

A large, moss-covered tree trunk in a rainforest. The tree trunk is the central focus, covered in thick green moss. The background is a dense forest with many other trees and foliage. The ground is covered in fallen brown leaves.

# *rainforest restoration*

a guide to principles and practice



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*tropical rainforest: an introduction*



Among all forest types on Earth, the greatest diversity of living organisms is found in the tropical rainforest. Also called tropical wet evergreen forest, this forest type occurs in those parts around the equator with over 2,000 millimetres of annual rainfall distributed over most of the year. Dry periods with less than 60 millimetres rainfall occur only for a few weeks at most. As a result, there is luxuriant vegetation and most trees remain green year-round.

Rainforests are found in all three tropical regions in the world: the Americas, Africa, and Asia. The famed rainforests of the Amazon and Orinoco basins, tracts along the Andes and Central America, and the forests of the Atlantic coast, comprise the rainforests of the Americas. In Africa, the rainforests are found primarily in the Congo basin and West Africa, besides the highly threatened rainforests in Madagascar. Second in extent only to the range of Amazonian rainforests, the rainforests of tropical Asia may be found in a great belt centred on the Malay Archipelago, but with tracts found as far west as parts of India and Sri Lanka all the way to the east in Papua New Guinea and northern Queensland in Australia and Pacific islands. Within India, tropical rainforests are found in north-east India (along the Eastern Himalaya, in Assam, and the hill states), in the Andaman and Nicobar Islands, and the Western Ghats mountain chain along the west coast of India.



Left: Canopy of a rainforest from the Western Ghats | P Jeganathan  
Above: Fruits of the endemic *Baccaurea courtallensis*, a mid-storey tree



### *Structure*

Trees and woody climbers called lianas dominate the vegetation of a tropical rainforest. A single hectare of tropical rainforest may hold from 100 to over 300 species of trees. The canopy reaches an average height of 25 metres or more, with some emergent trees reaching up to 80 metres in height, towering over the others. The tree canopy is dense, allowing less than 10% of the sunlight to reach the forest floor. There is a great diversity of herbs, shrubs, ferns, orchids, and plants called epiphytes that grow on top of the other plants. Even tree bark and leaf surfaces are micro-ecosystems that shelter a multitude of smaller plants, fungi, lichens, and mosses. The rich tapestry of vegetation supports a diversity of animals from minute mites and springtails in the soil to elephants and hornbills. The lives of these species are closely linked to form the complex rainforest habitat.

### *Complexity*

The complexity of the rainforest ecosystem stems from two reasons. The first is structural complexity: the forest has many layers ranging from subsoil belowground, leaf litter, to aboveground layers such as ground vegetation, understory, mid-storey, canopy, and emergent trees. A second reason is the varied dependence and interactions among the various rainforest organisms. For example,



there is competition for light and moisture among plants, mutualisms of pollination and seed dispersal between plants and animals, herbivory and predation, and dynamic interaction below-ground between fungal mycorrhizae and the roots of plants.

### *Dynamics*

Individual trees in tropical rainforest may live for hundreds of years and to a human observer the forest may look the same year after year. Yet, rainforests are dynamic ecosystems. Biologists have documented intricate details of many processes such as the birth and death of rainforest plants, competition among seedlings, fluctuations within years and across years in the patterns of flowering and fruiting, and their corresponding influences on animal populations and movements.

In relatively undisturbed rainforest, one major natural dynamic process is what has been called tree fall gap dynamics. Occasionally, large rainforest trees fall, bringing down other nearby vegetation and creating a gap in the dense canopy through which sunlight streams down to the floor. This triggers the germination of pioneer tree species from seeds lying in the soil and stimulates the growth of many rainforest tree seedlings as well. Rapid recovery ensues and in a matter of years, the gap closes again with the growth of evergreen vegetation in the case of undisturbed forests and deep forest interiors.



Above: Fungi play a key role in decomposition and the nutrient dynamics of rainforests



### Threats

Around the world, tropical rainforests are among the most threatened ecosystems today. Over 100 million hectares are lost or severely degraded every decade due to human-caused destruction. Clearing for agriculture, plantations of oil palm, tea, coffee, and *Eucalyptus*, roads, reservoirs, logging for timber, extraction of minor forest produce, invasions by weedy species, grazing, fire, climate change, unplanned development and urbanisation are some of the major threats to tropical rainforests today. Besides direct loss of forest cover (deforestation), these have resulted in fragmentation (leaving remnants of forest surrounded by non-forest habitats), and created large areas of secondary forest (second growth or regenerating vegetation in degraded or disturbed areas).

Even as thousands of species await discovery and study in the rainforests, the burgeoning threats continue to further endanger and drive species extinct at rapid rates in all tropical rainforest regions. Besides reducing the area, quality, diversity, and ecosystem services of these forests, such changes also impinge negatively on myriad indigenous peoples and tribal communities living in the rainforests around the world.

Top: Monoculture oil-palm plantations are among the greatest threats to rainforests worldwide

Above: Linear intrusions such as roads and power lines fragment rainforests leading to degradation and weed invasion

# reversing forest degradation: the four r's

For reversing the loss, degradation, or denudation of forest ecosystems several approaches have been used all of which of are often wrongly called restoration or eco-restoration. It is important to distinguish among these:

**Reforestation (or afforestation):** This approach, although used widely, is typically characterised by large-scale plantation of alien (locally or nationally non-native) species such as *Eucalyptus*, *Acacia*, *Pinus*, *Casuarina*, and many timber species. Planted as single-species stands (monocultures), these plantations have negative impacts on local ecology such as invading adjoining natural forest or grassland habitats (e. g., *Acacia auriculiformis*, *A. mearnsii*), depleting water tables (e. g., *Eucalyptus*), or degrading habitat for wildlife. Ecological or long-term considerations are conspicuously absent in such afforestation programmes that are usually aid-driven and target-oriented to cover as much area as possible with minimal effort and time. Sometimes, driven by the ingenuity and needs of local people, such programmes have had the incidental effect of providing fuel wood (e.g., wattle and eucalypts) or charcoal (e. g., *Prosopis juliflora*) for domestic use or sale.

**Reclamation:** This is similar to some of the afforestation programmes in that it principally uses alien species to overcome severe degradation or disturbance. These may be chosen for economic reasons such as timber production or based on ease of establishment in highly degraded areas such as mine spoils and sites where the top soil has been lost. For instance, the alien species *Acacia auriculiformis* is often used on abandoned mine sites.

**Rehabilitation:** In rehabilitation, mostly native species are used in the new forest, but some alien species may be included as they are ecologically or economically necessary. The purpose here is to bring back a semblance of function and utility to degraded sites.

