one significant obstacle to the planting of native species, which is not faced by those choosing to plant and harvest exotic species.

### Major Outcomes

The reported conditions of the early rainforestation sites range from "highly successful to completely abandoned" (Ota et al., 2018). Several surveys have been undertaken by external scholars to look at the social impacts, tree growth, and stand dynamics across the sites (Nguyen et al., 2014; Ota et al., 2018; Schneider et al., 2013; Schneider & Pohnan, 2012). Other studies have highlighted the positive effect on soil quality (Asio & Milan, 2002), community empowerment (Asio & Bande, 2005; Compendio & Bande, 2017), provision of stable income to farmer adopters (Ahrens et al., 2004; Voyeux, 2003), and high carbon sequestration potential which will contribute to the mitigation of global warming (Bande et al., 2014).

The VSU Institute of Tropical Ecology and Environmental Management continues to carry out the work of promoting and further developing RF. With strong advocacy from the Haribon Foundation, RF was also adopted by the DENR as an official reforestation strategy (DENR, 2004). Despite the formal acceptance of rainforestation by the DENR, the use of fast-growing exotics has remained fairly well-entrenched. The situation is slowly changing with a growing role for the use of native species in such government programs as the National Greening Program (NGP) of 2011–2016, which targeted the reforestation of 1.5 million hectares, together with the enhanced NGP of 2016–2028, which aims to reforest an additional 7.1 million hectares (Republic of the Philippines, 2011, 2015; Table 4.1). These changes in DENR policy and practice have not come easily but have required the ongoing engagement of rainforestation supporters, many of whom have come together as members of a voluntary network, known as the Rain Forest Restoration Initiative (RFRI). RFRI members have also been active in the restoration of a large number of RF sites throughout the Philippines.

#### Key Learnings

On the technical side, many lessons have been learned from the early Rainforestation pilot sites and have been integrated into subsequent rainforestation initiatives. The maximum tree planting density, for example, is now 2500 trees/hectare in completely open areas and it is recognized that fruit trees, which need more light, should be planted in areas where they will not be overly shaded by timber trees. Research underlying the individual growth characteristics of native trees has also progressed significantly. For example, it is now known that a number of dipterocarp species, including *Shorea contorta, Parashorea malaanonan, Hopea plagata, Hopea philippinensis*, and *Dipterocarpus alatus* are mid-successional species that grow quite well in open conditions. As such, these trees can be planted independently or simultaneously with early successional species, rather than relying on a two-stage planting as previously recommended.

On the social side, several studies by Schneider and Pohnan (2012) and Ota et al. (2018) have suggested that the original RF sites did not generate as much cash income as the adopters expected, though they did provide products such as fruits, timber, seedlings, and firewood that could be harvested for domestic consumption. Nevertheless, the RF implementers were generally pleased with the program and benefited in many other ways, including enhanced environmental services, greater resilience to disturbances like typhoons, access to other income-generating opportunities, and greater community self-confidence from working with outside experts. The two people's organizations also benefited greatly from their nursery operations and increased access to other government reforestation projects (Ota et al., 2018; Schneider & Pohnan, 2012). These findings have important implications for the way in which Rainforestation will be promoted in the future.

### *Study 5: East Kalimantan Indonesia*

#### Background

The restoration site in Indonesia is located in the lowlands of East Kalimantan, which is part of the Indonesian portion of Borneo (Kalimantan). This comprises about 70% of the island. East Kalimantan has experienced widespread deforestation and forest degradation primarily as a result of industrial-scale logging, conversion for plantations, and mining (Gaveau et al., 2014). The mixed dipterocarp forests were particularly hard hit by commercial exploitation, which started in the early 1970s, because the trees provide extremely valuable timber. They can constitute as much as 60% of the total basal area of the lowland forest, where harvest rates in the region ranged from 80 to 100 cubic meters/hectare compared to 30–50 cubic meters/hectare elsewhere in the tropics (Kartawinata et al., 2008).

As a result of consistent logging, the forests have become more susceptible to fires, particularly during prolonged dry seasons associated with the *El Niño*-Southern Oscillation. The danger presented by fires became particularly evident in 1982–1983, when fires burned approximately five million hectares of primary and secondary forests across Borneo (Goldammer & Siebert, 1990; Siegert et al., 2001). Given the frequency of fire events, many previously forested areas are now dominated by pyrophytic *Imperata cylindrica* grasslands, which now cover an area of over 2.2 million hectares in East Kalimantan. This area has been the focus of many reforestation efforts and attempts to use it for smallholder agriculture across Indonesia, but these have been mostly unsuccessful (Garrity et al., 1997).

