A Guidebook for Forest Restoration in Sri Lanka

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UNIVERSITY OF PERADENIYA

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Acronyms

AMF	Arbuscular Mycorrhizal Fungi
ANR	Assisted Natural Regeneration
BFBF	Biofilmed Biofertilizer
ER	Ecological Restoration
FAO	Food and Agriculture Organization
GBH	Girth at Breast Height
KCF	Knuckles Conservation Forest
IUCN	International Union for Conservation of Nature
LDN	Land Degradation Neutrality
MEA	Millennium Ecosystem Assessment
MFF	Mangroves for the Future
MoMDE	Ministry of Mahaweli Development and Environment.
MSP	Mechanical Site Preparation Technique
NGO	Non-governmental organisation
NPK	Nitrogen, Phosphorous and Potassium
SDG	Sustainable Development Goals
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-REDD	United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
WHO	World Health Organization
WRI	World Resources Institute

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Message from Dr. K. M. A. Bandara, Conservator General of Forests, Forest Department

In the late 19th century, the Forest Ordinance of Sri Lanka was enacted and the Forest Department was commenced for scientific forestry and to conserve forests. At that time, the forest cover in Sri Lanka was 84% of the land area.

Until 1949, when the Department of Wildlife Conservation was established, both wildlife and forests were managed by the Forest Department.

Forest policies have been formulated since 1929. The initial policy focused on ensuring that the country was self-sufficient in timber and other forest products, through simultaneous exploitation and afforestation, while preventing erosion and preserving native fauna. Since then, policies have changed dramatically. The last amendment of the Forest Ordinance in 2009 changed its title to the Forest Conservation Ordinance, created conservation forests and aimed for sustainable forest resource management.

Currently, natural forest cover is only 29.2% of the land extent. Just over half of these forests are under the purview of the Forest Department (with much of the balance under the jurisdiction of the Department of Wildlife Conservation). There is also a National Heritage Wilderness Area, 128 conservation forests (totalling 179,916 ha) and 747 reserved forests (totalling 1,160,286 ha). In addition, there are other state forests and 90,000 ha of forest plantations.

In 2019, the estimated population density of Sri Lanka was 348 persons per square kilometre. Because of this high population density, there is a colossal pressure on land for conversion to settlements, cultivation, irrigation and infrastructure development. Consequently, there is destruction, degradation and fragmentation, diminishing the extent and quality of Sri Lankan forests and the invaluable suite of ecosystem services that they provide.

In tandem with conserving Sri Lankan forests for posterity, the Forest Department has, for the last seven years, been engaged in the restoration of degraded and damaged forests. Our success stories include the restoration of 9,000 ha in 2020. Assisted Natural Regeneration, planting of local species in heavily degraded lands and removal of invasive species are the main forest restoration strategies used, for example, assisted natural regeneration at Maragamuwa, Naula. We have involved communities in these endeavours, so that they become ambassadors for forest conservation; engaged in public-private partnerships in restoration with the corporate sector, and to date, restored around 250 ha of degraded and damaged forests.

The guidelines provided in this book will be invaluable to attract more practitioners to support a national endeavour of forest restoration in this UN Decade of Ecosystem Restoration.

Message from Professor H. M. T. G. A. Pitawala, Director, Postgraduate Institute of Science, University of Peradeniya

Natural and semi-natural ecosystems, including urban green spaces, are vital for the well-being of all organisms on planet earth, because they provide many ecosystem services such as regulating the climate, protecting watersheds, provisioning food, clean water and medicines, supporting nutrient cycling, and providing spaces for recreation and education. Despite their importance, currently most of these ecosystems are being deforested or degraded due to human activities. As a result, restoration and conservation interventions are becoming essential as corrective measures for the re-establishment of natural ecosystems, so that food security may be enhanced, multiple benefits are provided for all organisms and resilience is developed for current and projected climate change.

The Board of Study in Plant Sciences of the Postgraduate Institute of Science (PGIS), Sri Lanka, has been involved actively in providing education, research and conducting outreach programmes related to biodiversity conservation and management, through several Boards of Study. Master and M.Sc. degree programmes offered by our institution cover forest science related content, enabling postgraduate students to gain knowledge, skills and attitudes towards biodiversity conservation and sustainable use of national and global forest resources. Since its establishment, the PGIS has conducted research concerning biodiversity conservation and management. Our researchers – with their students – conduct research to fill gaps related to the management of natural ecosystems in our country. We have established many collaborations with national and international institutions and organisations, enabling us to conduct world renowned research.

Successful forest restoration projects are driven by prior planning and effective team work among all stakeholders. Restoration principles guide the process of restoring ecological integrity and functioning of ecosystems through the use of restoration assessments, conducted at multiple levels, at different scales. However, there are no books published underlining restoration prescriptions for Sri Lanka. Thus, this book, which is written in easy-to-understand language, will be helpful to anyone who is keen to initiate a restoration project anywhere in Sri Lanka.

While appreciating the efforts of all who were involved in successful completion of the book ‘A Guidebook for Forest Restoration’ in Sri Lanka, I congratulate all the authors of the book for their scientific contribution.

Message from Dr. Ananda Mallawatantri, Country Representative, IUCN Sri Lanka

Sri Lanka, the island we call home, is filled with rich and unique biodiversity and is a landscape that extends from ridge to reef. Forests play a key role in providing ecosystem services and meeting the challenges of climate change within this continuum of ridge to reef.

At the ridge is the Central Highlands, where a healthy forest canopy is required to capture the clouds that are instrumental in generating rain. The forest canopy is also essential in reducing the impact of climate-induced, high intensity rainfalls, because forests can absorb water into their soils, which will, in turn, be released slowly to streams, tanks, and reservoirs. These water bodies are vital in ensuring water for irrigation, drinking, power generation etc. and are also key in reducing the impacts of droughts in the dry zone as a consequence of the availability/storage of water. Healthy forests will maintain biodiversity and support generation of seasonal waterfalls; reduce landslides and floods; enhance the tourism experience in our national parks and sustain tourism and agriculture livelihoods – all the while providing a multitude of societal benefits through poverty alleviation and climate resilience.

In coastal estuaries and lagoons, mangroves and coastal vegetation contribute to the quality of fish populations, minimise the impacts of climate-induced sea level rise and sea surges, filter sediments and chemicals from reaching lagoons, sea grass areas and coral reefs etc. In addition, coastal vegetation also provides food, energy, and tourism benefits. The application of forest landscape restoration techniques in coastal and marine environments, therefore, can ensure the sustainability of coastal biodiversity, while providing benefits to humans in the form of sustainable livelihoods.

The United Nations has named this decade the Decade of Restoration. It is encouraging to see how government departments and universities are joining hands with international agencies to promote forest restoration in Sri Lanka, taking advantage of both global and traditional knowledge. The knowledge and ecological restoration techniques presented in this book are vital for the sustainable development of Sri Lanka and to meet the challenges of climate change.

Executive summary

This decade has been declared by the UN as the *decade of restoration*. However, there is great confusion about what restoration entails – it is often misunderstood to mean planting trees. But restoration as a word means 'to bring back a situation . . . that existed before' (Oxford University Press, 2021) and therefore, in the context of forest restoration, this means bringing back the forest to what it was before it was destroyed – to the full complement of flora, fauna, microorganisms interdependent on and interacting with each other and with abiotic components – such as soil and water – to form a functional natural unit, that provides humans with a suite of life sustaining ecosystem services. Of these, one of most important services is the absorption of carbon dioxide from the atmosphere and the release of oxygen through the process of photosynthesis: carbon sequestration – providing a natural means of mitigating the impacts of climate change. This guidebook on forest restoration provides a holistic, practical, scientific approach to forest restoration for stakeholders who wish to support forest restoration.

Chapter 1 is an introduction to the Bonn Challenge, which aimed to restore globally 150 M ha of deforested and degraded land by 2020. Seventy-four countries pledged to do so, and by 2017, the 2020 target had been exceeded. The chapter also presents the current situation in Sri Lanka (where 29.7% of the total land area of the country is under forest cover) but notes there are various anthropogenic drivers of ecosystem change that cause forest loss. Because of this, forest restoration has been identified as one of the key conservation tools in Sri Lanka, with the aim of restoring 200,000 ha of degraded forest lands by 2030.

Chapter 2 presents the science of ecological restoration. Three approaches – reclamation, rehabilitation and ecological restoration – are used commonly to reforest degraded sites, but only ecological restoration assists ecosystem recovery through the enhancement of biodiversity and ecosystem services. This chapter provides a clear understanding of ecological fundamentals – such as understanding the relationships among organisms (biotic interactions), as well as with their physical surroundings; natural regeneration; primary and secondary succession; pioneer and climax species; and biotic and abiotic factors that retard succession. These technical terms are clearly explained. Finally, the chapter details the steps required for ecological restoration of degraded sites.

Chapter 3 describes how soil itself must be restored prior to attempting ecological restoration. The nutrients and organisms in soils play a vital role in ecological restoration. It emphasises that both above- and below-ground factors and limitations must be considered equally to make any restoration effort a success. Site preparation is important, and its main aim is to enhance the microsite conditions before planting/seeding. The chapter emphasises that choosing the right site preparation technique is vital and presents several mechanical methods, as well as methods for a range of landscapes – for example, those which are stony/rocky, exposed, windy, prone to fire and herbivory. It cautions that there is no universal restoration model to suit all conditions and situations.

Chapter 4 details nursery management for restoration. Selecting a site for nursery establishment, designing and the laying out the nursery to meet the objectives for establishing the nursery; the methods of collecting seedlings or producing propagules (for example by vegetative propagation, layering and cuttings); how to clean and store seeds; pre-treatments before sowing; the medium for growth; disease, predation and weed control within the nursery, as well as light conditions, are all detailed in this chapter.

Chapter 5 is about the effect of restoration on fauna. A diverse range of organisms within an ecosystem is the best indicator of its health. New vegetation after restoration provides a wide array of microhabitats, as well as connectivity among forest patches, and fauna then establish healthy interactions. Restoration may not succeed if it does not consider the re-establishment of these interactions (such as pollination and nutrient cycling) that are crucial for ecosystem functioning. Prioritised faunal groups considered in restoration practices are discussed in this chapter. For assessing the level of achievement in the restoration programme, faunal surveys are needed, and their methodology and species are detailed.

Chapter 6 discusses mangrove restoration. Although Sri Lanka's mangroves are small in extent and cannot be considered 'forests', they are included in this book because, with salt marshes and seagrasses, they comprise blue carbon ecosystems which sequester carbon at a rate 2-4 times greater than those of tropical terrestrial forests. This chapter emphasises the importance of conserving existing mangroves, as well the need to conduct mangrove restoration only in degraded mangrove areas, and not in any other part of the coast or into other coastal ecosystems such as tidal flats and salt marshes. Planting must be commenced only after the hydrological and tidal patterns have been studied, and carefully selected species must be planted in different zones.

Chapter 7 is about urban greening. Urbanisation has created areas that emit heat – heat islands – compared to rural areas which are shaded and cooled by vegetation. Studies have shown that green spaces in urban areas can lessen the negative impacts of climate change. This chapter discusses green roofs, green walls and green façades. It describes each intervention, with lists of suitable species and their maintenance. Urban greening with trees is also discussed in detail. The way forward for urban greening Sri Lanka includes a) introduction of native plants; b) promoting species with a potential of intercepting dust/particulate matter and c) low maintenance planting schemes for neglected/abandoned spaces.

Chapter 8 details the selection of plant species for forest restoration programmes. This chapter discusses how it is critical that selected species are not only suited to climatic conditions, but are also suited to the floristic zones of Sri Lanka, and the specific ecosystem of which they are a part. There are also species which are site-specific. This chapter provides a selection of tree species for restoration of different types of forests and for site-specific restoration. The chapter also lists species to be used based on the stage of succession. It cautions that seeds for restoration must be selected and collected from the same floristic region and similar plant assemblages. It emphasises that it is crucial to prevent indiscriminate planting, which may lead to homogenisation of species composition.

Chapter 9 gives locations of plant nurseries of the Forest Department as a list and map. Interspersed among various chapters are several **case studies** describing actual applications of methods or approaches. Also provided as an annex is a comprehensive list of plant species for forest restoration.

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‘They who plant orchards and gardens, who plant groves, who build bridges, who set up sheds by the roadside with drinking water for the travellers, who sink wells or build reservoirs, who put up various forms of shelter for the public, are those in whom merit grows by day and by night.’

Vanaropa Sutta

Sri Lankan culture has always promoted aligning with nature, respecting all living beings and knowing the value of protecting nature.

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Chapter 1: Introduction

W.P.N. Perera[1] and E.A.P.N. Edirisinghe[2]
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The global context

Forests are essential for the well-being of all humankind. They provide us essential ecosystem services[1] including oxygen, food, water, medicines, wood, amelioration of climate, prevention of soil erosion, regulation of floods and protection from extreme events (FAO, 2020).

One of the most important ecosystem services provided by forests is the absorption of carbon dioxide from the atmosphere and the release of oxygen through the process of photosynthesis. Known as carbon sequestration, this long-term process of removing carbon dioxide from the atmosphere, and storing it as carbon, is currently one of the most vital natural solutions to the climate change crisis (Selin, 2019). Carbon sequestration makes forests carbon sinks, that is, they absorb more carbon dioxide than they release (Hui et al., 2015).

Box 1. The amount of carbon sequestered by forests

- Globally, over half of the carbon stored in terrestrial ecosystems is in forests;
- The total amount of carbon stored in the biosphere is assessed at 2.19 X 10^{18} kg of carbon;
- Of this, about 50% more carbon that is currently in the atmosphere (1.0 X 10^{18}) is in forests; and
- Annually, forests sequester about 2.4 X 10^{12} kg of carbon.

(Source: Hui et al., 2015)

Despite the importance of forests, according to the Global Forest Watch (2020), annually, from 2001 to 2019, the world lost a total of 386 M ha of tree cover (a decrease of 9.7% since 2000). Worldwide, a total of 60.5 M ha primary humid forests were lost (a decrease of 5.9%).

Thus, it is vital not only that the remaining forest cover is protected, but also that degraded areas are reforested and rehabilitated.

The Bonn Challenge

Many countries recognise the potential of restoration to mitigate the impacts of global climate change. In 2011, International Union for Conservation of Nature (IUCN) and the government of Germany challenged the world to restore 150 M ha of deforested and degraded land by 2020 and 350 M ha by 2030 (Bonn Challenge, 2020). Seventy-four countries pledged to do so, and by 2017, the 2020 target had been exceeded (Bonn Challenge, 2020).

The Bonn Challenge aligns with the other global commitments such as Sustainable Development Goals (SDGs), the Land Degradation Neutrality (LDN) goal, and the Paris Climate Change Agreement, all of which aim for a sustainable future.

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[1] Defined as the benefits that ecosystems provide for human well-being (MEA, 2005).

In 2017, the Government of Sri Lanka also committed to restore 0.20 million ha of degraded lands by 2030, in line with their 2016 commitment to increase forest cover from 29% to 32% (Sri Lanka UN-REDD Programme, 2017).

There are several large-scale regional and national level restoration programmes that contribute to this common goal. For example, in 2007, Africa commenced 'the great green wall' – one of the largest ecosystem restoration projects in the world – which aims to green a very dry region extending east to west from Senegal to Djibouti, 8,000 km across the entire width of Africa (Great Green Wall, 2020). In Pakistan, the 10 Billion Tree Tsunami project, or Plant for Pakistan (Plant4Pakistan), commenced in 2018, for five years, in the north-western province of Khyber Pakhtunkhwa (UNESCO, 2019).

Forest restoration in Sri Lanka

The current forest cover (in 2019) of the Sri Lanka is 29.7% of the total land area of the country (Sri Lanka UN REDD Programme, 2017). However, at the beginning of the 20th century, it was 79% (Sri Lanka UN REDD Programme, 2017) and declined to 44% in 1956, and to 33% in 1992 (Forest Department, 2020) (Figure 1).

Further, there are still various anthropogenic drivers of ecosystem change, including agricultural expansion, encroachment, infrastructure development and many other localised issues. Such degradation and loss of forest cover result in serious consequences that affect the loss of biodiversity, disruption of the water cycle, soil erosion, diminishing/loss of life-sustaining ecosystem services, as well as leading to the occurrence of disasters – such as earth slips, floods and droughts.

In this context, forest restoration has been identified as one of the key environmental conservation tools, expected to provide multiple local, regional, national, as well as global level benefits – ranging from increasing local level livelihood opportunities, to contributing to global carbon sequestration and to minimising the impacts of global warming (IUCN & WRI 2014).

Therefore, Sri Lanka is aiming to restore 200,000 ha of degraded forest land by 2030, aligned with its National Tree Planting Programme (Growing Trees for Growing Country) which aims to increase forest cover from 29% to 30% (Government of Sri Lanka, 2020). The Government's approach to restoration includes (i) planting trees on heavily degraded lands; (ii) assisting natural regeneration of degraded forests; (iii) establishing commercial plantations; (iv) restoring animal habitats; and (v) protecting moderately degraded forests from human intervention. Accordingly, a total of 27,500 ha is planned for degraded forest restoration while 9,500 ha is planned for restoration through improved management of already restored forests (Dave et al., 2019).

The Ministry of Environment and Ministry of Wildlife and Forest Conservation are the key driving forces in the national forestry programme, while the Forest Department is main government agency responsible for the restoration programme across the country. In addition, several other government agencies including the Ministry of Defence, Department of Coast Conservation and Coastal Resource Management and the Mahaweli Authority are also involved in this restoration programme.

Restoration of 200,000 ha of degraded land is a challenging task, which can only be achieved through national level, multi-stakeholder participation. The Forest Department is currently working with some private sector companies for the national reforestation programme, while planning to secure further corporate engagement to achieve restoration targets.

Forest restoration is not just planting trees. It is a multi-disciplinary and technical process, which requires the understanding of a wide range of subjects including forest ecology; forestry techniques; physical, chemical and biological characteristics of soil; nursery management; plant nutrition; plant diseases and pest control, as well as plant-animal interactions. In the context of the current trend of engaging non-technical agencies (including private and civil society organisations) in forest restoration programmes, it is essential to disseminate sound and updated forestry knowledge and forestry techniques to stakeholders who are engaging in restoration programmes.

This forest restoration guidebook is published by IUCN in collaboration with the Forest Department and the Postgraduate Institute of Science, University of Peradeniya, to fulfil that need by providing theoretical and practical knowledge on forest restoration to stakeholders who are willing to engage in forest restoration.

> ***The forest is a peculiar organism of unlimited kindness and benevolence that makes no demands for its sustenance and extends generously the products of its life activity; it affords protection to all beings, offering shade even to the axe-man who destroys it.***
>
> ***Buddhist literature***

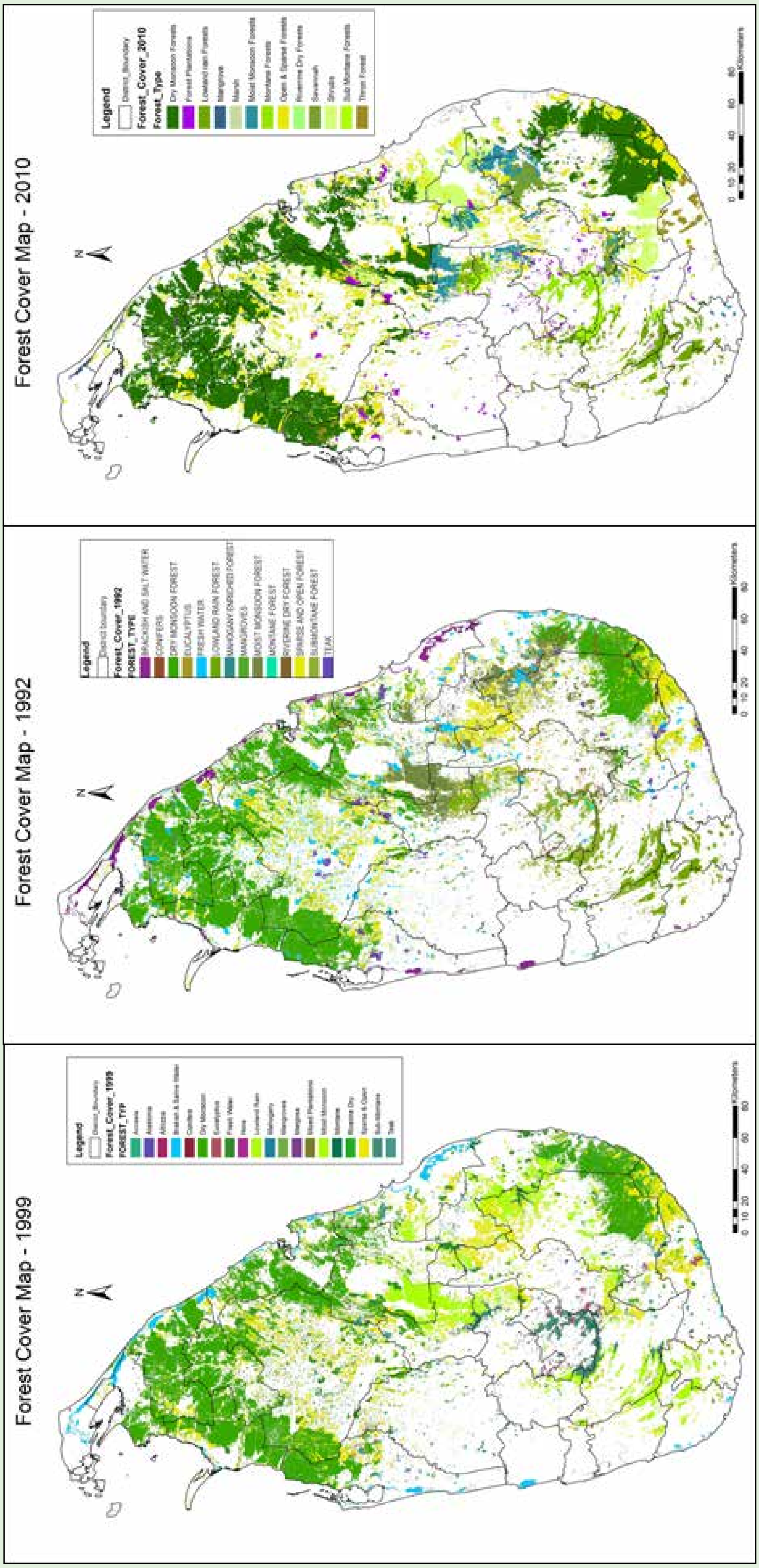

Figure 1. Loss of forest cover in Sri Lanka between 1992 and 2010
(Source: Sri Lanka UN REDD Programme, 2017)

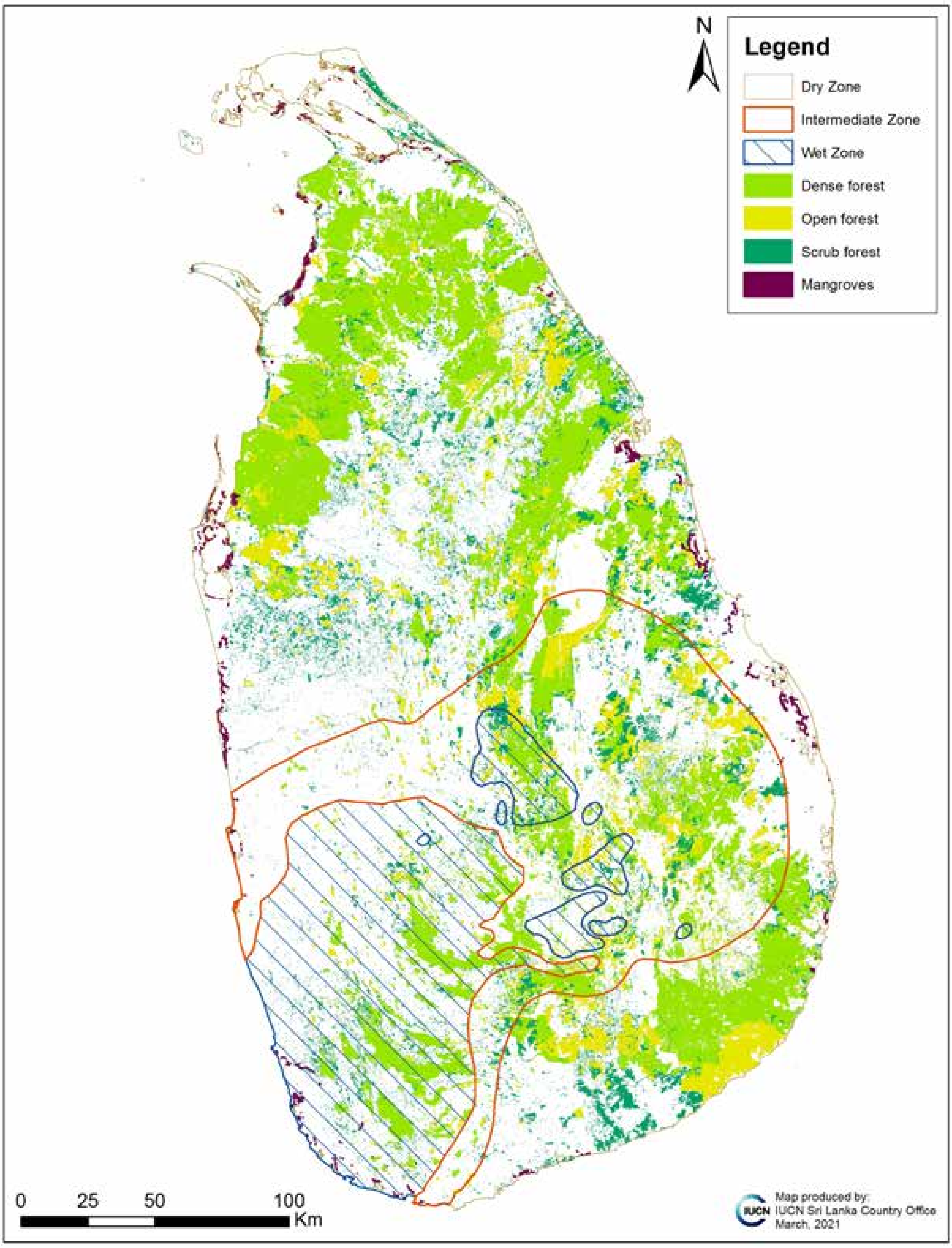

Figure 2. Forest cover in Sri Lanka
(Source: Ediriginhe et al., 2012)

Sri Lanka has a range of forest ecosystems – lowland wet evergreen forests in the lowland wet zone; mid-elevation evergreen forests in the submontane wet zone; montane evergreen forests in the montane zone; as well as moist-mixed evergreen forests in scattered areas of the dry zone; dry-mixed evergreen forests in the dry zone, arid-mixed evergreen forests in the driest areas of the dry zone (MoMD&E, 2016).

Figure 3. A selection of forest ecosystems of Sri Lanka

(Clockwise from top left: lowland wet evergreen forests; montane evergreen forests;
mid-elevation evergreen forests; arid-mixed evergreen forests;
moist-mixed evergreen forests; and dry-mixed evergreen forests
(© IUCN/Naalin Perera)

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Chapter 2: Ecological restoration: definitions, processes, principles and practices

A. M. T. A. Gunaratne
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For successful restoration, it is vital that practitioners have sound scientific knowledge of commonly used definitions, as well as the principles and process of ecological restoration, so that they may plan and practise successful ecological restoration programmes in different climatic zones of Sri Lanka. This chapter provides the definitions, processes, principles and practices related to ecological restoration.

Reforestation

Reforestation is the 'natural or intentional restocking of trees in areas of forest that have been deforested or depleted' (Yale University, 2020). Reforestation occurs in commercial plantations (cash crops/timber plantations), agro-forestry[2] (agri-silvo-cultural[3], silvopastoral[4], mixed), and community forestry[5].

Three approaches are used commonly to reforest degraded sites, all of which increase the productivity and stability of degraded lands. These three approaches are reclamation, rehabilitation and ecological restoration. They differ in the extent to which original biodiversity is recovered (Lamb & Gilmour, 2003).

Reclamation

Reclamation involves the recovery of the productivity of a degraded site, commonly by planting exotic tree species (Lamb & Gilmour, 2003). Because exotic plantations do not provide food and habitats for indigenous wildlife, they are poor substitutes for natural forest ecosystems, which support high biodiversity. Because reclamation results in 'biological deserts', it is not a desirable method of reforesting degraded lands inside or around forest reserves. Examples of reclamation in Sri Lanka are the pine plantations in the wet zone (Figure 4) and teak plantations in the dry zone. Because these monoculture plantations have many economic uses (for example, as timber, paper and resins), they are recommended outside conservation areas or in highly degraded sites, where no native species can establish themselves.

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[2] 'The collective term for land-use systems and technologies in which woody perennials (trees, shrubs, palms and bamboos, etc.) are used deliberately on the same land-management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence' (FAO, 2017).

[3] 'An agroforestry system that combines forestry components (woody plants) with agricultural (or non-woody) components. Timber crops are meant to belong to crops (tree crops) and non-timber plants to annual crops' (Young, 1989; Surya et al., 2020).

[4] 'An agroforestry system in which trees are combined with livestock. In these systems, tree canopies provide livestock with shade and wind protection and thus indirectly improve animal welfare, health and productivity. Silvopastoral systems yield additional income when trees and tree products are harvested' (FAO, 2017).

[5] 'All aspects, initiatives, sciences, policies, institutions and processes that are intended to increase the role of local people in governing and managing forest resources' (FAO, 1991).

Reclamation involves some recovery of ecosystem services, such as watershed and soil protection and carbon sequestration. This approach supports high socio-economic values, at the expense of low biodiversity (Lamb et al., 2005). Consequently, for the recovery of biodiversity a completely different approach is needed.

Figure 4. Monoculture of pine (*Pinus caribaea*) plantations, established in the Upper Hantana mountains, Sri Lanka

(Note the dominance of invasive guinea grass (*Panicum maximum*) in the understory. Seedlings and saplings of native tree species cannot grow in pine stands, mainly because of the lack of light. © Thilanka Gunaratne /University of Peradeniya.)

Rehabilitation

Rehabilitation involves re-establishing productivity and some, but not necessarily all, of the plant and animal species which were present originally (Lamb and Gilmour, 2003). Both exotic and native species may be used. However, there is no attempt to recreate the original ecosystem. The main objective of rehabilitation is to return the area to a stable and productive condition, such as, for example, enrichment planting of pine stands at Hantana and in the Knuckles Buffer Zone of Sri Lanka (Figure 5). In these silvicultural trials, many ecologically and economically important native species – such as *Bhesa ceylanica* (Sinhala name: *pelang*; Tamil name: *konnai*), *Artocarpus nobilis* (English name: wild breadfruit; Sinhala: *wal del*; Tamil: *arsini pala*), *Terminalia bellirica* (English: beleric; Sinhala: *bulu*; Tamil: *tanti*) and *Madhuca longifolia* (English: honey tree; Sinhala: *mee*; Tamil: *illupai*) – and exotic species – such as *Michelia champaca* (English: champak tree; Sinhala: *gini sapu*; Tamil: *chambuga*), *Khaya senegalensis* (English: African mahogany; Sinhala: *khaya*), *Azadirachta indica* (English: margosa/neem; Sinhala: *kohomba*; Tamil: *arulundi*), as well as *Swietenia macrophylla* (English: mahogany) were planted, after thinning to enhance ecosystem services.

> ***Deforestation is changing our climate, harming people and the natural world. We must, and can, reverse this trend.***
>
> ***Jane Goodall***

Figure 5. An enrichment pine stand at Hantana, Sri Lanka, in 2020
(This pine stand was established on dry *patana* grasslands in the 1970s, by the Forest Department.
In 2003, it was thinned and enriched by planting three native species (*Terminalia bellirica*, *Madhuca longifolia*, *Artocarpus nobilis* and one exotic species *Michelia champaca*.
This rehabilitation was carried out by the University of Peradeniya. The remaining pines were removed in 2010.
© Thilanka Gunaratne /University of Peradeniya.)

Ecological restoration

According to the Society for Ecological Restoration (2004), ecological restoration (ER) is 'the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.' This approach aims to assist ecosystem recovery through the enhancement of biodiversity and ecosystem services at a landscape scale[6]. Elliott et al. (2013) elaborate on ER as 'directing and accelerating ecological succession towards an indigenous target forest ecosystem of the maximum biomass, structural complexity, biodiversity and ecological functioning that can be self-sustained within prevailing climatic and soil limitations.'

The practice of ER uses scientific concepts from the discipline of restoration ecology. Biodiversity is maximised, but the socio-economic value may be lower with ER, compared to the previous approaches. Examples of ER are the restoration sites at Opatha and Knuckles Conservation Forest, Sri Lanka (Figure 6).

The importance of ecological restoration

Ecological restoration connects society with nature, by helping to recover damaged ecosystems through re-vegetation with native species, removal of invasive species, erosion control, and enhancement of ecosystem services at the landscape scale. Thus, ecological restoration is one of the best strategies to mitigate and adapt to climate change.

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[6] 'A large spatial scale, usually addressing a range of ecosystem processes, conservation objectives and land uses'.

Figure 6. Restoration sites at the Knuckles Conservation Forest, Sri Lanka
(Fifteen native species were transplanted to the site in 2017.
The project aims to reconnect lower montane forest fragments on either side of a degraded grassland.
© Thilanka Gunaratne /University of Peradeniya.)

To conduct an ecological restoration programme, a clear understanding of ecological fundamentals – such as understanding the relationships among organisms (biotic interactions) and those with their physical surroundings – is vital.

Ecological fundamentals: learning from nature

Disturbance in tropical forests

Tropical forests are dynamic, evolving and continuously changing ecosystems (Ashton et al., 2001). They are subjected to many disturbances such as tree falls, landslides, floods, logging, which vary in scale (small or large), origin (natural or anthropogenic), frequency (acute or chronic) and severity (lethal or non-lethal) (Ashton et al., 2001).

Natural regeneration

A small, natural, acute and non-lethal disturbance occurs when a tree falls, creating a forest gap. The ability of these gaps to regenerate (natural regeneration) is often very high, because of i) the presence of seed dispersers and ii) abundant sources of natural regeneration (for example, seed rain, a soil seed bank, seedling and sapling banks, and coppicing tree stumps (Figure 7) (Box 1). Thus, less time is required for small, natural, forest gaps to revert to forests. Natural regeneration is then defined as the process of establishment of new vegetation from seed rain, seed bank, seedling and sapling banks, and coppicing tree stumps.

Box 2. Definitions related to natural regeneration

Seed rain: seed deposition by wind, water or animals, etc.
Soil seed bank: dormant seeds in litter and upper soil layers
Seedling bank: populations of young trees recently germinated, still dependent upon seed endosperm
Sapling bank: populations of immature trees independent of seed resources, not yet flowering or fruiting – usually with slender stems.
Copping tree trunks: Meaning here, tree trunks which have naturally broken and are regrowing. Different researchers use different sizes to differentiate between seedlings and saplings.

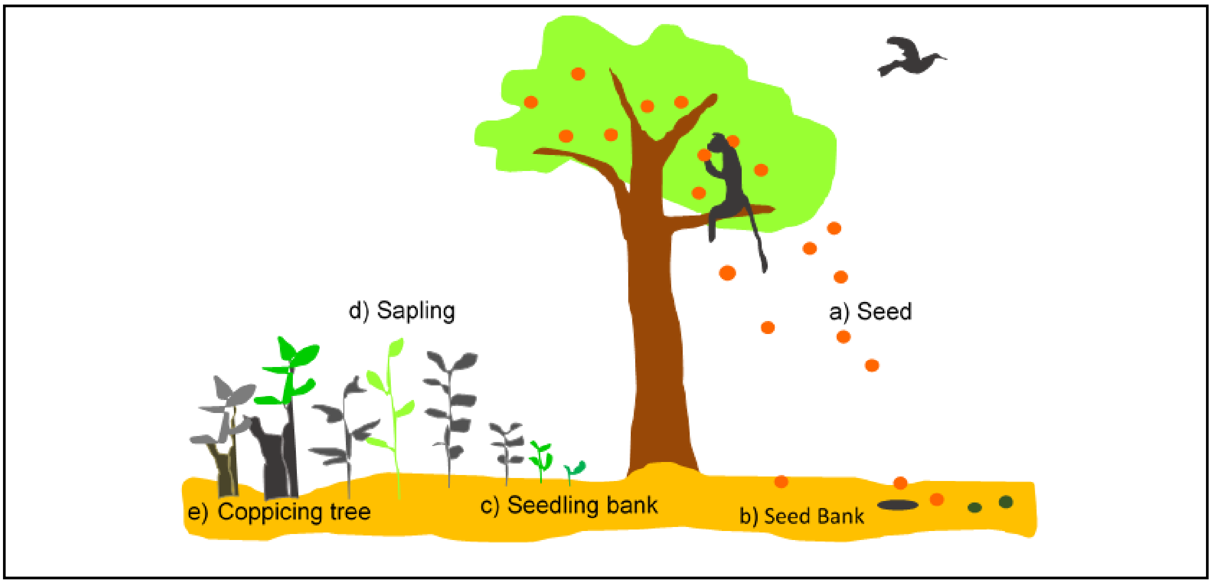

Figure 7. Sources of natural regeneration. a) seed rain b) seed bank c) seedling bank d) sapling banks and e) coppicing tree stumps

In contrast, extensive degraded areas recover much more slowly, because both seed dispersers and sources of natural regeneration are often more sparse. Because of this, it is vital to have a clear understanding of the mechanisms of natural regeneration that occur within the specific forest ecosystem that is being restored.

Ecological succession and natural regeneration

Ecological succession is defined as 'a series of predictable changes in the ecosystem structure and composition that occurs after disturbances' (Thompson, 2018) (Figure 8). Barren land is colonised by various species at different stages, and over time, reaches the end-stage of succession, called the climax stage. The climax stage reaches the maximum biomass and structural complexity that can be supported within climatic and edaphic[7] limitations.

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[7] Produced or influenced by the soil.

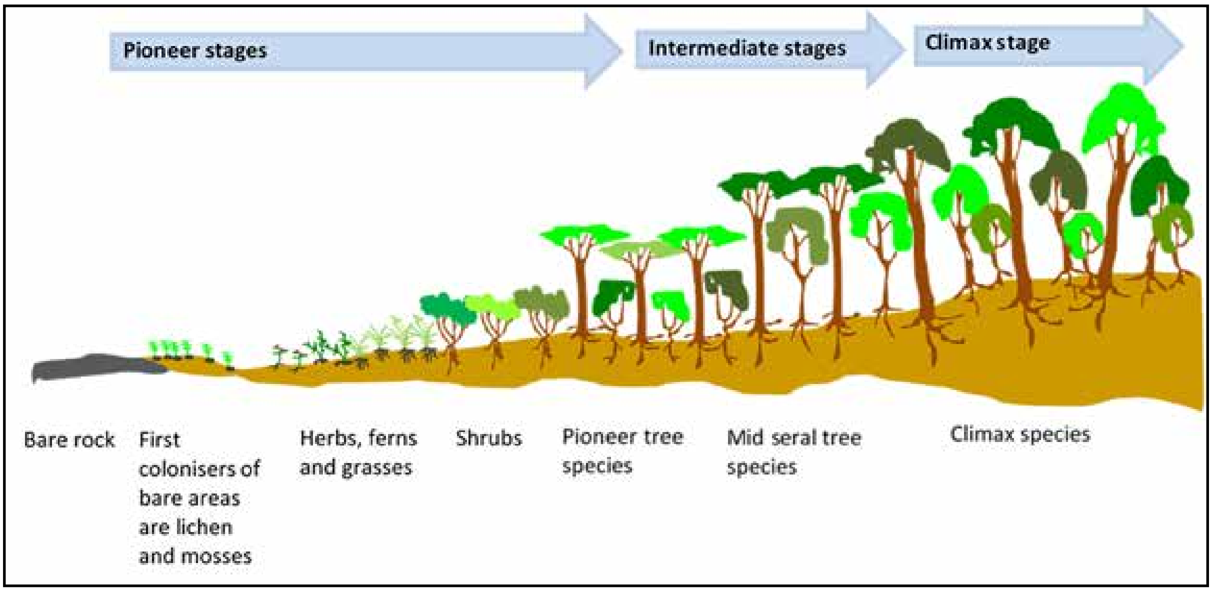

Figure 8. Diagrammatic depiction of primary succession

There are two types of ecological succession. *Primary succession* follows a major geological cataclysm (for example, a volcanic eruption starting from sterilised rock) (Figure 8), whereas secondary succession refers to gradual re-establishment of biotic communities, where elements (for example, soil, remnant trees) of the previous ecosystem still survive. Primary succession is rare and is not addressed usually by ecological restoration.

