Paper Presented at Conference on Developments in Forestry and Environment Management in Sri Lanka

Restoring a Rain Forest in Southwest Sri Lanka: Which Species to Use for What Sites?

B.M.P. Singhakumara[1], Harshi K. Gamage[1,2], Mark S. Ashton[3]

[1] Department of Forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka
[2] Present address: School of Integrative Biology, University of Queensland, St. Lucia, Brisbane, QLD 4072, Australia
[3] School of Forestry and environmental studies, Yale University, New Haven, CT 06511, United States

Introduction

Rain forests are some of the most complex and diverse ecosystems on earth, but they continue to be cleared largely for agriculture and industrial plantation systems at rapid rates around the world (Richards, 1996). Some of these lands are now being used productively, but many have had their topsoil eroded, and their nutrients and structure depleted. Restoration, the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed holds the key to returning productivity, biodiversity, and community benefits from these lands (Lamb, 1998).

The southwest of Sri Lanka is one of the most floristically rich rain forest biomes of South Asia (Gunatilleke *et al*., 1996). The endemic-rich mixed dipterocarp forest in this region comprise an important forest type that covers the upland hill, and lowland regions of most of Southeast Asia (Whitmore, 1990). This forest type has provided much of the region’s timber for both local use and export. After logging many of the more accessible regions have either been converted to large scale rubber and oil palm plantation, or to small-holder subsistence gardens. In the 1970’s the mixed dipterocarp forest in southwest Sri Lanka occupied the plains, the hills, and lower slopes of the central mountain formation. Now only 15% remain mostly restricted to the hills and montane areas, and almost all of which is in various states of degradation (Gunatilleke and Gunatilleke 1985, 1991). A critical issue is how to rehabilitate such lands to provide the various goods and services demanded by society, and to protect the scenic beauty and its wealth of endemic flora and fauna in Sri Lanka (Ashton *et al*., 2001).

For forest restoration, it is essential to understand what we are restoring and why? This requires an understanding of natural forest dynamics within the region. The principles of forest dynamics allow us to identify the critical factors in species–site interactions that can classify processes of forest degradation on the basis of severity of disturbance (Aber 1987). During the last 15 years, research has been conducted to investigate the rain forest dynamics of southwest Sri Lanka. Based on those studies, six principles have been identified for mixed dipterocarp forests in Sri Lanka (Ashton *et al*. 2001). The principles provide the basic guidelines for understanding the processes of forest degradation and potential pathways for their restoration (Ashton *et al*., 2001).

Understanding the processes of forest degradation is critical for the development of silvicultural prescriptions for rain forest restoration (Ashton and Peters, 1999). For mixed dipterocarp forests, two forest degradation processes have been described: ‘chronic’ and ‘acute’. Chronic degradation can be attributed to those disturbance regimes that have more or less continuous impacts on the forest. Often these impacts can appear innocuous and small. But as a continuous presence, they can be as damaging as the more obvious impacts of logging or land clearance. Acute degradation is caused by those disturbance regimes to the forest that have one-time, often dramatic impacts on forest structure, composition, and successional processes (Ashton *et al*., 2001). From these degradation processes, five different rain forest restoration pathways have been suggested.

The differing restoration pathways can be used to restore the native vegetation in Sri Lanka. These pathways range from: (i) simple prevention of disturbance to promote release of rain forest succession (ii) site-specific enrichment planting protocols of canopy trees (iii) sequential amelioration of arrested fern and grasslands by use of plantation analogs of old field pine to facilitate secondary succession of rain forest, and plantings of late-seral rain forest tree species and (iv) establishment and release of successionally compatible mixed-species plantations (Ashton *et al*., 2001).
In this article, first, we describe the differing forest dynamic processes in south west Sri Lanka, secondly, the environmental heterogeneity across and within canopy gaps with respect to elevation, and finally, we describe what species for which sites that can be used for restoration practices in Southwest Sri Lanka.