**Restoration:** Restoration is the process of returning an ecosystem to a relatively undisturbed condition as it is likely to have been prior to major disturbances or human impact. This is the preferred option if the main goal is the conservation of biodiversity because the emphasis is on returning the original assemblage of species and forest structure to the site. Most forest restoration projects use only native species with or without the removal of alien (non-native) species and control or removal of invasive alien weeds such as *Lantana camara*.

*To keep every cog and wheel is the first precaution of intelligent tinkering.*

*Aldo Leopold, A Sand County Almanac*

*restoration: principles and guidelines*



### *What is ecological restoration?*

Ecological restoration is defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoration International Science and Policy Working Group 2004).

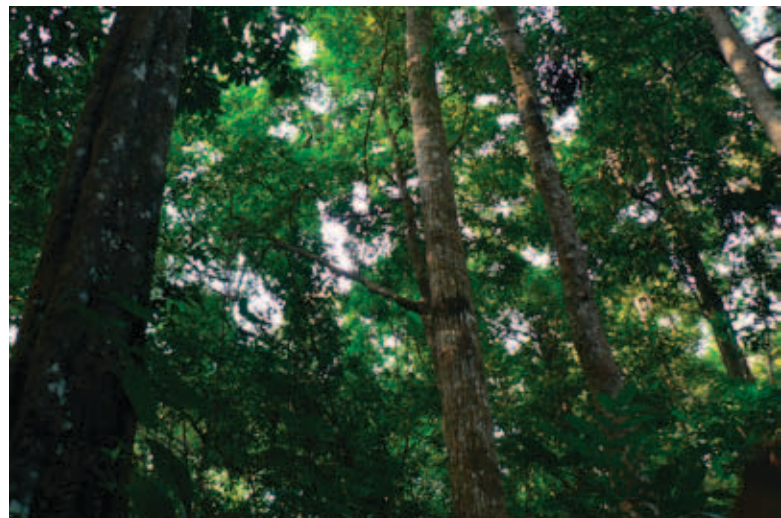
### *What is recovery?*

In the context of restoration, recovery means the process of returning to similar conditions as reference sites:

- The natural structural characteristics of the ecosystem such as multi-layer vegetation and tree canopy cover,
- The natural functional attributes and dynamics of the ecosystem such as pollination, seed dispersal, decomposition and nutrient cycling, and
- The characteristic native species assemblages and diversity of the ecosystem, such as the plants, animals, fungi, and other lifeforms found in reference sites.

### *What are reference sites?*

Restoration should always be towards a goal. Reference sites help determine that goal. A reference site may sometimes be the site itself as it was prior to being degraded or destroyed. For instance, if sites were thoroughly surveyed for their plants and animal communities before destruction due to logging or mining, then one can use that information as a reference for restoration. However, this is rarely the case and information



Left: An emergent tree towers over the rainforest canopy  
 Top: A degraded site  
 Bottom: The interior of a relatively undisturbed rainforest



on sites as they were prior to disturbance is usually lacking. Therefore, more frequently, reference sites are selected as relatively undisturbed sites located in the same geographical and environmental setting. These may be nearby locations with similar elevation, rainfall, and soil type, containing complete or near-complete communities of native plants and animals. For instance, many degraded areas can be restored keeping as a reference relatively undisturbed sites within nearby protected areas such as National Parks and Wildlife Sanctuaries.

### *When is restoration necessary?*

It is a common misconception that if we strictly protect any area, it will naturally recover because 'Nature knows best'. This may be true for large areas of little disturbed forests, or for smaller patches of disturbed vegetation adjoining more continuous undisturbed tracts. But we now know that many areas will not recover even after decades of protection or if we ignore the effects of continuing disturbances. In such areas carefully planned intervention in the form of restoration becomes necessary because:

- natural recovery of the original vegetation and associated animal communities will not occur even under strict protection following the removal or curtailment of disturbance factors,
- natural recovery may take an enormous amount of time (decades to centuries) unless we intervene to

Top: The unbroken canopy of a rainforest—a reference site

Bottom: In fragmented landscapes restoring degraded fragments can aid in biodiversity conservation

'assist the recovery' of the degraded site, and

- meeting specific conservation goals requires the revival of specific sites within a specific time period.

### *What kinds of sites need restoration?*

Restoration may be necessary in a wide variety of sites such as areas where:

- there is heavy infestation of weeds, grasses, and vines, choking natural vegetation,
- the soil seed bank is depleted or lost due to historical disturbance such as fire and grazing,
- parent trees that can produce seeds are locally extinct, as in isolated fragments,
- natural forests have been replaced by monoculture timber plantations or cash crops,
- settlements, plantations, or other land-use existed earlier but are now abandoned,
- soil nutrient status and symbiotic mycorrhizal fungal populations are lost or reduced,
- large areas have been cleared or mined with top soil lost, eroded, or depleted, or
- open areas have been created due to clear-felling, fires, or landslides.



Above: Degraded forests with alien trees and shrubs may be targeted for restoration



### *How do we prioritize areas in the landscape for restoration?*

Sites need to be prioritized for restoration in forest landscapes using specific criteria based on ecological and conservation needs. This could include, for instance:

- sites that are habitats of particular threatened or endemic species,
- stream sides and river courses,
- degraded areas within or along the edges of existing wildlife sanctuaries and reserved forests,
- edges of forest fragments, adjoining plantations or other habitats
- corridors linking forest fragments,
- along linear intrusions such as roads, power-line clearings, and fire-lines, and
- the land matrix (plantations, fields, streams etc.) surrounding fragments or reserves

### *What is the role for protection?*

Protection efforts need to go hand-in-hand with restoration. Larger areas of forest, especially relatively undisturbed forests, need continued protection. In most such cases, one should not carry out restoration or planting activities (including gap or supplementation planting, 'assisted natural regeneration', food species enhancement, etc.) and allow natural processes to operate.



# restoration protocol: guidelines for setting targets

From Society for Ecological Restoration International Science and Policy Working Group:

1. A legitimate and indeed important object of much ecological restoration is the reintegration of fragmented ecosystems and landscapes, rather than focusing on just a single ecosystem. A baseline ecological inventory describes the salient attributes of the abiotic environment and important aspects of biodiversity such as species composition and community structure.
2. Highest priority is best reserved for the control or extirpation of those species which pose the greatest threats. These include invasive plant species that are particularly mobile and pose an ecological threat at landscape and regional levels, and animals that consume or displace native species. Care should be taken to cause the least possible disturbance to indigenous species and soils as exotics are removed. In some instances, non-indigenous plants are used for a specific purpose in the restoration project, for example as cover crops, nurse crops or nitrogen fixers. Unless these are relatively short-lived, non-persistent species that will be replaced in the course of succession, their eventual removal should be included in restoration plans.
3. The importance of an ample recovery in species composition cannot be overstated in restoration. All functional species groups must be represented if a restored ecosystem is to maintain itself.
4. Many cultural ecosystems have suffered from demographic growth and external pressures of various kinds, and are in need of restoration. The restoration of such ecosystems normally includes the concomitant recovery of indigenous ecological management practices, including support for the cultural survival of indigenous peoples and their languages as living libraries of traditional ecological knowledge. Ecological restoration encourages and may indeed be dependent upon long-term participation of local people.