Ecological restoration usually involves measures to accelerate secondary succession. In ER, natural regeneration is the process that brings about succession. It involves recolonisation of a degraded site by plants and associated animals, re-establishment of biotic interactions and their subsequent growth and proliferation towards maximum sustainable levels.

Secondary succession is the process of community re-establishment after a habitat is disturbed or damaged due to natural (landslides, floods, windfalls, wildfires) or anthropogenic disturbances (burning, logging, mining, *chena* cultivation) (Figure 9). These disturbances do not eliminate all life (seeds, seedlings, saplings) and nutrients in the degraded site. When the disturbance ceases, fast-growing pioneer[8] shrub and tree species are readily established and they change the micro-climatic conditions (for example, air temperature, light levels, soil moisture) in the site. Newly created micro-climatic conditions by pioneer species are suitable for the next group of plants (representing mid seral stages), and eventually for climax species.

During uninterrupted succession, the ecosystem transitions through several seral stages. A seral stage is a temporary plant community of distinctive species composition that gradually changes into a succeeding different seral stage or into the climax ecosystem, for example, a grassland to shrubland to forest. Each seral stage modifies micro-climatic conditions (such as light quality and quantity, temperature, humidity) and substrate characteristics (such soil depth, pH and moisture) rendering the environment more suitable for plants of the subsequent seral stage. The severity of anthropogenic disturbance heavily influences the species composition of the initial seral stage. For example, agriculture, followed by burning, often results in grasslands; while clear-cutting usually results in a shrubland; and selective logging usually results in pioneer forest.

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[8] 'The first species to colonise an ecosystem that is previously damaged or disrupted' (Biology Online, 2021).

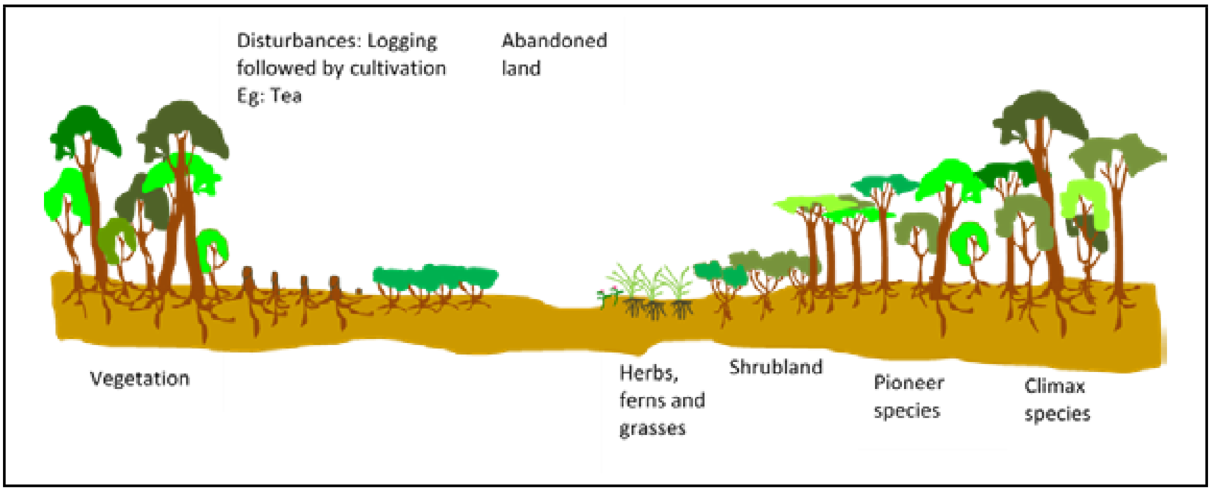

Figure 9. Secondary Succession

Pioneer and climax species

Traditionally, ecologists have divided plants into pioneer and climax species, depending on when they appear in the sequence of forest succession.

Pioneer species are first to colonise open sites. They produce seeds capable of dormancy that germinate in full sunlight. Their seedlings require full sunlight to grow (that is, they are shade-intolerant) and they grow fast and develop broad crowns. These species enhance soil development and cast shade, which ameliorate microclimatic conditions, and thus facilitate the establishment of mid seral and climax species. Examples of pioneer species in Sri Lanka include *Macaranga peltata* (Sinhala: *kenda*; Tamil: *vattakanni*) in tropical lowland wet evergreen forests and *Macaranga indica* (Sinhala: *kenda*) in tropical mid-elevation evergreen forests, both in the wet zone. (There are different pioneer and climax species in natural forest types of different climatic zones, although some species are common to several climatic zones.)

Ashton et al. (2001) recognised six successional tree guilds[9] in tropical rainforests of Sri Lanka (Figure 10). These six guilds include two groups of pioneer tree species (pioneers of initiation[10] and pioneers of stem exclusion[11]) and four groups of late successional tree species (late-successional dominants, late-successional non-dominants, late-successional subcanopy and late-successional understorey), which appear at different stages of rainforest succession. This information helps to match species to different successional stages, when conducting ecological restoration programmes in southwestern lowlands in Sri Lanka.

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[9] 'A guild is defined as a group of species that exploit the same class of environmental resources in a similar way' (Simberloff and Dayan, 1991).

[10] These are pioneer species 'that colonize sites lacking developed organic soil and initiate primary succession' (Dalling, 2008).

[11] Are pioneer species of the stage which 'occurs as soon as all growing space is occupied and new plants are excluded from regenerating. At first, the different trees occupy a single layer, or stratum – a condition referred to as the "brushy stage" (Gingrich, 1971). Eventually, trees in stands of a single species may differentiate into "crown classes," as some become larger, take growing space from others, and force the others to grow more slowly or to die. Some species in mixed species stands commonly lag behind in height grow, become overtopped and shaded, and grow very slowly in the shade. This process creates a "stratification" pattern (a layered appearance) in which large trees of some species occupy the upper stratum and small trees of other species occupy lower strata – even though they are all of the same age' (Oliver, 2007).

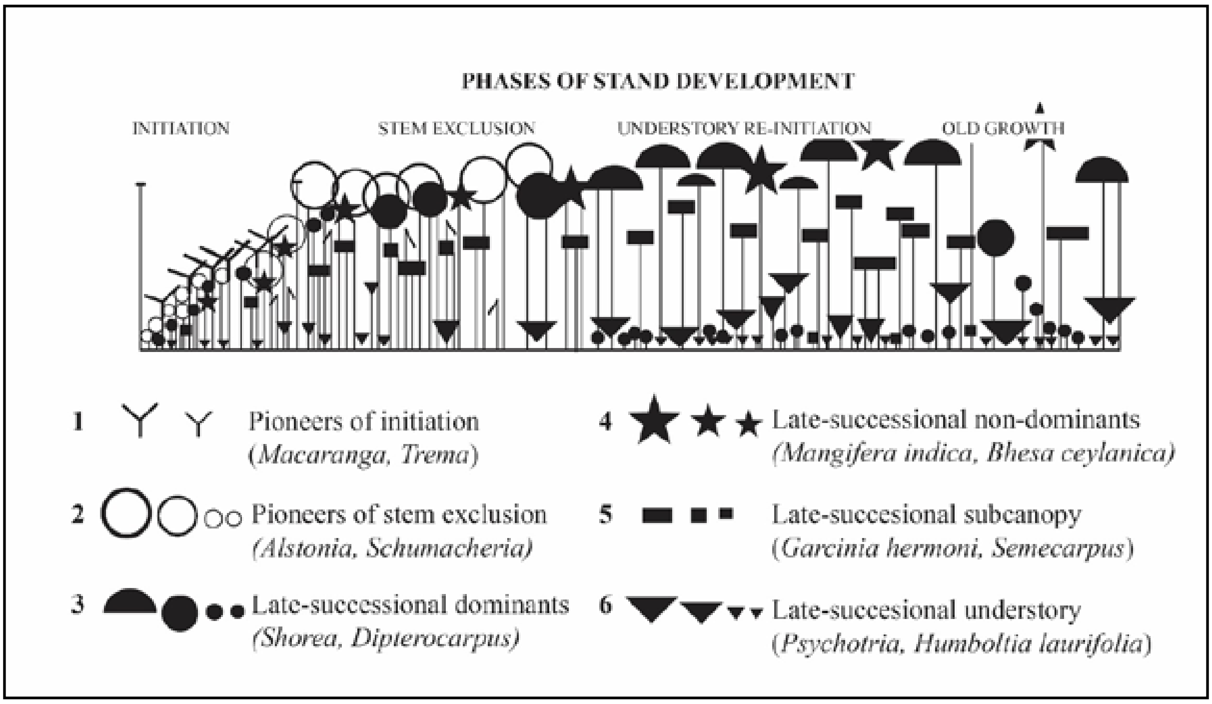

Figure 10. Recruitment frequency of six regeneration guilds and their canopy dominance at different stages of stand development

(Examples of species for each guild are listed for Sri Lankan mixed Dipterocarp forests in southwestern region of the island. Source: Ashton et al., 2001)

Climax species and climax stage

The final stage of succession is the climax community, which can endure for hundreds of years in a dynamically stable condition. It may undergo species turnover, resulting in slowly shifting species composition, but biomass, structural complexity and species diversity are maintained at the maxima that are sustainable within the limits imposed by climate and soil. Ecosystem respiration increases to become almost equal to primary production, at which point, living biomass approaches a stable maximum. However, dead wood and dead organic matter continues to accumulate in the ecosystem, rendering primary tropical forests a net carbon sink.

Climax species establish in the cool, moist and shady conditions created by the pioneer trees. They tend to have larger seeds than pioneer species do, which usually lack dormancy and can germinate in shade. Their seedlings are also shade-tolerant, and they grow more slowly than pioneer species. Examples include *Dipterocarpus zeylanicus* (Sinhala: *hora*) in tropical lowland wet evergreen forests of the wet zone) and *Manilkara hexandra* (Sinhala: *palu*; Tamil: *palai*) in the tropical dry-mixed evergreen forests of the dry zone.

Factors arresting succession

Where anthropogenic disturbances – such as fire, logging and agricultural conversion – are frequent, prolonged succession may be delayed for many decades or may not occur naturally at all. This in called arrested succession, which occurs when the natural regeneration mechanisms that bring about natural regeneration are destroyed.

Biotic factors arresting succession

Lack of seed source

In severely degraded landscapes where only a few seed trees or remnant forest patches remain, natural regeneration becomes impossible, because of the lack of seeds of target species in the seed rain and the soil seed bank (see below for descriptions). In tropical forests, the seeds of most tree species are dispersed by animals. Seed dispersers usually avoid crossing open sites because of the lack of resources (such as food, nesting and breeding sites) and high exposure to predators in open areas. In natural ecosystems, many medium-sized to large seed dispersers (such as macaques, civets, deer and elephants) have disappeared. Those that survive, face a high risk of extinction because of human impacts such as development projects and the expansion of agricultural lands. Even if remnant patches of the ecosystem remain in the landscape, if the centre of the degraded site is far from the nearest seed source, ecosystem recovery will be costly.

Soil seed bank

In degraded areas, because of recurrent disturbances such as fires, the soil seed bank, which is an important source of regeneration, is depleted. The original soil seed bank becomes non-viable within a year or two of forest clearance (Elliott et al., 2016). Thus, several years after disturbance, degraded sites must depend solely on seed rain coming from the surrounding landscape.

Seed predation

Many studies indicate that seed predation by rodents inhibits succession in degraded lands in the tropics (Holl, 2007).

Herbivory

Grasslands attract domestic cattle, as well as wild herbivores (such as sambur, deer and, hares), which not only graze on grasses but also browse and trample seedlings of trees species. Herbivory by domestic cattle can have adverse effects on natural regeneration, because, in many instances, cattle are released into grasslands in higher densities than wild herbivores (Gunaratne, personal observations).

Competition with herbaceous weeds

Degraded areas are dominated mostly by weedy species, most of which are invasive, exotic species. They create dense stands and act as a barrier for seeds of tree species to reach the ground, which is necessary for their germination. Weeds often compete aggressively with seedlings and saplings of native tree species for above-ground (light and space) and below-ground resources (water, nutrients and space), thus affecting the establishment of native tree species (Gunaratne et al., 2011).

Abiotic factors arresting succession

Fire

Most of the dominant vegetation – such as grasses and ferns in degraded areas – is highly flammable and its fuel load is high during dry seasons. Thus, in these areas, anthropogenic fires spread rapidly, killing established seedlings and saplings. Coppicing ability is highly variable among species, thus, only fire-resistant species – such as *Ficus* spp. – may re-sprout after fire.

Micro-climatic conditions

Harsh micro-climatic conditions such as high air temperature, high light intensity, high wind speed, low humidity and low soil water retention, which prevail in degraded sites, are not conducive to the establishment of seedlings of many tree species, particularly climax species.

Because most degraded sites are characterised by arrested succession due to the above mentioned biotic and abiotic factors, forest recovery is impossible in these sites without human intervention.

Ecological restoration of degraded sites

Ecological restoration reinstates the predominance of historical ecosystem services and functions into socially-dominated landscapes.

ER Approach: Planning and Implementing Restoration Projects

There are nine steps in ER projects (Figure 11).

1. Stakeholder identification

Collaboration is crucial for the success of ER projects. The key stakeholders involved in these projects include government institutions, non-governmental organisations, research institutes, universities, funding agencies and local communities living adjacent to the site to be restored. It is essential to verify the key roles of each stakeholder for the proposed restoration site during initial meetings (Table 1).

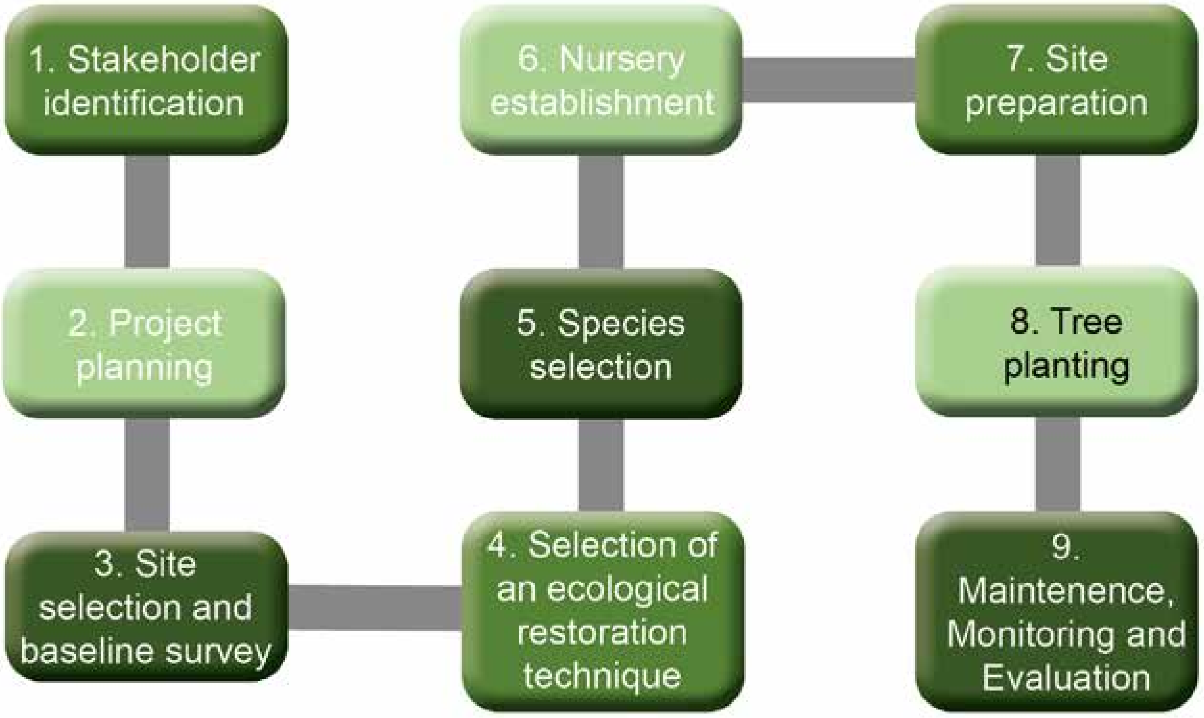

Figure 11. Steps in planning and implementing an ecological restoration of a degraded site

Table 1. Potential roles of different stakeholders involved in ER projects

Stakeholder	Role
Government officers (Forest Department, Wildlife Department, Central Environmental Authority, etc.)	Meet international obligations, experiment with new techniques at the national level, obtain permission to conduct the project, provide logistics and/or administrative support, monitor and evaluate the project.
Universities/Research institutes	Plan, experiment with new techniques at the national/international level, conduct research, contribute volunteer force, monitor and evaluate the project.
Funders/Sponsors/ NGOs (National and International)	Allocate funds, assist with logistics, plan, monitor and evaluate the project.
Local community/NGOs (National and International)	Plan, select plant species, collect seeds and establish and manage plant nursery, collect field data, maintain restoration site and monitor restoration site.

2. Project Planning

Successful projects are driven by the participation of all stakeholders at initial project planning meetings. At the first meeting, it is desirable to identify the aim/s and objectives of the ER project.

- *Goals of ecological restoration projects*: Most of the ER projects aim to maximise biomass, structural complexity, biodiversity and ecological functioning within soil and climatic limits.
- *Restoration objectives:* These are formal statements regarding the actions required to achieve the project goals. They must be specific, measurable, achievable, relevant (based on sound ecological information from a reference ecosystem or determined from the historic range of variability and/or desired future conditions for an ecosystem) and time-bound (Machmer & Steeger, 2002).
- *Budgeting:* Allocation of adequate funds for site maintenance, monitoring, evaluation and research ensures the success of the ER project. All the stakeholders must approve the project budget before commencing implementation of the project.
- *Activities:* Stakeholder meetings, drafting of the project plan including the budget, site selection, baseline survey, seed collection, nursery establishment and management, hardening and labelling of seedlings/saplings, transporting seedlings/saplings to the site, contacting volunteers, inviting volunteers, tree planting, site maintenance, monitoring and evaluation should be scheduled at initial stages of the project (at least during the first three months).
- *Identification of project constraints* – for example, budgetary, logistic, personnel – prior to project initiation.

3. Site selection and baseline survey

Site selection

Universally desirable sites for restoration projects are sites that are socially and ecologically compatible with surrounding land uses (Buckley & Crone, 2008). When sites are not socially compatible, they create direct negative impacts and will generate the most difficult conflicts to resolve. An effective approach for contested situations will involve open acknowledgment of concerns and problem solving with extensive community involvement.

Baseline survey

A baseline survey helps to collect site data before restoration treatments are applied. These data help to investigate the effectiveness of the restoration treatments. Knowledge on climatic zone and climatic factors, topographic factors and edaphic factors in the area where the restoration site is located is needed to plan ER projects.

Climatic factors: Sri Lanka is divided into three main climatic zones, *viz* wet, dry, and intermediate (Figure 12). Consequently, practitioners must know the climatic zone where the restoration site is located to plan the ER project. Spatial and seasonal variation of climatic factors (such as rainfall and temperature) of the site can be accessed from the Meteorological Department of Sri Lanka. This information assists practitioners to decide the schedule for seed collection and for tree planting activity in the project.

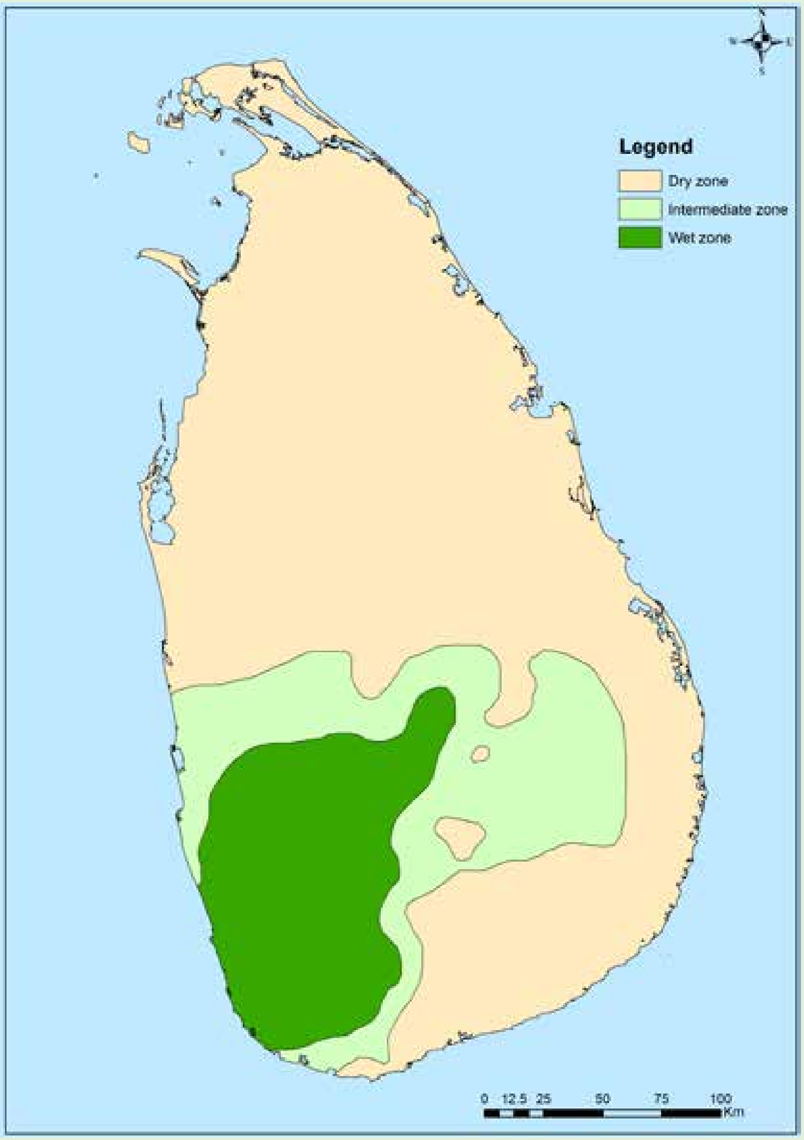

Figure 12. Climatic zones of Sri Lanka
(Source: Muthuwatta & Liyanage 2013 in MoMD&E, 2016)

Topographic factors: The slope, aspect[12] 'soil stabilisation techniques and elevation of the site should be recorded. This information aids practitioners to decide the tree planting design in the restoration site'.

Edaphic factors: Analysis of soil characteristics is invaluable: a) physical – such as soil bulk density, soil colour and texture; b) chemical – such pH, electrical conductivity, organic carbon, nitrogen, other nutrients associated with plant growth; and c) biological characteristics of soil (soil fauna: bacteria and fungi). (See Chapter 3 for details.) Measurements of soil carbon are vital, as the role of forest restoration in mitigation of climate change is increasing in importance and many restoration projects are funded by carbon trading. Baseline information on edaphic factors also benefits decision-making on soil improvement during the project.

The baseline survey helps to determine six critical thresholds in the degradation sequence, *viz* three site thresholds and three landscape thresholds (Elliott et al., 2013). These thresholds can be assessed using field observations, published articles, and information gathered from local communities.

Site thresholds

1. *On-site vegetation:* Observations should be made on whether trees dominate over weeds or weeds dominate over trees. Most degraded areas are dominated by secondary vegetation types such as grasslands in the montane zone (Figure 13) or fernlands in the wet zone of Sri Lanka.
2. During the baseline survey, permanent quadrats should be established randomly to represent the different microhabitat types in the site. In each quadrat, the percentage cover and height of the dominant vegetation type/s (grasses, ferns, weeds, shrubs, etc.) should be recorded.

   In each quadrat/circle[13], the numbers of the following should be counted and recorded:
   i) seedlings (<30 cm in height)/saplings (> 30 cm height & <30 cm GBH[14]);
   ii) live tree stumps and
   iii) trees >30 cm GBH. (Trees of unknown species should be identified to species level or their local names recorded. Herbarium specimens should be made and identified at the National Herbarium at Peradeniya, Sri Lanka. After species identification, the number of pioneer and climax species in the site should be determined. Indigenous knowledge could be used, as local villagers are familiar about which tree species readily recolonise abandoned fields and which are found only in mature forest.)

> ***The best time to plant a tree is twenty years ago.***
> ***The second best time is now.***
>
> ***Chinese Proverb***

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[12] The compass direction that a slope faces.
[13] Circles (1 pole and a piece of string 5 m long) are easier to locate and lay out than quadrats
[14] GBH: Girth at Breast Height (1.34 m height)

Figure 13. Degraded grassland in Knuckles Conservation Forest, dominated by the tussock grass *Cymbopogon nardus*
(© Thilanka Gunaratne /University of Peradeniya)

There are different microhabitats found in the site, such as streams and forest edges.

Box 2. The difference between a habitat and a microhabitat

Habitat: The natural environment of an animal, plant, or other organism.

Microhabitat: A habitat which is small and differs in character from the more extensive surrounding habitat.

3. *On-site sources of forest regeneration*: Regeneration potential should be determined by recording the availability of mature fruiting individuals, soil seed bank, seedling and sapling banks and live stumps[15] in the site, etc. in the permanent quadrats. The species and number of individuals of each species in quadrats should be recorded. Local villagers can be trained as field assistants to collect vegetation data.
4. *Soil characteristics:* Soil erosion in degraded areas can be noticeable, indicating infertile soils. The degradation status of the soil should be recorded by visual estimation of percentage exposed area, soil erosion levels, etc. Local villagers can be trained to collect soil samples and to send them to a research laboratory for analysis.

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[15] Live stumps: lower part of a tree, which sprouts after a disturbance

Landscape thresholds

1. *Presence of remnant vegetation (seed sources):* The remnant trees and tree islands surrounding the degraded site should be recorded. Online tools – such as Google Earth – are useful to obtain an idea about the extent of remnant forest patches adjacent to the restoration site.
2. *Presence of seed dispersers*: A faunal survey should be conducted to identify the seed dispersers that inhabit the area (see Chapter 5). Local people can also provide important information regarding animals that are pollinators, seed dispersers, and herbivores inhabiting the area.
3. *Fire history:* Burnt stumps and tree barks in the site should be noted, as these are indicators of past burns. Local people should be consulted to obtain information on the history of previous burns. Fire risk to the site should be assessed by checking on fuel load during the dry season. For instance, if weeds are dominating over trees, the fire risk is very high.

The degree of degradation can be identified depending on the above six thresholds in sites needing restoration.

Ecosystem services

A survey must be conducted on ecosystem services offered by the unrestored site to derive baseline information for future comparisons. (See Box 3 for a description and examples of ecosystems services.)

4. Selection of the technique for ecological restoration

The original stage of degradation in relation to the site and landscape thresholds determines the methods of ecological restoration that must be employed (Table 2). If the level of degradation is low in the site, less time and funds are needed to reinstate the site back to the former condition (Table 2).

Ecological Restoration Strategies

Protection of remnant vegetation

Because remnant vegetation (forest fragments and isolated trees) act as important sources for forest regrowth by providing seeds, it is vital to conserve them at the landscape level. These also provide insights to select plant species that can be used for restoration projects.

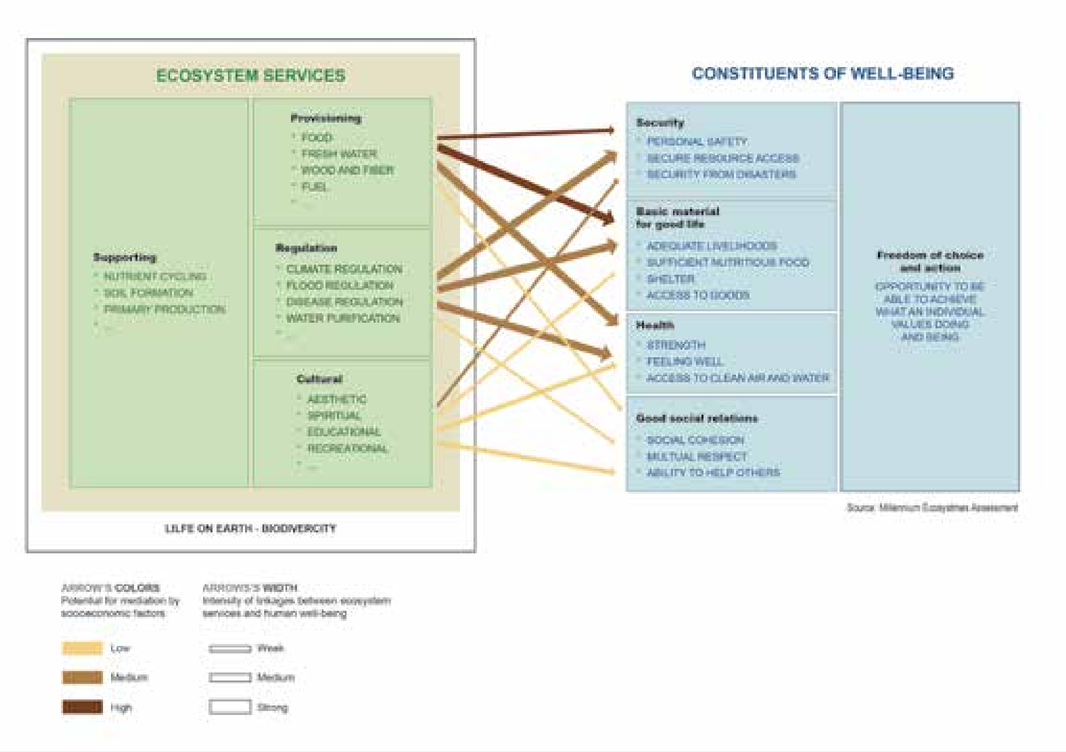
Assisted natural regeneration (ANR)

This is the cheapest method to use in restoring a site, if there are enough seeding trees, seedlings and saplings surviving in the degraded area. Generally, such sites are dominated by woody species over weedy species. In ANR, factors preventing succession/natural regeneration (such as fire, herbivory, competition with weeds) are removed from the site. These include preventing fire by the establishment of fire belts, excluding herbivores by fencing, eliminating above and below ground competition by removing weedy species. Assisted natural regeneration allows for the creation of a secondary forest dominated by pioneer species and cost little compared to other methods, which require seed collection, nursery establishment and tree-planting. Establishment of pioneer species will inevitably promote the arrival of climax species if the restoration site is surrounded by remnant forest fragments.

Box 4. Ecosystem services

(Source: MEA, 2005 and MoMD&E, 2016)

The Millennium Ecosystem Assessment provides a framework that clearly linked ecosystem well-being to human well-being (MEA, 2005). It showed how ecosystem services – defined as 'the benefits that ecosystems provide for human well-being' are critical to human welfare and survival.



Source: Millennium Ecosystem Assessment

Provisioning services include food; fodder; fibre; timber; genetic; medicinal and ornamental resources. Regulating services include air quality, water, erosion and climate regulation; carbon sequestration; pollination (providing habitats for pollinators); and pest and disease regulation (providing habitats for natural enemies of pests and vectors). Examples of supporting services are soil formation; primary production; nutrient and water cycling; provisioning of habitats for species. Cultural services include spiritual and religious services (for example, Peak Wilderness Nature Reserve, as well as the monasteries of Ritigala and Arankele); aesthetic value; recreation and eco-tourism; knowledge and educational services.

Sowing seeds or planting trees of species that are representative of the target ecosystem:

When weedy species dominate over woody species, seeding or tree-planting is the only option to recover the natural ecosystem. This is expensive because funds are needed to raise nurseries and for tree-planting.

Seeding

Many studies reveal that the success rate of seeding is very low, as most seeds fall into unsuitable microsites or are predated upon. The use of seed balls[16] for reforestation has been recommended for inaccessible sites, as the percentage survival of seeds is low in these sites.

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[16] A seed ball is a seed that has been wrapped in soil and dried – so that it is already protected – and can be sown and will usually be safe till germination occurs.

Table 2. Simplified guide to choose a restoration strategy
(Source: Elliott et al., 2013)

Landscape-critical thresholds			Suggested restoration strategy	Site-critical thresholds		
Forest in landscape	Seed-dispersal mechanism	Fire risk		Vegetation cover	Natural regeneration	Soil
Remnant forest remains within a few km of the restoration site	Mostly intact, limiting the recovery of tree species richness	Low to medium	**Protection**	Tree canopy cover exceeds herbaceous weed cover	Natural regenerants exceeds 3,100/ ha with more than 30 common tree species represented	Soil does not limit tree seedling establishment
		Medium to high	**Protection + ANR**[17]	Tree crown cover insufficient to shade out herbaceous weeds		
		High	**Protection + ANR + Planting framework tree species**	Herbaceous weed cover greatly exceeds tree crown cover	Natural regenerants sparser than 3,100/ha with fewer than 30 common tree species represented	
Remnant forest patches very sparse or absent from the surrounding landscape	Seed-dispersing animals rare or absent such that the recruitment of tree species to the restoration site will be limited		**Protection + ANR + Maximum diversity tree planting**			Soil degradation limits tree seedling establishment
		Initially low (soil conditions limit plant growth); higher as the vegetation recovers	**Soil amelioration + nurse tree plantation, followed by thinning and gradual replacement of maximum diversity tree planting**	Herbaceous weed cover limited by poor soil conditions		

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[17] Assisted Natural Regeneration

Tree-planting methods

Presently, this is the most popular method of restoration used worldwide. After site preparation by the removal of weedy species and establishment of proper soil conservation methods in the degraded site, pioneer species selected from the target forest system are planted in high density. Pioneer species quickly create canopy cover and shade off the weeds, resulting in the decrease in weed density. If site maintenance after tree-planting is effective, the site rapidly converts into a secondary forest.

Framework species method

The framework species method is the least intensive of the tree planting methods and it involves planting the smallest number of trees (20 to 30 indigenous tree species) necessary to shade out the weeds and attract seed dispersers (Elliott et al., 2006). Framework species must be selected carefully, considering their ability to attract seed dispersers to the site, as this method depends on enhancement of natural regeneration (Figure 14).

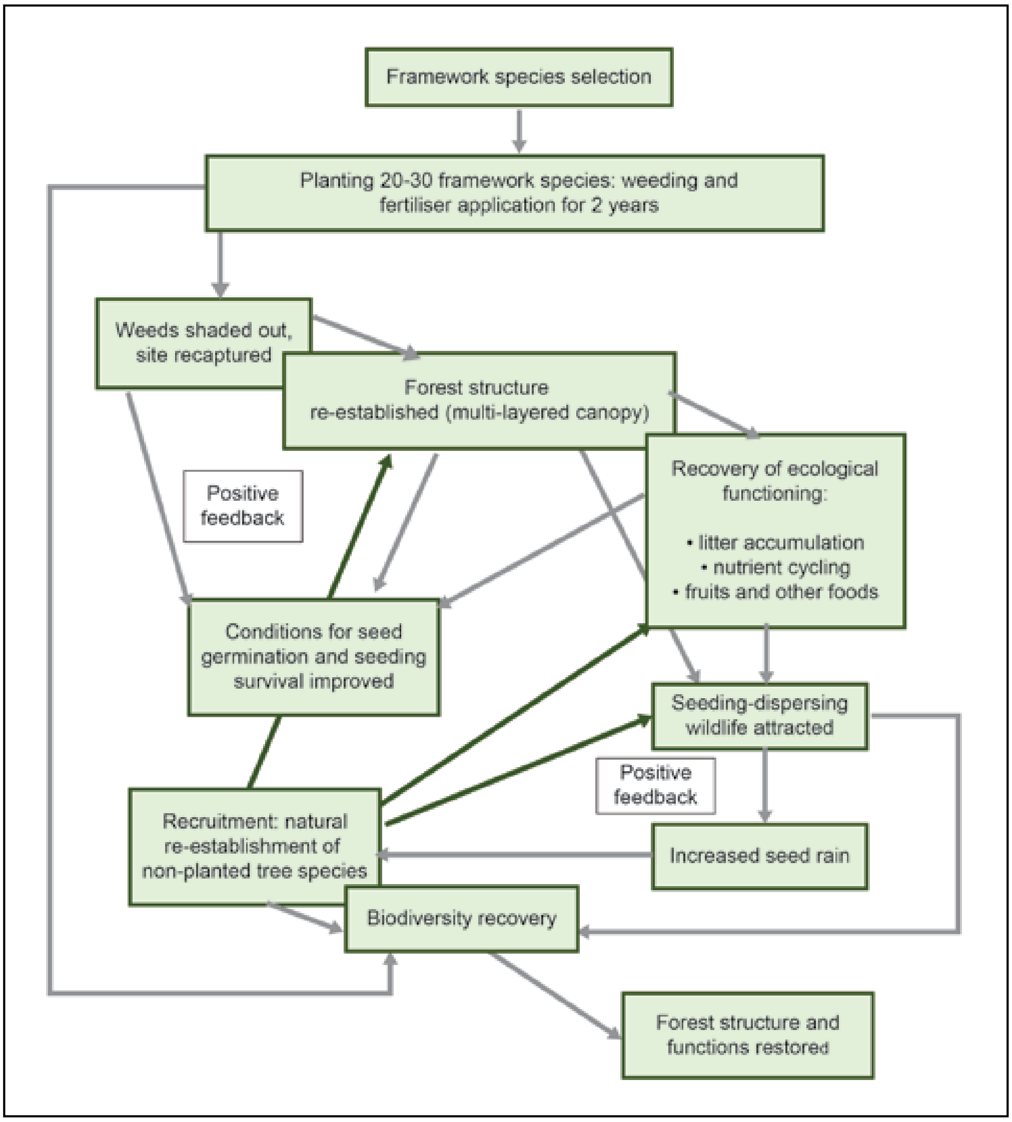

Figure 14. Framework species method
(Source: Elliott et al., 2013)

Maximum diversity method

The maximum diversity method attempts to recreate the original tree assemblage of the climax forest. It involves intensive site preparation, followed by a single planting event using mostly climax species. Because it is a more intensive and costly tree-planting method, it is suited for small-scale planting (Elliott et al., 2013).

In highly degraded sites, soil amelioration and nurse tree[18] planting, followed by the maximum diversity method, can yield successful results.

5. Species selection

See also Chapter 9 for detailed species lists for restoration.