Diverse Forest Dynamic Processes and Tree Species Regeneration

1) Disturbances provide the simultaneous initiation and or release of a new forest stand

Natural regeneration of mixed dipterocarp forest arises after the occurrence of one of many kinds of disturbances. Different species are adapted to different kinds of disturbances. Therefore, it is necessary to know which appears after what event. For example, late-seral species occupy growing space before a disturbance as "advance regeneration" while the early-seral pioneer species establishes immediately after a disturbance such as windthrow. Pioneer species are usually of buried seed or wind/bird dispersed origin that colonizes after a disturbance (Ashton *et al*., 2001). Examples include: *Acronychia pedunculata, Macaranga peltata, Melastoma malabathricum, Palaquium thwaitesii, Schumacheria castanaefolia, Trema orientalis*.

2) Disturbances are generally non-lethal to the groundstory vegetation

All tree species that dominate the late-seral stages of forest development are dependent upon regenerative disturbances such as wind, drought, disease, and pests that kill trees from the forest from the top canopy downward sparing most of the plants in the lower groundstory strata. The species that are pre-adapted to such disturbances are those that usually germinate and grow for a period of time beneath the intact canopy tolerating shade. These species differ in shade tolerance promoting differing degrees of survival among themselves in the forest groundstory (Ashton, 1995; Ashton *et al*., 1995, 2001). For example, Both *Shorea megistophylla* and *S. worthingtonii* are late-seral canopy tree species that can survive in the groundstory vegetation after a non-lethal disturbance. However, *S. megistophylla* which is more shade-intolerant and water-loving is restricted to low-lying sites that are periodically water-logged soils and prone to wind-throws, whereas the more shade-tolerant *S. worthingtonii* is restricted to better drained and more wind stable upper slopes and ridge tops (Fig. 1).

3) The Disturbances are variable in severity, type, and extent across rain forest topography

As alluded to above, in southwest Sri Lanka, trees on ridge sites and thin to bedrock slopes are susceptible to drought, and to lightning strikes. Areas with streams and rivers that are seasonally flooded have trees with shallow roots that are prone to windthrows from sudden downdrafts channeled into valleys (Ashton *et al*. 2000, 2001). The trees growing in ridge sties have lower stature (eg. *Shorea worthingtonii*, *Mesua nagassarium*) than trees growing in the valley sites (eg. *Shorea megistophylla*, *Mesua ferrea*). As a result, tree falls in ridge sites create smaller canopy gaps while larger gaps are created in valley sites. Thus, shade, soil moisture and nutrients availability vary affecting the tree seedling growth (Ediriweera *et al*., 2008).

4) Guild diversity (habitat diversity) is dependent upon advance regeneration

The trees in a mixed dipterocarp forest can be dispersed and established in a number of ways. Species have been grouped into six guilds based upon ecological similarity of regeneration origin (Ashton *et al.*, 2001).
(i) Pioneers that dominate stand initiation have seeds dispersed by wind, birds and bats into the stand or opening after severe disturbances (eg. *Macaranga*, *Trema*). Germination and growth is in high light conditions with rapid height growth to form large-leaved, umbrella-shaped crowns.
(ii) Pioneers that dominate stand stem exclusion also have seeds dispersed by wind, birds and bats into openings after disturbances create canopy gaps (eg. *Alstonia, Schumacheria*), but growth is relatively slower, with columnar crowns and strong epinastic control

(iii) Late-successional canopy dominants comprise species that exhibit strong masting events with seeds dispersed by gravity around and near the parent trees. Disturbances promote the release of pre-established groundstory regeneration that originated as a large cohort during a masting year and avoided predation (e.g. rodents). Examples of species include *Shorea*, *Dipterocarpus* and *Mesua*.
(iv) Late-successional canopy non-dominant tree species have seeds dispersed by large birds and primates. Seeds are ingested and are widely distributed. Disturbances promote the release of groundstory regeneration as individuals or small groups (eg. *Mangifera*, *Bhesa*).
(v) Late-successional subcanopy tree species exhibit similar patterns of dispersal and establishment as late successional canopy non-dominant species but species in this group never attain the forest canopy at maturity (eg. *Garcinia*, *Semecarpus*).
(vi) Late-successional understory trees are primarily established vegetatively; their low output of berries can be dispersed by small birds and rodents. Disturbances promote release of vegetative sprouting, layering and root suckering eg. *Psychotria* (Ashton *et al*., 2001).