*It's the little things citizens do. That's what will make the difference. My little thing is planting trees.*

*Wangari Maathai, Nobel laureate*



In sites selected for restoration using the criteria listed above, we need to ensure protection from disturbances that led to the degradation in the first place. For instance, sites degraded by grazing or fire need to be protected from cattle and fires. Sites degraded by fuel-wood removal and felling need to be protected from cutting of native species (although woody weeds such as *Lantana* may be cut and alternatives provided for local people).

#### *What are non-native or alien species?*

Alien species of plants or animals are those species introduced intentionally or accidentally into an area where they did not previously occur by human activities. While some alien species fail to spread on their own, others can rapidly propagate and spread into newer areas. Such species are called invasive alien species and they often compete with and replace native species. Weeds are proliferating species that are usually alien and often invasive, which establish and propagate widely. Alien species are sometimes referred to as exotics. Examples of alien species in tropical Asia include Australian tree species such as *Eucalyptus* spp. and some *Acacia* wattles, shrub species such as *Lantana camara* and *Prosopis juliflora* from the Americas, and trees such as *Maesopsis eminii* and *Spathodea campanulata* from Africa.

### Why should we deal with alien species?

Many alien species (e.g., *Eucalyptus* spp., *Acacia auriculiformis*, *Acacia mearnsii*, pines, *Casuarina equisetifolia*) have been planted widely, even inside wildlife sanctuaries and national parks. In addition, many herbaceous weeds have been introduced and spread due to various human activities and regular small-scale disturbances. Sometimes alien species have been planted as they are considered to provide food for wildlife (e.g., *Maesopsis eminii*). These alien species have various detrimental effects on natural ecological processes, native vegetation, and many wildlife populations through:

- Reduction in ground water table (e. g., *Eucalyptus* spp.)
- Alteration of soil characteristics and microclimate
- Suppression or alteration of native plant communities (e.g., *Maesopsis eminii*)
- Proliferation of other weeds (e.g., *Lantana camara* often grows in the understory of *Eucalyptus* plantations)
- Change in forest structure and function (many alien species)
- Invasion into surrounding landscape (many alien species, *Maesopsis eminii*, *Acacia mearnsii*, *Spathodea campanulata*)
- Reduction in native biological diversity, particularly affecting specialized mature forest animal species



Top: Alien weeds can aggressively invade into forests especially along degraded edges (in this case, *Montanoa* sp.)  
 Bottom: *Chromolaena odorata* (aka *Eupatorium*), is among the top 100 most invasive species in the world



### How do we deal with alien species?

A basic principle is that one should strictly avoid planting alien species close to or within wildlife conservation areas. Alien species need to be dealt with care. Most restoration programmes employ means of targeted removal or suppression of invasive alien species. These may include cutting and uprooting of rootstock as in the case of *Lantana camara*, hand-weeding, pressing down of grasses with boards, or even herbicide application on specific weeds. Care should be taken in such weeding operations not to disturb soil or native vegetation as disturbances can lead to further proliferation of weeds. Occasionally some alien species may prove useful in restoration, if they are non-invasive, by providing partial shade or leaf litter that may act as mulch.



### Can monoculture plantations be ecologically restored?

Experience from restoration projects and regeneration studies indicate that it is possible to restore rainforests in sites currently dominated by alien species. In sites under *Eucalyptus* and *Maesopsis* tree canopies, for instance, restoration efforts by removal of herbaceous understorey weeds (without cutting native vegetation) and planting of a diversity of native species has proved quite successful. Some monoculture plantations, if protected from disturbances such as fire, develop a diverse regeneration of native plant species when they are close to seed sources (natural forests). The diversity of species is, however, usually

Top: Alien weeds such as *Lantana camara* carefully cut and removed without damage to native plants in a restoration site

Bottom: Recovery of diversity in monoculture plantations including *Eucalyptus* can take place both through regeneration as well as ecological restoration | M. D. Madhusudan

lower than in relatively undisturbed forests.

### *How do we get seedlings for restoration?*

A plant nursery where an appropriate diversity of native species are raised is a critical need in any restoration programme. Seed collection and nursery development and maintenance are year-round activities as the plants require continuous nurture and because seeds of different trees become available at different times within a year. Mature seeds fallen on the ground may be collected from forest edges or along forest trails or roads. All seeds should be from plants in the same area and same vegetation type (species occurring in the reference sites). If there are a lot of seedlings along trails or roads that are likely to get run over or cleared during road maintenance, these can also be collected as 'wildlings' or 'rescued saplings' for nurture in the nursery. One should avoid collecting seeds or seedlings from within forest interiors or fragments as it may negatively affect the natural process of regeneration, and forest dynamics and recovery in case of forest fragments.

### *How do we select species for rainforest restoration?*

The primary protocol to be used for ecological restoration of rainforest is mixed native species planting of rainforest trees (with some lianas and shrubs). The species to be planted should be native species typical to the vegetation type, region, and altitude, as evidenced from their



Top: Developing a native plant species nursery is a crucial part of most ecological restoration programmes | M. D. Madhusudan

Bottom: Native species typical to the particular vegetation type need to be used in restoration; *Cullenia exarillata* being an obvious choice for mid-elevation rainforests in the southern Western Ghats



occurrence in the reference site. Factors such as slope, aspect, distance to water, canopy openness, and soil status need to be considered in the selection of which seedling is to be planted at a specific location within a restoration site. Two main species selection methods are used in rainforest restoration:

**Framework species method:** This involves the planting of one or, more often, a few species of pioneer and mid-successional species along with a mixture of mature forest species. Framework species are those that establish and grow well in disturbed areas, that produce flowers and fruits that attract animals relatively quickly, that have robust germination and vigorous production of branches and litter. One can plant 'keystone species' such as *Ficus* species, which attract many frugivorous animals to their fruit resources. The main advantages of this method are that it involves only one planting, it is self-sustaining, and it incorporates the need for attracting and sustaining wildlife and linking them with recovery of natural dynamics such as seed dispersal and regeneration. The method is best suited for sites that are close to other seed sources or habitats with populations of mammals and birds that can colonise and bring seeds into the restoration site.