## Rationale and Goals

Samboja Lestari was established in 1991 by the Balikpapan Orangutan Society now known as the Borneo Orangutan Survival Foundation (BOSF; Annex 1e). This is an Indonesian non-profit organization dedicated to the conservation of the Bornean orangutan (*Pongo pygmaeus*) and its habitat. The program's aim was specifically to rescue, rehabilitate, and, where possible, release orphaned or misused orangutans rescued from areas of habitat loss and the wildlife trade. In the early years, however, BOSF only had access to 3 hectares of forest for their orangutan rehabilitation and reintroduction efforts. Other forest areas nearby were undergoing deforestation or were being used for research so were not available since orangutans tend to damage the trees. Thus, BOSF launched a forest restoration program in 1999 to convert approximately 1850 hectares of land dominated by *Imperata cylindrica* into a young forest and wildlife sanctuary.

## Key Strategies Used

There were several key strategies in developing Samboja Lestari, which were as follows:

1. To clarify the legal status of the area: Land for the project was purchased by BOSF to minimize the chance of tenurial conflicts. A significant part of the land was a former transmigration site, where the Indonesian government had attempted to resettle people from Java and other more densely populated areas of the country. As a transmigration site, it had proven largely unsuccessful, so the land was purchased from the former inhabitants for a reasonable price. Other

areas of the site were purchased from members of older, more established communities.
2. To create the necessary infrastructure: BOSF built its offices on the site, together with an Ecolodge, which was established with the idea of housing volunteers and other supporters. It also developed a road system to improve access throughout the site for planting, to monitor plant growth and to facilitate fire suppression. A fire tower was established to aid in the monitoring of fire outbreaks, and a large pool and small ponds of water were also created in anticipation of firefighting needs.
3. To develop a partnership with local community members: The program was specifically designed to give multiple benefits to local community members. In this respect, during the restoration process, some farmers were given permission to cultivate the land between the growing trees in certain areas, and locally grown fruits were purchased at a premium from farmer groups by BOSF for the orangutans. Alternative livelihoods were also provided through sugar palm tapping and various types of carvings and handicrafts. Locals were also employed for fire prevention, nursery management, security, and tree planting, with others offered positions as staff in the office and the Ecolodge. BOSF also supported farmer field schools to teach agroforestry and provide environmental education for students.
4. To ground the project on the latest advances in scientific knowledge: The restoration approaches used at Samboja Lestari drew heavily on the Tropenbos Kalimantan Project, a long-term research project based at the nearby Wanariset-Samboja area. This project ran from 1985 until about 1997 and focused on facilitating the restoration of dipterocarp forests through research on mycorrhizae, species selection, soil and site classification, planting stock production, and growth and yield studies (Effendi et al., 2001). Dr. Willie Smits, founder of BOSF and the driving force behind Samboja Lestari, had formerly served as team leader of that project.

**Project Management**

As indicated, the restoration of Samboja Lestari significantly benefited from the legacy of the Tropenbos Kalimantan Project at nearby Wanariset-Samboja in terms of the facilities that had been developed, including a large nursery and one of the best herbaria in Indonesia. Plant propagation for the restoration efforts was initially carried out at Wanariset-Samboja, but a nursery was later built at Samboja Lestari in conjunction with a large site for creating compost out of orangutan feces and other organic waste, which was subsequently used for fertilizing tree planting.

Restoration of the site then focused on three different zones:

(a) The Sanctuary Zone, which was located in the interior. This roughly 300 ha zone contains the Ecolodge, an area for orangutan and sun bear cages, and islands where orangutans that cannot be returned to the wild can live. Trees were planted in this zone, but reforestation also relied on natural regeneration, some of which was facilitated by transferring seed-bearing soil from secondary forest areas.