Ecosystems (such as forests, wetlands, grasslands) have evolved over millions of years with the climate in different climatic zones of the island. They vary in their physiognomy (external appearance), structure (horizontal and vertical), and species composition. Each ecosystem contains a different array of floral and faunal species that have evolved in response to local environmental conditions. For instance, the plant species of tropical montane forests in Horton Plains in the wet zone, are rarely found in the tropical dry-mixed evergreen forests of Ritigala, in the dry zone. Therefore, tree species that are restricted to montane forests of in the wet zone, should not be planted in degraded sites in the dry zone. However, it should be noted that that some pioneer tree species are common to several climatic zones of Sri Lanka. For example, the pioneer tree species *M. indica* is found in the wet zone up to 2000 m (Figure 15a), whereas *Trema orientalis* (English: Indian charcoal tree; Sinhala: *gedumba*) is found in all climatic zones of the country (Figure 15b).

All ER projects use tree species indigenous to the target forest ecosystem. In species selection, it is vital to study the species composition and reproductive traits of species existing in remnant vegetation within the climatic zone where the restoration project is conducted. It is also desirable to determine the economic and ecological value of plant species, to gain acceptance of the project by locals. Ecological restoration seeks to re-instate the processes that accelerate succession towards the climax (or mature forest) condition. The forest actually created by ER tree planting is a hybrid between a pioneer and climax forest.

However, it is also important to acknowledge that the species composition of the future forest will change in response to climate change, thus forest restoration may have to aim at a moving target (Elliott et al., 2013). Thus, it is more about reinstating the processes of succession that will allow the forest to adapt to future changes, rather than creating an idealised climax ecosystem. In simple terms, ER will ‘put nature back in the driving seat.’

Steps 6 (Nursery management for ecological restoration) and 7 (Site preparation) will be detailed in following chapters.

8. Tree Planting

Tree planting must be initiated at the start of the main rainy season and this determines the schedule of activities of the ER project. Saplings for planting should be tagged in the nursery, before the planting date, for monitoring purposes. All materials needed for tree planting, such as organic fertiliser (ideally compost/ cow dung, pelleted organic fertiliser), poles for fencing, material for fencing, and saplings must be transported closer to the restoration site, a week

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[18] A nurse tree is a larger, faster-growing tree that shelters a small, slower-growing tree or plant.

before planting. Saplings must be kept shaded as soon as they are transported to the site. They must be moved to the open area closer to the restoration site for hardening, at least a week ahead of the transplanting event. It is essential to check whether the width of fire belts around the restoration site is appropriate to protect the site from dry season fires.

Invite all stakeholders for the tree-planting activity to develop positive attitudes towards conservation (Figure 16a). Before tree-planting, demonstrate how to remove the seedling/ sapling from the bag, how to place the transplant in the planting hole and how to fill the hole with fertiliser and soil. After tree-planting, as soon as possible, appropriate measures must be taken to exclude herbivores. Fencing of the entire site or individual transplants are commonly used practices in Sri Lanka. Many research studies indicate that the use of white polythene around transplants reduces herbivory (Figure 16b).

In addition, test trials can be run to check on which plants are not preferred by herbivores, as this will greatly reduce the expenditure on fencing. Any polythene and garbage remains from the tree-planting event should be removed and disposed of responsibly with the help of the volunteers who joined in this activity.

Figure 15. The pioneer tree species (a) *Macaranga indica* (3 yr old) established at the restoration site at the Knuckles Conservation Forest. (b) *Trema orientalis* is distributed in all climatic zones of Sri Lanka

(*M. indica* is common in the wet zone of Sri Lanka. *M. indica* and *Trema orientalis* are both pioneer species found on disturbed open sites. © Thilanka Gunaratne /University of Peradeniya)

9. Site Maintenance, Monitoring and Evaluation

Site Maintenance

Most ER projects fail because of low allocation or no allocation of funds for site maintenance. After tree-planting, often transplants are left without any care in hostile environments, especially with intensified weed competition from the surrounding vegetation. Planted trees must be maintained ideally at least for the first two years (until a closed canopy is developed, shading off the weeds) to ensure their successful establishment. Application of fertiliser and weeding with one metre radius, at least three times in the first rainy season, and three more times in the second rainy season will enhance the growth of planted trees.

The local community plays a crucial role in site maintenance, as in many cases they are the stakeholders who live closest to the restoration site. Thus, it is advantageous to have a team of locals to work on a daily/weekly basis at the restoring site, especially during the first two years. Their responsibilities should be clarified at the beginning of the project.

Daily/weekly checks at the restoration site are necessary for maintenance, including ensuring that that herbivore exclosures are intact. In addition, regular checks on weed invasions are required, as weeds reduce both above and below ground resources for the transplants. Thus, weeds around the transplants must be cleared (at least within a one metre radius) regularly.

Figure 16. a) Volunteers of Botanical Society, University of Peradeniya, officials of Forest Department and Noritake Lanka Porcelain (Pvt.) Ltd. and local community planting seedlings of native species into degraded grasslands at the Knuckles Conservation Forest, Sri Lanka. b) *M. indica* sapling covered using white polythene to keep away the herbivores
(© Thilanka Gunaratne /University of Peradeniya)

Biofilmed biofertilisers[19], formulated using native bacteria and fungi cultures, have shown promising results in increasing transplant performance in the Knuckles Conservation Forest. These can be improved and produced on a large scale to improve soil health, thus ensuring better establishment of native tree species. Clearing the fire belt during the dry season is essential to prevent fires. Locals living adjacent to the site must be trained to look out for fires (during the dry season) and to put out fires as and when needed.

Monitoring and evaluation

There are several steps in effectiveness evaluations, which is critical to ensure valid pre- and post-treatment comparisons (Figure 14) (Machmer & Steeger, 2002). Effective monitoring (EM) and evaluation enable stakeholders to identify appropriate prescriptions for restoration sites and failures in the project, assess and justify expenditure; and improve future project planning, implementation and evaluation. However, in Sri Lanka, in the past, effective monitoring and evaluation processes of ER projects have been overlooked. Most of the restored sites are not monitored, because there are low budgets or no budgets allocated for monitoring activities. In many cases, there are no databases to assess long-term effects of restoration. This leads to the creation of many gaps in research on restoration efforts and in turn, to a tendency to repeat treatments without questioning their efficiency or applicability to different climatic zones in the country.

A monitoring plan for the restoration project should be developed after examining the restoration objectives of the project. Stakeholder involvement in the process is crucial for the success of effective monitoring and evaluation, as it is they who should decide when and what to monitor.

The monitoring plan must include, monitoring objectives reflecting the restoration objectives. Monitoring objectives must be developed considering the appropriate level of evaluation for the project and associated constraints (Machmer & Steeger, 2002). Moreover, the restoration monitoring plan should include a description of the study site; restoration project design; and monitoring protocol (level of monitoring and key response variables to monitor). The best response variables used for monitoring must link closely to the restoration objectives. For example, if the objective of a forest restoration project is to increase the biomass of native species by 50% within five years, then the project should determine the biomass of native species at the initiation of the project and after application of biomass increment treatment in the site.

Response variables used for monitoring are broadly divided into two groups: biophysical factors and socio-economic factors.

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[19] 'Certain soil microbiota naturally exists as surface-attached microbial communities in a biofilm mode of growth. They have been shown to be more effective at functioning than monocultures or mixed cultures of microbes. Therefore, such beneficial biofilms have been formulated in vitro to be used as biofertilizers called biofilmed biofertilizers (BFBFs) in agriculture and plantations. . . The role of BFBFs is to reinstate sustainability of degraded agroecosystems through breaking dormancy of the soil microbial seed bank, and in turn restoring microbial diversity and ecosystem functioning. Thus, the concept of BFBFs is not only biofertilization, but also a holistic ecosystem approach' (Buddhika et al. 2016).

Biophysical factors

1. Biodiversity enhancement (faunal surveys, new recruits, percentage cover of newly establishing vegetation);
2. Tree performance (GBH, height and crown diameter of transplants, canopy cover, biomass);
3. Forest regeneration (seed rain, seed bank, seedling and sapling banks);
4. Factors that enhance ecosystem services such as microclimatic data, litter quality, the water-holding capacity of the soil, soil organic matter content, biotic interactions; and
5. Soil improvement (nutrient status, water holding capacity, soil carbon).

Socio-economic factors

1. Direct employment opportunities (socio-economic surveys); and
2. Use of restoration site for education, research and recreation (number of visits to the site).

The level of monitoring required will depend on the nature of the restoration project. There are two types of monitoring: routine monitoring and intensive monitoring. Routine monitoring involves rapid data collection at low cost, using mainly qualitative methods, to compare one or a few response variables before and after treatment. Intensive monitoring requires more in-depth quantitative monitoring, over a longer period, at a higher cost.

Re-sampling conducted on the site by field/research assistants or volunteers from the universities/research organisations/trained local villagers provide useful information on the success of the restoration project and recommendations in planning future restoration projects (Figure 17 a & b). Zahawi et al. (2015) used drones to upscale restoration monitoring beyond the plot level. The application of remote sensing technologies for Earth observation helps restoration ecologists to address several important challenges (selection of areas to be restored, distinction among restorative practices over the landscape and the quantification of vegetation structure and function, and diversity indicators) for monitoring much larger areas more rapidly and with higher accuracy (Almeida et al., 2019).

Figure 17. a) Volunteers of the Botanical Society of the University of Peradeniya measuring the height of transplants during a census and b) Volunteers of the Zoological Department of the University of Peradeniya conducting the faunal survey at the restoration site at the Knuckles Conservation Forest

(© Thilanka Gunaratne /University of Peradeniya)

There are several steps in effectiveness evaluation, which is critical to ensure valid pre- and post-treatment comparisons (Machmer & Steeger, 2002). Effective evaluation of the restoration effort allows for the determination of the ecological, social, and economic impact of the restoration programme to society.

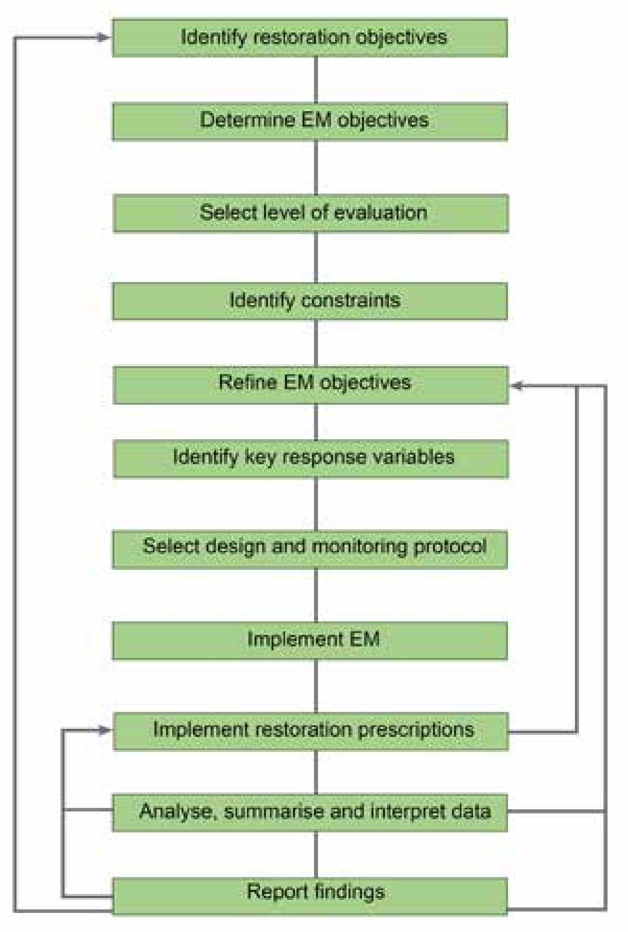

Figure 18. Steps of effective evaluation

Incorporation of a research component to the ER program is easily achievable through collaborations with stakeholders representing universities and research institutes, at the project planning stage. When identifying stakeholders, researchers should be selected considering the area/s of their expertise and a dialogue developed among relevant multidisciplinary researchers at initial stages of the project formation. The final steps of evaluation of a particular ER project involve data analyses, interpretation of monitoring data and reporting the results to society through scientific fora, as well as media (print, and multimedia such as TV programmes, social media).

Because restoration sites are information generators when used for multidisciplinary research, many research components can be identified with the help of relevant local research institutions including universities. Some research areas include the selection of best performers among transplants for a particular climatic zone; enhancement of biodiversity; improvement of the carbon stock and carbon sequestration[20] by transplants, enhancement of ecosystem services, etc. Ultimately, findings of these research can be used to plan successful site-specific restoration

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[20] Carbon sequestration is the long-term storage of carbon in oceans, soils, vegetation (especially forests), and geologic formations, over a specific period of time (ESA, undated; Krna & Rapston, 2013)

programs in the future. Moreover, the use of restoration sites for purposes of education can develop positive attitudes towards biodiversity conservation in the present as well as the next generation (Figure 19).

Figure 19. Postgraduate students of M.Sc. in Science Education of Postgraduate Institute of Science, University of Peradeniya, visiting a restoration site at the Knuckles Conservation Forest Sri Lanka, to learn about field techniques used for ecological restoration of degraded grasslands

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Case Study: A success story of Assisted Natural Regeneration (ANR) in the dry zone of Sri Lanka

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The dry zone forests of Sri Lanka are subject to being cleared for development projects and to the illegal felling of prized timber species (Perera, 2001 in litt. Lekamge et al., 2019). Restoration of dry zone forests is difficult because there is a range of alien invasive species and pioneer species which prevent the regeneration of the native seed bank of climax species. Slash and burn also depletes soil fertility further retarding regrowth. In ANR, it is the removal of factors suppressing natural regeneration that is given prominence, rather than planting (FAO, 2020). Lekamge et al. (2019) assessed restoration in the National Institute of Fundamental Studies (NIFS)-Popham Arboretum in Dambulla, established in 1963 by Mr. F.H. Popham from a plot abandoned by shifting cultivation, comprising degraded scrubland. In the Popham Arboretum there are four types of vegetation cover: restored forest, riverine forest, woodland and control blocks (Lekamge et al., 2019).

In 1963, initial ANR was commenced, in five-year cycles, on 3.7 ha. From 1989-1994, 7.8 ha of woodland were also brought under ANR. Annual ANR measures were carried out prior to the rains, when anything such as creepers, vines, shrubs and grasses surrounding forest tree seedlings were removed. Young trees were pruned regularly to stimulate growth. During the dry season to prevent water loss by transpiration, clearing was limited to areas around pioneer species of the target forest (Popham, 1993, in litt. Lekamge et al., 2019).

Lekamge et al. (2019) assessed the species richness (the number of species) in each type of vegetation, the Shanon-Weiner Index – which measures diversity (both species rich and species abundance) – as well as the Important Value Index (IVI) – a measure of how dominant a species is in each forest area – were computed.

Comparison of vegetation types to showed a significant difference between the control areas and the woodland and restored areas.

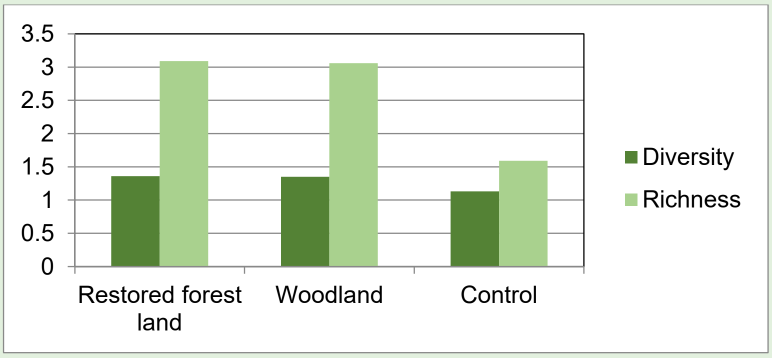

Figure 20. Species diversity and richness in the different vegetation areas in NIFS-Popham Arboretum
(Source: Lekamge et al., 2019)

Table 3. Results of Important Value Index (IVI): the ten most dominant species in each vegetation type

(Habitat: forest canopy= FC; forest sub-canopy= FS, forest understory= FU; scrubland= SL; forest gaps= FG)

Restored forest		Woodland		Control plots	
Species	**Part of forest**	**Species**	**Part of forest**	**Species**	**Part of forest**
Memecylon umbellatum	FU	*Diplodiscus verrucosus*	FS	*Grewia damine*	FG
Eugenia bracteata	FS	*Grewia damine*	FG	*Catunaregam spinosa*	SL
Chloroxylon swietenia	FC	*Diospyros ferrea*	FU/SL	*Phyllanthus polyphyllus*	SL
Diospyros ferrea	FU/SL	*Ixora pavetta*	FU	*Pterospermum suberifolium*	FC
Vitex altissima	FC	*Syzygium cumini*	FC	*Diospyros ferrea*	FU/SL
Lepisanthes tetraphylla	FC/SL	*Bauhinia racemosa*	FU/SL	*Diplodiscus verrucosus*	FS
Phyllanthus polyphyllus	SL	*Vitex altissima*	FC	*Lepisanthes tetraphylla*	FC
Pleurostylia opposita	FS	*Chloroxylon swietenia*	FC	*Eugenia bracteata*	FS
Clausena indica	FU	*Memecylon umbellatum*	FU	*Memecylon umbellatum*	FU
Bauhinia racemosa	FU/SL	*Phyllanthus polyphyllus*	SL	*Cassia roxburghii*	FS
Memecylon umbellatum	FU	*Diplodiscus verrucosus*	FS	*Grewia damine*	FG

Lekamge et al*.*, (2019) have shown that the ANR approach has been successful in restoring the abandoned slash and burn scrubland to secondary forest.

Figure 21. View of NIFS-Popham Arboretum

(© Chanaka Lekamge)

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Case study: Lessons learned by converting zero biodiversity mined lands to multi species dry land forests at Aruwakkalu limestone quarry, Puttalam, Sri Lanka

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The context

INSEE Lanka Pvt. (earlier Holcim Lanka Pvt.) produces cement by using limestone found in Aruwakkalu, in the Puttalam District. In the early decades of limestone mining (the 1960s-1990s), no attempts were made to actively re-vegetate cleared areas, and post-mining sites were left abandoned. However, some 15 years back, re-establishing the environmental well-being of post-mining sites was considered a priority by the then management, Holcim Lanka Pvt. and resources were allocated for restoring these neglected areas. This resulted – within a few years – in some newly created green areas. The trend was continued by the subsequent mining operation agency, INSEE Lanka Pvt., and exemplified the practice of re-greening of post-mining areas, as an obligation of a responsible resource extractive industry.

At the field level, the main objective was to establish forests in limestone mined areas, where there was no visible biodiversity. The expectation was to convert these barren lands to forests comparable to the surrounding undisturbed forest landscape (known as reference sites). This entailed the establishment not only of the natural structural characteristics of the ecosystem, but also its functions and biotic composition – such as both its fauna and flora. In addition, ecological restoration was selected because of the ecological linkage of the forest landscape with Wilpattu National Park, which is near.

The approach

Step 1: *Understanding in detail and using the reference forests as guidance, recording fauna, flora and relevant ecological attributes (vertical and horizontal)*.

In addition to reference forests, surrounding habitats of various levels of degradation were also studied. Long-abandoned mining areas were also observed to obtain information of trees species that grew in these areas. This was necessary as there were no previous examples for the restoration of dry forests for comparison. Native trees growing successfully under harsh conditions (for example, exposed to the sun, growing on infertile soil and tolerant of droughts) were identified for restoration planting in mined lands, which had similar, harsh environmental conditions. It was noted that there was a large population of free-grazing cattle that damages regenerating plants. Therefore, species that can tolerate grazing pressure or unpalatable species were given special consideration as plants used in restoration. In addition, trees that attract fruit-eating fauna or provide shelter for them, were also given priority, as that would contribute later to animal-mediated forest regeneration and enhanced faunal biodiversity.

Step 2: Indigenous trees, with as many as possible of the characteristics given in Step 1, were listed for planting in cleared areas.

In addition, some nurse tree species, that could provide shade for site-specific native flora in the early phase of the restoration, were also incorporated into lists of species identified for planting. Plant saplings potted in polythene bags (planted according to given specifications) were acquired through contractors, and the process coordinated by the INSEE management. Necessary creation of awareness of plant species, field planting and maintenance was conducted for both field workers and INSEE supervisory staff.

Step 3: Land preparation for field planting was carried out by heavy machinery and the restoration areas were turned into flat land.

Field planting was carried out by contractors based on the training they had received. It was ensured that planting was initiated with the onset of north-east monsoon rains in late October. Using permanent landmarks, biodiversity monitoring sample sites, in 5 m x 50 m transects, were established in the newly planted areas.

Step 4: The restoration process was monitored closely, using sampling studies, as well as thorough field observations that criss-crossed the planted area.

Monitoring of sample sites was carried out mid-year, annually since 2007. Indicators of restoration success indicators were a) abundance of live plants (tree, shrubs and herbs, including natural recruits); b) increase of forest canopy cover; c) enhanced vertical profile structure; and d) the sustained presence of fauna. A control sample site was also established at a location where there was a slow-growing forest, in an area abandoned after mining, some three decades ago, and which now remains completely neglected. General observations in the planting area allowed for the identification of various problems and the design of remedial actions. Soil erosion was mitigated using several structural and vegetative methods. Invasive plants and other problematic species were removed manually, and gaps were filled where necessary.

Step 5: Inspired by the success of establishing, within about a decade, forest cover in completely barren lands in Aruwakkalu, several on-site knowledge sharing events were held for diverse stakeholders, including officers from the Forest Department.

The success of this multi-pronged approach was shared, a) highlighting forest restoration challenges in this harsh climatic area; b) key steps of species selection; c) approach of ecological restoration that considers flora and fauna, as well the natural processes such as succession; d) evidence of restoration success, based on the presence of flora and fauna; and e) the state of the natural restoration process in abandoned mined lands. It must be emphasised that this was the first time in Sri Lanka that the private sector was involved in forest restoration. This case study exemplifies that extractive practices that lead to the degradation and loss of biodiversity must be followed by conservation efforts to restore ecosystems.

Lessons learned

1. Restoration of forests in dry areas in Sri Lanka is possible with site-appropriate strategies. Until recently, it was perceived that restoration with native plants, of such completely barren lands was nearly impossible.
2. Identification of site-appropriate key species of trees for planting is a critical step in the restoration process. Desirable tree characteristics are many and varied and identification; requires much trial-and-error and learning from errors, using an adaptive approach.
3. Field planting must be carried out precisely at the onset of the north-east monsoon rains in late October. The two-three months of rains allow for the retention of the amount of soil moisture necessary for establishing the root system of newly planted saplings in this dry area.
4. An understanding of the ecology of reference forests provides much needed guidance for restoration such as suitable plant species, characteristics of identified tree species and the requirements for fauna.
5. Survival of plants is higher in sites where the land is uneven, where there are scattered small puddles and depressions that accumulate. There is also better plant growth and habitats for animals when plant debris, logs and topsoil from newly cleared areas for mining were provided in restoration sites.
6. Periodic restoration assessment of success and course correction must be an integral part of restoration for at least the initial five years, until a momentum of self-recovery is achieved by the forest. Control of soil erosion, removal of problematic species and addition of soil organic matter aid in this process.
7. Restoration is an evolving and flexible process and must be adaptive. It is a continuous learning process, and a mix of approaches must be used for effective and cheaper restoration; for example, not only planting saplings but also promoting natural regeneration, as well as removing competing species and other threats.
8. The Aruwakkalu forest restoration site has become a valuable demonstration site for restoration in the dry zone for a range of different stakeholders interested in replicating such efforts in other parts of the country. Successful actions and innovations themselves provide restoration guidelines for future similar efforts. The involvement of the private sector in this example of forest restoration is an inspiration to a wider audience, motivating them to undertake similar efforts to contribute to national forest restoration efforts.

Figure 22. A successful restoration at Aruwakkalu
(Top left: a two-year-old plot of mostly bare land; right: monitoring plot; bottom: restored site
(all © IUCN/Sampath de A. Goonatilake)

Box 5. Restoration champions: tree species proven to be better performers, accelerating ecological succession under the aridity of Aruwakkalu

Positive characteristics		Tree species*											
		Limonia acidissima	*Manilkara hexandra*	*Schleichera oleosa*	*Syzygium cumini*	*Cassia fistula*	*Berrya cordifolia*	*Terminalia bellirica*	*Madhuca longifolia*	*Ficus benghalensis*	*Bauhinia racemosa*	*Pongamia pinnata*	*Trema orientalis*
1	Drought resistance	+++	+++	+++	+++	+++	+++	+++	+	+++	+++	+++	+++
2	Resistance to strong and dry winds	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
3	Requires little maintenance	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
4	Life span of over 20 years	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+
5	Thrives in less fertile sites	+++	+++	+++	+++	+++	+++	+++	+	+++	+++	++	+++
6	Fast growth	++	+	++	+++	+++	++	++	+++	+++	+++	+++	+++
7	Disease resistance	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
8	Not palatable to browsing animals	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
9	Dense canopy, providing shade	+++	+++	++	+	+	+	+	+++	+++	+++	+++	+
10	Already thriving in nearby natural habitats	+	+++	+++	+++	+++	+		+	+++			+
11	High level of natural regeneration	+	+	+++	+++	+++	++	+	+	+++	+++	+	+++
12	Provides food resources for wildlife	+	+++	+++	+++	+			+++	+++	+	+	+++
13	Attracts seed dispersal agents and promotes natural regeneration.	+	+++	+++	+++	+			+++	+++			+++
14	Fixes nitrogen and improves soil fertility	+									+++	+++	
15	Keystone species sustaining many animal species by providing food, places to rest, breed and find refuge.	+								+++	+		

*Common and vernacular names are provided in Annex 1.

Chapter 3: Restoring soils – a guide for site preparation

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Many restoration projects have been implemented to mitigate some of the negative impacts of habitat degradation. Despite large sums of money being spent on restoration efforts, there are very few success stories. The main reason for such failures is that the restoration model is incompatible with a particular setting and/or climatic condition. Though a specific model is good for a specific situation, it does not mean that the same model will be successful in another, with different habitat and climatic conditions.

The main approaches to restoration and the ecological processes involved have been discussed in Chapter 2. This chapter discusses the role of soil resources in restoration.

The role of soil resources in restoration

Soils play an important role in the restoration process, bridging the connection among different components of the community. Soil ecology – 'which emphasizes both soil organisms and ecosystem processes' – is critical for restoration (Heneghan et al., 2008). Not only soil nutrients, but also soil biota play a critical role in determining the growth of native seedlings and the ultimate composition of vegetation at a site. The lack of soil resources (both biotic and abiotic) can be one of the main drawbacks for low success rates of many restoration efforts.

In restoration, soils slowly build up a network of inter-connections among different components of the community and facilitate the successional dynamics and the functioning of the natural ecosystems. Once the restoration trajectory proceeds, the abundance and diversity of soil microbes gradually increase, and soil nutrients build up, stimulating the nutrient cycles. In contrast, the lack of soil resources may hamper and retard restoration (Liyanage et al., 2021). Therefore, to enhance the success of restoration efforts, soils also need interventions such as tilling, adding fertilisers, and clearing the background vegetation, which will reduce the competition for available soil resources (Gunaratne et al., 2010 & 2011; Alcázar et al., 2002).

The need for equal consideration of above- and below-ground factors in restoration

In many instances, above-ground factors and resources attract more attention than below-ground resources from scientists and practitioners. Furthermore, when measuring the success of restoration efforts, above-ground parameters (such as abundance, richness and diversity of the flora and fauna) are used frequently because they are conspicuous and easy to measure, compared to below-ground parameters (such as chemical, physical and biological parameters of the soil). Therefore, the focus is more on above-ground factors/parameters and less on soil-related factors, often leading to futile endings in restoration efforts.

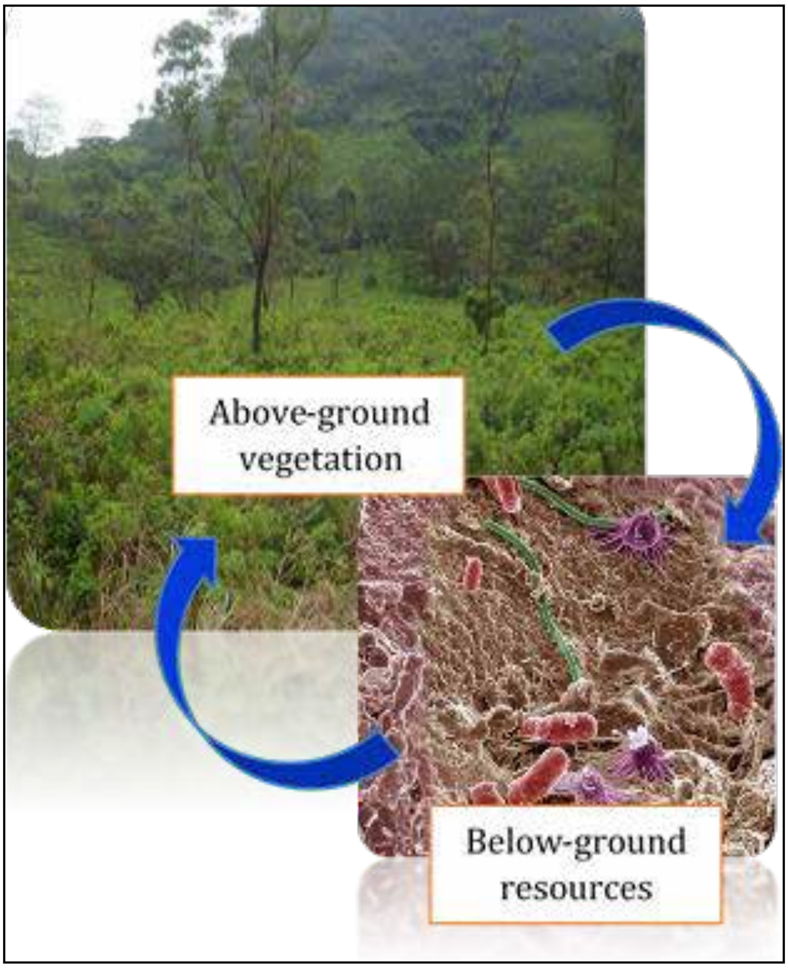

Figure 23. Above- and below-ground components are tightly inter-connected and depend on each other through positive and negative feedback

It is important to emphasise the fact that both above- and below-ground factors and limitations should be considered equally in order to make any restoration effort a success (Figure 23).

In restoration trials, choosing the most suitable plant species for the specific habitat-climate combination is critical for subsequent success. (See Chapter 2.) However, even with the most suitable species, restoration efforts could still fail, because most practitioners disregard other limiting factors – such as edaphic properties. For an example, in a grass-dominated landscape, grasses could exert high competition for available soil resources, thus hindering the growth of introduced native tree seedlings. Therefore, the lack of soil resources (nutrients, soil biota and water) could also be a contributory factor leading to poor seedling growth, as most habitats selected for restoration are already highly degraded, and experience harsh conditions. Poor soil structure, low soil fertility, drought or water-logged conditions, high intensity sunlight and wind are some of the common issues faced by practitioners in restoring highly degraded habitats. All these factors may lead to poor growth and survival of native tree/shrub seedlings, jeopardising the success of restoration projects (Nepstad et al., 1996; Holl et al., 2000; Hau & Corlett, 2003; Griscom et al., 2009).

The importance of site preparation

Understanding the ground situation of the specific site is a crucial, initial step in all restoration approaches. Once the on-site circumstances that could limit successful establishment of native seedlings/saplings are understood, appropriate steps should be taken to reduce those limitations. Once limiting factors are identified, appropriate measures should be identified to improve soil conditions, control competition from the matrix vegetation and reduce animal damage. To mitigate some of these negative influences, various site preparation techniques can be recommended. Of many site preparation techniques available for treating specific conditions, choosing the right technique/s is always a challenge.

Despite many site preparation techniques available for treating soils and other field conditions, these techniques have not been tested for all species used in restoration trials. Therefore, seedling responses to various site preparation techniques may differ, so generalisation is not advisable.

Mechanical site preparation

Site preparation is an age-old practice. Controlled burning and disturbing soils have long been recognised as site preparation techniques to improve natural and artificial regeneration. In the past, farmers used manual or animal power for site preparation; although currently, heavy machinery is involved. Using heavy machinery for site preparation is not always feasible because of financial and practical difficulties, thus site preparation techniques that can be implemented without heavy machinery, suitable for countries like ours should be chosen.

Choosing the right site preparation technique is vital. Thus, before arbitrarily selecting a technique, understanding the ground situation, and limiting factors that may hinder the growth and survival of emerging/introduced native seedlings, is a critical step towards success. Some site preparation techniques may cause more negative consequences to the landscape than anticipated positive effects.

The main aim of the site preparation is to enhance the microsite[21] conditions before planting/ seeding.

The following are the anticipated outcomes through site preparation techniques:

- Increased/decreased soil moisture;
- Increased/decreased solar radiation;
- Modified soil temperature;
- Increased soil nutrient availability;
- Reduced soil compaction;
- Controlled competing vegetation; and
- Reduced animal damage.

In addition to mechanical site preparation techniques (MSP), simple interventions such as clearing unwanted vegetation could remove competition exerted on newly emerging or

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[21] A term used in ecology to describe a pocket within an environment with unique features, conditions or characteristics.

introduced seedlings. It is well known that grasses exert severe competition on young tree seedlings.

However, if the particular landscape is invaded by an exotic species, clear-cutting the invader may not be the best approach, because it could lead to other problems such as erosion. Sometimes, the exotic invader can act as a nursing plant for emerging seedlings or else facilitate the habitat amelioration, which may eventually help emerging/introduced seedlings to establish and survive well. Removing logging slash[22] facilitates planting or direct seeding. Adding an initial dose of fertilisers may also help seedlings to establish well, though it is not sometimes feasible because of practical difficulties. Herbivory is known to be a huge issue that prevents the success of restoration trials, especially at the seedling stage of plants. Both large and small mammals can feed on young seedlings, while birds feed on seeds after an event of seeding.

In most instances, more than one site preparation technique is needed to address all issues at a particular site. The choice of technique/s may depend on the soil type, topography and the degree of disturbance needed for the restoration trial to establish and perform better.

The most common MSP techniques are:
- Scarification
- Mounding/bedding
- Subsoiling/ripping (Löf et al., 2012)

These MSP techniques can be achieved with the use of basic agricultural implements.

Scarification

The purpose of scarification is to create desirable planting spots in mineral soil or in the mixed mineral-organic soil layer. Scarification increases soil temperature and moisture, thus facilitating seedling growth. In scarification, the vegetation and the upper organic layer is removed to uncover the bare (mineral) soil layer (Figure 24a). Intermittent patch scarification is the most commonly used technique in restoration trials. After scarification, the planting spot is normally below the original ground level, therefore water may accumulate temporarily following a heavy rainfall. However, scarification does not influence the soil structure (Löf et al., 2012)

It is important to avoid planting or seeding in the organic layer. Planting or seeding in mineral soils facilitates water uptake, whereas planting in the organic layer could lead to desiccation.

Mounding/Bedding

Mounding/bedding is different to scarification, as it creates elevated planting spots (Figure 24b). Mounding/bedding also influences soil structure. Intermittent spot-wise mounding removes competitive vegetation, as well as the upper organic layer and the result is an inversion where mixed soil is on top of either the organic layer or bare soil (Löf et al., 2012).

The aim of mounding/bedding is to create elevated planting spots, free from water logging and with little/no competition from the existing vegetation. This also increases the soil temperature and nutrient availability, as well as improves the soil structure by reducing compaction and increasing soil aeration. If the soil is not water-logged, the mound is put back in the hole

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[22] Generally, slash refers to any material left on the ground after trees have been cut.

that has been dug out, and the planting is done. In such a situation, the planting spot is not normally elevated.

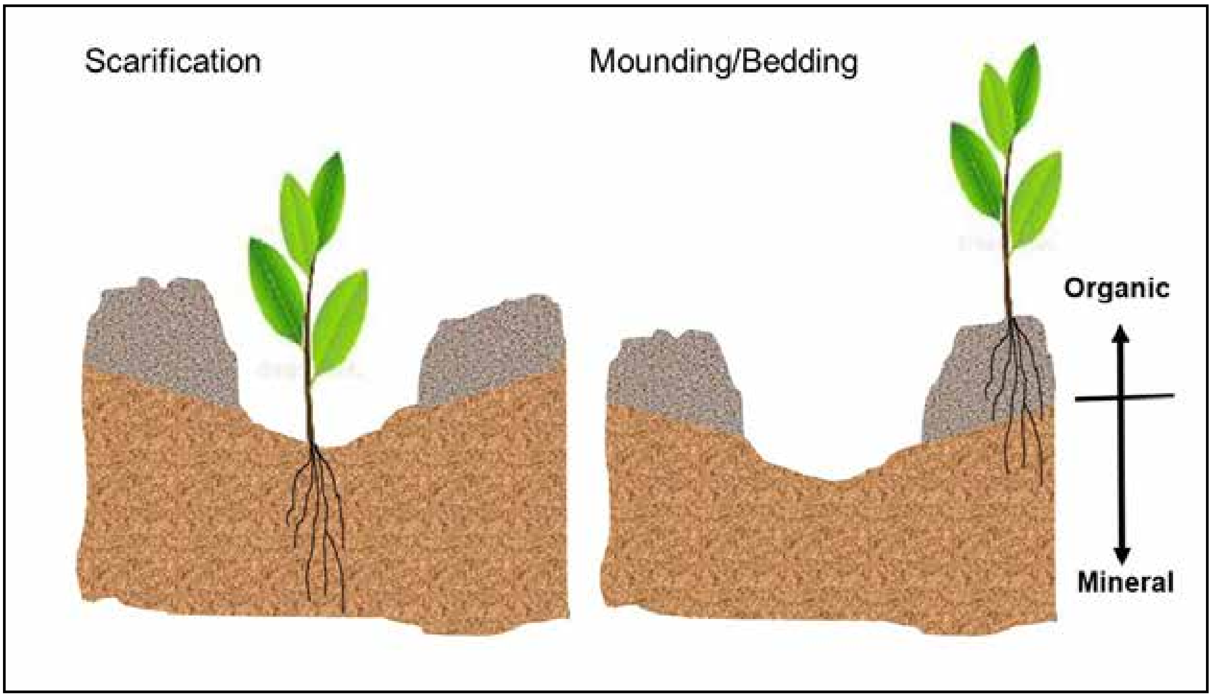

Figure 24. Common site preparation techniques: scarification and mounding/bedding

Sub-soiling /ripping

This is generally used in dry and compacted soils that restrict root growth and plant development (Löf et al., 2012). Hard pans[23] can develop because of the long-term use of machinery and grazing, which restrict root growth. In some restorations trials, despite promising early growth and establishment, plant growth can stagnate or slow down after few years. This is a clear indication of compacted soils. Sub-soiling/ripping may enhance soil structure, water infiltration and drainage, but it does not mix soil horizons or reduce competition from the existing vegetation (Figure 25).

It is hard to carry out sub-soiling or ripping using basic agricultural implements. Dug up holes (up to 1 m deep) filled with loosened up soil material would be a reasonable alternative for sub-soiling.

In addition to these site preparation techniques, there are other measures which are available to address specific problems in the field.

> ***He who plants a tree, plants a hope.”***
>
> ***Lucy Larcom***

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[23] A hardened impermeable layer, typically of clay, occurring in or below the soil surface and impairing drainage and plant growth.