**Maximum diversity method:** This involves the re-establishment of as many of the original pre-disturbance species as possible. In sites with few adjoining seed sources

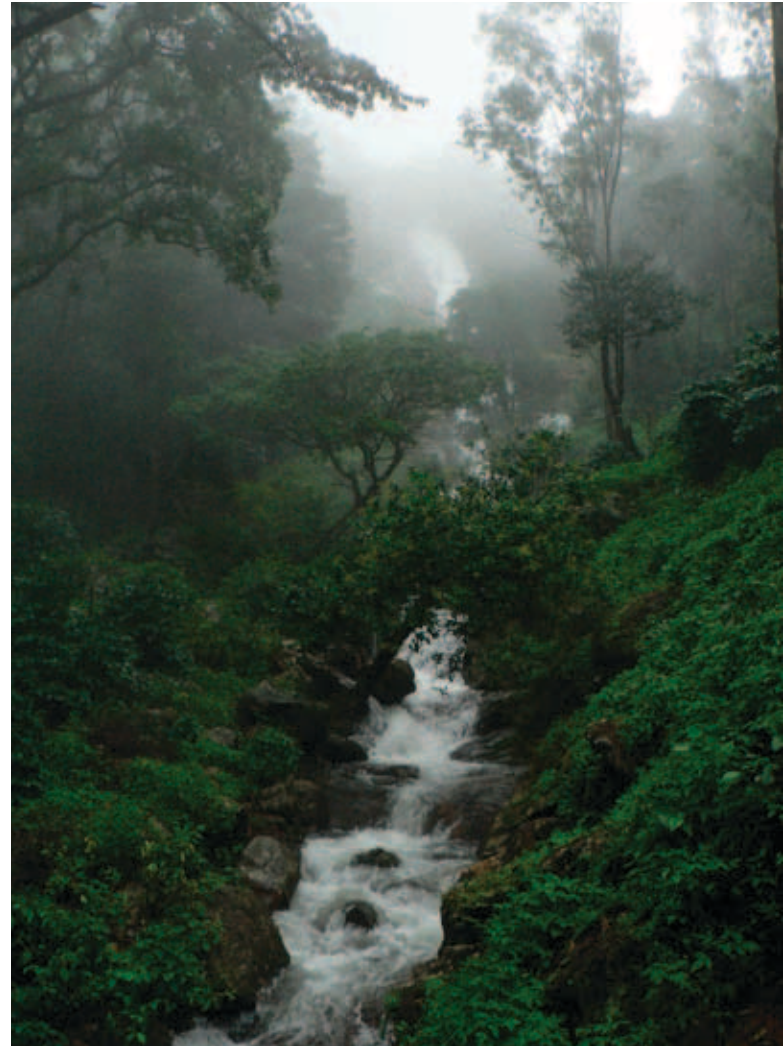
Above: *Macaranga peltata* is a common, fast-growing pioneer that may regenerate or be planted in highly open sites

or for plant species that are locally extinct or have poor dispersal, this may be the only means to bring back plant populations in restoration sites. This method involves more labour and maintenance (e. g., to raise seedlings, monitor survival, weeding) and may be slower as many mature forest species are likely to have slow growth rates. Also, recolonisation by animals may be poorer or slower if the sites are highly isolated. Although this is a highly preferable approach where the major goal is conservation of biological diversity, because of relatively high cost and effort it will be most useful in select situations and in key regions for biodiversity conservation.

### *What are the benefits of ecological restoration?*

Ecological restoration can have multiple benefits:

- Conserving native biological diversity
- Increasing wildlife habitat
- Enhancing forest connectivity in fragmented landscapes
- Provision of ecosystem services (such as watershed benefits, carbon sequestration)
- Provision of non-timber forest produce to indigenous forest people
- Enhancing aesthetic values of the landscape
- Restoring cultural links between people and nature



Above: Besides enhancing biodiversity, ecological restoration can provide substantial watershed and climatic benefits

# indicators of success

According to the Society for Ecological Restoration International Science and Policy Working Group, an ecosystem has recovered and is restored when:

1. It contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy.
2. It is suitably integrated into a larger ecological matrix, landscape, or contiguous ecosystems, with which it interacts in terms of biotic and abiotic flows and cultural interactions.
3. It contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure.
4. It consists of indigenous species to the greatest practicable extent.
5. All functional groups necessary for the continued development and/or stability are represented or, if they are not, the missing groups have the potential to colonize by natural means (corridors, river systems, row of trees).
6. The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired path.
7. Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.
8. The restored ecosystem is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely under existing environmental conditions. Nevertheless, aspects of its biodiversity, structure and functioning may change as part of normal ecosystem development, and may fluctuate in response to normal periodic stress and occasional disturbance events of greater consequence. As in any intact ecosystem, the species composition and other attributes of a restored ecosystem may evolve as environmental conditions change.

*Too often, reforestation projects ... become dominated by numerical targets and quotas, with 'success' measured in terms of seedlings planted, rather than forest established.*

~ Richard T. Corlett, *The Ecology of Tropical East Asia*





*How many key species can a rainforest lose before order becomes chaos, before the community collapses in an avalanche of extinctions?*

*~ George Schaller, A Naturalist and Other Beasts*



*rainforest restoration in the  
western ghats: an overview*

An ancient hill range, running along the west coast of India for 1,600 kilometres from the southern tip of the Indian Peninsula to the River Tapti in the North, the Western Ghats is a global biodiversity hotspot along with Sri Lanka.

The Western Ghats has a tropical climate that shows pronounced variation along north–south, east–west, and altitudinal gradients. In general, the vegetation becomes drier as one progresses from west to east (rain shadow) across the hills, more seasonal as one goes from south to north, and cooler and wetter as one ascends the hills. Thus, an impressive range of natural vegetation types is found in the Western Ghats from tropical dry thorn and deciduous forests to moist deciduous forests, semi-evergreen, and wet evergreen forests in progressively wetter areas. There are also unique types such as the *Myristica* swamps, the bamboo and cane brakes, and the montane grasslands and shola forests.

### *Tropical rainforests of the Western Ghats*

Among these vegetation types, the wet evergreen forests or rainforests are special. These rainforests occur all along Ghats from Maharashtra to Kerala. Some of the best tracts are found in the southern Western Ghats, the region south of the Palghat gap (a 40 km-wide break in the mountain range) that contains some of the highest peaks and vast stretches of mature evergreen forests. These forests also contain much of the plant and animal diversity, particularly endemic species (species not found anywhere else in the world).

In the southern Western Ghats, the Anamalai hills region is particularly special as it contains the entire range of natural vegetation types that one may encounter in the southern Western Ghats from dry thorn to shola forest, and reed brakes to grasslands. The tropical wet evergreen forests of the Western Ghats, are broadly classified into low- (mostly below < 700 m), medium- (700–1,400 m), and high-elevation (>1,400 m) types. In planning ecological restoration, it is important to identify the correct type of natural vegetation in the region and know their characteristic plant and animal species.