(b) The Reforestation Zone, where an array of different techniques were used. An arboretum was established on 82 ha with 281 tree species, focusing especially on species native to Kalimantan, particularly with an endemic nature. In some open areas, line plantings of trees using *Shorea balangeran*, *Vitex pinnata, Aquilaria mollucana*, *Durio* spp., and *Alstonia* spp. was carried out. These trees quickly shaded out the exotic *Imperata cylindrica* facilitating establishment of natural regeneration. An agroforestry approach was used in some areas with the trees being interplanted with agricultural crops, including pineapples, beans, corn, and ginger, as well as bananas and papayas. The crops reduced competition for the trees and the fertilizers applied to the crops helped promote tree growth. Finally, in large areas of Samboja Lestari, Assisted Natural Regeneration was applied where adequate numbers of species appropriate for natural regeneration was present.

(c) The Buffer zone, within which a 100 m ring of sugar palm (*Arenga pinnata*), was partially planted around the site to suppress fire and provide resources for local livelihoods. Sugar palm has very dense foliage, which not only kills off *Imperata cylindrica* but also provides thatch, ethyl alcohol, natural medicines, fibre, and many other useful products for community use.

A guiding philosophy underlying this entire restoration effort was finding "synergy with nature," in an attempt to accelerate natural succession. In order to do this, fast-growing local tree species that were attractive to wildlife in terms of fruit, nectar, and nesting sites were planted to entice wildlife to re-enter the area. It was anticipated that wildlife would bring seeds from the nearby forest areas such as Bukit Soeharto and Wanariset-Samboja into the site, thus enhancing species diversity. Silvicultural techniques were applied not only to the trees that had been planted but also to those trees that had emerged through natural dispersal. In general, this approach worked well, although the transition required that some traditional approaches needed to be modified. Field staff needed constant reminding that certain trees, which had previously been cut down as weeds, now needed to be treated and protected similar to those trees that had been intentionally planted (Neidel et al., 2012).

## Challenges

The greatest challenge to restoring the *Imperata* grassland area was due to the flammability of the grass, increasing the risk of fire during the dry season. To address this problem, a 35 m observation tower was built to make sure that fires were quickly detected. In addition, a fire break of sugar palm was planted around much of the site, and dispatch teams were formed to quell fires before too much damage could be done. BOSF also had a fire truck and other fire-fighting equipment on hand. Of equal importance was that the Samboja Lestari project was developed in conjunction with a consistent recognition of the local communities' economic needs, in order that the surrounding village members were disposed to help control threats to the site. These threats include illegal logging, clearance for conversion of land for agriculture, and the indiscriminate use of fire for clearing.

### Major Outcomes

The Samboja Lestari project determined that areas dominated by *Imperata* grassland need to be maintained in the face of anthropogenic fire events. If fires are quickly terminated, the land will undergo natural succession, allowing it to be restored to a high diversity secondary forest (Yassir et al., 2010). Over the course of this project, biodiversity recovery of the site was quite rapid, with 1221 plant species, 57 bird species, and 18 species of mammals having been recorded on the site by 2008–2009 (unpublished data). To some observers, Samboja is one of the most successful tropical forest restoration sites anywhere in the world (see, for example, Little, 2008). However, Samboja Lestari is not without its detractors. Meijaard (2009), for example, questioned a number of claims that Smits made about Samboja Lestari in his 2009 TED Talk. It has also been suggested that the funds would have been better used for the conservation of intact forest (Little, 2008; Thompson, 2010).

### Key Learnings

One of the key learnings is that maintaining local community support, even after active restoration activities are over, is extremely important. The Samboja Lestari project was designed to make sure that the local community members received economic benefits from the project in return for their continuing support. A major change in leadership at BOSF, however, led to a halt to the restoration work, a distancing from former staff who had been involved in those efforts, and a discontinuation of many of the community programs. The danger of losing community support became apparent in 2015, when outsiders started clearing part of Samboja Lestari for agriculture. The local community leaders, who would have previously intervened, did not act to stop the encroachment. Later when called upon to assist with the suppression of a fire that had broken out in the site, local community members were also unwilling to respond. As a result, approximately 300 hectares burned before outside help could be mobilized from a local mining company to suppress the fire. For a forest restoration site originally built on such strong social principles, this was a very unfortunate setback (Fig. 4.6).

**Fig. 4.6** Samboja Lestari in 2002 and 2016. (Courtesy of Dr. Ishak Yassir)

## Discussion

The case studies of this chapter show that active restoration with a high diversity of native species can lead to successful rainforest recovery. However, it should be understood that the long-term effects of these programs can be transient, which emphasizes that the retention and protection of existing mature, undisturbed rainforest sites from future disturbances will always remain the top conservation priority (Di Sacco et al., 2021). Ecological restoration is not a complete substitute for habitat and landscape conservation, and the pledges of restoration elsewhere should not be used to justify existing forest conversion to other land uses in critical habitat areas.