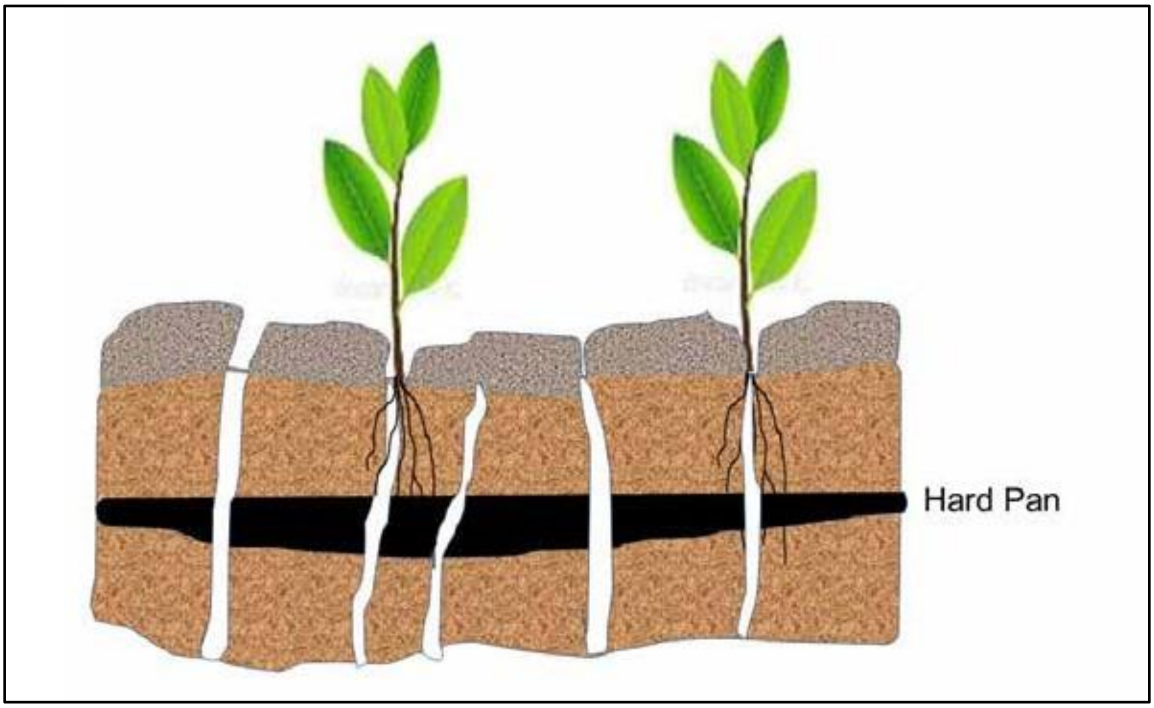

Figure 25. Sub-soiling or ripping

For a landscape that is stony/rocky

If the existing substrate is stony or rocky, first, the substrate should be loosened up at least up to 0.5 m, using field implements. Soil fertility and soil structure can be enhanced by adding topsoil, organic material or fertiliser.

It should be noted that adding organic matter or inorganic fertiliser is a costly exercise and risks introduction of weedy seeds and pathogenic microbes. However, it is still worth trying.

For a landscape where competition from the existing vegetation is severe

Before planting the native seedlings, the existing vegetation can be removed (clear one metre patch for each plant), thus reducing the competition for water, nutrients and sunlight. This is a particularly important measure in grassland restoration, as grasses exert high competition on tree seedlings.

Once cleared, regular maintenance is important. Tree seedlings should be introduced preferably within a week following clearing. If not, the cleared area can be mulched to reduce weed invasion and to conserve soil moisture. The use of herbicides can also be recommended (but avoid this as much as possible, as they also can kill native plants).

Over-clearance should be actively discouraged, as weeds will more readily re-invade disturbed grounds. Instead, clear patches more rapidly (patch clearance). Too much topsoil should not be removed. All plants should not be cleared. When clearing, important tree and shrub species should be retained.

For a landscape that is highly exposed

In exposed habitats, transplanted seedlings may suffer from desiccation because of strong sunlight and wind. In such a situation, existing trees/shrubs (native or exotic) should be retained, or nurse plants should be introduced, as it is important to provide shelter for transplanted native seedlings. Unnecessary clearance may increase the cost, enhance soil erosion, create new weed problems and eliminate valuable shelter too.

Even in highly invaded areas, complete removal of the invader should always be avoided. Past experience confirms that invaders may facilitate the establishment of native tree seedlings in highly degraded landscapes, by providing a 'nursing effect' for emerging/introduced seedlings.

Box 6. Invasive alien species can sometimes be useful

A study conducted in the invasive artificial grasslands at Knuckles Conservation Forest highlighted the importance of the invasive alien shrub species, *Austroeupatorium inulifolium* in enhancing the micro-habitat conditions that facilitated the recruitment of tree and shrub seedlings under its canopy (Haluwana & Madawala, 2013). The study also confirmed that the invader enhances the edaphic properties through the addition of high quality and easily decomposable litter, compared to *Cymbopogon nardus* dominated grasslands, indicating its facilitative role in stimulating the nutrient cycling processes (Piyasinghe et al., 2019). Soil biological properties were also enhanced following the invasion (Madawala, 2014).

These grasslands are otherwise highly impoverished, therefore, clear-cutting the invasive alien shrub may not be a sensible option in the restoration of these sites. The invader shows its potential to provide a 'nursing effect' for the establishment of tree/shrub seedlings, thus a complete clearance of the invader is not recommended.

Figure 26. *Austroeupatorium inulifolium,* an alien shrub species, invades grasslands in the Knuckles Conservation Forest
(It shows a 'nursing effect' for naturally emerging forest seedlings in these highly degraded grasslands. Inset: The inflorescence of *A. inulifoilum.* © Inoka Piyasinghe)

Box 7. Selecting a good nurse plant/tree

Nurse plants/trees facilitate the growth and development of target species beneath their canopies, as they provide a more favourable micro-habitat for seed germination/seedling recruitment and growth compared to exposed areas.

It is critical to choose a suitable nurse plant, as incorrect selection may sometimes lead to other problems such as the nurse plant expanding its population beyond limits; and exerting high competition on the natives. Sometimes rather than facilitating growth of target seedlings, nurse plants interfere with the target plants, negatively affecting their growth (Figure 27).

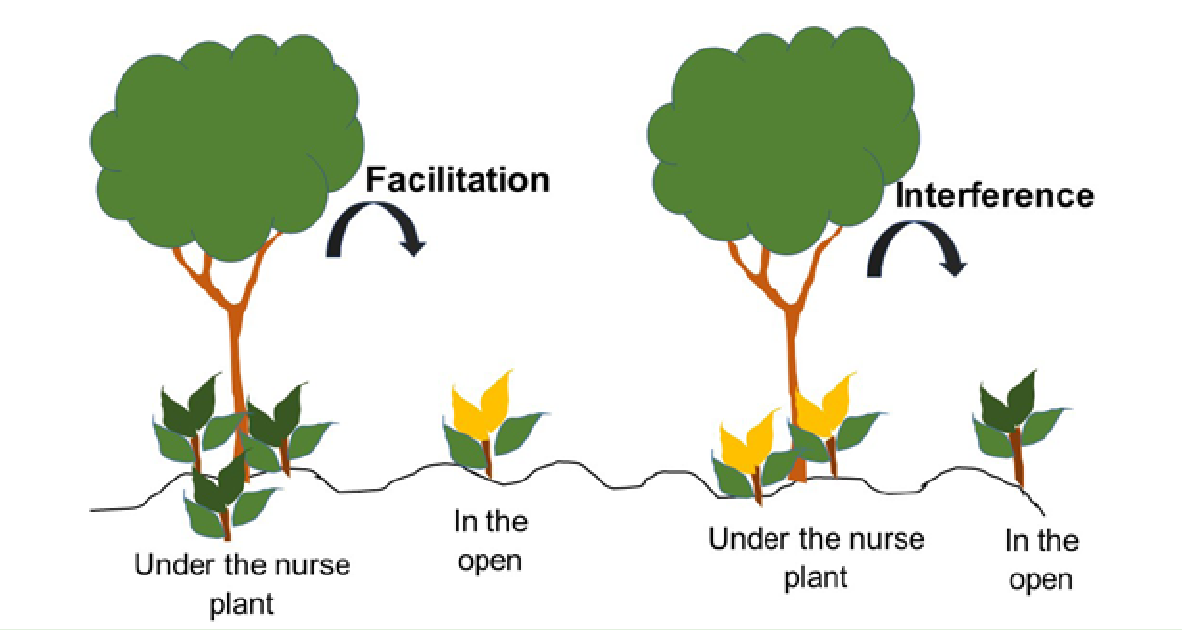

Figure 27. A nurse plant facilitates the growth and development of target species, but it could compete also with the target species, thus interfering with growth and development

Criteria for selecting a good nurse plant:

- Native species should be used as much as possible;
- The species should suit the climatic conditions;
- The species should be relatively fast growing;
- The species should have edible fruits (to attract seed dispersers);
- If the target habitat is severely grazed, then an unpalatable nurse plant species should be selected;
- N-fixing ability could be an added advantage (only if the target species is non-N fixing); and
- In some cases, even fast-growing, exotic species can serve as good nurse plants (for example, *Acacia* spp. and *Gliricidia sepium*), especially if the target habitat is highly degraded.

Box 8. Introducing fertilisers and nurse plants need caution

A study experimentally manipulated the influence of a grass sward and soil nutrient availability in the presence or absence of a nurse tree, *Gliricida sepium,* to determine how these factors influence growth and survival of seedlings of the tropical pioneer tree, *Macaranga indica* in human-induced grasslands in the Knuckles Conservation Forest in Sri Lanka. The presence of *Gliricidia sepium* did not have a positive effect on the growth and survival of *Macaranga* seedlings, perhaps because of its own poor overall performance. The study recommended that the use of *Gliricidia* as a nurse plant is not a viable measure in improving the growth of *M. indica*.

The study also confirmed that the addition of nutrients (cattle manure) was beneficial for growth of *M. indica* saplings, only in the absence of the grass sward. The study highlights the importance of field trials before implementing restoration interventions on a large-scale (Wickramaratne et al., unpublished).

For a landscape that is highly windy

If the area is windy, creating borders with dense, shrubby species can act as windbreaks to minimise the impact of the wind (Figure 28).

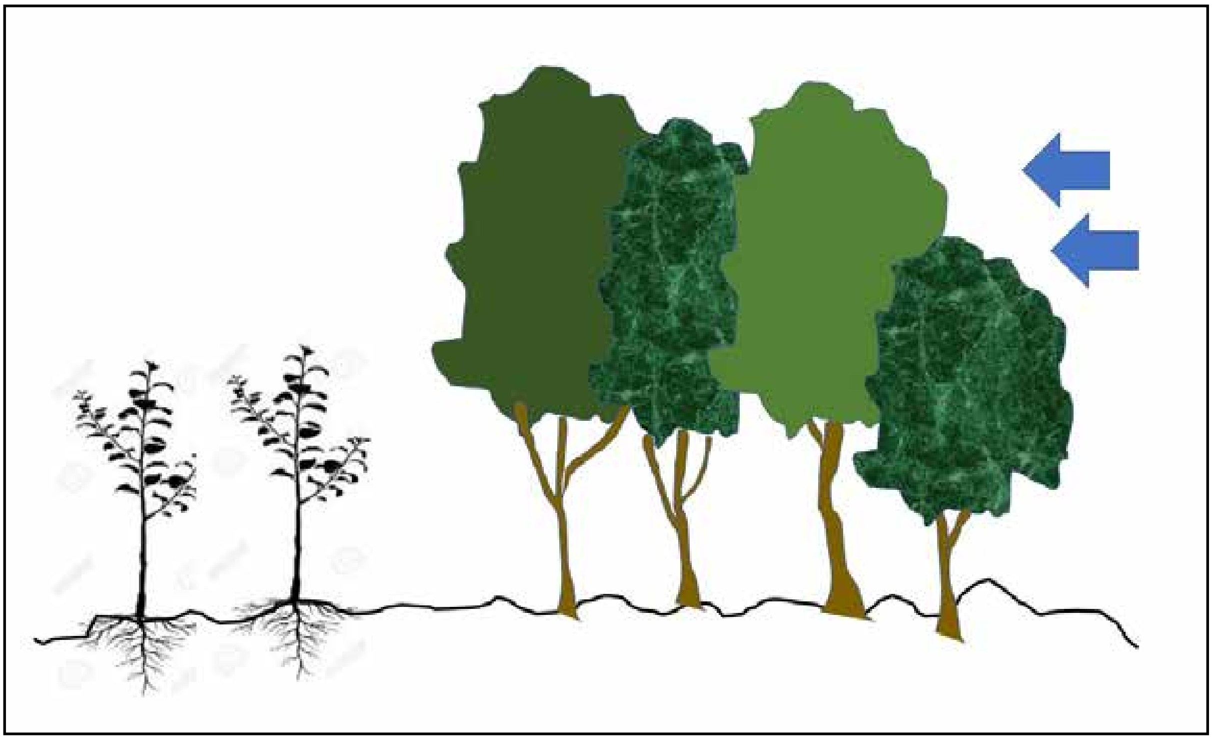

Figure 28. Establish a windbreak by planting shrubs behind each other

> ***Destroying rain forest for economic gain is like burning a Renaissance painting to cook a meal.***
>
> ***Edward O. Wilson***

For a highly impoverished landscape

When the plant growth is severely limited by lack of nutrients, adding organic fertiliser can be a good option. Adding a starter dosage at the time of planting is highly recommended. However, adding fertiliser sometimes may trigger more competition from the existing vegetation, further deteriorating the seedling performance. Therefore, patch clearance is critical when adding fertilisers. It is important to use a fertiliser that is freely available locally, otherwise there will be an added cost to the project.

Box 9. Impoverished landscape needs interventions to ameliorate edaphic conditions

Restoration of lands under *Dicranopteris linearis* faces many challenges. Though the physical removal of the fern is known as a way to assist natural succession, the attempts to restore these fern-dominated landscape demonstrated limited achievements. International Union for Conservation of Nature (IUCN) in Sri Lanka carried out a pilot project in order to revert these fernlands back to forests by transplanting native species following strip cutting. However, transplanted seedlings showed rather poor growth. A study evaluated some edaphic resources [soil nutrients and arbuscular mycorrhizal fungi[24], (AMF)] in *D. linearis* dominated landscape to examine their implications for restoration potential. The results revealed that the soils are generally poor in nutrients. A low AMF abundance, low richness and low diversity also revealed in fernlands compared to nearby lowland rainforests. The results indicate that resource-starved fernlands show rather poor potential for revival on their own or to support transplanted native seedlings. Therefore, carefully selected interventions are needed (*i.e.* addition of an initial dosage of chemical, organic and/or bio-fertilisers) to enrich the edaphic environment prior to introducing native seedlings to convert these highly degraded fernlands into some form of vegetated landscape (Liyanage et al., 2021).

For transplanted seedlings that are prone to severe herbivory

Fencing is essential to keep off grazing animals, though it can be an expensive practice that needs regular maintenance. Fencing can be effective in minimising damage to emerging plants by small mammals such as hares, rodents, porcupines. However, it is ineffective for large mammals such as elephants, cattle and sambur. Local material should be used as much as possible to erect fences to keep the cost minimal. Short and straight fences are cheaper and more effective too (Figure 29).

> ***Each generation takes the earth as trustees. We ought to bequeath to posterity as many forests and orchards as we have exhausted and consumed.***
>
> ***Julius Sterling Morton***

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[24] The most common symbiotic association between a plant and a fungus

Figure 29. Establishment of fences to ward off small mammals
(© Inoka Piyasinghe)

For landscapes prone to fire

Some habitats, especially grasslands, are prone to fire during the dry season. Fire can severely affect the survival of transplanted seedlings, as they may be unable to withstand it, unlike their mature counterparts. To avoid fire impacts, fire belts should be established (Figure 30). However, to obtain the most effective fire protection, frequent maintenance is needed, thus making fire belts a costly method of protection from fire.

Conclusion

In summary, it is important to evaluate the ground situation, before selecting a site preparation technique or a combination of techniques to mitigate negative impacts. However, it should be noted that techniques for site preparation are costly. Some site preparation techniques disturb soils and the existing vegetation, thus leading to new problems such as weed infestation or erosion. The responses to site preparation techniques may vary depending on the species and on-site characteristics. So far, there is no universal restoration model to suit all conditions and situations. Thus, prior assessment of the ground situation and budgetary facilities are critical before undertaking site preparation techniques.

Figure 30. Establishment of fire belts
(© Inoka Piyasinghe)

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Chapter 4: Nursery management for restoration

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Nursery management is an important aspect of forest restoration projects. Unless the plantlets are supplied by a third party, supply of the required number of plantlets at the required time for restoration activities depends on the proper maintenance of a plant nursery. Thus, it is important to give due concerns to the nursery management activities. Although the nursery management protocols depend on several factors, it is mainly reliant on the type of plantlet production: bare-root[25] plantlet production versus containerised plantlet production. However, bare root plantlet nurseries are rare in tropical settings (Lavender, 1984; Krishanan et al., 2014). Thus, in this chapter, more attention will be focused on containerised plantlet production[26], which is the most frequent type of nursery management in the tropics (Krishanan et al., 2014).

Nursery establishment

The first step of nursery management is establishing a nursery. Selection of a proper site for the nursery is extremely important. Several factors should be considered when selecting a site for a nursery (Morby, 1984; Krishanan et al., 2014). Climate and the environment of the nursery should be related to the restoration site. If the climatic conditions of the restoration site are compatible with those at the nursery site, acclimatisation of the plantlets to the environmental conditions of the restoration site is not required. Otherwise, propagules[27] must be transported gradually to the restoration site, i.e., after keeping propagules in an intermediate site for several days. Wind direction and, dry and wet seasons are also significant climatic factors that should be considered during site selection. Establishing a nursery, where the entire infrastructure necessary for nursery operations is available, is an ideal, rarely achieved. However, an access road for plantlet transportation from the nursery is one of the essentials that must be achieved. In addition, the location chosen for a nursery should have a continuous supply of water. Not only the quantity of water but also the quality of water used for the nursery operation is important, and thus, water supply must be monitored regularly. Soil and topography of the selected site are important, as these two factors determine the drainage conditions of the site. It is advisable to maintain a 0.2 - 1% slope in nursery beds to maintain proper drainage. Proper/improper drainage in the nursery ultimately reflects on survival and the growth of plantlets. It is strongly advised against using sites that have soils with high clay content. Soils with high clay content result in poor drainage. Improper drainage cause plantlets to die. Finding the requisite labour is another factor that should be considered in selecting a site for a nursery. Volunteers or paid labour can be used for work at the nursery.

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[25] Bare root plants are dormant (not actively growing) perennial plants that are dug up and stored without any soil around their roots

[26] A plantlet grown in a culture vessel and container substrate

[27] Any structure that functions in propagating an organism to the next stage of its life cycle

Design and layout of the nursery

After selecting a suitable site for the nursery, it is vital to pay attention to the layout of the nursery. Design and the layout of the nursery should match with the objectives of the nursery (for example, whether it is for commercial production or conservation). Further, it depends on the type of production techniques (bare root vs. containerised plantlet production), and required production capacity (Forest Department Peninsular Malaysia, 1998). A specific area must be allocated for each major operation activity needed for nursery maintenance. Preparing planting materials, raising plantlets in plant beds, keeping nursery tools, preparing fertilisers and agrochemicals (see Box 8) and finally, dispatching plantlets, are the major operations in a nursery established for conservation purposes (Figure 32). Keeping access to all the locations designated for above-mentioned operations will allow for the smooth functioning of the nursery.

Box 10. Adaptations shown by mangroves to their habitat

As in other areas of agriculture, agrochemicals are misused in many ways in nursery management. In a nursery setup for a restoration activity, it is extremely important to understand that there are many other methods to overcome pathogenic and nutrient deficiency problems, other than with the use of agrochemicals. It is only when other management practices fail in controlling the problem that it is advisable to use agrochemicals. Further, if agrochemicals are used, suitable and recommended procedures must be followed. Most agrochemicals are toxic compounds and therefore, minimised use is essential for ecosystem and soil recovery.

Figure 31. Production of *Dipterocarpus zelanicus* plants in a field nursery near a restoration site. The large size of nursery bags helps plants to grow healthily with an extensive root system

(© IUCN/ Naalin Perera)

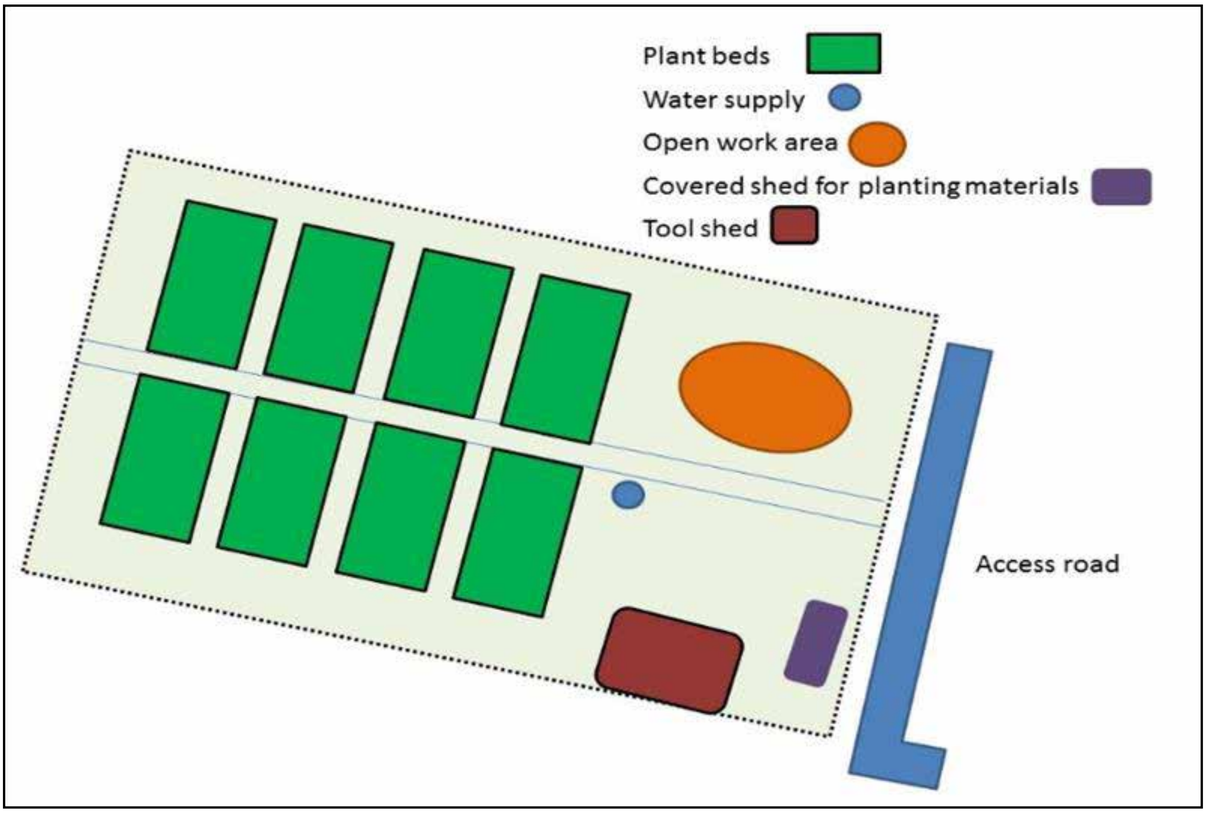

Figure 32. Design of a general-purpose nursery designed for conservation activities
(Source: modified from Forest Department Peninsular Malaysia, 1996)

Propagule types and required nursery activities

Collected seedlings

Already established seedlings are an easy source of propagules for a plant nursery. However, during the collection of seedlings, care must be taken to ensure minimum damage to the environment. There are several sources of seedlings. Roadsides, crevices of buildings and rocks are the most common sources for seedling collection (personal experience of the author). A plant that grows alongside roads will be removed anyway to keep the road clean; therefore, they can be used as propagules for nurseries, with minimum damage to the environment. Roadside plants along forest paths are good places to collect seedlings of native species for restoration activities. However, permission and guidance of relevant authorities are required if seedlings are collected from these sites.

Plants that grow in building crevices will not survive for long in that environment. Thus, collecting these will also not harm the environment. When collecting seedlings, attention must be paid to collect disease-free seedlings, without predatory insects. Further, the seedling must be uprooted with care, without damaging the taproot. Suitable equipment (such as handheld dibbles[28], spading forks[29] ,digging hoes[30] and garden trowels[31]) can be used to uproot seedlings

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[28] A pointed implement used to make holes in the ground in which to set out plants or to plant seeds

[29] A gardening implement, with a handle and several (usually four) short, sturdy tines. It is used for loosening, lifting and turning over soil in gardening and farming

[30] Primarily used to dig and till the soil: to chop through sod to break it up and allow removal. In Sinhala and Tamil this is called a mammoty

[31] A hand tool with a pointed, scoop-shaped metal blade and handle

depending on the relevant situation. Uprooted seedlings must be transported immediately to the nursery and protected from drying. Transporting uprooted seedlings in water-filled buckets (Figure 33a) or wrapping seedlings with a moistened towel (Figure 33b) protect seedlings from wilting during the transportation. As soon as seedlings are transported to the nursery, they must be planted in a nursery bed or in containers.

Figure 33. Transporting collected seedlings (a) in a water filled bucket and (b) by wrapping seedlings with a moistened towels

Propagules produced through vegetative propagation

Layering, cuttings, root suckers, obtaining plantlets from other vegetative propagative structures and tissue culture are some means of producing vegetative propagules (Hartmann et al., 2010). However, propagules prepared from vegetative parts are genetically homogenous and therefore, many advantages and disadvantages are associated with it. Genetically homogenous[32] plant populations could be wiped off easily in a disease outbreak or under natural stress such as drought or changes in temperature. However, vegetative propagation is a good method to establish a plant population, with desirable characters selected to cope with particular stressors occurring in the proposed restoration site. As an example, in the late 1900s, when American chestnut (*Castanea dentata*) tree populations were devastated by a fungal pathogen (*Cryphonectria parasitica*) attempts were made to restore these populations with a fungus-resistant chestnut variety, produced through breeding with the Chinese chestnut (*C. mollissima*) and propagated through the vegetative method (Thompson, 2012).

Layering

Plant layering is recommended for propagating hard-to-root plants, as plant layering ensures the support of the mother plant to the propagule till it is detached from the mother plant. Therefore, there is a higher chance for the layered branch to survive until the roots are formed (Hartmann et al., 2010), as compared to a plant cutting. First, suitable plants and branches must be selected for layering. Disease-free, healthy plants must be selected as mother plants for layering. About 30.5

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[32] Alike in all characteristics

cm long and ~1 cm diameter branches can be used for layering. Part of the stem must be girdled[33] off from the selected branch with sharpened grafting knife (Figure 34a). A commercial hormone mixture containing auxin should be applied to the wounded stem, if the species is a hard-to-root one. The wounded area is packed with a moistened substrate such as compost, sawdust and coir dust. However, before using it as a substrate, sawdust and coir dust must be treated, to leach off the phenolic compounds that otherwise, will negatively affect root formation. The wound covered with moistened medium should be wrapped in polythene and each end tied (Figure 34b). Care must be taken to keep the layering medium moistened throughout. After about 3-4 weeks, roots will appear and can be seen from the outside. When roots are visible, the rooted stem can be separated from the mother plant and grown in a container or in the nursery bed.

Plant cuttings

There are two types of plant cuttings (Hartmann et al., 2010). Softwood cuttings are produced from new shoots which are not woody, while hardwood cuttings are taken from woody stem parts. Softwood cuttings can be attacked easily by pathogens and become wilted easily. In contrast, hardwood cuttings are tough and therefore, will not be attacked easily by pathogens. However, there may be hard structures in hardwood cuttings that may restrict the root protrusion. Thus, the cutting type must be selected according to the situation.

Figure 34(a). Grafting knife used in layering and (b) layered branch covered with polythene tapes

Like the selection of a mother plant for layering, selecting mother plants for cuttings is also particularly important. Healthy mother plants, with little predation, must be selected. Healthy predation-free branches without structural abnormalities must be used for cuttings. If branches are cut from a tree in a natural habitat, care must be taken to ensure minimum damage to the tree. Branches collected from the field should be brought to the nursery as quickly as possible, taking precautions to minimise wilting. Cuttings can be prepared in the nursery. A knife with a sharp blade should be used to prepare plant cuttings (Figure 34a). A commercial plant hormone mixture (containing auxin) should be applied to the cut surface of the end which will be immersed in soil, while Vaseline should be applied in the cut surface of the other end. Although there is no hard and fast rule about the size of cuttings, a manageable size should be used. Ten to twelve centimetre-sized softwood cuttings are recommended, while for hardwood

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[33] Also called ring-barking, girdling is the complete removal of the bark from around the entire circumference of either a branch or trunk of a woody plant

cuttings 10 -20 cm size is recommended. Cuttings can be grown in a nursery bed or in a container. Removing leaves, incubation in a plant propagator (Figure 35b) and supplying an adequate amount of water regularly are recommended to protect cuttings from wilting.

Figure 35. Plant cuttings grown in pots containing topsoil, sand, compost medium
a) leaves were half cut and exposed cut ends of cuttings were sealed with Vaseline.
b) cuttings grown in a plant propagator to conserve water
(Source: Perera, unpublished data)

There are some species that have chemical or structural barriers against the formation of roots in the cuttings. They may contain a high amount of phenolic compounds, which inhibit callus[34] formation and root initiation (Hartmann et al., 2010). There are many treatments to remove phenolic compounds from branches. One of the successfully tested methods involves the preparation of sodium tungstate and sodium carbonate solution (Eganathan & Rao, 2001; Perera et al., 2000). The stock solution of sodium tungstate and carbonate solution should be prepared by dissolving 5 g of each of the above compounds in 25 cm^3 distilled water. The cuttings must be immersed in 10 % dilution of the above solution for 10 min, and again with 5 % dilution of the solution for 30 min, to remove phenolic compounds from the cut surface. Additional cuts could be made in the cuttings in the rooting surface if there are structural barriers to root protrusion.

Seedlings from seeds

Mother tree selection for seed collection is the first step in the production of propagules from seeds. The mother plant for seed collection should be a disease-free plant, with a high amount of seed production. It is better if seeds can be collected from more than one mother tree. Collecting seeds for the nursery from more than one mother plant, adds more genetic diversity of the same species to the restoration site. Mother trees selected for seed collection should reflect the normal morphology of the species and it is better if those mother trees are from the same climatic zone as the site for restoration (Mbora et al., 2009; Schmidt, 2000). It is important to collect the required amount of seeds without damaging the vegetation, i.e., a

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[34] Soft tissue that forms over a wounded or cut plant surface, leading to healing

considerable amount of seeds must be left on each mother plant for natural regeneration to continue. Seeds can be collected from the tree or from the ground. However, there can be more predated, diseased and non-viable seeds on the ground. Thus, care must be taken to collect non-predated, healthy, viable seeds when collecting seeds from the ground. When seeds are collected from the mother tree, it is important to collect fruits of the correct stage of maturity. The colour of the fruits and seed hardness can be used to determine the maturity level of seeds depending on the species.

Brown paper bags, jute bags and porous bags are the best to collect seeds. When bags are porous, they allow air circulation and thus, reduce the rate of deterioration of seeds. Polythene bags are also another option, but the lack of air circulation can increase the CO_2 content inside the bag and can trap heat, increasing rates of ripening and deterioration (Rzpeka et al., 2019). Therefore, as quickly as possible, seeds must be brought to the nursery and processing must be carried out.

Seed cleaning

After the seeds/fruits are brought to the nursery, several pre-processing operations must be conducted. The first step of this processing is seed cleaning. Seed cleaning varies with the fruit type. Seeds can be removed from dry fruits by threshing[35] them. After threshing dry fruits, fruit debris must be removed by blowing, fanning or sieving. Fleshy fruits are very hard to clean, as the fruit pulp is bound tightly to seeds. To clean fleshy fruits, soaking and fermenting them in distilled water for 2-3 days is required. After soaking fruits, it is easy to remove the fruit pulp from seeds easily. Sieving or rubbing seeds against each other can be used to remove fruit pulp from seeds. After removing fruit debris, seeds should be treated chemically to remove surface pathogens that could be present in seeds. Seeds must be rinsed with 1 % NaOCl solution and with distilled water for six consecutive times for 30 seconds each time (Athugala et al., 2016). Finally, seeds must be washed with distilled water for 1 min to clean off the remaining chemicals. After cleaning, seeds should be air-dried for 1-2 days and then, seeds are ready to be sown in a nursery bed or to be stored.

Seed storage

Seeds are divided into two storage behaviour categories. *Recalcitrant seeds* have a low storability and lose viability when the moisture content of seeds is reduced below a certain threshold (generally to < 15 % moisture content). In contrast, *orthodox seeds* can be stored for a longer period (> 9 months) and retain viability, when dried to a lower moisture content (Hong & Ellis, 1996). Most species in tropical environments produce recalcitrant seeds (Daws et al., 2005). High technology such as cryopreservation[36] must be used for long-term storage of recalcitrant seeds. However, recalcitrant seeds of some species can be stored for short-term periods in a moist medium, at low temperatures (5-15 °C). Orthodox seeds can be stored under ambient conditions for long time periods. Thus, understanding the seed storage behaviour is important, before deciding the storage conditions, if storage is needed. Unfortunately, a series of scientific experiments are required to determine the seed storage behaviour (Hong & Ellis, 1996). However, there are several rules-of-thumb to predict seed storage behaviour, for example, using different seed and other characteristics. For example, there is a high probability for large seeds with a high moisture content and seeds of climax species to be recalcitrant seeds (Daws et al., 2005). Scientists have determined the recalcitrance of seeds of some important species.

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[35] Threshing is the removal of grains from the rest of the plant (FAO, undated).

[36] Cooling to very low temperatures

Seed pre-treatments for breaking seed dormancy

Seeds of some species are dormant, that is, even if all favourable conditions for seed germination are provided, dormant seeds will not germinate (Baskin & Baskin, 2014). However, even in a seed lot containing a large number of dormant seeds, there can be some non-dormant seeds. Thus, the general practice of most of the nursery producers is to sow a lot of seeds and get the seeds germinating within few days for nursery seedling production. However, selecting non-dormant seeds for use in restoration projects could reduce the genetic diversity of species. Instead, the best practice is to use germination pre-treatments to break dormancy and use all the germinating seeds for seedling production. Successes of the seed germination pre-treatments depend on the type of dormancy of the seed. Seeds are classified into five classes of dormancy depending on the cause of dormancy (Baskin and Baskin, 2014). *Morphologically dormant seeds* just require time for the under-developed embryo of the seeds to develop inside the seeds under favourable conditions. Thus, they do not require any dormancy breaking treatment. *Physiologically*[37] or *morpho-physiologically*[38] dormant seeds require dry storage or hormone treatments to alleviate dormancy. *Physically*[39] *dormant seeds* require acid or manual scarification treatment to alleviate dormancy, while seeds with *combinational dormancy*[40] require both dry storage and scarification treatment to relieve seed dormancy. To identify the precise germination pre-treatment, a series of experiments are required. Seed scientists have identified germination pre-treatments to alleviate seed dormancy of many species. Athugala et al. (2021) determined the dormancy of 80 montane forest species of Sri Lanka and this information is available in their paper's supporting files.

Seed sowing

Seeds that have no-dormancy or dormant seeds after seed pre-treatments can be sown directly in a nursery bed. However, if the exact germination treatment is not known, it is better to sow seeds in a tray containing moistened sand. The seed tray must be maintained until all the seeds germinate. Until that, tray must be watered adequately. Germinating seeds can be transplanted in nursery beds.

Growth medium

A suitable growth medium for plant seedlings depends on the species. There are several common growth media that could be used to grow seedlings of many species. Compost: sand: coir dust (1:1:1), topsoil: compost (1:1) and topsoil: sand: compost (1:1:1) are some of the proven media, which have worked for many species (Jayawardane, unpublished data). It is better if the pH of the growth medium is maintained between 6.0 – 6.5.

Fertiliser application

Fertiliser application for nursery plants is recommended only if plants have deficiency syndromes. When there is leaf yellowing, urea can be applied in a recommended dose, while NPK[41] fertiliser can be applied when leaf tips yellow in darker coloured leaves. Magnesium deficiency is the cause of dark veins. Although these are the most common deficiency syndromes, there can be other deficiency syndromes that occur among nursery plants. Moreover, nursery plants could suffer from toxicity syndromes because of the occurrence of toxic elements in the medium. If observed these plants must be treated accordingly.

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[37] Dormancy caused by lack of growth potential of embryo to penetrate seed coat

[38] Dormancy caused by lack of growth potential of the underdeveloped embryo

[39] Dormancy caused by water impermeable fruit or seed coat

[40] Dormancy caused by lack of growth potential of the embryo covered with water impermeable fruit or seed coat

[41] Nitrogen, Phosphorous and Potassium

Disease, predation and weed control

Mechanical control of diseases, predation and weeds is the best means of managing these is a nursery. However, regular observation of nursery plants is needed to identify diseases and predatory insects in plants and labour is required to hand-pick the diseased plant parts and predatory animals on plants. Fungal diseases are the most common among nursery plants. The recommended dose of fungicide can be applied if the disease is spreading rapidly. If the disease is severe, removing and burning of diseased plants is recommended. Predation is normally high at the seedling stage. If there is severe predatory damage, an appropriate pesticide, at the recommended dose, could be used. Maintenance of sanitation of the nursery site is important to reduce predatory and pathogenic damage. All unnecessary plants must be removed from the nursery site.

Light conditions

Pioneer species are light-loving species, while climax species prefer medium light conditions. Thus, seedlings of pioneer species can be grown in direct sunlight, if an adequate water supply is available. However, seedlings of pioneer plants can also become wilted when they are in full sunlight, especially when they were not supplied with an adequate amount of water. Seedlings of climax species will not survive under full light conditions, as they are physiologically adapted for low light conditions. Thus, seedlings of climax species must be grown in a shade house, covered with 20-50 % shade nets. They could also be grown under shade of nurse trees like *Glyricidia sepium*.

A nursery is a place where there must be intensive attention to raise healthy, vigorous seedlings. If the above-mentioned good practices can be followed, production of the above type of seedlings will not be a problem. Seedlings, which are about 15 centimetres tall and one centimetre in diameter, are ready to be transplanted in the restoration site. Healthy seedlings with a low amount of predation must be selected, while diseased and predated seedlings are removed and destroyed.

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Chapter 5: Effect of Restoration on Fauna

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Introduction

A diverse range of organisms (both plants and animals) inhabiting the environment is the best indicator of the health of an ecosystem (Bastian et al., 2013). These organisms affect ecosystem processes and functions, and thereby influence ecosystem services (Brook et al., 2013). There is a direct and strong association between the diversity of animal groups and the diversity of woody natural vegetation (Harvey et al., 2006). However, woody natural vegetation has been converted to agricultural and industrial lands to fulfil human needs. Such human-influenced vegetation change causes transformation of ecosystems, with organisms losing their nesting sites, breeding grounds, as well as feeding sites, ultimately leading to their extinction (Williams, 2003). Restoration approaches with respect to animals are, therefore, mainly considered as the re-establishment of their niche habitats, despite the challenge of prior natural conditions. In that context, increased attention has been given in the recent past to providing habitat conditions for sensitive species – such as threatened species (Kollmann et al., 2016). Thus, in successful and self-sustained restoration practices, the distinct goal is to re-establish the natural habitats to re-initiate plant-animal interactions. The ultimate success of a restoration project depends on the establishment of the natural vegetation and effective responses of faunal groups to the introduced vegetation. However, these faunal groups may not reach the pre-degradation levels or the levels in similar natural ecosystems.