Left: An *Elaeocarpus serratus* tree towers into the canopy of a rainforest in southern India | Kalyan Varma

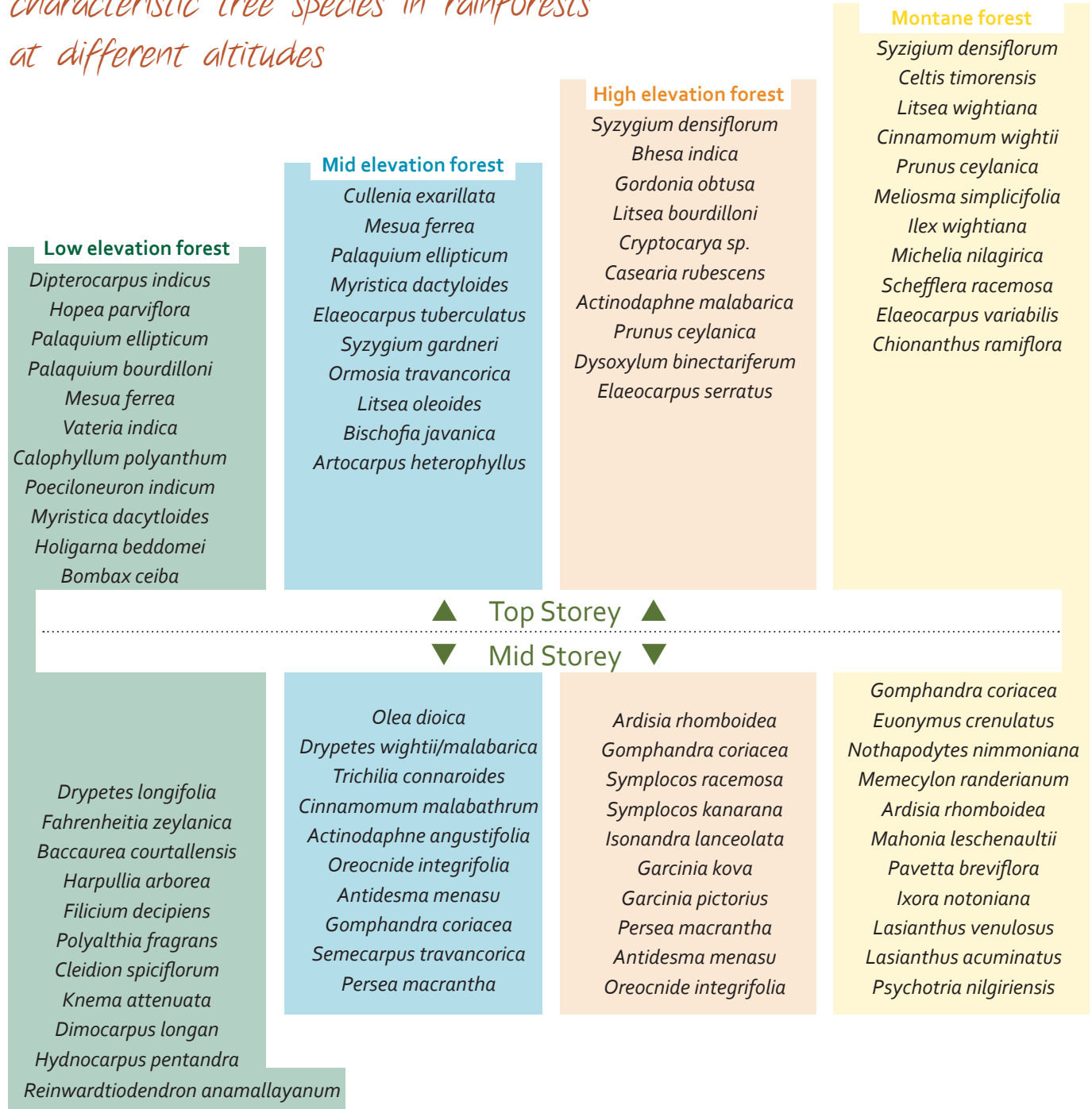
Above: The plants of the rainforest are exquisitely adapted in morphology and ecology to life in the tropical environment

## major rainforest types in the southern western ghats

At least five major types of wet evergreen forest or rainforest are found in the Anamalai hills region depending on elevation above sea level and aspect (eastern versus western slopes of the main hill range):

- 1. Plains and low elevation wet evergreen forest:** This type is found at elevations below 700 m, particularly on the western side of the Ghats. It is characterized by tall dipterocarp trees including many endemics: *Dipterocarpus indicus* and *Dipterocarpus bourdillonii*, *Vateria indica*, *Hopea ponga*. Historically, much of this type has been lost, especially in the plains. Examples exist in areas near Manamboli and Vazhachal.
- 2. Medium elevation wet evergreen forest:** This is the most extensive wet evergreen type in the Anamalai hills today, found at elevations between 700 m and 1,400 m. It is characterized by tree species such as *Cullenia exarillata*, *Mesua ferrea*, *Palaquium ellipticum*, and *Myristica dactyloides*. Much of this rainforest type occurs as fragments, including on private lands in the Valparai plateau and Nelliampathy hills. Examples of this type can be found at Iyerpadi near Valparai, near Uralikal-Surulimalai and near Malakkiparai.
- 3. Transitional forests with Lauraceae:** As we move higher, between 1,400 m and 1,700 m, the above forest type changes to montane forest through this transitional forest type. This type has many Lauraceae species such as *Persea macrantha*, *Neolitsea* sp. and *Litsea* sp. An example is Akkamalai forest.
- 4. Shola forest:** The typical shola forest, a kind of stunted montane wet evergreen forest, is found at elevations above 1,800 m. This type is found only in the hills of the Nilgiris, Anamalais, and Palnis in the Western Ghats. Characteristic trees include *Schefflera racemosa*, *Michelia nilagirica*, and *Prunus ceylanica*. Examples are seen in Konalar-Grass Hills and in Eravikulam.