5) Tree canopy stratification is based on both 'static' and 'dynamic' processes

The 'static' process includes the long-lived species that occupy different vertical strata within a mature forest stand. The 'dynamic' process includes the species of different successional status that sequentially gain dominance of the canopy. Both stratification processes are intimately mixed and occur at the same time after a disturbance (Ashton *et al.,* 2001). For example, in "dynamic stratification" *Macaranga peltata* attains the canopy early in stand development, but this position is usurped first by *Alstonia scholaris* and then by *Shorea trapezifolia* (Ashton *et al*., 2001). While this process continues other species of the true subcanopy (*Garcinia*) and understory (*Psychotria*) are growing into subcanopy and understory strata and will not change stratum position over time.

6) Canopy dominant late-successional tree species are usually restricted to particular topographic positions of the rain forest

Late-seral species appear to differ among themselves in shade and drought tolerance. This promotes their differential ability to compete effectively on particular combinations of soil and disturbance type in relation to one another (Ashton 1995, Ashton *et al.,* 1995).

Environmental Heterogeneity Within the Rain Forest Environment

Environmental heterogeneity created by physical and biological processes of the rain forest affects species growth. Due to the nature of disturbance to the canopy by wind throw, drought, lightning strikes, insects and pathogens and their interactions with underlying in-situ soil weathering, hydrology and geology, shade, soil moisture, and soil nutrients can dramatically vary across and within canopy openings. Therefore, for restoration purposes the combination of all those factors in canopy gaps across elevation and topography gradient and within the forest understory need to be considered (Singhakumara *et al.,*; 2003 Ediriweera *et al*., 2008).

Shade is a primary determinant of seedling growth and is one of the major limiting factors in tropical rain forest understoreys (Lee *et al*., 1996). Only 2% of photosynthetic photon flux is transmitted through the canopy and R: FR ratio can be decreased by a factor of six (Ashton, 1992). Canopy openings or tree fall gaps allow more sunlight to penetrate to the forest understorey and are an important environmental variable for establishment and release of tree seedlings (Ashton *et al*., 1998). In different sizes of canopy gaps and in different locations within the same gap light quality and quantity differ and affect seedling establishment and growth (Ashton *et al*., 1995). For example, understanding tree species ranking in shade-tolerance is important for restoration practices. Late-seral climax species are more shade-tolerant and establish in shaded canopy gaps in the understorey whereas the early-seral pioneer species which are more shade-intolerant can be established in more open sites.

Both soil moisture and soil nutrients vary with change in topographic position in the rain forest environment. The rain forest in southwest Sri Lanka experiences both supra-annual and seasonal variation in soil moisture availability. In addition, there is soil moisture variation across the topography. In valley sites more soil moisture is available compared to the upper slopes and ridges (Ashton *et al.* 2006, Ediriwera *et al*., 2008). Thus, more drought sensitive species can be found in mid slopes and valley sites whereas drought tolerant species are restricted to upper slopes and ridge tops. For example, both *Dipterocarpus zeylanicus* and *D. hispidus* are restricted to similar sites in respect to light but more drought tolerant *D. hispidus* is restricted to higher elevations whereas *D. zeylanicus* grows only along riverbanks and in moist soil (Ashton *et al*., 2001).

Soil nutrients across the elevation of rain forest also vary. With the increase in elevation, there is a decrease in temperature, slower soil decomposition and an increase in wind. In addition, the change in geology across the elevation affects the availability of nutrients (Ediriweera *et al.*, 2008). For example, in mixed dipterocarp forests in southwest Sri Lanka, Al decreased with increasing elevation beneath the forest canopy while K and Ca increased with increase in elevation beneath both canopy openings and within the understorey (Ediriweera *et al*., 2008). Therefore, elevation, geology, and topographic position needs to be considered when selecting species for restoration practices.