Factors that need to be considered in selecting a site for a restoration programme

- Type, size and the pre-restoration condition of the selected ecosystem;
- Reasons for its degradation;
- Abundance and species composition of current and historically present animal species;
- Distribution and movements of animals (dispersal, home range, migration);
- Niche relationship and resource acquisition (feeding and breeding requirements); and
- Role succession plays in species turnover.

> ***Only after the last tree has been cut down. Only after the last river has been poisoned. Only after the last fish has been caught. Only then will you find that money cannot be eaten.***
>
> ***Cree Indian prophecy***

Roles of terrestrial fauna in ecosystem restoration

Figure 36 summarises the responses of terrestrial fauna to early-stage vegetation in restoring habitats. Faunal groups are attracted to the appearance of the green cover in the restoring sites (recolonisation) and construct diverse habitats through browsing, stem-cutting, seed dispersal, and other activities (restoring). These animals act as passengers in the restoring sites and influence the floristic diversity and its composition and establishing food webs (ecosystem functions) during re-vegetation. The recovery of the faunal groups in restored sites mainly depends on the age of the restoration and the re-vegetation techniques that are applied (Catterall, 2018). Proximity to the source populations in habitat and the type of dominant habitat and intrinsic mobility of different species are significant factors that influence the rate of dispersal and the establishment of faunal groups in restoring sites (Catterall, 2018). Faunal groups are, however, the ultimate beneficiaries of the restoration programmes, as the new vegetation provides a wider range of microhabitats, as well as connectivity among forest patches. Thus, animals can establish healthy interactions with the environment. Restoration may not succeed if it does not consider the re-establishment of interactions that are crucial for ecosystem functioning (such as pollination and nutrient cycling).

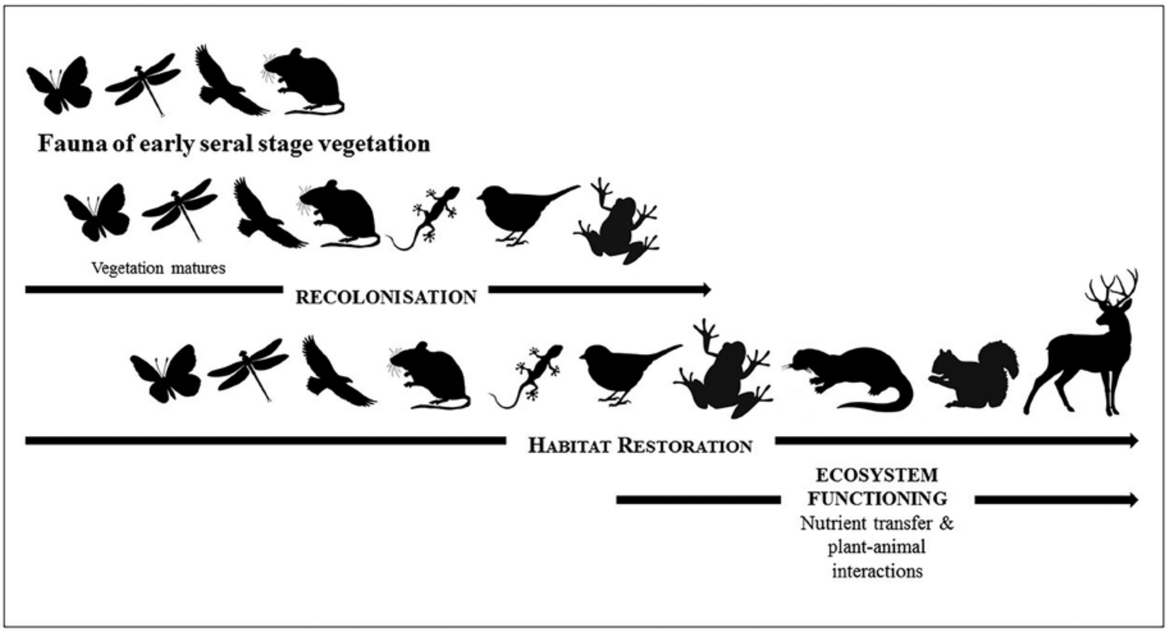

Figure 36. Sequence of the colonisation of terrestrial fauna in a restoring habitat

Animals directly influence early-stage plant colonisation through seed predation and seedling herbivory (Figure 37). For example, rodents and birds are important seed predators and dispersers in forests. They are early visitors to any restoration site and contribute significantly to the rate of spread of seedlings. These animal groups are important in maintaining top-down cascades (where the top consumer/predator controls the primary consumer population) of the ecosystem.

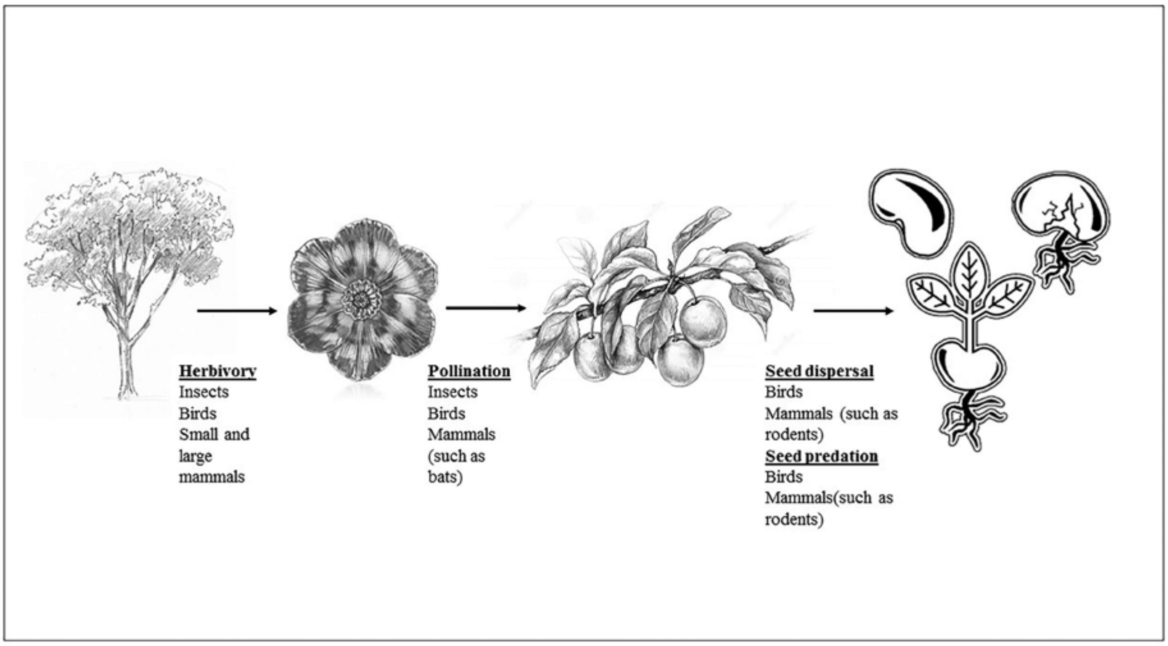

Figure 37. Plant-animal interactions that shape the regeneration dynamics of restoration sites

Prioritised faunal groups considered in restoration practices

Planned restoration programmes select degraded sites considering the existing faunal groups in the site. The site selection and the vegetation type need to be decided according to the status of the animal groups.

Threatened species

Threatened species are always given priority. These include Critical Endangered, Endangered and Vulnerable species based on quantitative criteria for threat of extinction, used for classification within categories (IUCN, 2012). These species are prioritised conservation species, thus, restoration programmes are focused on them to re-establish conditions for them, assuming that other less threatened species may also be conserved.

Species with important roles in ecosystem functioning

Those species that have important roles in ecosystem functioning (for example, nutrient cycling, seed-dispersal, and pollination) are the second most important animal group that is considered in restoration. (See Figure 37 for examples for seed dispersal and pollination. Insects – such as beetles – are important detritivores and are, therefore, important in nutrient cycling.)

Keystone species

Keystone species are critical for the overall structure and function of an ecosystem, and therefore, in the absence of a keystone species, many ecosystems would fail to exist. These species are also in the priority list. Large mammalian predators are usually considered keystone species.

Umbrella species

An umbrella species is a "species whose conservation confers a protective umbrella to numerous co-occurring species" (Fleishman et al., 2000 in litt. Roberge & Angelstam, 2004). Restoration for such species requires large areas of habitat, and therefore, is beneficial for numerous other species. Elephants and leopards are considered umbrella species.

Charismatic species

These are well-known and usually "likable" species which are also considered, as these organisms attract public interest and support for the restoration activities.

Monitoring procedure to determine the effectiveness of the restoration through animal colonisation

Continuous monitoring of the establishment of flora and fauna is required to understand the effectiveness of the restoration programme and the achievements of project milestones. The comparison of selected ecosystem performance variables between degraded and restored lands and also between restored and natural lands is the ideal approach to evaluate the effectiveness of the restoration activity. Through this approach, the researcher can understand the level of survival and effective reproduction of native organisms in the newly restored area. When the conditions of the newly restored area reach stability and are favourable for natural ecosystem services, the organisms are able to reproduce viable offspring to establish a stable population. The qualities of the vegetation indicate habitat sufficiency (feeding and breeding grounds) for fauna. To monitor the level of habitat development, key indicator organisms that represent the functioning of the ecosystem should be chosen. Faunal surveys can be carried out to understand the level of achievements in the proposed restoration programme.

Faunal survey

Vertebrates

The commonly used vertebrate fauna includes common bird species, lizards and amphibians (herpetofauna), as well as mammals (such as mongooses and squirrels) in the selected site.

Birds are the most commonly used indicators, as they are relatively easy to observe compared to other fauna. Also, birds are insectivores, granivores, or carnivores. They are highly sensitive to environmental change. Therefore, the increasing number of diverse bird fauna over time in a restoration site is evident in the development of feeding guilds[42]. Thus, the survey information of birds in a restoration site provides crucial information in understanding the establishment of successful interacting processes such as primary productivity, food webs, and pollination.

Invertebrates

Invertebrates are the main contributors to species diversity in an ecosystem. They are linked directly to diverse ecosystem processes, including nutrient cycling and the development of soil structure. As invertebrates species are abundant and diverse, they are easily collected for surveys. Invertebrates such as butterflies, dragonflies, bees, and spiders are key species that are surveyed in restoration practice.

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[42] A group of species that have similar requirements and play a similar role within a community

Identifying organisms to lower levels of taxonomy, such as an order or family is important to determine the faunal composition of the restored site; in turn, to measure the level of achievement of the goals of the project. However, to elaborate on the success of the restoration activity for conservation purposes, species-level identification is required, because some species have specific habitat requirements. The faunal surveys should be carried out over at least six months and between seasons to understand the colonisation pattern.

Line transect method

A line transect is simple method used in the field surveys. A transect line is any predetermined line that is marked at regular intervals. All animals seen on and from the transect line are counted and recorded. The perpendicular distance from the transect line to the seen animal is measured and the number of animals seen in the vicinity is also recorded (Figure 38).

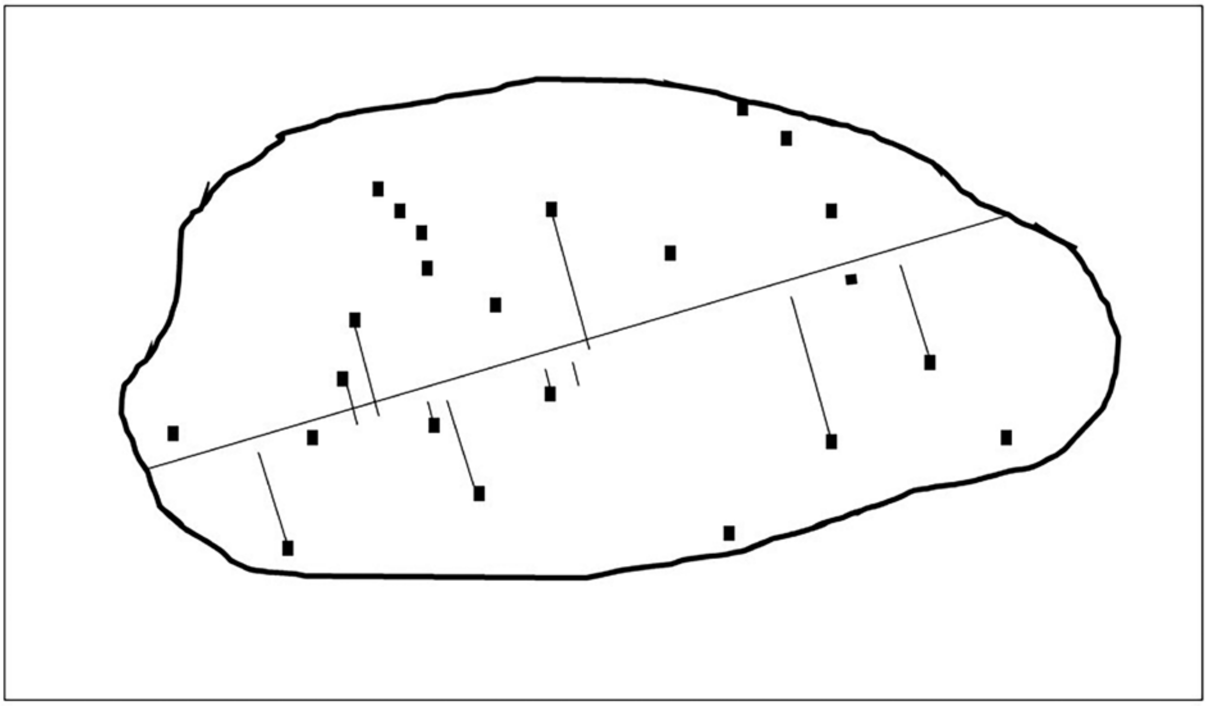

Figure 38. An illustration of a line transect

Point count method

The researcher stands in a specific location and counts birds. The number of individual birds of each species is counted within a circle of a certain radius for a specific period. The radius of the circle needs to be in the observer's visible range but also as large as possible to maximise the collection of information. The most common practice is to collect information for 10 minutes from a 20 m radius circle (Figure 39).

> ***. . . every green tree is far more glorious than if it were made of gold and silver.***
>
> ***Martin Luther King, Jr.***

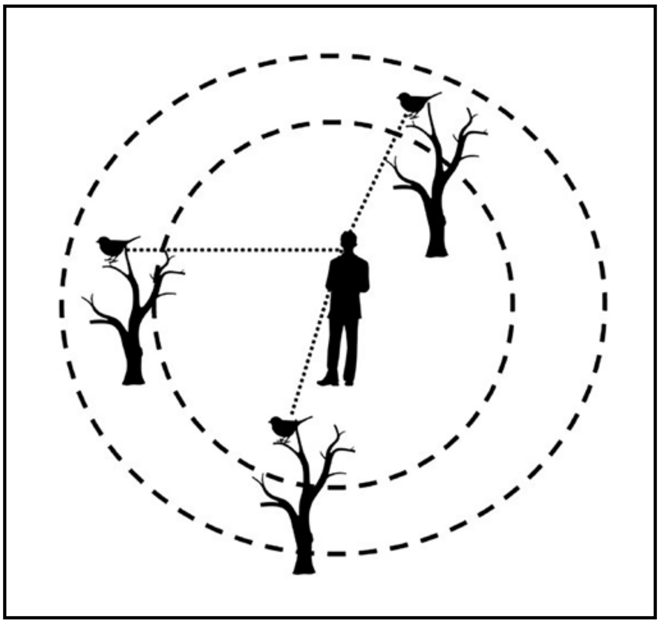

Figure 39. 20 m radius point count circle

Quadrat method

A series of a pre-determined size of squares (quadrats) is placed in the selected habitat and the animal species within those quadrants are counted and recorded. The organisms in the field can be photographed for detailed analyses. Abundance of organisms found at the study site are calculated using the number found per quadrat and the size of the quadrat area (Figure 40).

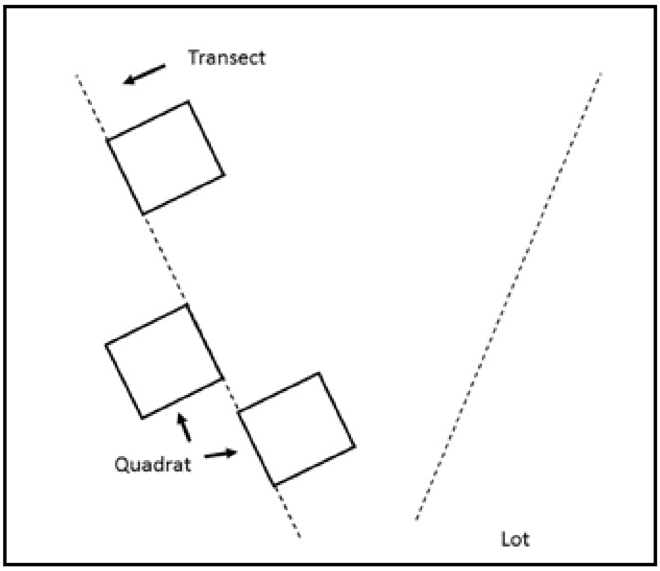

Figure 40. Quadrat method

Through the above methods, the efficacy of restoration can be assessed using fauna

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Case study of a systematic restoration programme in the Knuckles Mountain Range: effect on fauna

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The Knuckles Mountain Range (*Dumbara Kanduwatiya*, “Mist-laden Mountain Range”) lies in central Sri Lanka (in the districts of Kandy and Matale) and extends over about 21,000 ha. This mountain range is unique, with varying topographic and climatic conditions, a wide variety of ecosystems, within which is associated high faunal diversity. The high endemism of the fauna and flora characterise this area to be among the most biodiversely rich of Sri Lanka. Six hundred and three species of fauna, among which are 186 endemics, are known residents in this area (Perera et al., 2018). From known species, 21 are point endemics[43] and 178 are nationally threatened species (Perera et al., 2018). However, this world heritage site is subjected to forest degradation because of human interventions that affect the flora and fauna of the region. Therefore, we proposed a systematic reforestation activity to connect fragmented areas to enhance the habitats for threatened species (Figure 41). Our conservation approach to conserving unique faunal groups restricted to Knuckles mountain region is described below. The effort is to conserve those organisms through the restoration of the degraded land areas in the Knuckles region.

Restoration project introduced to conserve the fauna of Knuckles

Objective

To significantly increase the health and integrity of the ecosystem through ecological connectivity. This may facilitate the stabilisation of affected, threatened, and functionally important faunal groups in the restoration site.

Expected outcomes

The outcomes of the project are conservation-focused, in particular, the expansion of habitat access for the unique and diverse fauna of the Knuckles region. The expanding habitat increases ecological connectivity within the local landscape to benefit the threatened faunal groups in adjacent forest patches.

Focus faunal groups

- Yellow-eared Bulbul (*Pycnonotus penicillatus*);
- Kirtisinghe’s rock frog (*Nannophrys marmorata*);
- Hump-nosed lizard (*Lyriocephalus scutatus*);
- Knuckles pygmy lizard (*Cophotis dumbara*);
- Leaf-nosed lizard (*Ceratophora tennentii*); and
- Soil fauna. (See Figure 42 for some of the above.)

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[43] Point endemics are often small and live in very restricted, difficult-to-access areas made up of only a few square kilometres of land

Figure 41. Restoration site in Knuckles

Faunal survey:

The point count method, line transect method (2×100 m line transects) and litter sampling was carried out to observe the faunal diversity and abundance.

During a period of one year, the following was observed:

- Because of flowering and fruiting plants introduced at the restoration sites, there was habitat enrichment.
- The diversity of fauna increased noticeably. A significant increase of the focus faunal group is expected within at least a three years of the restoration.

The quality of the physical properties of the soil (i.e. moisture, pH, and humidity) improved substantially affecting the diversity of soil fauna and many more soil invertebrates such as insects, other Hexapods44 such as Diplurans45 and Collembolans46 as well as , Arachnids[47], Gastropods[48], and Oligochaetes[49]. There was a noticeable increase of the abundance of drywood termites and Zorapterans[50] after the restoration.

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[44] Hexapods include three orders of wingless arthropods (Collembola, Protura, Diplura), as well as the insects. They have with three body segments joining to form the thorax, and one pair of legs from each thoracic segment (Tree of Life Project, 2004).

[45] These are commonly known as two-pronged bristletails. The name for the group refers to two filaments at the end of the body. These Hexapods are common in moist soil and leaf litter, but not seen easily because they are small and hidden (Koch, 2009).

[46] These are commonly known as springtails and are among the most abundant of all soil-dwelling arthropods. They live in a variety of habitats where they feed as scavengers on decaying vegetation and soil fungi. They are named for the forked jumping organ found on abdomen which allows them to avoid predation (ENT 425 - General Entomology, 2015).

[47] Arthropods with eight pairs of legs

[48] Snails and slugs belonging to the group Mollusca

[49] Aquatic and terrestrial worms, including all of the various earthworms

[50] Sometimes called angel insects, there are tiny insects found in warm climates, found inside barks or in rotting wood or leaf litter. They are scavengers (Amateur Entomologists' Society, 2021).

Figure 42. Some of the faunal focus groups

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Chapter 6: Mangrove Restoration

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Introduction

Mangrove forests are found in inter-tidal coastal areas of the tropical and subtropical regions of the world. These forests are characterised by salt tolerant trees and bushes adapted to the daily fluctuations in flooding and salinity that occur with the tides. Under suitable conditions, mangrove forests form one of the most productive ecosystems of the world. The term ‘mangrove’ describes both the ecosystem and the plant species that have developed specialised adaptations (see Box 9), which enable them to live in this inter- tidal environment (Tomlinson, 1986).

Mangroves ecosystems are found along shallow-water lagoons, estuaries, coastal areas of rivers, and sheltered coastlines or deltas in 124 tropical and subtropical countries (FAO, 2007). The exact number of mangrove plant species is still under discussion, and ranges from 50 to 70 according to different classifications (Tomlinson, 1986; FAO, 2007), with the highest species diversity found in Asia, followed by eastern Africa (FAO, 2007). The major genera that represent these species are *Rhizophora, Bruguiera, Avicennia, Lumnitzera* and *Sonneratia*. Using abundance and distribution, mangroves can be categorised as very common, common, rare and very rare (FAO 2007). The common species of Sri Lankan mangroves are *Rhizophora mucronata, R. apiculata, Bruguiera gymnorrhiza, Avicennia marina, Excoecaria aggalocha, Lumnitzera racemosa,* and *Sonneratia caseolaris* (Amarasinghe & Perera 2017).

In Sri Lanka, out of a total land extent of 65,6I0 km^2, 24% is found in the coastal region and mangroves are covers only 0.1-0.2 % of total land area (MFF/IUCN, 2017). Mangroves in Sri Lanka occur along the sheltered intertidal coastlines associated with estuaries and lagoons, and only two patches of mangroves – in the north-western coast and in the Kala Oya estuary function as shoreline mangroves. The last estimate of the extent of mangroves, carried out by the Forest Department quoted in MoMD&E (2019) appears to be 19,726 ha. In Sri Lanka, the largest tracts of mangrove ecosystems are found along the north-western coast in the Mannar district, the Kala Oya basin, as well in the Jaffna Peninsula and in the Trincomalee District. Further, there are also mangroves fringing the lagoons of Puttalam, Chilaw, Negombo, Koggala, Rekawa, Panama and Kokilai. Bolgoda Lake and Madu Ganga are other important mangrove areas of Sri Lanka. Many mangroves in Sri Lanka occur in discrete, fragmented small patches (MoMD&E, 2019) and hence, should not be termed mangrove forests[51]. The distribution of the mangroves of Sri Lanka is shown in Figure 43.

The importance of mangroves

Mangroves have historically provided invaluable ecosystem services to coastal communities, as well as to the entire island. Many mangrove species provide food (Ranawana, 2017) traditional medicines (Bandaranayake, 1998) and wood and firewood (Kaleel & Nijamir, 2017)

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[51] In contrast, the Sunderbans of Bangladesh and India, is a mangrove forest that extends over 140,000 ha (UNESCO, 2021).

Box 9. Adaptations shown by mangroves to their habitat

(Sources: Tomlinson, 1986; Kathiresan & Bingham, 2001, Miththapala, 2008)

Salinity, as well as availability of fresh water, fluctuates in this inter-tidal habitat due to the daily movement of the tides and also due to the changes in the rate of flow of the rivers that bring water and sediment down to the sea. Mangrove plants cope with the high levels of salt and lack of fresh water through several xeromorphic[52] characters that enable them to conserve water (for example, thick, waxy cuticles that reduce evaporation of water from the plants, positioning of stomatal pores in such a way as to reduce loss of water from their leaves, the presence of water storage tissue). Halophytic[53] characteristics also enable them to tolerate high concentrations of salt (for example, salt excretion glands in the leaves, excluding the uptake of salt through their roots, having a higher than usual concentration of sodium chloride in the sap.)

The substrate in mangrove ecosystems is usually a muddy, water-logged soil and mangrove trees have specialised roots, which enable them to cope with a substrate that shifts with the flow of water (for example, the stilt roots in *Rhizophora*) and is also anaerobic (low in oxygen). Several mangrove trees have structures called pneumataphores in special, above-ground roots, which allow oxygen to be transferred to the below–ground root system. These vary in structure and may be pencil-shaped as in *Rhizophora* and *Avicennia* or like a bent knee in *Bruguiera*.

Several mangrove species display a characteristic called vivipary, where seeds germinate while still attached to the parent tree. The mature seedling has a long root-like structure which lodges in the mud when the mature fruit finally drops off the tree and holds the shoot of the seedling above water at high tide.

for nearby communities. In addition, mangroves are critical hatching and nursery grounds for commercially important fin and shellfish. It is estimated that 36 t/yr of finfish and 10.8 t/yr shrimp are caught from Rekawa lagoon (Gunawardena & Rowan, 2005).

Mangroves retard the force of water from storm surges and other extreme hydrological weather events and therefore, they significantly decreased risk from such extreme events, providing protection by their natural infrastructure (Blankespoor et al., 2016). In Sri Lanka, mangroves protect lagoon and estuary banks (in which they are found) from floods and storm surges except in the northwestern coast (Swan, 1983, in litt. NSAP, 2009), where they provide shoreline protection. Their roots also function as filters sifting out pollutants that reach from inland waters. Therefore, they improve the quality of water reaching sensitive coastal ecosystems — such as coral reefs and seagrasses. Decaying organic matter from mangroves is broken down into free nutrients that are washed away to the sea and enrich coastal food webs, and with it, coastal fishery production.

Mangroves support diverse communities of flora and fauna. In a study in Chilaw lagoon (Sarathchandra et al., 2018) found 25 species of true mangroves,18 mangrove associates and 28 species of vertebrate and invertebrate fauna. A much older study (Bambaradeniya et al., 2002) of the mangroves of Maduganga in the southwest reported 303 species of plants and 248 vertebrate species as well as nesting and roosting sites of water birds, crocodiles and bats.

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[52] Having characteristics that serve as protection against excessive loss of water

[53] A plant adapted to growing in saline conditions

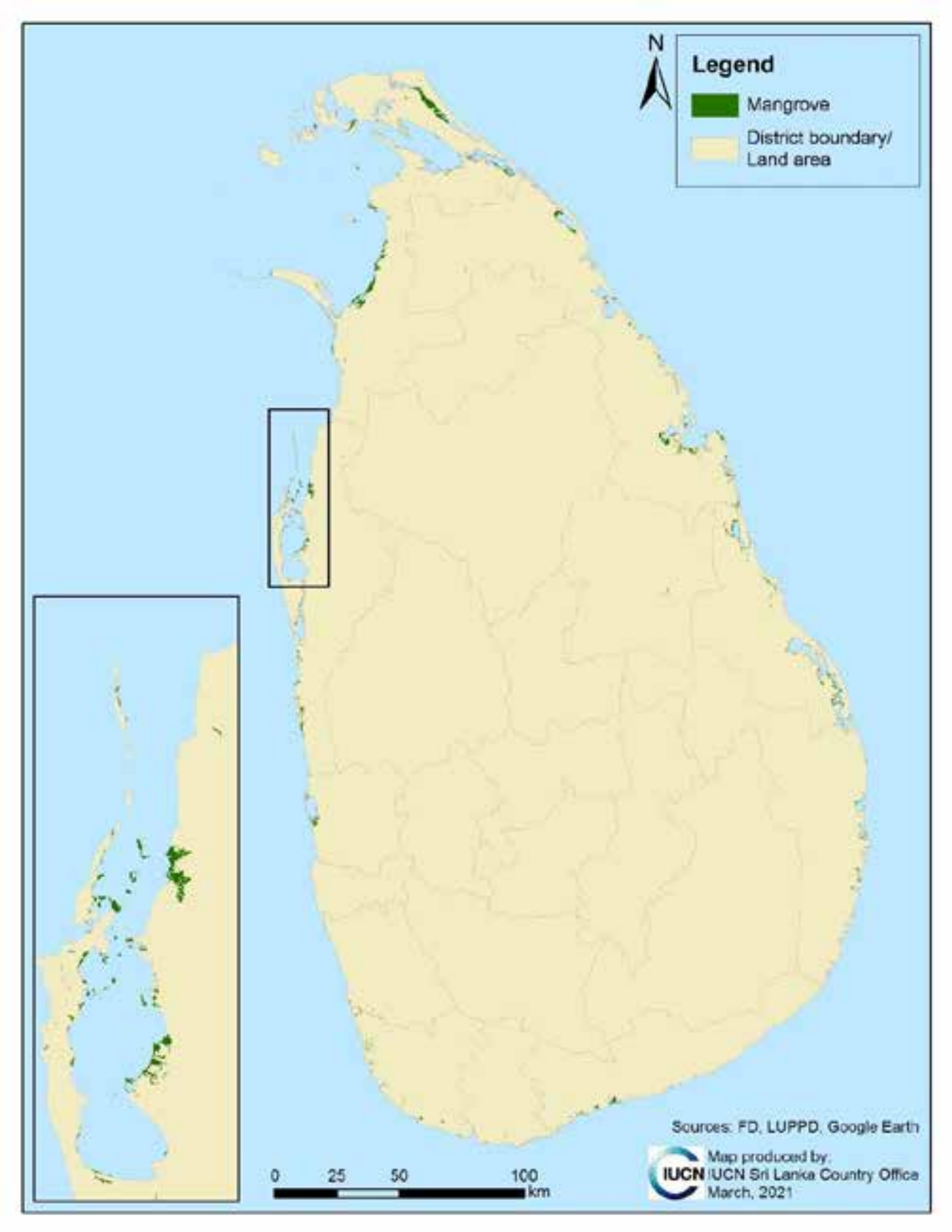

Figure 43. Distribution of mangroves in Sri Lanka
(Source: IUCN, 2021)

Mangroves are productive areas. Net primary production in Negombo lagoon has been calculated as 2280 ± 125 g m^{-2} y^{-1} (Perera & Amarasinghe, 2016).

Among the services provided by mangroves, perhaps the most important relevant to this book is carbon sequestration. Blue carbon ecosystems (mangroves, salt marshes, and seagrass meadows) are inter-tidal ecosystems that are known to sequester carbon at a rate 2-4 times greater than those of tropical terrestrial forests and store this carbon not only in their above- and below-ground parts, but also in the soils in which they are found (Conservation International, 2019). Mangrove soils are huge carbon sinks (Atwood et al., 2017). It is estimated that the mean annual carbon sequestration rate for mangroves is 6-8 Mg CO_2e/ha[54] (Conservation International, 2019).

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[54] Tons of CO_2 equivalent per hectare

In Sri Lanka, in the Negombo lagoon/estuary, it was estimated that 499.45 Mg C ha^{-1} of carbon was captured by the mangroves left in the area (Perera et al., 2018). Of this, 418.98 Mg C ha^{-1} (84%) is sequestered in soil and 80.56 Mg C ha^{-1} (16%) in the vegetation (Perera et al., 2018). Seven mangroves areas in lagoons and estuaries assessed representing all three climatic zones showed that carbon captured ranged from 316.29-580.84 Mg ha^{-1} (Perera & Amarasinghe, 2019).

Mangroves under threat

However, mangrove ecosystems – like their terrestrial counterparts – have been destroyed or degraded (Figure 44), because of continuing unplanned and unsustainable anthropogenic activities.

Mangroves and other coastal wetlands have long been considered unimportant and for centuries mangroves have been cleared to make space for agriculture, and the expansion of human settlements, and later, infrastructure development and the establishment of industrial areas.

Mangroves have also been destroyed to establish aquaculture projects, including shrimp farms. In the 1980s and 1990s, when shrimp farms proliferated around the Puttalam Lagoon, large tracts of mangroves were destroyed (Bournazel et al., 2015). A study showed that between 1991 and 2012 shrimp farms increased by 2,777%; salterns increased by 60%, coconut plantations increased by 17% while mangroves decreased by 34%, with an estimated net carbon loss of 191,584 tC (Bournazel et al., 2015). There is also cryptic degradation – where mangrove associates replaced mangroves (Dahdouh-Guebas et al., 2005).

The mangroves of the North and East, untouched previously because of the civil war, are now being fragmented by culverts, barrages and cross-roads Chirutivu, Thodaimanaru lagoon, Katys and Uppu Aru (Gnaneswaran, 2015 in litt, Weerakoon et al., 2018). Vidattaltivu, one of the largest patches of mangrove in Sri Lanka (and a nature reserve under the DWC) is under threat for the creation of a 1,000 ha aquaculture park.

If mangroves are lost, then globally CO_2 emissions from soils are predicted to be ~7.0 Tg CO_2e yr^{-1} (Atwood et al., 2017).

Mangrove trees are very commonly used for firewood, fish traps, construction materials, charcoal production and animal fodder. Much of this extraction has now become unsustainable, for example, in the Northern Province (Weerakoon et al., 2018).

Point pollution and non-point pollution (such as agrochemicals which are used by farmers in highland areas) degrades ecosystems such as mangroves ultimately, decreasing availability of food and reducing buffering capacity against extreme weather events. Solid waste dumping – of domestic garbage and industrial waste – is another source of degradation in mangrove habitats (Saenger et al., 1983).

Inland irrigation systems and water diversion from natural waterways reduce the amount of water reaching mangrove ecosystems, changing the salinity level of the water in these habitats. If salinity becomes too high, mangroves – adapted to the ebb and flow of the tides – cannot survive. In addition, increased erosion due to land deforestation can hugely increase the amount of sediment in rivers and causing siltation in mangroves (Saenger et al., 1983).

Figure 44. Mangrove destruction in the Puttalam Lagoon area
(© IUCN/Naalin Perera)

The impact of climate change will also have profound effects on mangroves. For example, high temperatures increase evaporation, which increases salinity. The combined impacts of both of the above also influences species composition and productivity (Ward et al., 2016). Increased rainfall may decrease salinity in some mangrove ecosystems, while decreased rainfall and increased evaporation will lead to increased soil salinity, with an ultimate loss of productivity, affecting regulating and provisioning services of this system, including carbon sequestration (Ward et al., 2016). Sea level rise will result in the loss of land occupied by mangroves and to plant death at the seaward margins. This will again affect both species composition and productivity (Ward et al., 2016). Changing wave climates increase coastal erosion and damage mangroves; while saltwater intrusion will also alter the salinity regimen in mangroves, both changing the species composition and productivity (Ward et al., 2016) ultimately affecting provisioning and regulatory services.

Guidelines for the restoration of degraded mangrove ecosystems

These guidelines are designed to assist those who intend to undertake mangrove restoration projects in degraded mangrove areas of Sri Lanka. However, it is of paramount importance to emphasises that *conservation of existing mangroves is more important than restoring degraded mangrove ecosystems.*

A second point that cannot be over-stressed is that mangrove restoration should be carried out only in degraded mangrove areas: mangroves should not be introduced into any other part of the coast or into other coastal ecosystems such as tidal flats and salt marshes.

It is recommended to that a multi-disciplinary expert/team is formed to develop a restoration plan for degraded mangrove areas. The following experts may be needed for ecological restoration planning, based on the extent and type of mangrove restoration proposed: botanist, forester, coastal ecosystem expert, hydrologist, coastal environment engineer and nursery management expert.

Restoration planning

In order to run a successful restoration, programme the following steps are recommended.

1. Understand the environmental factors, terrain, and extent of the proposed restoration area. Study the ecology, and hydrology of the selected mangrove ecosystem and also any undisturbed mangrove area nearby – in particular the composition and abundance of the mangrove species present and their zonation, the patterns of reproduction, propagule distribution, and successful seedling establishment and also the presence of herbivores.
2. Understand the normal hydrological patterns that control the distribution and successful establishment and growth of the targeted mangrove species. Further, it may be necessary to identify the need for hydrological improvement of the targeted restoration site.
3. Assess modifications of the original mangrove environment that currently prevent natural secondary succession (recovery after damage). It is possible to consult the local community or researchers who work in the area to understand the pre-destruction status of the proposed mangrove area. Historical maps, images and reports should also be used for this purpose.
4. Design the restoration program to restore appropriate hydrology and, if possible, use natural mangrove propagules for plant establishment.
   Only after determining steps 1-4, to ensure that natural recruitment will *not* provide the quantity of successfully established seedlings, rate of stabilisation, or rate of growth of saplings established as objectives for the restoration project, should the steps below be followed.
5. Identify the stakeholders who can contribute to restoration, for example, community members may help in nursery management and planting.
6. Estimate the total cost, including a breakdown of costs for different activities and requirements such as the number of seedlings needed, costs of nursery management, fencing, and labour requirements.
7. Prepare a target-oriented activity plan for restoration work.
8. Develop a proposal based on the above steps.
   Once a project proposal is approved by the relevant authority/organisation/or person, it is recommended that the following steps are taken.
9. Identify staff responsible for the restoration program including a project manager, restoration professionals and field staff.
10. Seek participation of the local community. Involvement of the local community where mangrove rehabilitation is to be carried out is essential to the long-term survival of the restored forest. Local community members may be involved with the restoration project in several activities such as mangrove seed collection, nursery management, planting, after care and monitoring.

11. Identify the site for establishment of a nursery and prepare an access road.
12. Choose the plant species to be used in the mangrove restoration based on the following factors,
    i. Species already present at the proposed restoration site or once present according to the historical records.
    ii. Growth potential and adaptability of species to the local conditions at the site.
    iii. The ecology of the mangrove species at the site; in particular, the patterns of reproduction, propagule distribution, and successful seedling establishment should be studied and understood.

Mangrove seed collection

It is important to gather propagules in good condition, that are relatively unblemished, to increase the chance of successful germination. Apart from being intact, signs of a viable propagule include fullness of shape, and a characteristic, even colour. Propagules with visible physical damage, for examples, from crabs or from tidal wash, should be rejected. Signs of non-viability include withering, desiccation, missing parts or holes made by either crabs or larvae or because of wave action.

Nursery establishment and potting

Nurseries are essential parts of reforestation programmes that help to produce healthy planting stocks and subsequently high survival rates when seedlings are planted in restoration sites. (See Chapter 4).