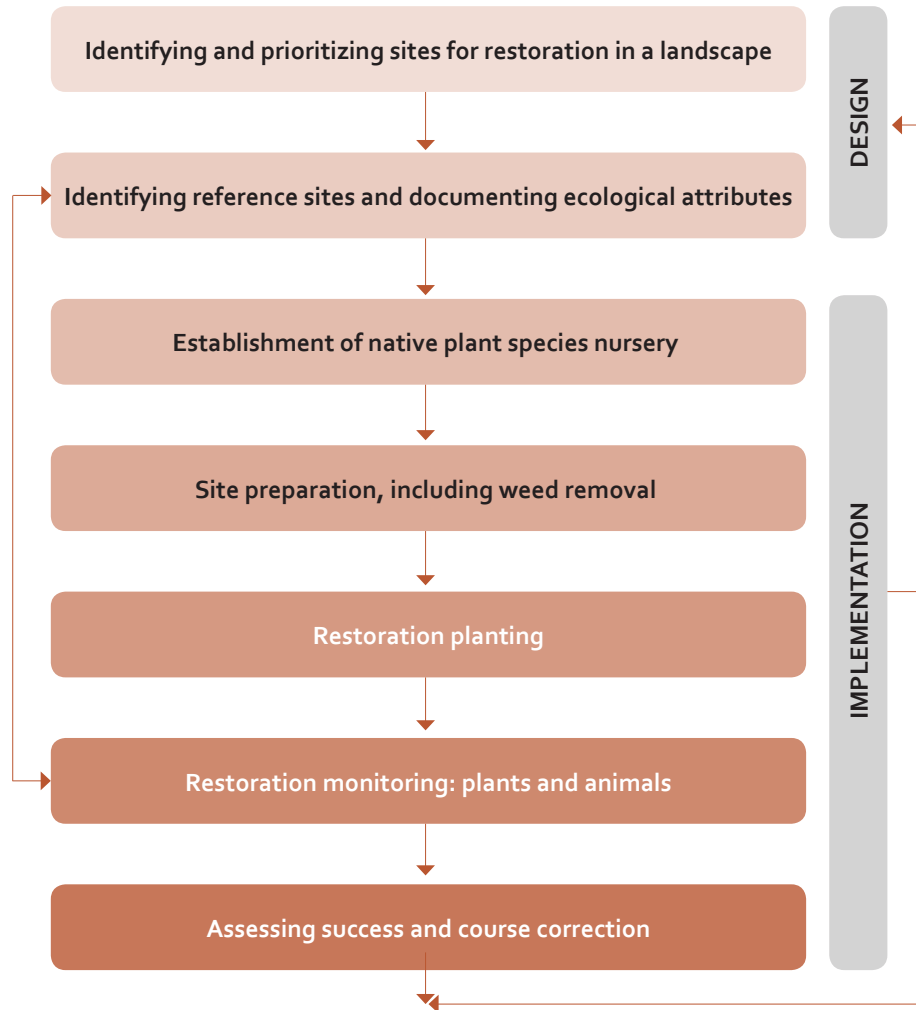
## characteristic tree species in rainforests at different altitudes



A top-down view of a grid of black plastic nursery bags. Each bag is filled with dark, rich soil and contains a single, bright red seed. The seeds are arranged in a regular pattern across the bags. The text "rainforest restoration in the western ghats: practical aspects" is overlaid in white, handwritten-style font in the upper left quadrant of the image.

*rainforest restoration in the  
western ghats: practical aspects*

## components of a rainforest restoration project



# the anamalai hills experience



Successful models of rainforest restoration have emerged from Australia and Thailand, Brazil and India, in recent times (see References). While many learnings can be gleaned from these projects, ecological restoration requires much trial-and-error, and learning from the errors. Some practical aspects of restoration gained from a project aiming to ecologically restore degraded rainforest fragments in the Valparai plateau of the Anamalai hills are presented here. Over the last ten years, this project has worked in partnership with tea and coffee plantation companies to restore degraded sites in twelve rainforest fragments lying within their estates. More than 160 native tree and liana species were raised in a rainforest plant nursery, planted out and monitored in this restoration effort.



## Nursery protocols

### Nursery infrastructure establishment

The important parts of a nursery include:

- A 0.5-1 m deep trough or raised bed of well aerated soil which can be used to plant small seeds such as *Ficus*, and most of the pioneer species.
- Beds of nursery sleeves (at least 15 cm tall) filled with soil in the proportion of 1:1:6 of sand, organic compost, and soil, respectively.
- A rodent-proof enclosure built of wire-mesh to protect some species whose seeds are attacked by rats and squirrels.

Top: Beginnings—a *Bhesa indica* seed germinates in the nursery | S. U. Saravanakumar

Bottom: Seeds of some species may be protected from rats and squirrels in the nursery using simple wire-mesh enclosures



- Shade netting of 90%, 75%, and 50% shading. These are required for various stages between seed planting and seedling growth. If suitable tree canopy is available, shade netting may not be required.

### **Seed collection and identification of species**

Since the aim of the restoration programme is to reverse the trends of degradation, certain precautions are of utmost importance while establishing the seed and sapling bank for the nursery. These include:

- Fresh seeds fallen on the ground have to be collected only from the edges of forests, along trails or roads going through or along the edges of forests.
- Collecting seeds or seedlings from within the forests (even if they are fragments) will negatively affect the natural process of regeneration and forest dynamics and recovery in case of forest fragments. This would defeat the purpose of restoration.
- Match seeds with fruit and leaf specimens in the field itself and the species should be identified using reliable regional floras and field guides.
- For each species, seeds should be collected from as many different parent trees as possible to maximize genetic diversity.
- All seeds should be from trees in the same area and same vegetation type. For example, one should not collect seeds from trees in the Nilgiris range for



Top: If standing trees are unavailable, shade nets may be used to provide the required shade for nursery seedlings  
 Bottom: Seeds of a large diversity of rainforest species are best collected from roads and trails along forest edges



planting in Anamalai hills, even if it is the same species.

- The seeds have to be separated as good and bad seeds. Those with fungal attacks, rotten, or with pest infestation have to be discarded. Only healthy and whole seeds from ripe fruit should be planted to maximize the returns for the efforts.
- If there are a lot of seedlings along trails or roads that are likely to get run over or cleared by the forest, public works, or highways departments, these can also be collected as “wildlings” or “rescued saplings”.

#### Seed and seedling care in nursery

- Seeds of most rainforest species have low dormancy. The seeds do not survive long after they mature and are difficult to store for long periods. Seed viability is moderate to high in most species if seeds are collected at the right time (mature) and planted out into appropriate conditions soon after collection. However, in the nursery, some species may take up to a year to germinate.
- Many rainforest fruits and seeds are prone to predation and fungal attack especially if they are planted deep in the soil. Therefore, the seeds must be placed in such a way that the seed is partly exposed above the soil surface.
- Care should be taken to identify species that could get

Top: Adoption of proper nursery practices can help minimise the need to use agro-chemicals for control of pests and diseases  
 Bottom: Soil preparation and filling into sleeves in the nursery

predated (based on past knowledge or field experience) and these have to be planted in the rodent-proof enclosure only.

- Sometimes seedlings tend to get browsed by snails or hare. These also can be protected largely within a nursery enclosure.
- Although water is very important, sleeves should not remain waterlogged.
- Weeds have to be regularly removed from the sleeves containing seeds or seedlings, taking care that the roots of the seedlings are not damaged. Weeds compete with seeds and seedlings for nutrients and affect their growth.
- An occasional caterpillar or most other pests need not be considered a major problem in most cases.
- Use of pesticides is usually unnecessary. If the shade is managed well, based on the seasons, even fungal attacks can be avoided without the use of fungicides.
- Water is a major limiting factor for the germination and growth of seedlings. Therefore, in the first few weeks/ months (depending on the species), they have to be watered everyday, being mostly wet evergreen forest or montane shola species.
- Seedlings earmarked for planting in the following season may be watered less frequently during the period of hardening.