Our studies have thus underscored the unequivocal need to protect all rainforest fragments, large and small, including those that occur outside protected reserves, especially in global biodiversity hotspots. These fragments act to conserve rich biodiversity and contribute to the delivery of important ecosystem services. With respect to future restoration activities, these fragmentary areas can provide seeds and seedlings and serve as reference forests that can enhance our understanding of the structure, function, and composition of local forests which are the target of restoration efforts. Forest fragments can also be incorporated as key nodes in the establishment of forest corridors, as has been shown in the Western Ghats case study.

The case studies of this chapter have showcased how the ecological knowledge of native plant species in nearby reference forests and species trials can be successfully employed in restoring degraded heterogeneous landscapes typical of south and southeast Asian lowland and lower montane rainforests. This is an important outcome since lack of sufficient ecological information about native forest species of conservation and utility value have contributed to restoration failures in the past (Vivekanandan, 1989). For example, the identification of the successional gradients of species in terms of their needs for direct sunlight or differing amounts of shade is a key consideration, and in some cases, this research has brought about a much more nuanced understanding of the needs of different tree species. Conventional wisdom in Indonesia and the Philippines, for example, held that all dipterocarps were late successional species requiring significant shade, whereas we now know that a number of species have high survival and growth in open conditions. Indeed, one species in East Kalimantan, *Shorea belangeran,* has even performed well in a completely open and highly degraded coal mine rehabilitation site (Yassir & Adman, 2015).

For other species, these case studies have underscored the need to provide appropriate partial shade conditions for late successional species. In Sri Lankan rain forests, *Shorea trapezifolia* stand out as highly successful mid-successional native tree species and is emerging as among the best candidate native species for incorporation into landscape restoration activities in lowland rain forest areas (Kathriarachchi et al., 2004; Fig. 4.1b). Suitable plantations or secondary forest stands of pioneer/early successional trees, which have already successfully replaced invasive grasses and ferns, are often available in the landscape as readymade nurse tree stands for restoration planting of mid-late successional species. In Sri Lanka, *P. caribaea* plantations and mixed stands of *Alstonia macrophylla, Macaranga peltata, Trema orientalis, Symplocos* spp. provide good examples of mixed nurse stands that are often available outside protected areas (personal observations). In Indonesia and the Philippines, existing plantations of *Acacia mangium* and *Paraserianthes falcataria* can play a similar role (Otsama, 2000). A cautionary note is that some species, such as *Acacia mangium* and *Alstonia macrophylla,* have proven highly invasive in some circumstances. This means that special care needs to be taken when planting new plantations for this purpose (Koutika & Richardson, 2019).

In addition to concerns with the differential effects of light environments, species chosen for restoration have to be well-suited to site conditions in terms of belowground resource availability. This concern is linked to the available parent material, the topographic position, and the extent of soil degradation. For example, in Sinharaja, Sri Lanka, incorporating the topographical affinities of different species into the selections for enrichment planting of *P. caribaea* plantations played an important role in the success of this restoration strategy (Ashton et al., 1997, 2011). Notwithstanding this understanding, in other areas such as the Philippines, where forest restoration has moved from research to broader scale implementation, some of these affinities are known, but more random patterns of tree planting are commonly practiced.

It is known that symbiotic root-inhabiting mycorrhizae play an important role in tropical forests by enhancing trees' ability to take in water and nutrients (Hodge, 2017). Thus in almost all of our case studies, native forest soils have been used in nursery work to ensure the introduction of native microbial inoculum from the earliest stages for the healthy growth of seedlings. In the Knuckles forest case study in Sri Lanka, biofilmed biofertilizer application has had an additional benefit for enhanced survival and relative growth rate of the seedlings of the native tree species in the nursery and under field conditions (Gunasekera, 2022; Seneviratne et al., 2011). Whether some of the established plantations (such as with the *P. caribaea* trees in Sri Lanka) facilitate the establishment of the newly planted dipterocarps, through mycorrhizal connections, is currently unknown. The role of root-associated mutualists in enhancing the success of restoration programs is therefore an important area of future research.