Propagules collected for restoration purposes can be potted into 6” x 8 “biodegradable nursery bags, to conserve nursery space and maximise the total number of plants. For better root establishment or if the plants are to be held for an extended period (for example, longer than six months), it is recommended that 8” x 12” nursery bags are used. Strategies for stopping seeds floating out of the potting mixture include spearing the cigar-shaped propagules (for example, *Rhizophora* spp., *Bruguiera* spp.) at least halfway into the soil. Grey mangrove (*Avicennia marina*) seeds can be germinated in a propagation tray containing 100% sand until four leaves are visible. They are then potted into 6” x 8” pots.

Mangrove plants are raised to larger sizes than terrestrial plants in nurseries, to withstand the harsh conditions of degraded and open coastal environments in which they will be planted.

Nursery management

Watering

Seedlings must be watered twice a day with lagoon water at the early stages. Later, they can be watered once a day until planting at the restoration site.

Shading

Shade the newly potted seedlings from intense sunlight. Dry coconut leaves can be used for temporary nurseries, while nursery mesh can be used for permanent nurseries before the acclimatisation/hardening process.

Weed the nursery at least once a week. Weeding is especially necessary when the nursery is located in home gardens or on other agricultural land. Manually remove any plants that are not mangroves. Weedicides are not recommended for mangrove nurseries. Conduct daily inspections for insects and other pests and remove them.

Figure 45. A mangrove plant nursery
(© IUCN/Naalin Perera)

Young seedlings that were grown under nursery conditions will need a period to adjust and acclimatise to conditions of mangrove habitats, prior to planting in the field. It is recommended to gradually expose them to longer periods of sunlight to acclimatise saplings before planting.

Planting

It is recommended that the hydrological pattern and also tidal patterns be studied before starting the planting. It may be necessary to restore the hydrology of the restoration site before commencing planting work. If the restoration site is isolated from the lagoon by a barrier, there may be a need to create strategic breeches, on the advice of the hydrologist, to facilitate free movement of water.

> ***We're suffocating ourselves by cutting things down. And the awful thing is that the knowledge is there. Fifty years ago when we exterminated things, we did it without realising. Now there's plenty of evidence of what it is we're doing, and yet we keep on doing it.***
>
> ***Sir David Attenborough***

Proposed zonation for mangrove restoration

Table 4. Proposed zonation for mangrove restoration and proposed species

Zone	Proposed species	Density
Waterfront	*Rhizophora mucronata*	High density
	Lumnitzera racemosa	Low density
Middle area	*Bruguiera gymnorrhiza,*	Low density
	Bruguiera sexangula	Low density
	Aegiceras corniculatum	Low density
	Lumnitzera racemosa	Low density
	Ceriops tagal	Low density
Terrestrial end (intertidal and supra tidal zone)	*Avicennia marina*	High/Low density
	Avicennia officinalis	Low density
	Excoecaria agallocha	Low density
	Heritiera littoralis	Low density

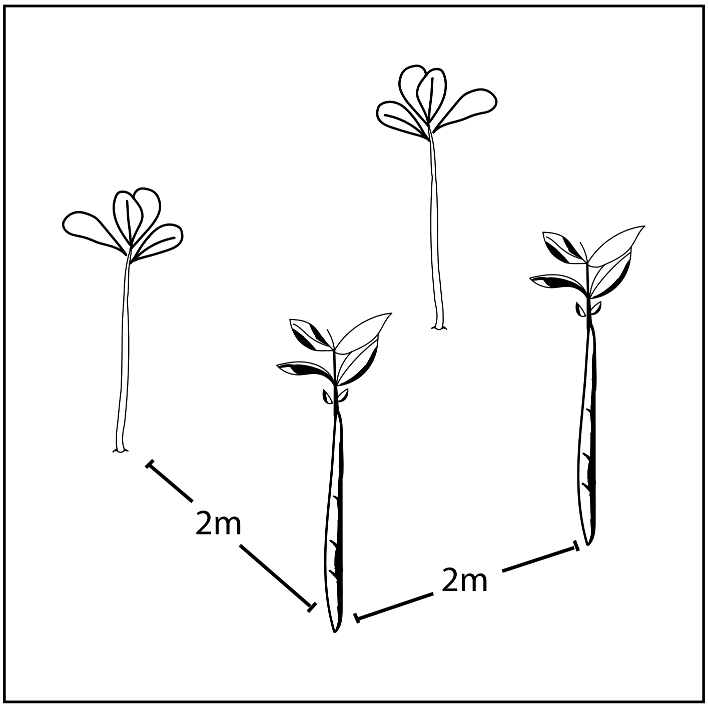

Figure 46. Pattern for planting mangrove samples in the field

Monitoring and gap-filling

The purpose of monitoring is to examine the growth of plants and to collect useful information to improve the restoration project. Many lessons can be learned concerning site selection, choice of species, and causes of mortality, which can inform future projects. The first two to three years after planting are the most critical and intensive for management, requiring regular monitoring of growing seedlings and gap-filling work. Generally, from the third year onward, the level of care required becomes less, but may involve thinning the trees if they were planted densely and for gap filling to replace damaged or destroyed plants.

Figure 47. Mangrove restoration site on the South coast in Sri Lanka
(Source: © IUCN Naalin Perera)

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Chapter 7: Urban greening

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Introduction

Currently, most people in the world live in urban areas. In 1800, only 3% of people lived in urban areas. However, by 1900, this had increased up to 14% (Verhasselt, 2009). According to the United Nations, in 2008, for the first time in world history, the population of the world was split equally between urban and rural areas. Now the scale and speed of urbanisation is faster than ever before. The urban population of the world is expected to increase up to about 65% by 2025 (Kong & Nakagoshi, 2005). Further, it has been predicted that 70% of the world's population would live in urban areas in 2050 (Cui & Shi, 2012). Most of the current urbanisation is occurring in the small towns of Asia and Africa (UN, 2018). The current rate of growth in urban populations has drastically changed the natural environment and its associated ecological balance and has had a significant effect on urban green spaces. Urbanisation has created areas that emit heat – heat islands – in contrast to rural areas where vegetation shades and cools the region (Száraz, 2014). Studies have provided evidence that green spaces in urban areas can lessen the negative impacts of climate change (Száraz, 2014). The establishment and maintenance of green spaces in urban areas is also vital as these spaces can make a major contribution towards creating more liveable, sustainable cities. Urban green spaces can be defined as public and private open spaces, primarily covered by vegetation, including or not including small water bodies, which are directly or indirectly available for users in urban areas (WHO, 2017).

Greening urban spaces includes activities involving planting trees, establishing lawns, creating parks, play areas and cemeteries as well as installing green walls, green façades and green roofs. Urban greening can be defined as public and private landscaping activities and urban forestry projects, that create mutually beneficial relationships between people living in cities and their environments (WHO, 2017). In other words, it is an activity which makes urban areas greener.

Box 11. Urban green space standards

Per capita green space is a quantitative measurement used to evaluate environmental sustainability of a city. The World Health Organization recommended the availability of a minimum of 9 m^2 of green space per individual, with an ideal value of 50 m^2 per capita. Green spaces in the Colombo city are declining and according to a study conducted by LI and Pussella (2017) a decrease of green space in the Colombo city area from 31 km^2 in 1980 to 5.02 km^2 in 2015 can be observed, resulting in a per capita value of 7.16 m^2 in 2015.

Urban green spaces can be broadly categorised into three groups (WHO, 2017):

1. Smaller green space features such as street trees and roadside vegetation;
2. Green spaces not available for public access or recreational use such as green roofs, walls and façades, or residential gardens; and
3. Larger green spaces with public access – such as playgrounds, public parks, cemeteries and arboretums – that provide various environmental, social and recreational functions.

Benefits of urban greening

Research into urban green spaces has grown considerably and these findings have led to evidence-based conclusions regarding their benefits to human beings (Lee & Maheswaran, 2011). These findings could be broadly categorised into environmental, social, health and economic benefits (Table 5).

Table 5. Benefits of urban greening

(Sources: Coley et al.,1997; Commission for Architecture and the Built Environment, 2005; Kardan et al., 2015; Sorensen, 1997; Troy et al., 2012; Zhou and Rana, 2012).

Environmental benefits	**Social benefits**
• Mitigating the urban heat island effect • Cooling buildings and outdoor areas • Shading outdoor areas • Reducing glare • Urban trees can act as a wind break • Vegetation can protect domestic properties from noise sources • Reducing runoff of urban storm water • Reducing aerial pollutants • The long-term removal, capture or sequestration of CO_2 from the atmosphere • Increasing urban biodiversity • Improving the aesthetic quality of a city	• Helping to reduce crime levels in urban areas • Mature trees can provide meeting places • Creating play areas • Contributing to the cultural identity of the city • The presence of trees reduces the speed of drivers, and reduces the frequency of accidents • Stimulating social cohesion and bringing neighbours together • Providing educational and recreational opportunities for urban residents
Health benefits	**Economic benefits**
• Promoting opportunities for physical activity/ exercise, providing mental health benefits and reducing stress • Improving the quality of life	• Increasing property value • Improving business due to high consumer demand • Generating a source of income (urban agricultural activities) • Urban greening projects are often labour-intensive and provide employment opportunities

Urban green space interventions

Urban green space interventions are defined as urban green space changes that significantly modify green space availability and features by creating new green space, changing or improving existing green space, or by removing or replacing green space (WHO, 2017). Urban green space interventions could lead to physical changes in urban spaces such as creating new or improving existing green space which could be accompanied by environmental, health, economical and/or social changes mentioned in Table 4. These changes/benefits can deliver positive outcomes in all population groups, particularly among lower socioeconomic status groups. If green space interventions are planned, designed and implemented with the participation of the local community and the intended green space users, it will ensure the derivation of benefits for the intended group. Some examples for urban green space interventions are street trees, mini parks, green infrastructure for storm water management, green roof, green wall and green façade. In this chapter, three popular green space interventions namely green roofs, green walls and green façades are discussed.

Green roofs

A green roof system is an addition made to the roof of an existing building for growing plants. Roofs can represent up to 32% of horizontal space of built-up areas (Frazer, 2005), therefore, converting these into green spaces is important in an urban context. Green roof designs may be tailored to suit a range of shapes and sizes from high-rise public parks and rooftop gardens to calm urban spaces. Green roofs are usually categorised as ‘intensive’ or ‘extensive’.

Categories of green roofs

Extensive green roofs (Eco roofs):

Extensive green roofs help to increase plant diversity and provide habitat for wildlife. They are light in weight and use a shallow layer of growing substrate (<200 mm deep). Usually, small, low-growing, succulent species and grasses are planted. This system is rarely irrigated, and the maintenance cost is low. This system is not designed to entertain people.

Intensive green roofs

This is the most common type in Sri Lanka. Intensive green roofs are accessed readily by people and are heavier than the extensive roof. This system has a deeper layer of growing substrate (usually 30-90 cm) and support a wider variety of plant types including trees. This system needs more irrigation and maintenance activities.

Layers of a typical green roof

A typical green roof consists of several layers, including waterproofing, drainage, insulation, soil substrate and actively growing plants which are not found on regular roofs (Figure 48). Each of these layers perform a specific function to keep the plants on the rooftop alive and to protect the structure of the roof.

The roof structure (roof deck)

This is the bottommost layer of a green roof. It is the main separation between the green roof above and the structural support below. Because of the weight of the growth medium, plants and excessive amounts of water associated with green roofs, the roof structure must be strong enough to support this weight.

Waterproofing layer

This is one of the most important layers. Failure to waterproof a roof garden can lead to water leakages and subsequent structural failures in the building. Liquid treatments (waterproof paint) or preformed sheets can be used as a waterproofing layer.

Protection layers

The roof's membrane needs protection to prevent deterioration. This layer makes a roof garden resistant to moisture, temperature fluctuation and root penetration. The protective layer can be a slab of lightweight concrete or thick plastic.

Drainage layer

The objective of this layer is to discharge rainwater. A gravel layer or a modular tray system (Figure 49) can be used as the drainage layer. This layer intends to retain only the amount needed for plant growth. The excess water is drained away through a channel system to prevent waterlogging or increasing the weight of the system.

Filter layer

To separate drainage layer and growing substrate, a filter layer is used. This layer prevents media particles from blocking the drainage layer below. This layer also can prevent roots from penetrating the bottom layers. Geotextile material is commonly used as the filter layer.

Growth substrate

This layer creates a suitable growing environment on a rooftop to grow plants. It is designed to be lightweight and to drain water readily yet retain some water for plants. Usually, the soil is supplemented with organic and mineral additives. A low organic component (35 %) for example, coir or compost, is mixed together with an inorganic component, for example, sand, gravel or crushed brick (in developed countries, low weight inert material such as Polystyrene or Perlite are incorporated) and then mixed with soil.

Vegetation

The top layer of a green roof consists of vegetation. Container-grown nursery plants are ideal for planting, as they already have established a root system. During plant selection for a green roof, it is important to consider the depth of the soil layer, level of maintenance of plants, the level of exposure to drought and wind. Specifically, plants with untidy leaves, flowers and fruits should be avoided.

> ***By felling the trees which cover the tops and sides of mountains, men in all climates seem to bring upon future generations two calamities at once; want of fuel and a scarcity of water.***
>
> ***George Perkins Marsh, 1864***

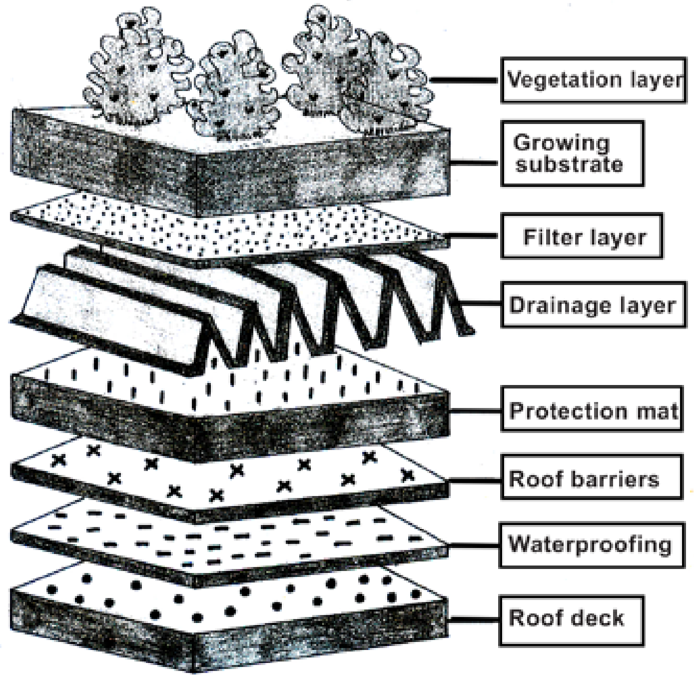

Figure 48. Cross section of a roof garden, depicting the typical layers

Plants suitable for a tropical green roof

Some examples of plants suitable for a tropical roof garden are given below.

Trees: *Bauhinia variegata* (English name: orchid tree), *Tecoma stans* (English name: yellow trumpet flower; Sinhala name: *kelanitissa*; Tamil name: *manjal alari*), *Nerium oleander* (English name: oleander, Sinhala name: *kaneru*; Tamil name: *alari), Plumeria obtusa* (English name: temple tree/frangipani*;* Sinhala name: *araliya*; Tamil name: *alari/therma*), *Barringtonia asiatica* (English name: fish poison tree; Sinhala name: *mudilla*), *Senna auriculata* (English name: Matara tea; Sinhala name: *ranawara*; Tamil name: *avarai*) *Murraya paniculata* (English name: orange jasmine; Sinhala name: *atteriya*), *Saraca asoca* (English name: Asoka, Sinhala name: *diya-rathmal*; Tamil name: *asokam*). Palms including *Cocos nicifera* var. *aurantiaca,* (English name: king coconut; Sinhala name: *thambili*; Tamil name: *sevilanir*).

Shrubs: *Codiaeum variegatum* (English name: Croton), *Pandanus odorifer* (English name: screw pine; Sinhala name: *weta-keyiya/mudu keyiya*; *Tamil name: tala), Bougainvillea* (Sinhala name: *kadadasi mal*; Tamil name: *kadadasi poo*), *Tecomaria capensis* (English name: Cape honeysuckle), *Durantha repens*, *Phyllanthus myrtifolius*, *Ixora coccinea.*

Herbaceous plants and succulents: *Crossandra infundibuliformis* (English name: firecracker flower), *Catharanthus roseus* (English name: rosy periwinkle; Sinhala name: *mini mal;* Tamil name: *patti poo*) *Sansevieria trifasciata*[55] (English name: mother-in-law's tongue/ snake plant*,* *Aloe vera* (Sinhala name: *komarika*; Tamil name: *kathraalai*).

Ground covers: *Ophiopogon jaburan* (English name: mondo-grass), *Ophiopogon japonicus* (English name: 'Kyoto dwarf'/Dwarf mondo-grass), *Rhoeo, Lantana camera* dwarf

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[55] Formerly *Dracaena trifasciata*

varieties, *Tradescantia pallida* (English name: purple heart), *Hemigraphis alternata* (English name: red flame ivy), *Alternanthera ficoidea* (English name: 'White carpet'), *A. sessilis* ('Red') *Sansevieria trifasciata* (English name: mother-in-law's tongue/snake plant), *Cuphea hyssopifolia* (English name: false heather), *Pandanus pygmaeus.*

Lawn grass: Some green roofs are constructed specifically to install lawn grasses such as *Zoysia japonica* or *Axonopus compressus* (English name: carpet grass).

Box 12. Modular tray system

Modular tray systems are now popular in Sri Lanka as they are low maintenance and can create an instant effect. They are easy to install, which minimizes construction and labour costs. Plants can be grown on modular trays and can be directly placed on rooftops. In addition to facilitating drainage, these are capable of harvesting rainwater (Figure 49).

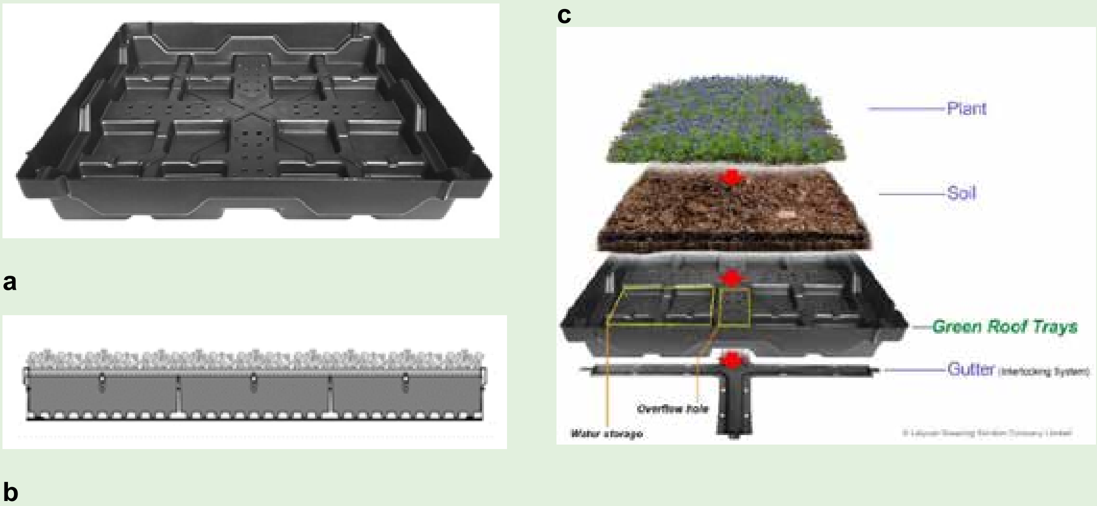

Figure 49. Modular tray system a) individual tray b) growing plants in a series of trays and c) detailed layout of a green roof modular tray system
(Source: Leiyuan Greening Solution Company)

> ***The world's forests need to be seen for what they are —giant global utilities, providing essential public services to humanity on a vast scale. They store carbon, which is lost to the atmosphere when they burn, increasing global warming. The life they support cleans the atmosphere of pollutants and feeds it with moisture. They act as a natural thermostat, helping to regulate our climate and sustain the lives of 1.4 billion of the poorest people on this Earth. And they do these things to a degree that is all but impossible to imagine.***
>
> ***Charles, Prince of Wales***

Figure 50. Left: Media incorporated modular tray covered with a geotextile layer and right: plants grown in a modular tray system on a balcony of a hotel
(© K. M. A. M. Karunarathne)

Weight loading on buildings

The buildings' load-bearing capacity must be determined prior to planning a green roof, wall or façade. Building roofs will require proper reinforcement before a roof garden can be grown safely as the structure and weight of a roof garden can cause problems for the whole building. Hence, it is vital to consult the advice of a structural engineer before and during construction to ensure a design that could last without causing problems. Consideration of the weight of plants used (particularly of shrubs and trees), and their weight at maturity is imperative, as these grow to be significantly heavier over time. The weights of different vegetation types are given in Table 6. During the weight load calculation, the weight of the substrate and weight after irrigation must also be factored in. The load of a roof in general can be calculated using the following equation (Francis et al., 2014).

Weight load = dead load + live load + translent load

(Dead load: components associated with the roof/wall assembly + plants + growing medium + water held in the system
Live load: The weight of people + mobile equipment
Translent load: short-term loads, including wind load)

Table 6. Green roof vegetation weight loadings
(Source: FLL Guidelines, 2018)

Green roof vegetation type	Weight loading (kg/m^2)
Low herbaceous (succulent and grasses)	10.2
Perennials and low shrubs up to 1.5 m	10.2 – 20.4
Lawn	5.1
Shrubs up to 3 m	30.6
Small trees up to 6 m	40.8
Medium trees up to 10 m	61.2
Large trees up to 15 m	150

Plant maintenance

Maintenance is key to keeping the green roof healthy. The type of plant maintenance activities required for a green roof will depend on the type of plantings and climate of the area. Routine plant maintenance activities involve irrigation, weeding, fertilising and pruning. For irrigation, a garden hose may be used in residential gardens or in small properties with easily accessible areas, but this is not ideal for other areas. In larger spaces, it is important to install an irrigation system. For this, a pop-up sprinkler system can be installed for a lawn, whereas for shrubs and trees, a drip system is ideal. It is important to visually inspect green roofs at least once a month and to remove weeds before they set flowers and seeds to minimise future efforts in weeding. Fertilising should be carried out as in other areas, as well as occasional pruning, as required for trees and shrubs. Apart from these practices, mowing and trimming is also required for lawns. Naturally failed plants should be replaced and unwanted plant material, including leaf litter should be removed from the roof surface, rainwater outlets and gutters, as it is vital to prevent blockages and to avoid mosquito-breeding sites.

Green façades

A green façade is created by growing climbing plants up and across the façade (exterior wall) of a building. This is a low-cost vertical greening technique. Green façades occupy very little ground space, and the installation and maintenance costs are low when compared to other greening methods Francis et al (2014). Green façades can be used in urban areas to prevent the sticking of posters and against writing (graffiti) on the walls.

Techniques of planting in green façades

Green façades can be planted either in garden beds at the base of the wall (Figure 51a) or as container plantings, installed at different levels across the building wall (Figure 51b).

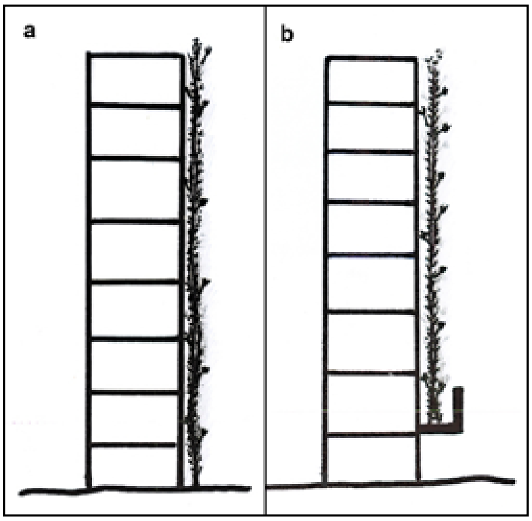

Figure 51. Establishing climbers in green façades a) at the base of the wall in a garden bed and b) in a container installed at a higher level of a wall

Plants for green façades and maintenance practices

In Sri Lanka, green façades are widely covered with perennial climbers, particularly with *Thunbergia grandiflora* (English name: blue trumpet vine) and (*Ficus pumila,* English name: creeping fig). *Thunbergia grandiflora* may grow to about 20 m in height and have a long root system with a deep tap root. It has a fast growth rate and is easy to propagate with stem cuttings or with root portions. The climber can tolerate pruning and can survive under adverse conditions and in unfertile soils. As it is a low maintenance plant, it has become popular and is widely used all over the country. However, it is an aggressive plant, hence one should take extra care not to release this plant into the natural environment. *Ficus pumila* is widely used to cover parapet walls in Sri Lanka.

In other countries, wall shrubs are also popularly used in green façades and plants such as *Bougainvillea glabra* (reaching to about 4 m) *Holmskioldia sanguinea* (English name: Chinese hat plant) (reaching to about 5 m) can also be used to cover shorter walls, as they do not reach high levels.

Some plants attach directly to the wall surface through morphological adaptations (plants with adhesive roots such as *Ficus pumila*), while other plant species require a supporting structure to climb. Certain climbers twine around their support or climb with leaf or stem modifications, hence a vertical support is required. In Sri Lanka, to support *T. grandiflora* a wire mesh fixed to a metal frame is widely used (Figure 52). In addition, a wire rope also can be used.

Figure 52. A green façade. Left: at an early stage; middle: at a later stage, established with *T. grandiflora*. Right: *Ficus pumila* used to cover a parapet wall

(The left and middle photographs are from the Faculty of Agriculture & Plantation Management, Wayamba University of Sri Lanka. Note the green mesh fixed to the metal frame attached to the wall)

Appropriate plant maintenance activities as described above, in the section on green roofs should be practised. Particularly with *T. grandiflora*, removing excessive roots, may be required from time to time, to avoid the plant spreading into adjacent areas.

Green walls

A green wall (living wall) comprises plants grown in supported vertical systems. Green walls are incorporated with vegetation, growth medium, irrigation and drainage into a single system (Manson & Castro-Gomes, 2015).

There are two types of green walls.

1. Attached system: the system may be attached to an internal or external wall (Figure 53).
2. Freestanding system: as the structure is not attached to the wall, the system can be moved if necessary (Figure 53).

Figure 53. Green wall system attached to top: an external wall; middle: an internal wall and bottom: a freestanding system that could hold plants in a green wall

Green wall systems

For both of the above two types of green wall systems, either hydroponic or substrate-based systems can be used to provide nutrients and/or anchorage to plants (Francis et al., 2014).

Hydroponic system

Plants are established in pots (plastic net pots) and fixed to the holes made in the system (PVC pipes). Coir dust or rice husk or a mixture of both may be used as media to fill the net pots.

Box 13. Hydroponic system

Hydroponics or soil-less culture is a technology for growing plants in nutrient solutions that supply all nutrient elements needed for optimum plant growth with or without the use of an inert medium to provide mechanical support. Plants in hydroponic systems are more susceptible to adverse acidic conditions of the solution than in soil. Hence, maintaining correct pH levels is important to ensure availability of plant nutrients. The optimum range is 5.8- 6.5 and ideal electrical conductivity (EC) is between 1.5 and 2.5 dS/m. In a hydroponic system, the plant root must be kept in darkness and adequate aeration is also important for optimal growth. In large scale systems liquid can be circulated, while in small units a non-circulation method can be used.

Substrate-based system

In this system, substrate-holding containers are used to grow plants. The containers are oriented in racks and anchored to the wall or may be free standing. Pots are filled with a suitable media and a drip irrigation system can be incorporated for irrigation. Drip trays are used to collect excess irrigation water**.**

Plant selection for green walls

Low growing, spreading and cascading plants are ideal for a green wall. A trailing vine is a smart choice for a vertical garden as it can be encouraged to spread and fill any gaps. In addition to plants with green foliage, those with colourful leaves and long-lasting flowers can be good additions to a green wall. Yellow-green leaves offer a bright contrast against darker greens in a wall composition.

Plants for indoor green walls/ shaded areas:

Herbaceous perennials: *Hedera helix* (English name: common ivy), *Peperomia* spp*.*, *Philodendron scandens* (English name: sweetheart plant), *Epipremnum aureum* ‘neon’, Anthuriums*, Chlorophytum comosum ,Syngonium podophyllum, Begonia* spp*.*
Ferns: *Nephrolepis exaltata, Asplenium nidus*
Succulent plants: *Rhoeo discolour, Tradescantia pallida,* (English name: purple heart).

Plants for outdoor/exterior green walls:

Herbaceous plants: *Hemigraphis alternata,* (English name: red flame ivy)*, Chlorophytum comosum* ‘Ocean’, *Syngonium podophyllum*, *Coleus scutellarioides*[56] (Common name: Coleus).
Shrubs: *Schefflera arboricola, Polyscias fruticosa* ‘Elegans’*, Polyscias fruticosa, Dracaena* spp*., Codiaeum variegatum* (English name: croton), *Asparagus* spp*.*
Grass-like forms: *Pandanus pygmaeus, Ophiopogon jaburan* (English name: mondo-grass).

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[56] Formerly *Plectranthus scutellarioides* (The International Plant Names Index and World Checklist of Selected Plant Families, 2021)

Urban greening with trees

Trees can be considered permanent material in landscapes, as once established, they will be there for a prolonged period. For the Bonn Challenge, the priority need for urban green spaces with trees, is that they sequester carbon (see Chapter 1). In addition, urban greenspaces can become memorable with the selection of correct trees. Mature trees can contribute to a healthier environment viz., air, soil and water in urban areas. Trees also provide aesthetics to urban green spaces in terms of shape, scale and seasonal changes. However, urban areas typically do not generously support the growth of trees and trees are often planted in places with suboptimal conditions for growth. Therefore, selection of suitable species of trees and adopting correct management practices is vital for the survival of these trees. In urban areas, trees can be planted in many places including roadsides, school grounds, parking areas, parks, vacant areas and residential gardens where space is available.

Classification of trees of urban greening

In urban areas, the availability of vertical and horizontal space may be a limiting factor. Hence based on space availability, the correct species of tree should be selected. Based on height, trees can be classified into three groups.

Tall trees: height of 20 m or more. Examples include *Azadirachta indica* (English name: margosa/neem, Sinhala name: *kohomba*; Tamil name: *arulundi*), *Filicium decipiens* (English name: fern tree; Sinhala name: *pihimbiya*; Tamil name: *chittirai vermbu*), *Madhuca longifolia*, (English name: honey tree; Sinhala name: *mi*; Tamil name: *illupai*), *Terminalia arjuna* (English name: arjun tree; Sinhala name: *kumbuk*; Tamil name: *marudu*), *Lagerstroemia speciosa*, (English name: queen's flower/ pride of India Sinhala name: *murutha*; Tamil name: *kadali*); and *Delonix regia* (English name: flamboyant; Sinhala name: *mai mara*; Tamil name: *mayaram*).

Medium trees: height of 10 – 20 m. Examples include *Bauhinia racemosa* (Sinhala name: *maila*; Tamil name: *atti*), *Barringtonia asiatica* (Sinhala name: *goda midella/diya midella*) *Calophyllum inophyllum* (English name: Alexandrian laurel; Sinhala name: domba; Tamil name: *dombai kottai*), *Cassia fistula* (English name: golden shower tree/ Indian laburnum Sinhala name: *ehela*: Tamil name: *thirukkondrai*), *C. roxburghii* (English name: red cassia; Sinhala name: *rathu va*; Tamil name: *vahai*), *Mimusops elengi* (English name: Spanish cherry, Sinhala: *munamal*; Tamil name: *makil*), and *Jacaranda mimosifolia* (English name: jacaranda).

Small trees: height of 5 – 10 m. Examples include *Murraya paniculta* (English name: orange jasmine; Sinhala name: *atteriya*), *Vitex negundo* (English name: Indian wild pepper; Sinhala name: *nika*; Tamil name: *nochchi*), *Nerium oleander* (English name: oleander, Sinhala name: *kaneru*; Tamil name: *alari)* and *Woodfordia fruticosa* (English name: fire-flame bush; Sinhala name: *malitta*).

Choosing the right tree for the right place

Before selecting a tree for an urban space, space availability, the climate of the area and the environment of the specific site should be evaluated.

Problems faced by urban trees

Trees are subjected to stresses in urban areas such as being exposed to extremes of temperatures, moisture and pollutants; soil compaction; development work reducing the available space of existing trees; urban soils being poor in condition; construction activities and vehicles damaging trees; obstructions such as above ground wires and buildings close by or underground pipes and drains. Therefore, urban trees must be selected correctly, professionally inspected, maintained and replaced when necessary.

Properties of trees

In addition to the environmental factors of the area, the following factors of trees should be considered when selecting a tree for urban planting (Harris et al., 2013; Gillman et al., 2020): mature size (width and height), growth rate, shape of the tree, wood strength, root spread, deciduous / evergreen nature, leaf / flower colour, and presence of untidy leaves, flowers or fruits.

Selection of saplings

A good start helps to establish a healthy tree. Hence, the following factors should be considered when selecting a suitable sapling for planting (Roloff, 2016).

- The sapling should have a good form;
- The trunks of saplings should be straight and strong;
- There should be a good balance between the shoot and root systems; and
- The sapling should be free of physical damage, pests and diseases.

Establishment of trees

For the establishment of trees, two methods are used widely.

1. Root balled and burlapped plants:
   Trees are extracted with soil and the root ball is wrapped with burlap (coarse canvas). This is tied with a rope so that trees can be transported and kept for a longer period. This is the most commonly used method as even mature trees can be established to get a quick effect.
2. Containerised plants:
   Trees are planted in containers. Establishment is easy and the root system is not damaged. These trees can be kept for a longer period of time in a nursery.

Site preparation for planting

A suitable location is selected and weeds and surface debris in the area are removed. Then a planting hole is dug, where the depth of the hole depends on the root mass, root ball or container size. During planting, an area two to three times the diameter of the root ball or root mass should be de-compacted. Decompaction improves both root growth and the process of tree establishment. The planting hole should be no deeper than the existing root ball. The soil removed from the planting hole can be used for backfilling (filling the hole again). However, if the condition of the soil is poor, backfill soil should be improved. During planting, it is important that the upper roots of the plant are placed more than a few centimetres below the soil surface. After planting, adding a layer of mulch away from the tree trunk is recommended for the retention of moisture, control weed growth and avoid soil compaction (Harris et al., 2013).

Tree spacing

Space in urban areas is limited and hence, expensive. Therefore, knowing the space requirements of the tree species to be used is vital. The key variable that should be considered before planting trees is the space that will be occupied by the tree (the canopy size). Unless it is a requirement, close spacing of trees creates problems later, because it can lead to deformed trees, or become a problem to buildings, streets and lights. Hence, before planting, the mature tree size and landscape purpose such as screening and wind breaks should be considered. Unless otherwise stated, recommended spacing for large trees is 10 – 12 m, medium trees 8 -10 m and for small trees is 5 -6 m (Harris et al., 2013).

Management of trees

The following post planting management practices are important to ensure success in establishment and subsequent survival of urban trees.

1. *Weed control*: Weed control is important during the establishment period. Maintaining a 1 m^2 weed free area around the trunk is recommended. Weeds can be controlled manually or by applying a suitable mulch.
2. *Pruning*: Pruning is the deliberate removal of branch/es to achieve a specific objective. Pruning ensures good growth, long-term structural stability and other functional benefits. Pruning can be practised to obtain a desired shape, to get light, to compensate for root loss, during tree removal and replacement, to achieve selective thinning to enhance the view, to promote flowering and fruiting and to encourage the vigour and health of the trees. Utility pruning is practised when trees are planted under power lines. The pruning technique may depend on the target branch and intended function. During pruning, correct tools such as chainsaws, bow saws or pruning saws should be used.
3. *Tree staking and tree guards*: Trees establish themselves quite well under normal situations. Hence, tree support systems such as staking and guards are unnecessary in most instances. However, in special situations, a support system such as staking may be required to hold trees upright until roots anchor the sapling/tree firmly to the soil. Once the tree can stand unsupported without bending or shifting in the ground, the support system must be removed. Tree guards (Figure 54a) can be used with newly established trees to protect the tree from herbivory, equipment and from vehicles. Anchor staking is used during the young/establishment stage until the roots are established. These may be single stakes or double stakes (Figure 54b and c). Bare-root trees, root-balled trees and trees planted in sites exposed to strong winds need to be supported with stakes. An angled stake is used for trees planted on slopes (Figure 54d).
4. *Tree root management*: Tree root management is important in an urban setting as the space available for growing roots is limited. Root barriers can be used to guide roots away from infrastructure and to protect pavements and kerbs from cracking and lifting. Paving up to the tree trunk is not a good practice, as roots also need oxygen to breathe, nutrients and water for survival. Therefore, burying them in concrete or tar will impair the tree's health. Further, soil compaction close to the root system can also create problems to tree health. According to Gillman et al., (2020), 90-95% of a tree's root system exists in the top three feet of soil (about a metre) with more than half in the top one foot. Porous paving materials can be used to avoid the above-mentioned problems, as they have open voids between their units allowing the movement of water and air around the paving material.

Healthy trees established in urban spaces are an investment for future generations of people as trees in green spaces provide a range of benefits that can address some of the persistent problems faced by urbanised areas. Hence, once planted, trees should be managed effectively from the inception of planting to full maturity in order to reap the benefits.

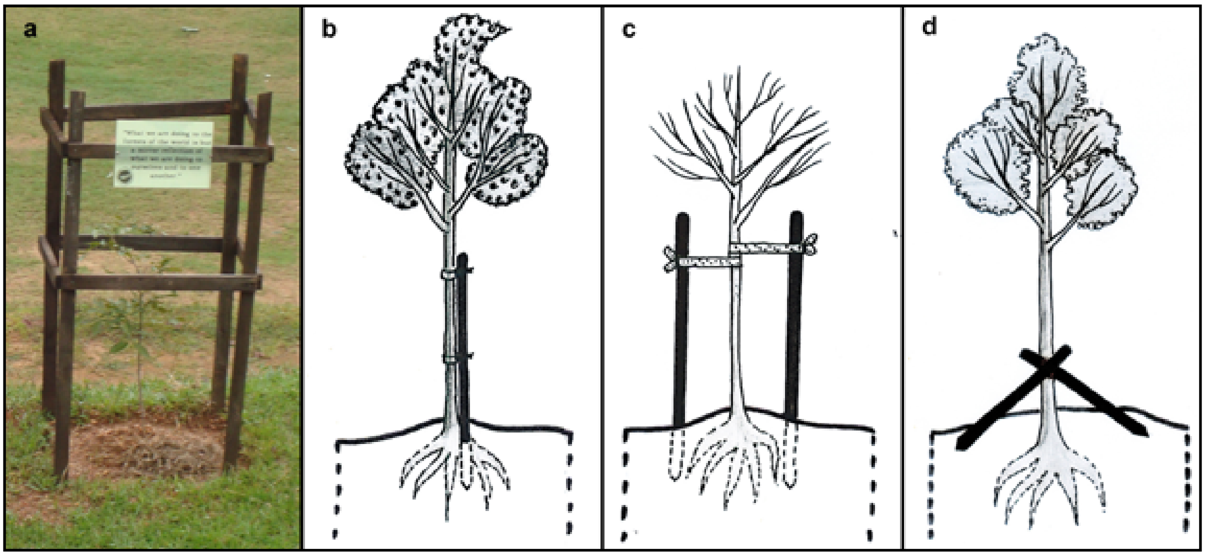

Figure 54. Tree staking and tree guards a) a tree guard; Anchor staking; b) a single stake (most common) and c) a double stake[57] and d) angle stakes

The way forward

Globally, in recent years, there has been a substantial amount of research carried out exploring the value of urban greening and related activities for the betterment of human and environment health Braubach et al., (2017). However, comparatively few studies have been completed in the developing world, including Sri Lanka. Nevertheless, the following aspects adopted in developed countries and research information generated in Sri Lanka should be considered for effectively enhancing urban greening activities.