Top: Small-seeded species such as the *Bischofia javanica* here may be germinated in soil beds and later transplanted

Bottom: Seedlings are stacked in the nursery for easy care and monitoring; mixed-species collections may help reduce pest and disease outbreaks



### Site preparation

The boundaries of each restoration site should be measured and clearly demarcated. Invasive weeds such as *Lantana camara*, *Chromolaena odorata* (*Eupatorium odoratum*), and *Mikania* sp. should be cut with machetes and all *Lantana camara* uprooted with mattocks one to four months prior to planting. Two practices should be strictly followed during weed clearing. First, take special care not to cut any naturally regenerating native vegetation, including shrubs and climbers, found growing amidst the weeds. Second, larger (>1 cm girth) woody stems of *Lantana camara* may be cut into small lengths and removed outside the fragment to prevent their sprouting. The people in nearby settlements can also use this as fuel-wood. The finer cut stems and all green leafy material should be left on the site to form a mat-like ground layer to avoid soil exposure and erosion.



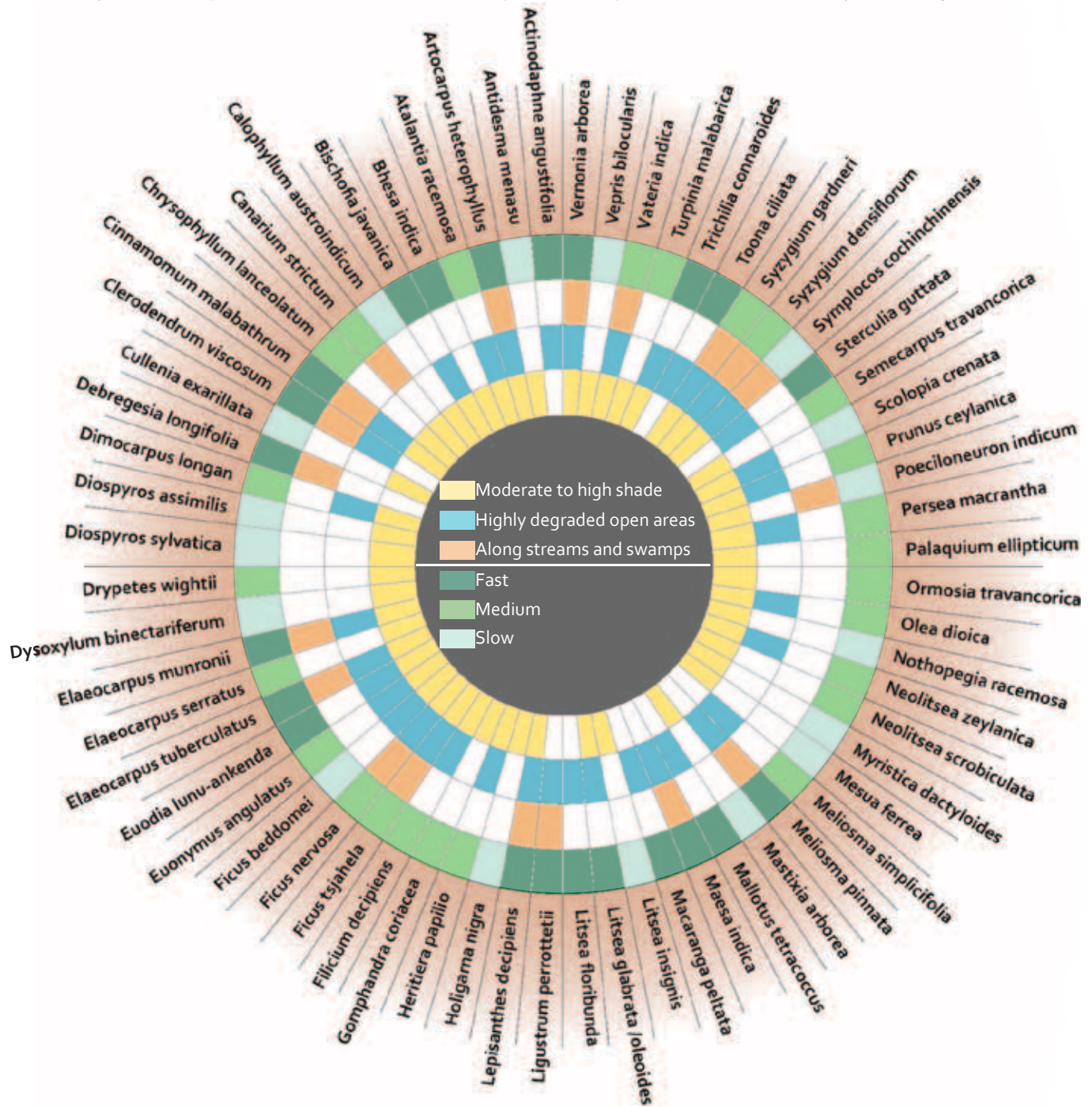
### Selection of seedlings

Planted seedlings need to be at least 45 cm – 75 cm tall at the time of planting. The seedlings are hardened in the nursery through regular exposure to direct sun and reduced watering for 3 – 4 months prior to planting. A subset of seedlings can be raised in larger 'jumbo' sleeves to large sapling size (c. 1.5 m tall) for planting. Large seedlings may be expected to better withstand episodes of grazing and drought.

Top: A restoration site may require fencing and targeted removal of weeds before planting

Bottom: Seedlings of appropriate native species for each site are selected and transported to the planting site

## tree species of mid-elevation rainforests for restoration planting





### Planting protocol

Seedlings are planted in pits of around 10 cm – 15 cm diameter and 45 cm depth. At the time of planting, they are also provided with fertilizer (circa 100 g organic manure mixed with the soil and 25 g rock phosphate on the sides and bottom of the pit) and with a layer of litter mulch around the base. All seedlings may be tagged conspicuously to be located easily for survival monitoring. The seedlings are planted at a spacing of 1.5 m to 3 m (to facilitate monitoring) based on the density of existing seedlings and saplings at the site, the size of the site, and the size and availability of seedlings.

### Weeding and plot maintenance

Special care should be taken not to cut any naturally regenerating native vegetation, including shrubs and climbers. Hand-weeding, using sickles or machetes, may be preferred. Indigenous tribal people may be employed for the task as they are skilled in the task and in identifying native versus non-native species. Invasive weeds such as *Lantana camara*, *Chromolaena odorata*, and *Mikania* sp. may be cut with machetes and all *Lantana camara* regenerating may be uprooted by hand or with mattocks. Post-planting hand-weeding may be needed three to six times within the site during the first year and two to three times in the second year after planting.