Studies involving isolated small populations of canopy tree species in Sri Lankan rainforest fragments have shown that an understanding of the initial pool of genetic variation seems to be a critical element in the design and implementation of an FLR project (Gunatilleke & Gunatilleke, 2013; Nef et al., 2021). Genetic diversity is tightly linked to species' reproductive ecology, fitness, and adaptive potential, which are often correlated with life-history traits characteristic of divergent subpopulations of localized species (Nef et al., 2021; Richards et al., 2016; Smith et al., 2018). Integration of intraspecific genetic diversity attributes in ecogeographic scale restoration planning is potentially significant for the longer-term sustainability of forest restoration initiatives. These population genetic considerations will help capture intraspecific ecoregional diversity and conserve their nuanced adaptive variations in climate-resilient populations, especially in biodiversity hotspots (Gaisberger et al., 2022). This feature warrants greater emphasis in broader, regional-scale spatially explicit conservation *cum* restoration planning in the face of continuing threats of genetic erosion in a changing climate.

These five case studies illustrate the critical importance of co-developing restoration programs with local communities. In addition to the need for community help in protecting and maintaining the site, one benefit of doing so is that these communities possess indigenous knowledge on species' traits, habitat affinities, and utility values that might take a lengthy research program to otherwise uncover. Integration of such knowledge at the early stages of restoration planning in Sri Lanka and the Philippines contributed to their early success. Working with local village communities also allows an avenue for local demonstration of successful approaches and an opportunity to encourage rapid uptake of new techniques for management of their private land, for example, in analog forests and agroforestry gardens.

Our experience suggests that uptake will be enhanced if the restoration program adopts species that deliver products that have been harvested traditionally from the natural forest (Ashton et al., 2014). Planting a mixture of utility species and native forest species is integral to the rainforestation farming initiatives in the Philippine case study, and this attribute of the system contributes to improvements in food security through climate resilient agroforestry (Milan & Margraf, 1994; Veridiano et al., 2020). A further step is to actively promote and develop cottage industries based on the products of restoration plantings, for example, sugar palm, rattans, medicinal plants, honey, and health foods. This approach has been taken in partnership with tea plantation companies in Sri Lanka that are incentivized by opportunities for the tea companies to diversify into agro-ecotourism (https://www.dilmahconservation.org/initiatives/sustainability/biodiversity-corridor-endana.html). In India, large plantation companies could be successfully engaged as partners in restoration if they are willing to set aside areas for protection and restoration, but the lack of firewood resources for workers who live alongside these forest patches poses a continued challenge for protecting restored sites from future degradation.

Additional demonstration projects with evidence-based site-specific prescriptive guidelines and strong rural socio-economic underpinnings are urgently needed for implementation of large-scale restoration programs across the multitude of landscapes that exist across wet tropical Asia. Demonstrating the economic viability of these programs enhances the likelihood that they would be taken up at larger scales. For example, we have compared the relative economic merits of restoring pine-clad hilltops and upper slopes in the wet lowlands of Sri Lanka using native species with conversion to small-holder tea gardens (Ashton et al., 2014). The financial analysis demonstrated that planting a native forest for timber and non-timber products may be more profitable than cultivation of tea smallholdings. This financial analysis excluded any payments for ecosystem services, which, if available, would have undoubtedly strengthened the financial incentive for ecosystem restoration. One example of a successful Payment for Environmental Services (PES) scheme was the Environmental Protection Fee introduced by Bago Local Government Unit (LGU) in Negros Island, Philippines, which has been levied on all city water users since 2016. This revenue has been used to fund the conservation of forest and biodiversity initiatives, forest protection measures to ensure sustained water flows, and alternative livelihood programs for forest communities (Global Forest Goals Report, 2021). Similar reward schemes could be developed for conversion of non-native plantations into mixed-species forests in critical watersheds for ecosystem restoration and rehabilitation activities using the methods which have been proven to be successful in our case studies.