- ***Introduction of native plants in urban greening***
  Many urban trees previously planted in Sri Lanka are exotics (for example, *Delonix regia, Tabebuia rosea*) but now there is a tendency to use native trees in urban areas (for example, *Terminalia arjuna, Madhuca longifolia*). However, almost all the shrub species currently used are exotics. Current research has identified many native plants such as *Helicteres isora* (De Mel & Yakandawala, 2003), *Lawsonia inermis* (Yakandawala & Adikari, 2014), *Osbeckia octandra* (Yakandawala et al., 2013), *Woodfordia fruticosa* (Napagoda & Yakandawala, 2008), *Memecylon umbellatum* (Senarathne & Yakandawala, 2004) with an ornamental potential which, together with propagation techniques, make them available for use in urban greening. These plants could also be promoted as low maintenance plants to conserve water and energy.

- ***Promoting species with a potential of intercepting dust/particulate matter in urban areas***
  Plants have a capability to intercept particulate matter present in the air. However, certain plants such as *Terminalia arjuna, Mangifera indica, Murraya paniculata* (Wijesinghe and Yakandawala 2013), *Helicteris isora, Durantha repens, Acalypha inferno* and *Acalypha wilkesiana* 'Marginata' (Wijesinghe & Yakandawala, 2009) have a higher capability to intercept particulate pollutants. Hence, these plants could be promoted in urban greening.

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[57] good for windy sites

- ***Low maintenance planting schemes for neglected/abandoned urban green spaces***
  In temperate climates, planting schemes such as meadows are common and wild species that are frequently found in other habitats are generally incorporated to give aesthetic beauty and to increase species richness. These designs play an important role in attracting insects including pollinators. Studies conducted in Sri Lanka have also revealed that wild (ruderal) planting designs and mixed designs enriched with ornamental *Zinnia elegans* could provide aesthetics and attract insects in large numbers – 77 and 87 species respectively (Wijesinghe et al., 2020). Hence, low maintenance planting schemes could be promoted.

Apart from the above research findings, given below are other important areas that need to be addressed in further promoting urban greening.

- Developing policies to address challenges, and approaches to the development of a sustainable national urban greening programme.
- Developing institutional capacity, using appropriate technology and securing sustainable funding sources.
- Overcoming institutional obstacles due to lack of coordination among various levels of government institutions and local government bodies.
- Economic valuation for urban green resources in Sri Lanka.
- Prioritising activities of urban greening, in the political agenda, at both local and national levels.
- Generating new information and dissemination of good practices relevant to urban greening among government officials, the local business community, concerned community members and schoolchildren.
- Improving the quality and condition of parks and other urban green spaces outside Colombo by providing financial and technical support.
- Involvement of the local community in urban greening activities.

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Chapter 8: Selecting plant species for forest restoration programmes

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Although selection of species for forest restoration seems a simple and straightforward task, it is complex, and many factors must be studied comprehensively prior to the commencement of the restoration programme. Such factors include the condition of the selected site; the degree of degradation (See Chapter 2); the state of the soil (Chapter 4); the supply of seedlings (Chapter 5); and the objective of the forestry/ restoration programme. For example, if the objective of the forestry programme is to establish a woodland of harvestable timber species, the monoculture of fast-growing species, using standard procedures of silviculture should be practised. In contrast, if the objective is to restore a degraded area of forest for the conservation of biodiversity and improving ecosystem services, native species, which can support native biodiversity and contribute to restoring ecosystem services, should be selected.

In addition, it is critical that species are not only suited to climatic conditions (see Chapter 2), for example, wet, dry and intermediate zones, but also suited to the floristic zones of Sri Lanka (Figure 55), and the particular ecosystem of which they are a part. There are also species which are also site-specific.

Selection of species based on floristic zones

In Sri Lanka, the variability in climatic, topographic, climatic and edaphic factors have resulted in a range of terrestrial ecosystems (MoMD&E, 2016) — primarily, types of forests (Ashton et al., 1997). These ecosystems show a distinct distribution pattern (MoMD&E, 2016). Ashton & Gunatilleke, 1987 (in litt. Ashton et al., 1997) identified 15 floristic regions in Sri Lanka (Figure 55). In the dry zone are dry mixed-evergreen forests and riverine forests (along the banks of rivers), and in the driest areas of the island, arid mixed-evergreen forests (scrub/thorn forests) (Ashton et al., 1997). In the intermediate zone are moist mixed-evergreen forests, while in the wet zone, are lowland wet evergreen forests, mid-elevation evergreen forests and montane evergreen forests (Ashton et al., 1997), in the 1st, 2nd and 3rd peneplanes[58] of the island respectively (See Figure 2 and Figure 3 in Chapter 1).

Shown in Table 7 are selected species for given ecosystems. Annex 1 provides a complete list of species for forest ecosystems.

> ***At first I thought I was fighting to save rubber trees, then I thought I was fighting to save the Amazon rainforest. Now I realize I am fighting for humanity.***
>
> ***Chico Mendes***

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[58] A step-like arrangement of the elevation in Sri Lanka: 1st =0-300 m; 2nd =301- 1,500 m; 3rd = 1501-2524 m (MoMD&E, 2016).

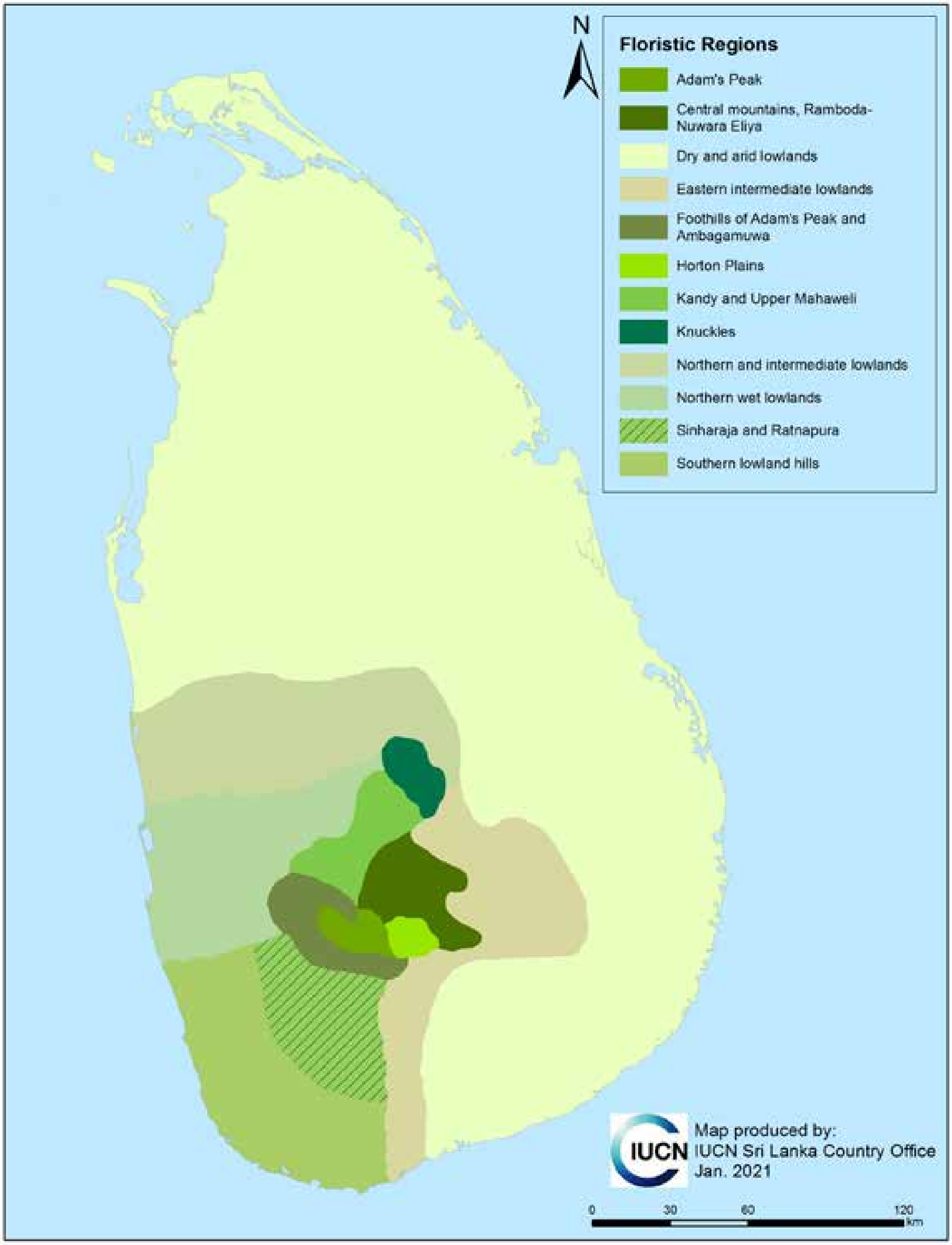

Figure 55. Floristic regions of Sri Lanka
(Source: Ashton and Gunatilleke, 1987 in litt. MoMD&E, 2016)

Table 7. A selection of tree species for restoration in different ecosystems of different floristic regions of Sri Lanka

A selection of tree species for restoration of lowland wet evergreen forests		A selection of tree species for restoration of mid-elevation and montane evergreen forests	
1	*Anisophyllea cinnamomoides*	1	*Calophyllum walkeri*
2	*Artocarpus nobilis*	2	*Cinnamomum ovalifolium*
3	*Bhesa ceylanica*	3	*Glochidion coriaceum*
4	*Canarium zeylanicum*	4	*Ilex walkeri*
5	*Cleistocalyx operculatus*	5	*Melicope lunu-ankenda*
6	*Dillenia retusa*	6	*Magnolia nilagrica*
7	*Dipterocarpus zeylanicus*	7	*Rhodomyrtus tomentosa*
8	*Mangifera zeylanica*	8	*Syzygium revolutum*
9	*Pometia pinnata*	9	*Wendlandia bicuspidata*
10	*Vitex altissima*	10	*Gordonia ceylanica*
A selection of plant species for restoration of dry mixed-evergreen forests		**A selection of plant species for restoration of moist-mixed evergreen forests**	
1	*Acacia leucophloea*	1	*Bridelia retusa*
2	*Bauhinia racemosa*	2	*Careya arborea*
3	*Berrya cordifolia*	3	*Diospyros ebenum*
4	*Chloroxyclon swietenia*	4	*Filicium decipiens*
5	*Diospyros ebenum*	5	*Grewia damine*
6	*Dimocarpus longan*	6	*Pongamia pinnata*
7	*Dillenia retusa*	7	*Pterocarpus marsupium*
8	*Lannea coromandelica*	8	*Pterospermum suberifolium*
9	*Schleichera oleosa*	9	*Syzygium cumini*
10	*Manilkara hexandra*	10	*Terminalia bellirica*

Box 14. Selection of species for specific sites

There are also artificial (human-made ecosystems) such as forest and agro- mixed and monoculture plantations, as well as small tank cascades[59] (MoMD&E, 2016). In these instances, considering the exact site of restoration has a critical bearing on species selection. For example, in dry zone tank cascades, just as there are specific tanks for specific purposes, each tank has several elements, each of which has a particular ecological function and therefore provides a specific ecosystem service to communities that live in the surrounds (IUCN, 2016). For example, there is always a windbreak of trees (*gasgommana*) to minimise evaporation from the tank; and an interceptor (*kattakaduwa*): the stretch between the tank bund and paddy fields that serves as wind barrier downstream. When small tank cascades are restored, it is critical to choose the correct species for each component of the tank. Such species will be completely different from planting programmes in wet zone marshes, or in the coastal zone.

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[59] A series of tanks along the drainage system of a river, distributed within a micro-catchment of the dry zone. Water is recycled and re-used across a system of small to large tanks (IUCN, 2016).

Table 8. A selection of tree species for site-specific restoration

A selection of plant species for restoration of dry zone tanks (tank bunds and upland areas)		A selection of plant species for restoration of dry zone tanks (for the *kattakaduwa* and seasonally flooded areas)	
1	*Azadirachta indica*	1	*Caryota urens*
2	*Berrya cordifolia*	2	*Berrya cordifolia*
3	*Bauhinia racemosa*	3	*Diospyros malabarica*
4	*Chloroxylon swietenia*	4	*Madhuca longifolia*
5	*Ficus benghalensis*	5	*Nauclea orientalis*
6	*Limonia acidissima*	6	*Pandanus kaida*
7	*Millettia pinnata*	7	*Syzygium cumini*
8	*Pterospermum suberifolium*	8	*Vitex leucoxylon*
9	*Tamarindus indica*	9	*Terminalia arjuna*
10	*Vitex altissima*		
A selection of plant species for restoration of wet lowland floodplains and associated marshes		**A selection of plant species for restoration of beach front vegetation**	
1	*Areca concinna*	1	*Barringtonia asiatica*
2	*Berrya cordifolia*	2	*Calophyllum inophyllum*
3	*Caryota urens*	3	*Cassine glauca*
4	*Cerbera odollam*	4	*Heliotropium foertherianum*
5	*Dillenia triquetra*	5	*Morinda citrifolia*
6	*Barringtonia racemose*	6	*Pisonia grandis*
7	*Lagerstroemia speciosa*	7	*Pandanus odoratissimus*
8	*Syzygium caryophyllatum*	8	*Scaevola taccada*
9	*Pandanus kaida*	9	*Terminalia catappa*
		10	*Thespesia populnea*

Selection of plant species based on the stage of succession

Chapter 2 discussed ecological succession and natural regeneration, and the succession from barren land to forest. It also described primary and secondary succession, where the former refers to the slow, evolutionary conversion of bare land to forest or a climax community. Secondary succession, it was noted, refers to the 'process of community re-establishment after a habitat is disturbed or damaged' for natural or anthropogenic reasons (Gunaratne, this book).

The selection of species based on the seral stage of the restoration site is essential. As noted in Chapter 2, it is very rare that restoration involves primary succession and usually involves secondary succession. In tropical areas, most degraded forest areas are colonised by exotic and invasive alien herb and shrub species (Starr et al., 2013). Therefore, it is necessary to select the best option to manage these IAS species. For example, some IAS species can be used as nurse trees (see Chapter 2 and Box 5) or intermediate species in some restoration practices, such as ANR (see Lekamge et al., this book).

Usually, plants that can tolerate strong sunlight (among other characteristics listed in Chapter 2), are categorised as pioneer species (the first or second seral stage), and those which are shade-tolerant (among other characteristics listed in Chapter 2) are climax species (Gunaratne, this book). In general, plant species which grow in climax conditions cannot grow in first and second succession stages. However, there are some of climax species (canopy species) which can be grown in early seral stages, if provided with extra care – such as organic fertilisers and physical support to stay upright. See Table 9 for a selection of species.

Table 9. A selection of species for planting in different seral stages

A selection of pioneer species which can be grown in early seral stages (for planting in lowland wet evergreen forests		**A selection of climax species which can be grown early in lowland wet evergreen forests**	
1	*Erythrina variegata*	1	*Artocarpus nobilis*
2	*Gliricidia sepium*	2	*Anisophyllea cinnamomoides*
3	*Hedyotis fruticosa*	3	*Bhesa ceylanica*
4	*Macaranga peltata*	4	*Bridelia moonii*
5	*Mallotus tetracoccus*	5	*Campnosperma zeylanicum*
6	*Melastoma malabathricum*	6	*Canarium zeylanicum*
7	*Trema orientalis*	7	*Cleistocalyx operculatus*
		8	*Dipterocarpus zeylanicus*
		9	*Mangifera zeylanica*
		10	*Palaquium canaliculatum*
		11	*Pometia pinnata*
		12	*Vitex altissima*

A selection of climax species to be grown at during the intermediate stages[60] in lowland wet evergreen forests	
1	*Calophyllum bracteatum*
2	*Cullenia ceylanica*
3	*Diospyros insignis*
4	*Shorea dyeri*
5	*Schumacheria castaneifolia*

> ***Healthy forests and wetlands stand sentry against the dangers of climate change, absorbing carbon dioxide from the atmosphere and locking it away in plants, root systems and soil.***
>
> ***Frances Beinecke***

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[60] There are some plants which cannot be introduced at the early stages, but can, when there is some shade.

Selecting planting materials (seeds, nursery plants) based on floristic zones

Some plant species can be found in more than one bio-climatic zone or vegetation zone. For example, *Dipterocarpus zeylanicus* is a common canopy species in lowland wet evergreen forests. However, this species is also found in other vegetation zones including the foothills of Adam's peak and Ambagamuwa, and in the southern lowland hills of Ratnapura, as well as a few areas in the lowlands of the eastern intermediate zone.

Planting materials (seeds) for restoration must be selected and collected from the same floristic region. For example, *Dipterocarpus zeylanicus* seeds collected from the Gilimale-Bambarabotuwa area (Ratnapura) should not be planted in restoration programmes of southern Sinharaja or Kanneliya (Galle/Matara district) as they not in the same vegetation zone (see Figure 55). It is also necessary to select assemblages of plants based on the floristic region. This is important because although there are many floristic regions in the wet zone, each floristic region has unique floristic assembles. It is crucial therefore to prevent indiscriminate planting, which may lead to homogenisation of species composition.

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Case studies: Restoring lower montane forests – examples from Knuckles Conservation Forest, Sri Lanka

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Introduction

In Sri Lanka, natural forests have been reduced to half their extent over the last three decades, because of large-scale clearance of forests for infrastructure development and agriculture. As a result of these human pressures, by 2015, Sri Lanka was left with a mere 22% its original cover of dense forest (Premakantha et al., 2020). Of the total land area of the country, only 1.04% comprises montane evergreen (> 1500 m a.s.l.) and mid-elevation evergreen forests (900 – 1500 m a.s.l.). These forests supply crucial ecosystem services that support human well-being – such as harbouring of high biodiversity, soil conservation, carbon sequestration, fog interception[61] and fresh water for generation of hydro-electricity, agriculture and for water security in downstream areas (Gunaratne, 2007; Premakantha et al., 2020). Destruction of these forests may bring irreversible degradation of the ecosystem services necessary to all Sri Lankans.

Most of the lower montane forests in the island were cleared during the colonial era for the cultivation of cash crops, such as coffee and tea. Unsustainable soil management measures in tea plantations have led to their abandonment and these abandoned lands have transitioned into grasslands dominated by the native grass, *Cymbopogon nardus* (English name: Citronella grass; Sinhala name: *pengiri mana*) (Gunaratne et al., 2010). In the 1970s, some of these grass-dominated degraded lands were reforested by the Forest Department, using exotic species of *Pinus*, *Acacia* and *Eucalyptus*. This action resulted in further fragmentation of lower montane forests and at present, they are found as patches in a sea of other land use types such as residual tea plantations, forests plantations, grasslands and scrublands (Figure 56). Because of their immense value in provisioning of vital ecosystem services, it is important to preserve the existing forest fragments and link them using ecological restoration strategies, to reduce their further degradation and to conserve them for the well-being of future generations.

Accelerating forest recovery on degraded lands

Secondary succession on degraded post-agricultural lands in the tropics may become arrested by a variety of site-specific biotic and abiotic factors (Gunaratne et al., 2014, Holl & Loik, 2000). Understanding the ecological mechanisms that constrain forest recovery of highly degraded areas, is a prerequisite to designing techniques to restore their original

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[61] ‘Occurs when fog droplets are intercepted by the canopy and fall to the forest floor’ (Holder, 2004).

biodiversity and ecosystem processes. The aim of our research was to deduce ecologically and socially acceptable restoration techniques to accelerate natural forest recovery in Knuckles Conservation Forest (KCF).

In 2003, the first research project was initiated to investigate the biotic and abiotic factors that inhibit forest succession on degraded anthropogenic grasslands in a tropical lower montane forest landscape in KCF, and to identify native species for restoration (Gunaratne, 2007). In 2006, the second research project was begun to investigate the growth and survival of *Macaranga indica*, after soil improvement (unpublished data). In 2011, a third research project was commenced to determine the feasibility of native tree islands to link the remaining forest patches and to catalyse natural succession in these degraded grasslands (Gunasekara, 2022).

Figure 56. Highly patchy distribution of lower montane forest fragments interspersed with grasslands, scrublands and forest plantations within the Knuckles Conservation Forest (KCF)
(Note: on mid slopes at 1000 –1300 m a.s.l; © Thilanka Gunaratne/ University of Peradeniya)

The study site

Between 2003 and 2016, the above studies were conducted in the Riverston, Deanston and Madulkelle areas (7°27′N 80°48′E’) of the KCF (Figure 57: top). This area is within the buffer zone of the Central Highlands World Heritage Site. The degraded areas in the KCF were dominated by *Cymbopogon nardus*, which persists because the grasslands are burnt annually during the dry season to maintain favourable grazing grounds for domestic cattle and buffaloes as well as to facilitate hunting, and to protect villagers from wild animals (Figure 57: bottom). Although these grasslands are surrounded by remnant patches of lower montane forest, they appear to resist natural succession and remain degraded for several decades. Seedlings and saplings of forest species were rarely found in these grasslands (personal observation).

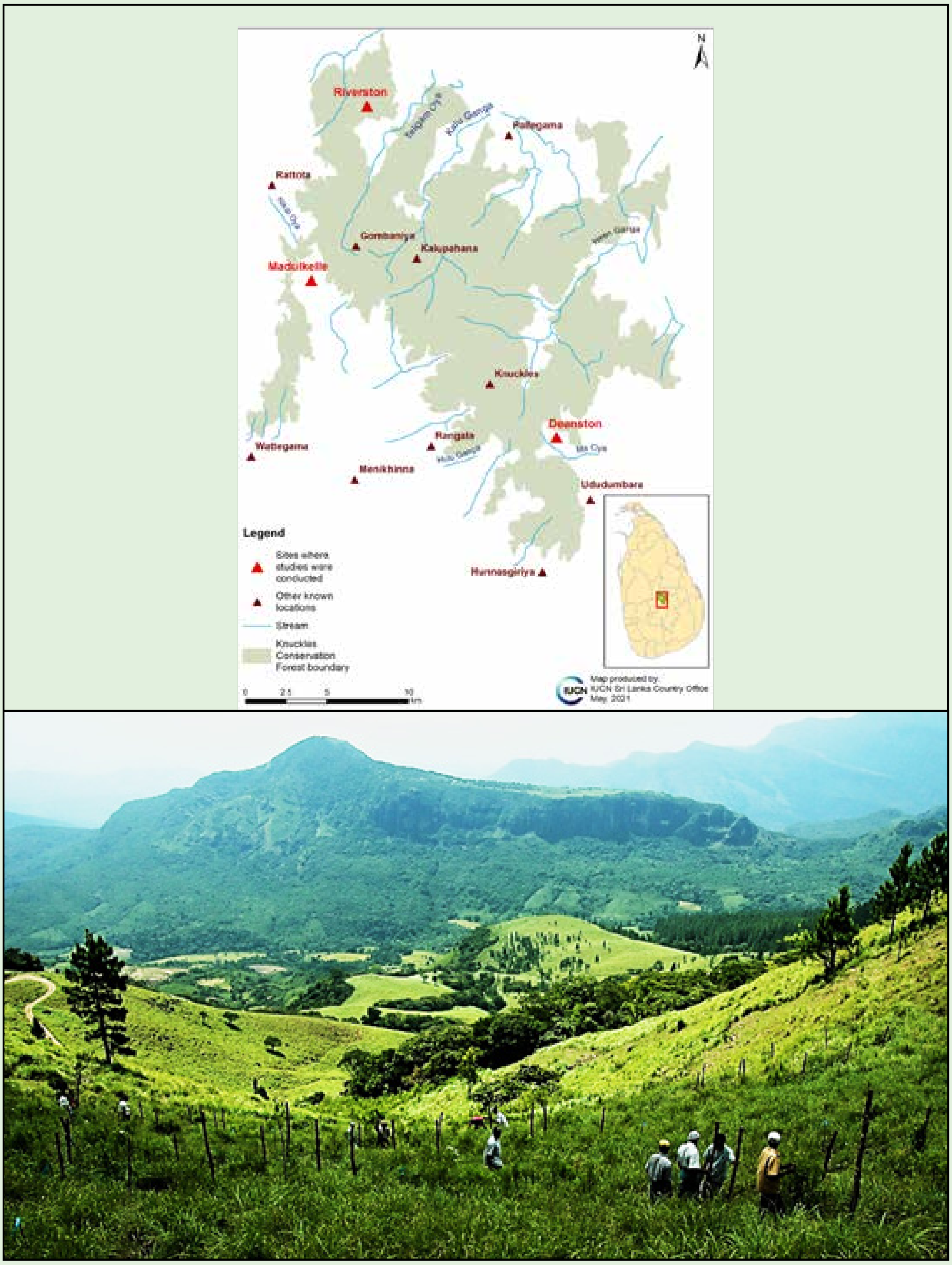

Figure 57. Top: map of Knuckles Conservation Forest in Sri Lanka and the study sites (red triangles); and bottom: the research site at 1157 m a.s.l. at KCF in 2003

(Note: the map also shows the conservation forest boundary, main peaks, townships and streams originating from it. Sources: top: Bambaradeniya and Ekanayake, 2003; bottom: © Thilanka Gunaratne /University of Peradeniya)

Case Study 1: Factors inhibiting forest recovery in degraded sites at Knuckles Conservation Forest

In 2003, a study was initiated to investigate the biotic and abiotic factors inhibiting forest recovery on degraded grasslands in the buffer zone of KCF. The biotic factors included in this investigation were (i) seed availability (seed dispersal and size and composition of the soil seed bank); (ii) seedling emergence; (iii) herbivory and (iv) competition from the grass matrix. The abiotic factors were (i) fire; (ii) micro-climatic conditions; (iii) soil nutrients; (iv) water availability; and (v) disturbance. The experiments were conducted in four blocks of forest patches and their adjacent grasslands (Gunaratne, 2007; Gunaratne et al., 2010, 2011 and 2014).

The results revealed that low seed availability is a critical factor that inhibits secondary succession in these anthropogenic grasslands (Gunaratne et al., 2014). Despite the availability of seed sources from remnant forest patches, colonisation of trees in the grassland is highly constrained by limited dispersal of seeds (Figure 58). For the few tree seeds that are dispersed into grasslands, vertebrate herbivory and annual fires further reduce the likelihood that they establish and emerge as seedlings. Furthermore, the removal of the grass canopy by clipping or tilling increased the emergence of woody plant seedlings, at least close to the boundaries of forest patches, but with no effect further into grasslands. This suggests that competition with the grassland community is an important constraint on tree establishment but is only relevant when tree seeds are present in sufficient numbers (Gunaratne et al., 2010).

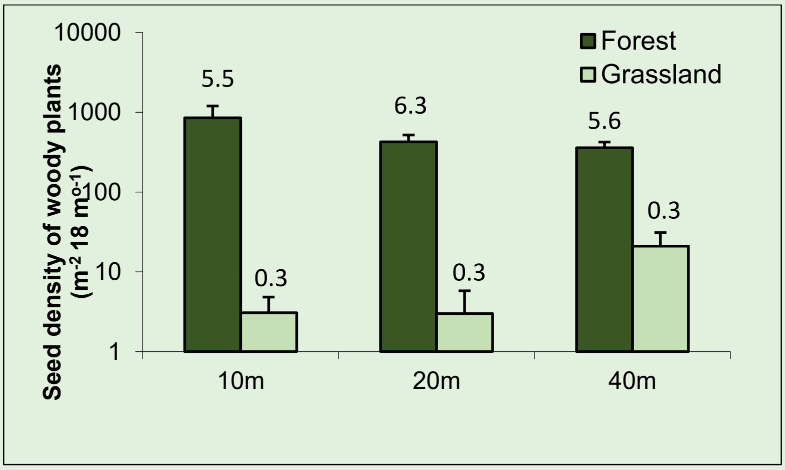

Figure 58. Mean (and standard error) rate of seed dispersal of woody plant to traps in the forest and the grassland habitats at different distances from the edge

(Numbers above the error bars indicate the mean total number of woody plants morphospecies[62] per trap collected during the 18-month period; mean rate of seed dispersal of woody plant species is in m^{-2} 18 mo^{-1}; distances are 10 m, 20 m and 40 m away from the edge. Source: Gunaratne, 2007)

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[62] 'Morphospecies do not involve the identification of species per se, but rather the separation of taxa based on morphological characters that are easily observable' (Derraik et al., 2002).

Case Study 2: Species selection and transplantation into degraded grasslands

A second study was initiated in 2005 to test the feasibility of establishing native tree species, in patches of the grassland (Gunaratne et al. 2011). Four native tree species were tested, *Dimocarpus longan* (English name: Longan; Sinhala name: *mora*; Tamil name: *nurai*), *Syzygium spathulatum* (Sinhala name: *kola heen*), *Macaranga indica* (Sinhala name: *kenda*) and *Symplocos cochinchinensis* (Sinhala name: *bombu*; Tamil name: *kambli-vetti*) with/without above-and below-ground competition and with/without herbivory. The early-successional species such as *Macaranga indica* recorded the highest relative growth rate in height, while *Symplocos cochinchinensis* recorded the highest percentage survival after 18 months of planting. Isolation of seedling root systems from competing grasses increased the growth and survival of tree seedlings transplanted directly into grassland swards, while above-ground competition and herbivory had no effects on seedling growth and survival of the tested species (Figure 59).

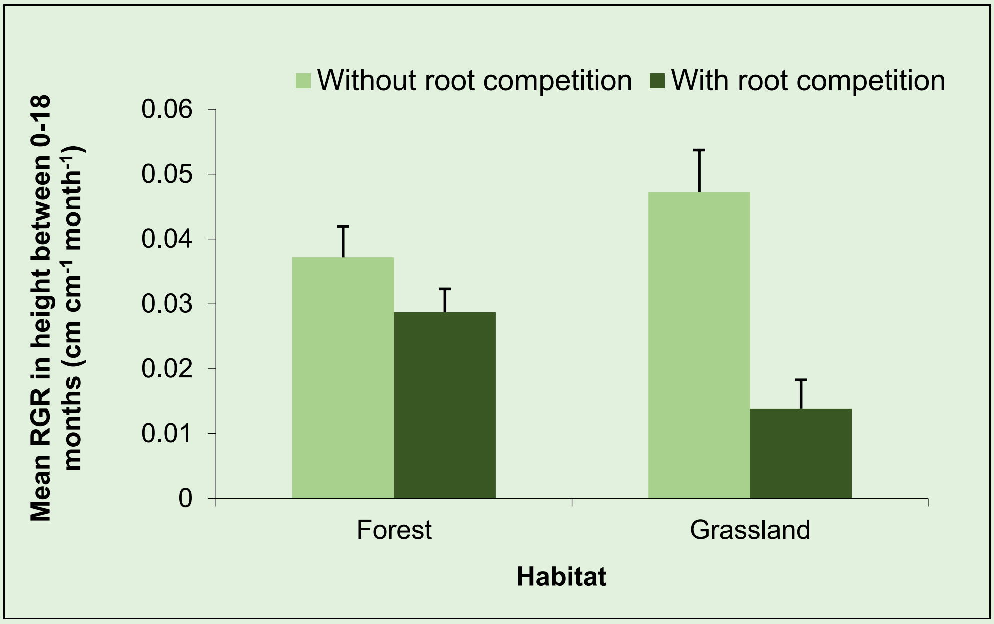


Figure 59. Mean (and standard error) relative growth rate of height per month of seedlings in the grassland and forest habitats with and without root competition

Based on the research findings, we proposed a strategy to catalyse the restoration of these anthropogenic grasslands back to their original status as lower montane forests (Figure 60). Accordingly, a model was proposed to connect forest remnants by creating vegetation islands with early-successional native tree species. Other treatments included the application of a tilling treatment around remnant forest patches, removal of weedy species, creation of fire belts around tree islands, and the protection of isolated individual trees/shrubs and tree/shrub patches naturally established within the grasslands.

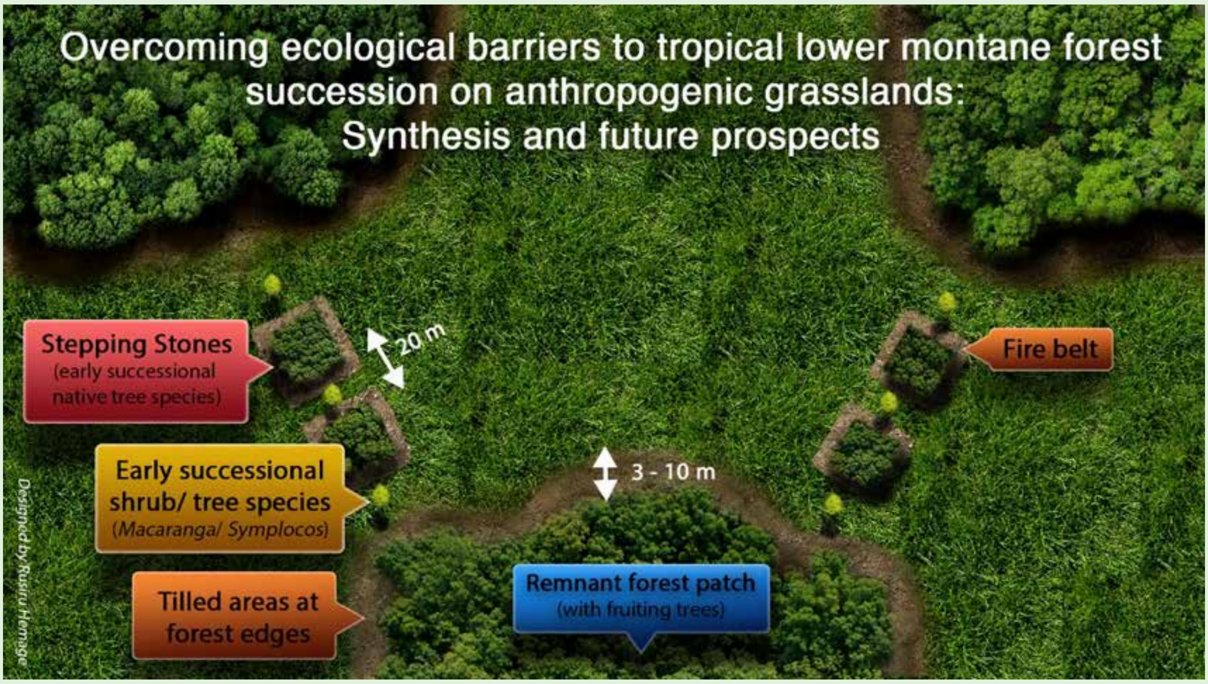


Figure 60. Restoration model for catalysing recovery of lower montane forests on degraded grasslands at lower montane region between 1000 to 1500 m in Sri Lanka
(Source: Gunaratne, 2007)

Case study 3: Effect of *Gliricidia sepium* and organic manure to enhance the growth of transplanted seedlings of native species

In this study, we experimentally manipulated the influence of grass competition and soil nutrient availability in the presence or absence of nurse trees of *Gliricidia sepium* (English name: Mexican lilac; Sinhala name: *kona/vetamara*; Tamil name: *kona*) to determine how these factors influenced growth and survival of seedlings of a tropical pioneer tree species – *Macaranga indica* – when planted into the anthropogenic grasslands in the KCF. Competition from the grass reduced the growth of *Macaranga* seedlings in the presence of added nutrients, but seedlings responded positively to nutrients in the absence of competition from the grass. The young *G. sepium* did not affect the growth or survival of the *Macaranga* seedlings, perhaps due to its poor overall growth in all study sites. Based on the results, we would recommend that the use of *Gliricidia* as a 'nurse plant' is not an appropriate restoration intervention, at least in the climatic conditions and treatments we tested. The study confirms that nutrient (organic manure) addition is beneficial to the growth of *Macaranga* saplings, but only when grass competition is removed. It highlights the importance of scrutinising all confounding factors, before introducing facilitative measures to restore highly degraded grasslands.

Case Study 4: Establishment of native tree islands in degraded grasslands in the Knuckles Conservation Forest, Sri Lanka

An experiment was initiated in 2011, with the aim of determining the effects of the size of tree islands of native plant species, and the presence of *G. sepium* as a nurse plant on the establishment of four native tree species, and a second experiment examined the effects of the application of Biofilmed Biofertilizer (BFBF) on nursery performance, and enhancement of soil nutrients and fungal-bacterial ratio in degraded soils. Three tree island sizes (small 4 m^2, medium 16 m^2, and large 64 m^2) were established in grasslands in 2012 (Figure 61). The attitudes of local villagers towards conservation were also investigated through a questionnaire-based survey, using 100 households in five different villages close to the field research site in the KCF.

Figure 61. View of the tree islands in block 2 and 3 established in KCF, Sri Lanka in 2012
(© Rasanga Gunasekara/ University of Peradeniya)

Islands of different sizes in half of each block were planted with *G. sepium* stakes and the other halves were kept as controls without planting *G. sepium stakes* (Figure 62). Seedlings of *Macaranga indica, Bhesa ceylanica* (Sinhala name: *pelang*; Tamil name: *konnai*), *Symplocos cochinchinensis* and *Eugenia bracteata* (Sinhala name: *tembiliya*; Tamil name: *venkali kaya*) were planted randomly (same density) into the islands. Biofilmed Biofertilizers were formed through the isolation of fungi and bacteria from the roots of the four native plant species. This study is one of the first attempts to investigate the potential of using BFBF to promote the establishment of native tree species, in the presence of *G. sepium,* in different island sizes, to restore degraded lands.

The highest Relative Growth Rate in height (RGR_h), and survival after 24 months was recorded by *S. cochinchinensis* in the presence of *G. sepium* and with application of BFBF (+G+B) in small islands. Application of both treatments (+G+B) also improved soil nutrients and the fungal-bacterial ratio in the plant islands, compared to soils that were sampled prior to the establishment of the native plants. The increase of fungal-bacterial ratio in soils may indicate speeding up of land restoration rate.

There was no significant relationship obtained among the attitudes of villagers towards conservation and their education, land tenure, employment or, gender. According to 85 % of villagers, banning of slash and burn (*chena*) cultivation reduced the income of local communities and they strongly emphasised the need for practicing *chena* cultivation in the buffer zone of the KCF for livelihood improvement. Thus, we propose agroforestry systems with *G. sepium*, useful native species and addition of BFBF, to replace *chena* (slash and burn) cultivation in the buffer zone of the KCF to enhance the livelihoods of local communities.