Top: Digging of pits for planting at a restoration site  
 Bottom: A rainforest sapling is planted and mulched

### Fertilization

Although growth rates of seedlings vary substantially according to species, in most cases providing planted seedlings with fertilizer at regular intervals over the first two years will help speed up vegetative growth. Standard nitrogen-phosphorous-potassium (NPK) mixtures and dosages may be used for this purpose.

### Monitoring protocol

Monitoring restoration efforts is very important. It involves monitoring at regular intervals (every six months or annually) various aspects such as: seedling survival (by recording survival of tagged seedlings), regeneration (through vegetation plots), and recovery of forest structure and function, and animal population and community, following standard methods of sampling. It is useful and illustrative to establish specific locations (photo-points) from where the site can be photographically monitored over time. Such photo-point monitoring can illustrate changes in sites as they were before and then after restoration. One can use information from monitoring as indicators of restoration success and plan course corrections.



Above: Research and monitoring of native and alien plant communities, regeneration, and seedling survival are crucial components of ecological restoration projects as are long-term monitoring of recovery of forest structure and function and animal communities

## alien species in mid- and high-elevation areas of the anamalai hills

Shrubs and herbs	Common name	Invasiveness
<i>Lantana camara</i>	Lantana	Highly invasive
<i>Chromolaena odorata</i>	Siam weed	Highly invasive
<i>Ageratina adenophora</i>	Crofton weed	Highly invasive
<i>Coffea canephora</i>	Robusta coffee	Highly invasive
<i>Coffea arabica</i>	Arabica coffee	Moderately invasive
<i>Montanoa</i> sp.	Montanoa	Highly invasive
Climbers and creepers		
<i>Ipomoea</i> sp.	Morning glory	Highly invasive
<i>Mikania micrantha</i>	Mikania, mile-a-minute	Highly invasive
<i>Mucuna pruriens</i>	Bengal bean, itchweed	Indian species, locally invasive creeper
<i>Sphagneticola trilobata</i>	Wedelia, creeping ox-eye	Invasive ground cover
Tree species		
<i>Spathodea campanulata</i>	African tulip	Shade and avenue tree, invasive in forests,
<i>Maesopsis eminii</i>	Maesopsis	African shade tree, invasive in forests
<i>Acacia mearnsii</i>	Wattle	Australian wattle, invasive in grasslands
<i>Eucalyptus</i> sp.	Eucalyptus	Australian species, disturbs vegetation
<i>Grevillea robusta</i>	Silver oak	Australian species, shade tree in plantations
<i>Pinus</i> sp.	Pine	Introduced, disturbs grassland vegetation





*Wherever actions are taken to promote forest restoration and regeneration, new forests emerging in human-impacted landscapes will not match the original old-growth forests in species composition. But forest restoration can restore many ecosystem functions and recover many components of the original biodiversity.*

*~ Robin L. Chazdon, 2008*

# gallery: before & after restoration



Top: An open grazed meadow site before planting in 2002 (left) and eight years later (right) in Stanmore fragment

Bottom: A degraded site after removal of weeds such as *Lantana camara* in 2005 (left) and three years later (right) in Iyerpadi fragment





Top: Removal of weeds under alien canopy of *Eucalyptus* and *Maesopsis* for restoration planting (2004) and recovery three years later in Injipara fragment  
Bottom: Seedlings planted in degraded site (2007) and the same site three years later in Selaliparai fragment



# a restoration glossary



**Biodiversity** refers to the naturally occurring taxonomic and genetic diversity of life forms present and the community structure thereby created, and the ecological roles performed. Two related aspects of biodiversity are species composition, i. e., the taxonomic array of species present, and species richness, i. e., the number of different species present.

**Endemic species** are species found only within a restricted geographical region. For instance, the lion-tailed macaque *Macaca silenus* (in photo) is a primate endemic to the rainforests of the Western Ghats.

**Ecological processes or ecosystem functions** are the dynamic attributes of ecosystems, including interactions among organisms and interactions between organisms and their environment. Ecological processes are the basis for self-maintenance in an ecosystem.

**Ecosystem management:** Action intended to guarantee the continued well-being of either a relatively undisturbed or restored ecosystem.

**Ecosystem services** refers to the benefits that natural ecosystems provide such as hydrology and watershed benefits, carbon sequestration, pollination and dispersal, decomposition and cycling of nutrients.

**Ecological restoration:** The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed

**Destroyed ecosystem** refers to an ecosystem where degradation or damage has removed all macroscopic life, and commonly ruins the physical environment as well.

**Biotic homogenization** is the gradual replacement of native plant and animal communities by widespread species non-native to the ecosystem, usually as a consequence of habitat disturbance or fragmentation or deliberate species introductions.

**Alien species** (also called exotic, non-indigenous, or non-native species) of plant or animal is one that was introduced into an area where it did not previously occur. If the alien species proliferates and spreads on its own, they are referred to as **invasive alien species (IAS)**. Common examples of alien tree species in the Western Ghats include silver oak *Grevillea robusta*, *Eucalyptus* spp., *Acacia mangium* and other wattles (*A. mearnsii*, *A. melanoxylon*, *A. auriculiformis*).

**Invasives** are species (usually alien) that proliferate into natural or disturbed areas, often replacing and suppressing natural vegetation and growth of indigenous species. Common invasives in the Western Ghats are *Lantana camara*, *Chromolaena odorata*, *Mikania* sp., wattle *Acacia mearnsii*, and scotch broom *Cystisus scoparius*.

**Locally exotic species:** While alien species usually refers to species introduced from other countries, in the context of biotic homogenization, species indigenous to the

country but from other habitats or geographical areas may represent local exotics (e. g., *Alnus nipalensis* from Himalaya introduced in Western Ghats, or *Gmelina arborea* introduced from deciduous forests to wet evergreen forest zones).

**Weeds** are proliferating species that are usually alien and often invasive, which establish and propagate widely. Some native species may appear weedy (e.g. *Strobilanthes* sp., *Rubus* sp.) in certain tropical rainforest areas, along edges, or in disturbed sites.

**Succession** is the dynamic and continuous process of establishment and maturation of an ecosystem in a newly exposed or disturbed area.

**Pioneer species** are species that first appear, easily establish, and grow in open, highly degraded sites; in forest areas, these may include grasses, herbs, vines, and trees such as *Macaranga* species.

**Sustainable cultural practices** are traditional human land uses that maintain biodiversity and productivity. In this context, the biota is valued as much for its importance to ecosystem stability as it is for its short-term worth as commodities. Perhaps all natural ecosystems are culturally influenced in at least some small manner, and this reality merits acknowledgement in the conduct of restoration.

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*The loss of forest in the past half-century is one of the most profound and rapid environmental changes in the history of the planet. Its impact on biodiversity is automatic and severe... Such is likely to be the world of 2100—if present trends continue. The most memorable heritage of the twenty-first century will be the Age of Loneliness that lies before humanity.*

*~ E. O. Wilson, The Future of Life*











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