A study somewhat akin to rainforestation in the Philippines, but using a mixture of native species and fast-growing non-native eucalypt spp. in the Atlantic Forest regions in Brazil, has yielded promising results in offsetting restoration implementation costs without undermining the ecological outcomes of restoration within a period of only 7 years since planting. The income from eucalypt wood production has offset 44–75% of restoration implementation costs (Brancalion et al., 2019). Likewise, non-native early successional species, such as those of *Acacia, Alstonia, Eucalyptus, Macaranga, Paraserianthes*, *Melia,* and *Pinus,* that are already established in degraded forests in Sri Lanka could be used either as mixed nurse tree populations in a relay floristic method or growing simultaneously with native species. Some of these species, such as *A. macrophylla* and *Melia azedarach* which were introduced to the island more than a century ago are now naturalized to a greater extent and emerging as potential nurse tree stands for native species establishment beneath them in degraded lowland rain forest landscapes. Furthermore, these non-natives are utility timber species widely popular among local communities. Experimental trials need to be initiated for silviculturally managing these stands in facilitating native species restoration for their ecological and socio-economic feasibility. This approach has the potential to be used in community-led forest landscape restoration programs, particularly in small-holder-dominated economies off-setting at least a part of the restoration cost, but only in areas where adequate infrastructure for transport, marketing, and utilization already exist or where some sort of PES scheme is feasible.

Certification of agricultural products can also provide an economic incentive for improvements in land management, which can include investments in restoring degraded forest patches that do not contribute to the land area under cultivation. For example, larger tea plantations in the lower montane Knuckles region and Valparai

Plateau in Western Ghats, India, contain embedded forest fragments that could be restored under a certification scheme that promotes sustainable management of biodiversity and ecosystem services in production landscapes (Chowdhury et al., 2021), such as those that exist for certification of sustainable palm oil (Brandi et al., 2015). This scheme could be designed in a way that member organizations are mandated to conduct a land use planning exercise that identifies lands that are marginal for tea production and promote restoration initiatives that engage plantation communities with enhanced livelihood opportunities.

Similarly, Payment for Ecosystem Services that prioritize biodiversity, soil and water conservation, preventing floods and landslides, provision of timber, fuelwood and non-timber resources, and promotion of ecotourism may leverage tea plantation companies to diversify their investments in ways that support increased tree cover. For example, multiple crop certification systems focusing on landscapes rather than just a single end product (such as tea) may trigger diversification from monoculture tea plantations into a mosaic of land uses that support greater native biodiversity, ecosystem services, and the livelihoods of people dependent on them (Chowdhury et al., 2021). Small landholder tea producers who provide the majority of tea exported by Sri Lanka are more amenable to this type of multiple crop analog-forest landscape certification system including mosaics of homegardens as well as smallholder tea plots. These high-biodiversity agroecosystems, reinforced with elements of nature-based and sustainable land management practices, may find value-added niche markets for such products (FAO/INRA, 2016; Padulosi et al., 2012).

## Conclusions

The case studies presented in this chapter illustrate how the goals of the UN Decade on Ecosystem Restoration could be achieved in practice across multiple settings in wet tropical Asian biodiversity hotspots, where conservation of biodiversity is a priority. Development of the concept of ecosystem services over the last two decades, with its emphasis on the market valuation of the wide array of goods and services provided by natural ecosystems, has the potential to generate a paradigm shift in forest restoration. Government natural resource management agencies throughout the region, whether it be the DENR in the Philippines, the Forest Departments in Sri Lanka and India, or the Ministry of Environment and Forestry in Indonesia, have persistently practiced reforestation using only a very narrow suite of mostly non-native trees, frequently planted as monocultures. These trees, while usually performing well from a narrow production forestry perspective, have failed to achieve other management objectives, such as enhancing biodiversity, supporting local community livelihoods, or improving local hydrology. Fortunately, a broader diversity of restoration approaches, like those discussed in this chapter, are becoming increasingly popular. Overcoming the inertia and vested interests in conventional reforestation, however, remains a major challenge.

Instituting innovative payment schemes for ecosystem services as a way to finance forest restoration is a pragmatic way forward. The lack of a mechanism to generate regional data on the economic value of ecosystem services provided by restoring landscapes has been a constant barrier to progress. This is so important in geographically and socio-culturally similar regions like the south and SE Asian region. To address this need, the Economics of Ecosystem Restoration (TEER) initiative, a standard framework to assess the cost and benefits of restoration projects, was recently developed under the aegis of the UN Decade on Ecosystem Restoration and could be a key tool for mobilizing donors, investors, project implementers, governments, and other stakeholders (Bodin et al., 2021). Coupling these types of initiatives with enabling national policy environments for their larger-scale implementation based on ecologically sound field trials may create investment opportunities for forest landscape restoration (Lamb, 2018). Green or Climate Bond marketing portfolios which support a wide range of nature-based solutions toward sustainable land management are an emerging opportunity for natural capital investments that include forest landscape restoration especially suited for Global Biodiversity Hotspot regions of the world, e.g. Rainforest Impact Bond program in Indonesia (Innovative Rainforest Bond Structure Unveiled at Indonesia (globenewswire.com), (https://www.globallandscapesforum.org/wp-content/uploads/2020/10/How-can-Green-Bonds-catalyse-investments-in-biodiversity-and-sustainable-land-use-projects-v12_Final.pdf).