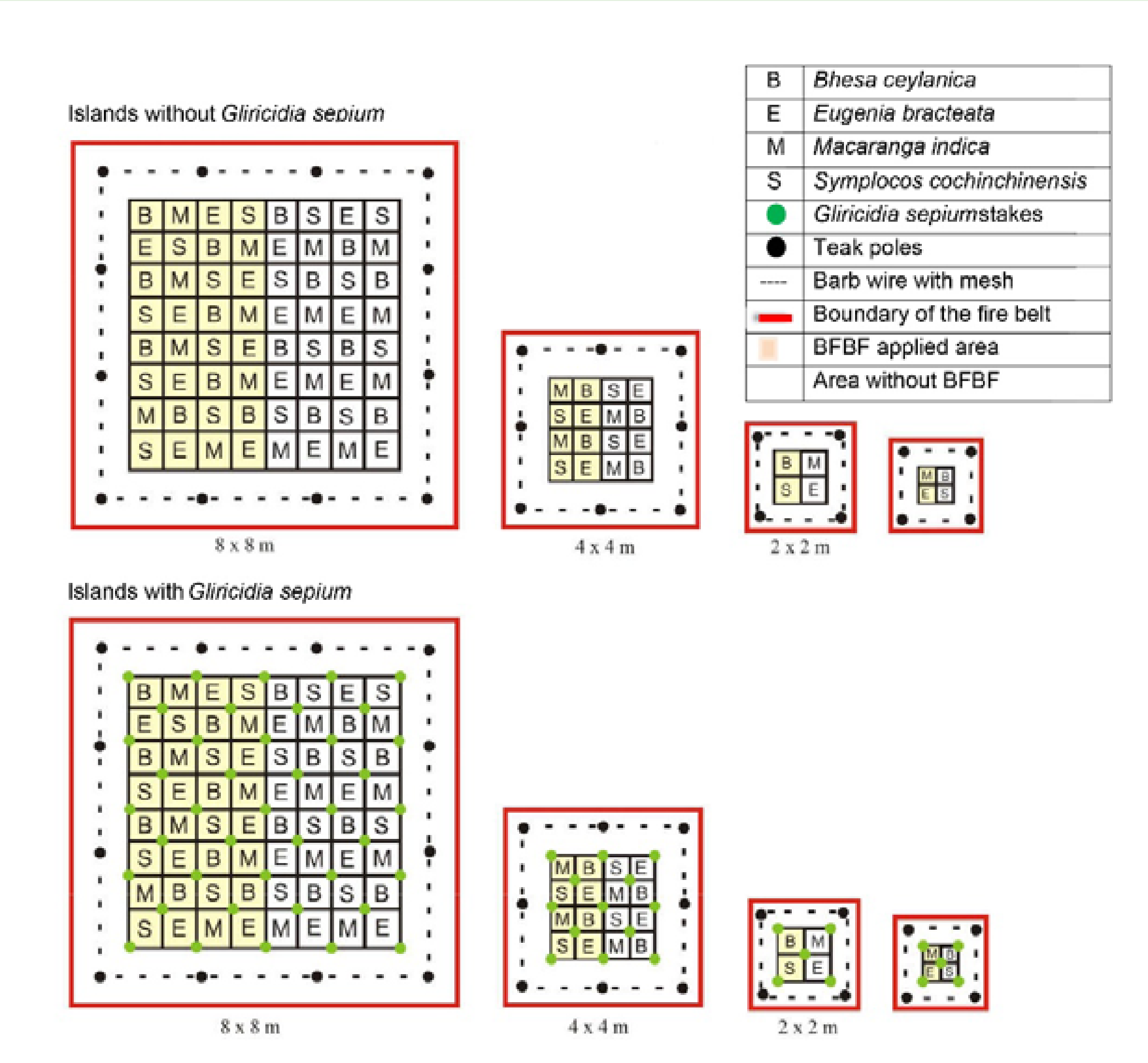


Figure 62. Experimental design layout established in the degraded grassland, showing the varying plot sizes and placement of the different species in them

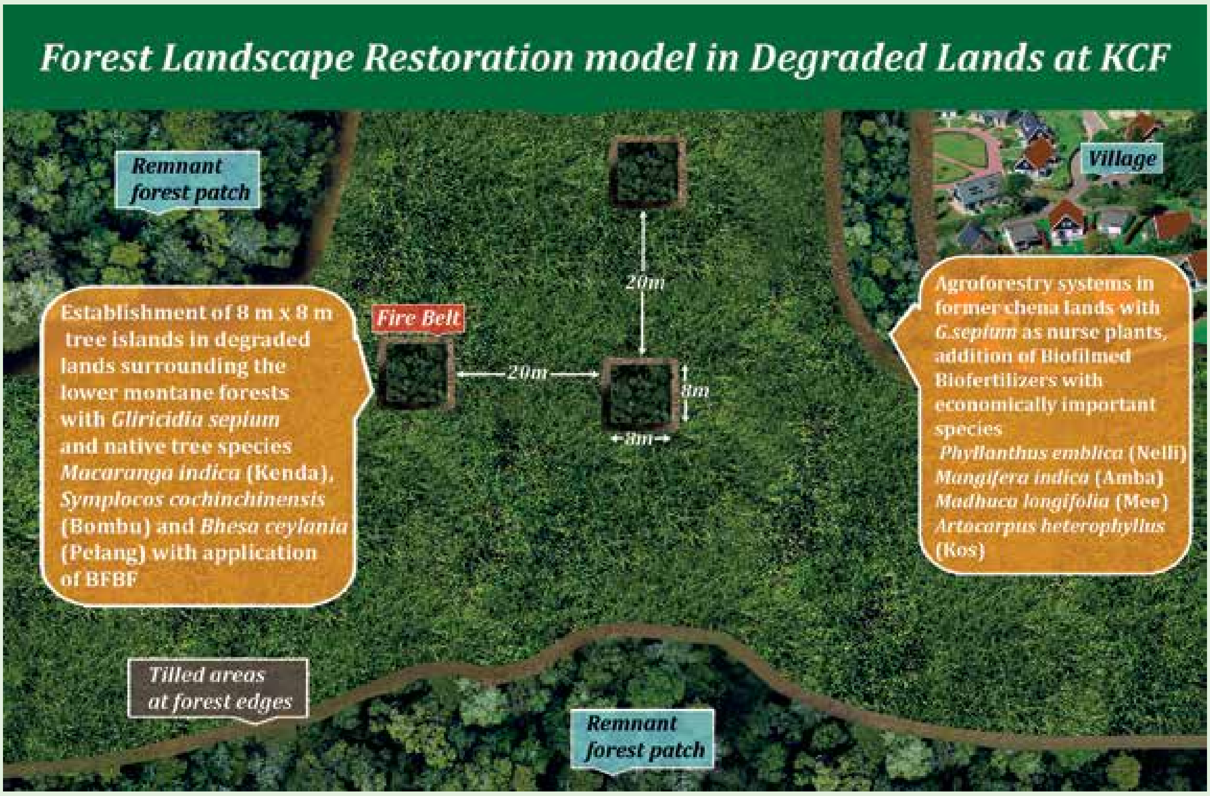
Figure 63. Established plants a) *Macaranga indica* (taller) and b) *Bhesa ceylanica* (shorter) in a 16 m^2 tree island one year after planting in 2013 at KCF
(© Rasanga Gunasekara/ University of Peradeniya)

Based on our findings, the most effective combination of treatments for promoting the establishment of *S. cochinchinensis, B. ceylanica and M. indica* seedlings on the eastern slope of the KCF was to grow them in large islands (64 m^2), in the presence of *G. sepium* stakes and to apply Biofilmed Biofertilizer at the time of planting (Figure 64). Awareness programmes must be conducted for the local community to promote acceptance of the importance of preserving ecosystem services to sustainably manage these lands in future.

Future Directions

In order to fine-tune the restoration model, research must be conducted in the areas listed below:

- Ecology and biology of pollinators, seed dispersers and seed predators.
- Regeneration traits of native tree species.
- Livelihood development through ecological restoration and promotion of nature-based, sustainable and responsible tourism.
- Enhancement of ecosystem services through ecological restoration.



Forest Landscape Restoration model in Degraded Lands at KCF

Establishment of 8 m x 8 m tree islands in degraded lands surrounding the lower montane forests with *Gliricidia sepium* and native tree species *Macaranga indica* (Kenda), *Symplocos cochinchinensis* (Bombu) and *Bhesa ceylania* (Pelang) with application of BFBF

Agroforestry systems in former chena lands with *G.sepium* as nurse plants, addition of Biofilmed Biofertilizers with economically important species *Phyllanthus emblica* (Nelli) *Mangifera indica* (Amba) *Madhuca longifolia* (Mee) *Artocarpus heterophyllus* (Kos)

Figure 64. Restoration model to assist forest recovery in degraded grasslands in KCF

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We are delighted that Sri Lanka's younger generation, having recognized the Island's fast depleting Natural Forests, has brought out this publication. They believe that "both conservation and restoration, like two sides of the same coin" must be implemented together. May the years ahead bring their efforts to fruition.

Emeritus Professor Nimal Gunatilleke and
Emerita Professor Savithri Gunatilleke

Chapter 9: Restoration information (General information such as locations of plant nurseries of the Forest Department)

Figure 65 provides a map of the following locations.

Division	Range	Name and Address of the Nursery
Ampara	Ampara	Paragahakele Central Plant Nursery, Ampara
Anuradhapura	Anuradhapura	Kopakulama Central Plant Nursery, Kopakulama
Anuradhapura	Thambuttegama	Central Plant Nursery, Kala Oya,Tambuttegama
Badulla	Badulla	Central Plant Nursery, Meedumpitiya, Passara
Badulla	Badulla	Plant Nursery, Meegahakiula
Badulla	Mahiyanganaya	Plant Nursery of RFOs Office, Mahiyanganaya
Badulla	Mahiyanganaya	Plant Nursery, Ulhitiya
Badulla	Haputale	Plant Nursery, Haputale
Badulla	Welimada	Plant Nursery, Erabedda
Batticaloa	Wellaweli-Batticaloa	Plant Nursery, Kalawnchikudi
Batticaloa	Batticaloa	Plant Nursery of DFO Office, Batticaloa
Colombo	Head Office	Plant Nursery adjacent to the Head Office, Battaramulla
Galle	Galle	Central Plant Nursery, Kottawa
Galle	Elpitiya	Plant Nursery of R.F.O.s Office, Elpitiya
Galle	Elpitiya	Plant Nursery of R.F.O.s quarters, Yakkatuwa
Galle	Thawalama	Adjacent to the R.F.O.s office Thawalama
Galle	Thawalama	Plant Nursery, Koralegama,Hiniduma.
Galle	Kanneliya (Conservation Center)	Central Plant Nursery, Kanneliya, Hiniduma
Galle	Neluwa	Plant Nursery adjacent to the R.F.O.s office, Neluwa
Hambantota	Hambantota	Plant Nursery, Ridiyagama, Ambalantota
Kalutara	Mathugama	Plant Nursery, Nagoda
Kalutara	Matugama	Plant Nursery of RFOs Office, Matugama
Kalutara	Ingiriya	Plant Nursery, Ingiriya
Kalutara	Agalawatta	Plant Nursery of RFOs Office, Agalawatta
Kalutara	Depanama	Plant Nursery, Depanama

Division	Range	Name and Address of the Nursery
Kalutara	Waga	Plant Nursery, Indikada, Waga
Kalutara	Ratmalana	Plant Nursery, Ratmalana
Kandy	Kandy	Plant Nursery, Polgolla, Katugastota
Kandy	Kandy	Plant Nursery, Uda Peradeniay, Peradeniya
Kandy	Hunnasgiriya	Plant Nursery of the RFOs quarters – Hasalaka
Kegalle	Kegalle	Plant Nursey of RFOs Office, Kegalle
Kegalle	Rambukkana	Central Plant Nursery, Narambedda, Rambukkana
Kegalle	Kitulgala	Plant Nursery of RFOs Office, Kitulgala
Kegalle	Dehiowita	Plant Nursery of RFOs Office, Dehiowita
Kilinochchi	Kilinochchi	Plant Nursery of D.F.O.s Office, Kilinochchi
Kurunegala	Kurunegala	Plant Nursery, Kumbalpola
Kurunegala	Kurunegala	Plant Nursery of R.F.O.s quarters, Lakeround
Kurunegala	Kuliyapitiya	Plant Nursery of R.F.O.s Office, Kuliyapitiya
Kurunegala	Malsiripura	Plant Nursery of R.F.O.s Office, Ibbagamuwa
Kurunegala	Galgamuwa	Plant Nursery of R.F.O.s Office, Galgamuwa
Kurunegala	Mahawa	Plant Nursery of Rakaula
Kurunegala	Mahawa	Plant Nursery of R.F.O.s Office, Mahawa
Mannar	Mannar	Plant Nursery of D.F.O.s Office, Mannar
Matale	Matale	Plant Nursery,Imbuladanda,Matale
Matale	Naula	Plant Nursery, Inamaluwa
Matara	Kamburupitiya	Central Plant Nursery Wilpita, Kamburupitiya
Matara	Deniyaya	Plant Nursery, Diyadawa, Deniyaya
Matara	Akuressa	Plant Nursery of the RFOs Office, Akuressa
Matara	Matara	Central Plant Nursery, Nadugala, Matara
Monaragala	Wellawaya	Plant Nursery, Handapanagala, Wellawaya
Mullaitivu	Mullaitivu	Plant Nursery of D.F.O.s Office, Mullaitivu
Nuwara Eliya	Nuwara Eliya	Plant Nursery Ramboda, Ramboda
Nuwara Eliya	Nuwara Eliya	Central plant Nursery, Kandapola
Nuwara Eliya	Nuwara Eliya	Plant Nursery, Kande Ella Conservation Center
Nuwara Eliya	Nuwara Eliya	Plant Nursery, Konical hill
Nuwara Eliya	Nuwara Eliya	Plant Nursery, Bopaththalawa
Nuwara Eliya	Halgranoya	Plant Nursery, Walapane
Nuwara Eliya	Halgranoya	Plant Nursery, Mahakudugala

Division	Range	Name and Address of the Nursery
Nuwara Eliya	Halgranoya	Plant Nursery, Nildandahinna
Polonnaruwa	Dimbulagala	Plant Nursery Piburaththawa.
Polonnaruwa	Dimbulagala	Plant Nursery of the RFOs Office – Dimbulagala.
Polonnaruwa	Polonnaruwa	Plant Nursery of RFOs Office, Polonnaruwa.
Polonnaruwa	Polonnaruwa	Plant Nursery, Elahara.
Polonnaruwa	Habarana	Central Plant Nursery, Irigeoya
Puttlam	Puttlam	Plant Nursery Kala Oya, Puttlama
Puttlam	Chilaw	Plant Nursery of RFOs Office Chilaw
Puttlam	Chilaw	Plant Nursery, Panirendawa, Chilaw
Puttlam	Anamaduwa	Plant Nursery, Inginimitiya, Anamaduwa
Ratnapura	Balangoda	Plant Nursery, Raththanagolla
Ratnapura	Balangoda	Plant Nursery, Rajawaka
Ratnapura	Balangoda	Plant Nursery RFOs Office, Balangoda
Ratnapura	Kalawana	Plant Nursery of RFOs Office, Kalawana
Ratnapura	Ratnapura	Central Plant Nursery, Muwagankanda, Ratnapura
Ratnapura	Sinharaja	Plant Nursery, Kudawa, Sinharaja
Ratnapura	Rakwana	Plant Nursery of RFOs Office, Rakwana
Ratnapura	Rakwana	Plant Nursery, Madampe
Ratnapura	Embilipitiya	Central Plant Nursery Thimbolketiya, Thimbolketiya
Trincomalee	Trincomalee	Plant Nursery of DFOs Office, Trincomalee
Vavunia	Vavunia	Plant Nursery of DFOs Office, Vavunia

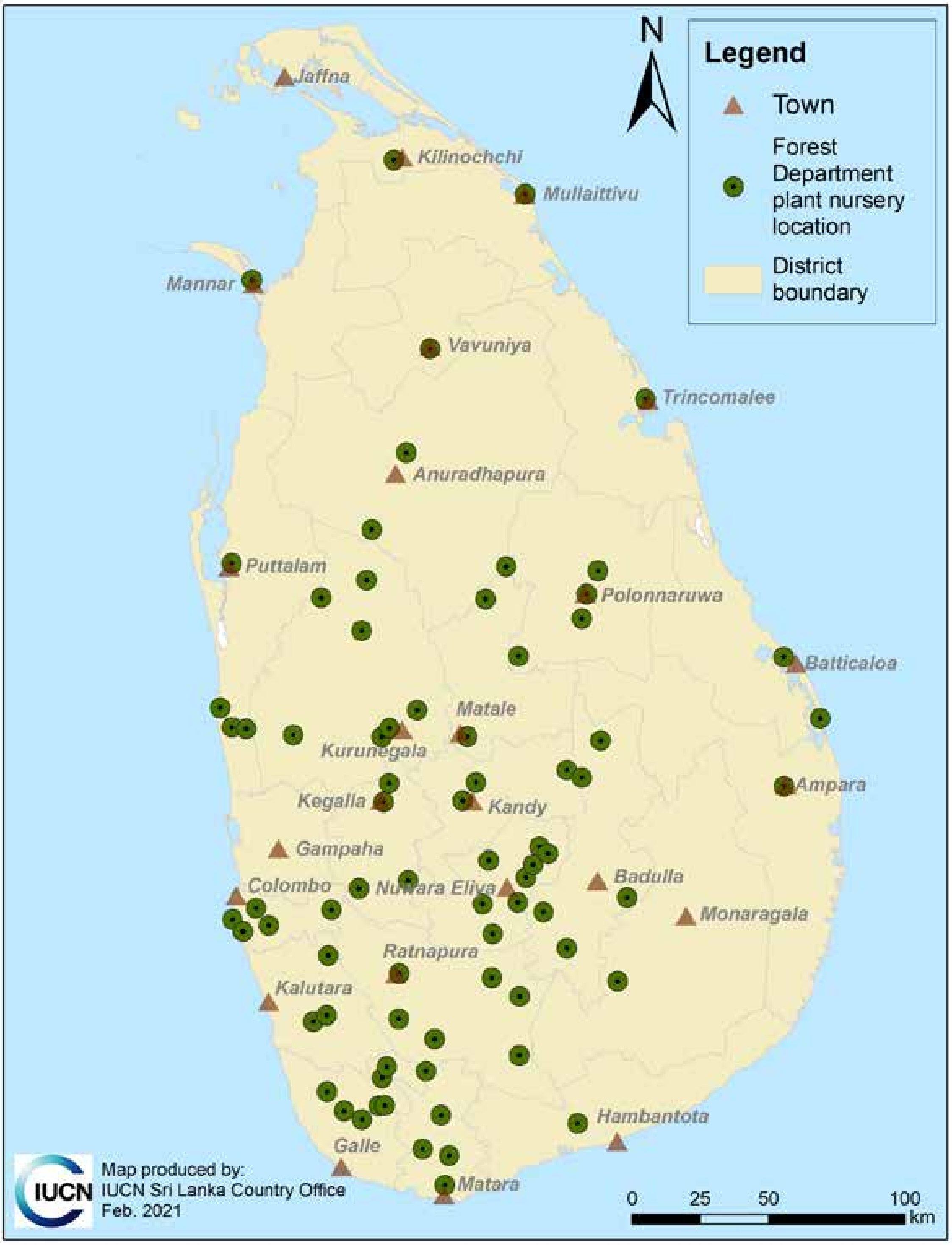

Figure 65. Locations of plant nurseries of the Forest Department

Annex 1: Plant species for forest restoration

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Table 10. A selection of suitable plants for the restoration of lowland wet evergreen forests

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Anacardiaceae	*Campnosperma zeylanicum*	No name known	*Aridda*	No name known	Can be introduced at an early stage.
Anacardiaceae	*Lannea coromandelica*	No name known	*Hik*	No name known	
Anacardiaceae	*Nothopegia beddomei*	No name known	*Bala*	No name known	
Anacardiaceae	*Semecarpus nigro-viridis*	No name known	*Badulla*	No name known	
Anacardiaceae	*Mangifera zeylanica*	No name known	*Etamba*	*Kaddu-ma*	
Anisophyllaceae	*Anisophyllea cinnamomoides*	No name known	*Weli piyana*	No name known	Can be introduced at an early stage.
Annonaceae	*Alphonsea hortensis*	No name known	No name known	No name known	
Arecaceae	*Caryota urens*	Fish-tail palm	*Kitul*	*Tippilipanai*	Can be introduced at an early stage. Suitable for wet areas or riverbanks.
Burseraceae	*Canarium zeylanicum*	No name known	*Kekuna*	*Pakkilipal*	Can be introduced at an early stage.
Calophyllaceae	*Calophyllum bracteatum*	No name known	*Walu keena*	No name known	
Cannabaceae	*Trema orientalis*	Charcoal tree	*Gadumba*	No name known	Pioneer species. Highly vulnerable to herbivory. Plant protection nets are recommended

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Centroplacaceae	*Bhesa ceylanica*	No name known	*Pelang*	*Konnai*	Highly vulnerable to herbivory. Plant protection nets are recommended.
Clusiaceae	*Garcinia quaesita*	No name known	*Goraka*	*Korakkaipuli*	Highly vulnerable to herbivory. Plant protection nets are recommended.
Dilleniaceae	*Dillenia retusa*	No name known	*Godapara*	No name known	
Dilleniaceae	*Dillenia triquetra*	No name known	*Diyapara*	No name known	Suitable for wet areas or riverbanks.
Dilleniaceae	*Schumacheria castaneifolia*	No name known	*Kekiri wara*	No name known	
Dipterocarpaceae	*Dipterocarpus hispidus*	No name known	*Bu hora*	No name known	
Dipterocarpaceae	*Dipterocarpus zeylanicus*	No name known	*Hora*	*No name known*	Can be introduced at an early stage.
Dipterocarpaceae	*Vateria copallifera*	No name known	*Hal*	*Kungiliyam pinai*	Suitable for wet areas or riverbanks.
Ebenaceae	*Diospyros insignis*	No name known	*Porawa mara*	No name known	
Elaeocarpaceae	*Elaeocarpus serratus*	Wild olive	*Weralu*	No name known	
Elaeocarpaceae	*Elaeocarpus subvillosus*	No name known	*Gal weralu*	No name known	
Euphorbiaceae	*Bridelia moonii*	No name known	*Patkela*	No name known	
Euphorbiaceae	*Bridelia retusa*	No name known	*Ketakela*	*Mul-venkai*	Highly vulnerable to herbivory.
Euphorbiaceae	*Macaranga peltata*	Macaranga	*Kenda*	*Vattakanni*	Pioneer species.
Euphorbiaceae	*Mallotus fuscescens*	No name known	No name known	No name known	
Euphorbiaceae	*Mallotus tetracoccus*	Rusty kamala	*Bu kenda*	*Mullupolavu*	Pioneer species.

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Fabaceae	*Adenanthera bicolor*	No name known	*Mas-mora*	No name known	
Fabaceae	*Gliricidia sepium*	Mexican lilac	*Glyricidia*	No name known	Not a native species. But this species can be used as a nurse tree.
Lamiaceae	*Vitex altissima*	No name known	*Milla*	*Kaaddmanakku*	Can be introduced at an early stage.
Lauraceae	*Cinnamomum capparu-coronde*	Camphor cinnamon	*Kapuru kurundu*	No name known	
Lauraceae	*Cinnamomum zeylanicum*	No name known	*Kurundu*	*Kuruva*	Can be introduced at an early stage.
Lauraceae	*Neolitsea cassia*	Wild cinnamon	*Davul kurundu*	No name known	
Melastomataceae	*Melastoma malabathricum*	No name known	*Maha bovitiya*	No name known	Shrub, pioneer species.
Moraceae	*Artocarpus nobilis*	No name known	*Wal del*	*Arsini-pla*	
Moraceae	*Ficus hispida*	No name known	*Kota dimbula*	No name known	Suitable for wet areas or riverbanks.
Myristicaceae	*Horsfieldia irya*	No name known	*Iriya*	No name known	
Myristicaceae	*Myristica ceylanica*	No name known	*Maloboda*	No name known	
Myrtaceae	*Cleistocalyx operculatus*	No name known	*Bata damba*	No name known	Can be introduced at an early stage.
Myrtaceae	*Syzygium alubo*	No name known	*Alubo*	No name known	
Myrtaceae	*Syzygium rubicundum*	No name known	*Kurumbatiya*	No name known	
Phyllanthaceae	*Bridelia moonii*	No name known	*Path keela*	No name known	
Rubiaceae	*Hedyotis fruticosa*	No name known	*Veraniya*	No name known	Pioneer species.

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Sapindaceae	*Pometia pinnata*	No name known	*Na imbul*	No name known	Can be introduced at an early stage.
Sapotaceae	*Palaquium canaliculatum*	No name known	*Elakirihembiliya*	No name known	Highly vulnerable to herbivory. Plant protection nets are recommended.
Symplocaceae	*Symplocos cochinchinensis*	No name known	*Bombu*	No name known	

Table 11. A selection of suitable plants for the restoration of mid-elevation evergreen forests and montane evergreen forests

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Aquifoliaceae	*Ilex walkeri*	No name known	No name known	No name known	
Calophyllaceae	*Calophyllum walkeri*	No name known	*Keena*	No name known	
Elaeocarpaceae	*Elaeocarpus glandulifer*	No name known	*Gal-veralu*	No name known	
Euphorbiaceae	*Glochidion coriaceum*	No name known	No name known	No name known	No name known
Euphorbiaceae	*Mallotus tetracoccus*	Rusty kamala	*Bu kenda*	*Mullu polavu*	
Fabaceae	*Abarema subcoriacea*	No name known	*Mimini mara*	No name known	
Fabaceae	*Erythrina variegata*	Indian coral tree	*Erabadu*	*Mullu-murukku*	In the early stages, this species can be used as a nurse species.
Lauraceae	*Actinodaphne ambigua*	No name known	No name known	No name known	
Lauraceae	*Cinnamomum ovalifolium*	No name known	*Wal kurundu*	No name known	
Lauraceae	*Neolitsea fuscata*	No name known	*Davul kurundu*	No name known	

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Rubiaceae	*Canthium montanum*	No name known	No name known	No name known	
Rubiaceae	*Ixora calycina*	No name known	No name known	No name known	
Rubiaceae	*Wendlandia bicuspidata*	No name known	*Rawan idala*	No name known	
Ruthaceae	*Acronychia pedunculata*	No name known	*Ankenda*	*Vidukanalei*	
Ruthaceae	*Melicope lunu-ankenda*	Melicope	*Lunu-ankenda*	*Kattucampakam*	
Magnoliaceae	*Magnolia nilagrica*	Nilgiri champa	*Wal-sapu*	*Vellachempakam*	
Myrtaceae	*Rhodomyrtus tomentosa*	Wild guava	*Seetha pera*	*Malai--koyya*	
Myrtaceae	*Syzygium revolutum*	No name known	*Damba*	No name known	
Phyllanthaceae	*Actephila excelsa*	No name known	*Et-pitawakka*	No name known	
Sapindaceae	*Allophylus zeylanicus*	No name known	*Wal-kobbe*	No name known	
Symplocaceae	*Symplocos cochinchinensis*	No name known	*Wal-bombu*	No name known	
Theaceae	*Gordonia ceylanica*	No name known	*Mihiriya*	No name known	
Theaceae	*Gordonia speciosa*	No name known	*Ashoka*	No name known	

Table 12. A selection of suitable plants for the restoration of moist-mixed evergreen forests (intermediate zone)

Family	Scientific name	English name	Sinhala name	Tamil name	Comments
Combretaceae	*Terminalia bellirica*	Beleric	*Bulu*	*Tanti*	
Ebenaceae	*Diospyros ebenum*	*Ebony*	*Kaluwara*	*Karunkali*	
Euphorbiaceae	*Bridelia retusa*	*No name known*	*Keta kela*	No name known	
Fabaceae	*Pongamia pinnata*	*Pongam*	*Magul karanda*	*Poona*	
Fabaceae	*Pterocarpus marsupium*	*No name known*	*Gammalu*	*Venkai*	
Lecythidaceae	*Careya arborea*	*Patana oak*	*Kahata*	*Kachaddai*	
Sapindaceae	*Filicium decipiens*	*Fern tree*	*Pihimbiya*	*Chitteraivempu*	
Malvaceae	*Pterospermum suberifolium*	No name known	*Welang*	No name known	
Myrtaceae	*Syzygium cumini*	Java plum	*Dan*	*Naval*	
Sapindaceae	*Filicium decipiens*	Fern tree	*Pihimbiya*	*Chitteraivempu*	
Sapindaceae	*Schleichera oleosa*	Ceylon oak	*Kon*	*Puvu*	
Tiliaceae	*Grewia damine*	No name known	*Daminiya*	*Cadachi*	

Table 13. A selection of suitable plants for the restoration of dry mixed-evergreen forests

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Achariacea	*Hydnocarpus venenata*	No name known	*Makulu*	*Makul*	Suitable for riverbank restoration.
Anacardiaceae	*Buchanania axillaris*	No name known	*Kiripalu*	*Kolamau*	
Anacardiaceae	*Lannea coromandelica*	No name known	*Hik*	*Odi*	
Combretaceae	*Terminalia arjuna*	Arjun	*Kumbuk*	*Maruti*	Suitable for riverbank restoration.
Combretaceae	*Terminalia bellirica*	Beleric	*Bulu*	*Tanti*	
Ebenaceae	*Diospyros ebenum*	Ebony	*Kaluwara*	*Karunkali*	Suitable for later stage of restoration.
Ebenaceae	*Diospyros malabarica*	Indian persimmon	*Timbiri*	*Panichchai*	Suitable for riverbank restoration.
Ebenaceae	*Diospyros montana*	No name known	*Sudu*	*Katukanni*	
Euphorbiaceae	*Antidesma ghaesembilla*	No name known	*Bu-embilla*	No name known	
Euphorbiaceae	*Bridelia retusa*	No name known	*Keta kela*	No name known	
Euphorbiaceae	*Cleistanthus pallidus*	No name known	No name known	*Visa*	
Euphorbiaceae	*Dimorphocalyx glabellus*	No name known	*Weli-wenna*	*Tentuikki*	
Euphorbiaceae	*Mallotus philippensis*	No name known	*Hamparila*	*Kapila*	
Euphorbiaceae	*Putranjiva roxburghii*	No name known	No name known	*Karippalai*	
Fabaceae	*Acacia leucophloea*	No name known	*Maha andara*	*Velvalayam*	

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Fabaceae	*Bauhinia racemosa*	No name known	*Maila*	*Atti*	
Fabaceae	*Cassia auriculata*	Matara tea	*Ranawara*	*Avarai*	
Fabaceae	*Cassia fistula*	Indian laburnum	*Ehela*	*Thirukkondrai*	
Fabaceae	*Pongamia pinnata*	Pongam	*Karanda*	*Punku*	
Fabaceae	*Tamarindus indica*	Tamarind	*Siyambala*	*Pulli*	
Lecythidaceae	*Careya arborea*	Patana oak	*Kahata*	*Kachaddai*	
Meliaceae	*Azadirachta indica*	Neem	*Kohomba*	*Vembu*	
Myrtaceae	*Syzygium cumini*	Java plum	*Dan*	*Naval*	
Olacaceae	*Olax scandens*	No name known	*Theratiya*	No name known	
Picrodendraceae	*Mischodon zeylanicus*	No name known	*Thammanna*	*Tampanai*	
Putranjivaceae	*Drypetes sepiaria*	No name known	*Weera*	*Weerai*	
Rubiaceae	*Morinda coreia*	No name known	*Ahu*	*Manchavanna*	
Rubiaceae	*Haldina cordifolia*	No name known	*Kolon*	*Raja murunkai*	
Rutaceae	*Chloroxyclon swietania*	Satinwood	*Burutha*	*Muruthai*	
Rutaceae	*Murraya koenigii*	Curry leaf tree	*Karapinchcha*	*Karivempu*	
Sapindaceae	*Dimocarpus longan*	Longan	*Mora*	*Nurai*	
Sapindaceae	*Schleichera oleosa*	Ceylon oak	*Kon*	*Puvu*	

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Sapotaceae	*Madhuca longifolia*	Honey tree	*Mee*	*Kuligam*	
Sapotaceae	*Manilkara hexandra*	No name known	*Palu*	*Palai*	Can introduced at an early stage. But will need support to remain upright.
Tiliaceae	*Berrya cordifolia*	Trincomalee wood	*Halmilla*	*Chavandalali*	
Tiliaceae	*Grewia damine*	No name known	*Daminiya*	*Cadachi*	
Tiliaceae	*Grewia hirsuta*	No name known	No name known	No name known	
Tiliaceae	*Grewia carpenifolia*	No name known	No name known	No name known	

Table 14. A selection of suitable plants for the restoration of dry zone tank associated habitats

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Arecaceae	*Caryota urens*	No name known	*Kitul*	*Tippilipanai*	Suitable for the intercept (*kattakaduwa*).
Combretaceae	*Terminalia arjuna*	Arjun	*Kumbuk*	*Maruti*	
Ebenaceae	*Diospyros malabarica*	Indian persimmon	*Timbiri*	*Panichchai*	
Euphorbiaceae	*Drypetes sepiaria*	No name known	*Weera*	*Weerai*	
Fabaceae	*Cassia fistula*	Indian laburnum	*Ehela*	*Thirukondrai*	
Fabaceae	*Pogamia pinnata*	Pongam	*Karanda*	*Poona*	Suitable for tank bunds and catchments.
Fabaceae	*Tamarindus indica*	Tamarind	*Siyambala*	*Pulli*	Suitable for tank bunds and catchments.

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Pandanaceae	*Pandanus kaida*	No name known	*Watakeiyya*	No name known	Suitable for the intercept (*kattakaduwa*).
Meliaceae	*Azadirachta indica*	Neem	*Kohomba*	*Vembu*	Suitable for tank bunds and dry areas in catchments.
Moraceae	*Ficus benghalensis*	Banyan	*Nuga*	*Ari*	Suitable for tank bunds and dry areas in catchments.
Myrtaceae	*Syzygium cumini*	Java plum	*Dan*	*Naval*	Suitable for tank bunds and catchments.
Rubiaceae	*Nauclea orientalis*	No name known	*Bakmi*	*Vammi*	Suitable for the intercept (*kattakaduwa*) and catchments.
Rutaceae	*Chloroxyclon swietania*	Satinwood	*Burutha*	*Muruthai*	Suitable for tank bunds and catchments.
Rutaceae	*Limonia acidissima*	Wood apple	*Divul*	*Vellai maram*	Suitable for catchments.
Sapindaceae	*Schleichera oleosa*	Ceylon oak	*Kon*	*Puvu*	Suitable for tank bunds and catchments.
Sapotaceae	*Madhuca longifolia*	Honey tree	*Mee*	*Kuligam*	
Sapotaceae	*Manilkara hexandra*	No name known	*Palu*	*No name known*	Suitable for dry areas in catchments.
Sterculiaceae	*Pterospermum suberifolium*	No name known	*Welang*	*Tadu*	Suitable for catchments.
Tiliaceae	*Berrya cordifolia*	Trincomalee wood	*Halmilla*	*Chavandalali*	Suitable for tank bunds and catchments.
Verbenaceae	*Vitex leucoxylon*	No name known	*Nabada.*	*Nirnochi*	Suitable for catchments.
Verbenaceae	*Vitex altisima*	No name known	*Milla*	*Kaaddamanakku*	Suitable for tank bunds and catchments.

Table 15. A selection of suitable plants for the restoration of wet lowland flood plains and marsh-associated ecosystems

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Arecaceae	*Areca concinna*	No name known	*Lenteri*	No name known	
Arecaceae	*Caryota urens*	Fish tail palm	*Kitul*	*Tippilipanai*	
Apocynaceae	*Cerbera odollam*	No name known	*Gon-kaduru*	*Nangi-Ma*	
Apocynaceae	*Pagiantha dichotoma*	Eve's apple	*Divi-kaduru*	*Nanthia-Vattai*	
Combretaceae	*Terminalia arjuna*	Arjun	*Kumbuk*	*Maruti*	A dry zone species, now widely used in tree planting programmes.
Clusiaceae	*Garcinia quaesita*	No name known	*Goraka*	No name known	
Dilleniaceae	*Dillenia indica*	No name known	*Hondapara*	*Akku*	
Dilleniaceae	*Dillenia retusa*	No name known	*Godapara*	No name known	
Dipterocarpacea	*Vatica paludosa*	No name known	*Mandora*	No name known	
Elaeocarpaceae	*Elaeocarpus serratus*	No name known	*Weralu*	No name known	
Lauraceae	*Cinnamomum zeylanicum*	Cinnamon	*Kurundu*	*Kuruva*	
Lecythidaceae	*Barringtonia racemosa*	No name known	*Diya-midella*	No name known	
Lythraceae	*Lagerstroemia speciosa*	Queen's flower	*Murutha*	*Kadali*	
Malvaceae	*Thespesia populnea*	Tulip tree	*Gan Suriya*	*Kavarachu*	

Family	Scientific name	English name	Sinhala name	Tamil name	Comment
Moraceae	*Ficus racemosa*	No name known	*Attikka*	*Atti*	
Myrtaceae	*Syzygium caryophyllatum*	No name known	*Heen-dan*	No name known	
Pandanaceae	*Pandanus kaida*	No name known	*Wata-keyiya*	No name known	
Rutaceae	*Murraya paniculata*	Orange jasmine	*Etteriya*	No name known	
Simaroubaceae	*Quassia indica*	No name known	*Samadara*	No name known	

Table 16. A selection of suitable plants for the restoration of beach front vegetation

Family	Scientific name	English name	Sinhala name	Tamil name	Note
Boraginaceae	*Heliotropium foertherianum*	Beach heliotrope	No name known	No name known	Suitable for coastal areas of the intermediate and dry zones.
Calophyllaceae	*Calophyllum inophyllum*	Alexandrian laurel	*Domba*	*Dommakottai*	Suitable for coastal areas in the wet and intermediate zones.
Celastraceae	*Cassine glauca*	No name known	*Neralu*	*Piyari*	Suitable for coastal areas in the dry zone.
Combretaceae	*Terminalia catappa*	No name known	*Kottan*	*Kottai*	Non-native but a naturalized species more suitable to urban and suburban coastal areas.
Goodeniaceae	*Scaevola taccada*	No name known	*Takkada*	No name known	
Lythraceae	*Pemphis acidula*	No name known	No name known	*Kiri-Maram*	Suitable as a mangrove associate in coastal areas of the dry zone.
Lecythidaceae	*Barringtonia asiatica*	No name known	*Mudilla*	No name known	Suitable for coastal areas of the wet and intermediate zones.

Family	**Scientific name**	**English name**	**Sinhala name**	**Tamil name**	**Note**
Malvaceae	*Thespesia populnea*	No name known	*Gansuriya*	*Kavarachu*	
Nyctaginaceae	*Pisonia grandis*	Lettuce tree	*Lechchakotta*	*Chandi*	
Pandanaceae	*Pandanus odoratissimus*	Screw-pine	*Wetakeyiya*	*Talai*	
Rubiaceae	*Morinda citrifolia*	Great morinda	*Ahu*	No name known	

During the last 15 years, the Sri Lanka Country Office of IUCN has been involved in various forest restoration projects – including a long-standing partnership with the private sector to restore degraded lands in the North-western Province; watershed forest restoration and restoration of village tank cascades. The Sri Lanka Country Office of IUCN also implemented the Bonn Challenge Barometer of Progress to record information on landscape restoration within the country.

The Forest Department has, for the last seven years, been engaged in the restoration of degraded and damaged forests. The department has restored 9,000 ha in 2020. It also encourages active participation of communities and engages the corporate sector in public-private partnerships in restoration of degraded and damaged forests.

The Faculty of Science and Postgraduate Institute of Science (University of Peradeniya) is committed to improving the well-being of the present and future generations through education, research, training, and outreach activities. Academics in nine departments engage in high-quality research of local and international relevance, including the conservation and sustainable use of natural resources.

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