As the pace of innovation in forest and landscape restoration increases, there is also a need for establishing national and regional networks for sharing practical experience (WRI, 2021), and the joining together of communities, governments, financial supporters, and research agencies to overcome barriers inhibiting planning, financing, and policy reform. Only by working together to develop robust ecological, social, and economic foundations for forest restoration and empowering people to make these changes will we be able to realistically meet the Bonn Challenge targets of our respective regions. This is especially relevant for endemic-rich Global Biodiversity Hotspots threatened with rapid forest degradation and deforestation, especially during this UN Decade of Ecosystem Restoration (https://www.bonnchallenge.org/about).

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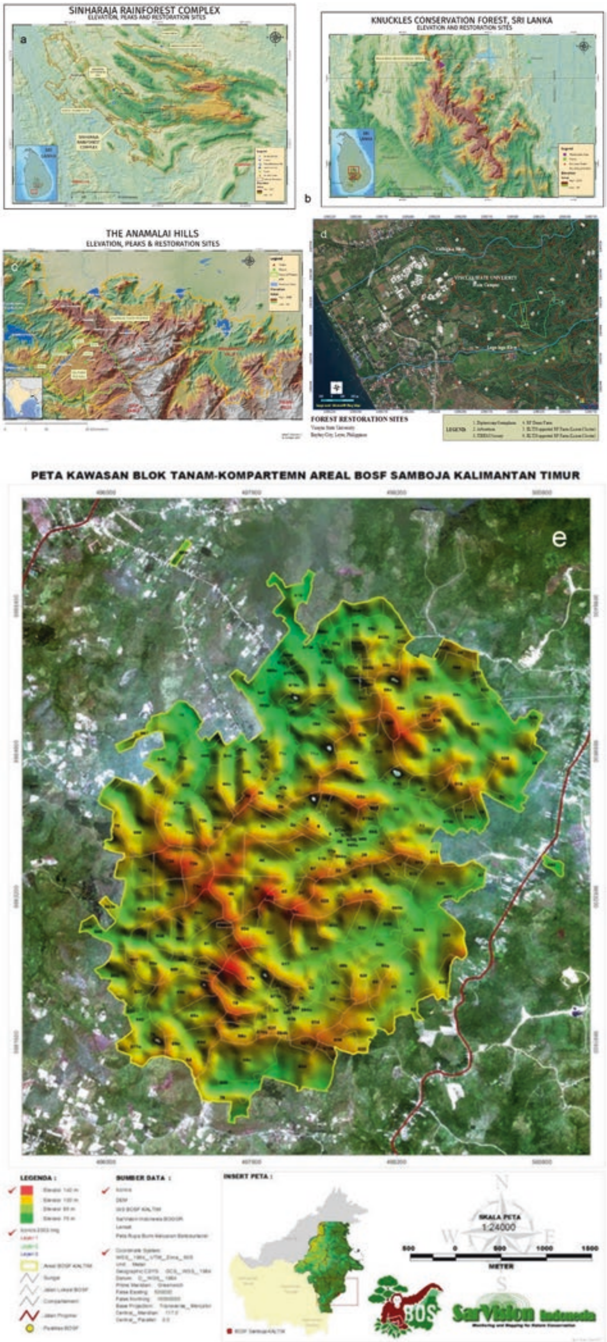
# Annex 1




Location of each restoration study site in relation to the elevation and relief of the broader landscape in (**a**) Sinharaja WHS, Sri Lanka, (**b**) Knuckles region of the Central Highlands WHS, Sri Lanka, (**c**) Valparai Plateau, Western Ghats,India (**d**) Leyte, Philippines, and (**e**) Kalimantan, Indonesia

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