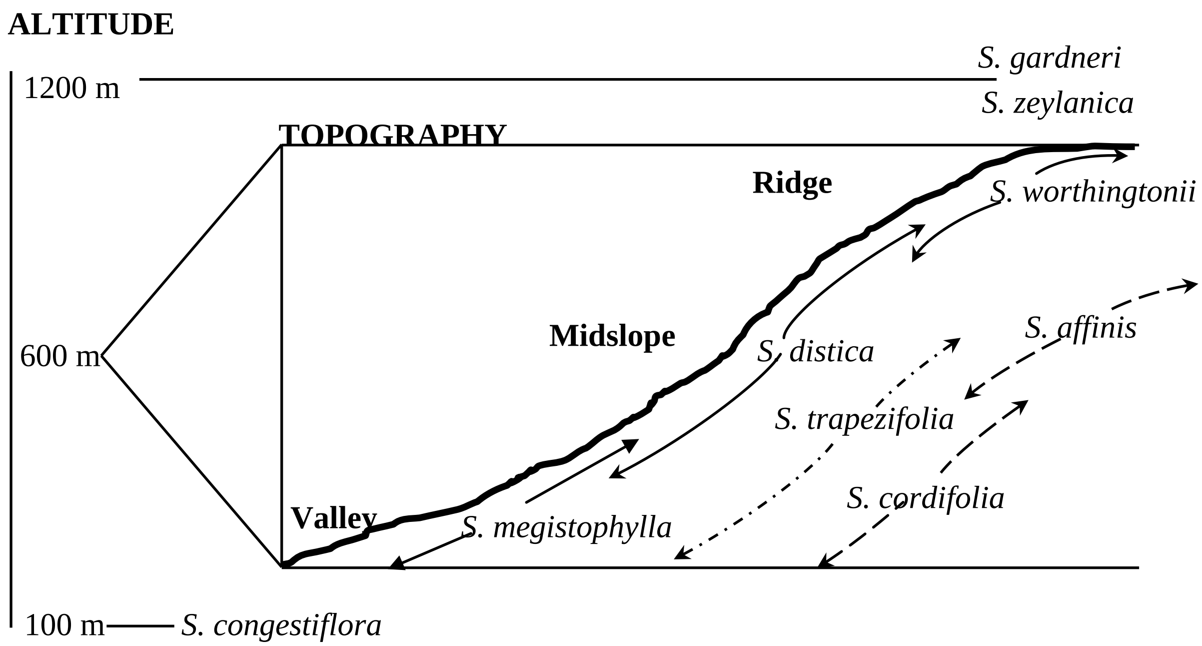

Figure 1: Stylized diagram for site-restricted *Shorea* species. Species distributions are depicted across an altitudinal ranges from coastal lowlands (100 m) to undulating middle hills (600 m), to montane forest (1200m) - Diagram from Ashton *et al.*, 2001

Tree Species for Restoration

Understanding the differing processes of forest dynamics and the resulting forest degradation is critical for the development of silvicultural prescriptions for forest restoration (Ashton and Peters, 1999). Tree species distribution also varies due to the environmental heterogeneity across the altitudal gradient within the rainforest. All the above should be taken into account when selecting species for rain forest restoration. During the last 15 years, research has been conducted examining rain forest tree species ecology both in controlled and field experimental settings. From that knowledge, below in Table 1, we list canopy and sub canopy species that can be used for restoration practices in southwest Sri Lanka.

Table 1: Canopy and sub canopy tree species for restoration of degraded lands in southwest Sri Lanka (Data from Ashton *et al*., 2001; Gamage *et al.*, 2003)

Species	Family	Strata	Ecology	Sites suitable for restoration
Bhesa ceylanica	Celastraceae	Canopy	Shade intolerant	Large canopy openings (>400 m^2)
Diospyros quaesita	Ebenaceae	Canopy	Shade tolerant	Medium canopy openings (100- 200 m^2)
Dipterocarpus zeylanicus	Dipterocarpaceae	Canopy	Shade intolerant Drought tolerant	Large canopy openings (>400 m^2) in low elevations and large waterways
D. hispidus	Dipterocarpaceae	Canopy	Shade intolerant Drought intolerant	Large canopy openings (>400 m^2) in higher elevations
Mangifera zeylanica	Anacardiaceae	Canopy	Shade intolerant	Large canopy openings (>400 m^2) in low elevations and large waterways
Mesua ferrea	Clusiaceae	Canopy	Very shade tolerant	Small to medium canopy openings (80-250 m^2) in sheltered upper slopes/ridges
M. thwaitesii	Clusiaceae	Canopy	Shade-tolerant	Small to medium canopy openings (80-250 m^2) in sheltered toe slopes and seepage ways
Palaquium petiolare	Sapotaceae	Canopy	Shade-tolerant	Small medium canopy openings (80-250 m^2) in sheltered mid-slopes and ridges
Shorea distica	Dipterocarpaceae	Canopy	Shade tolerant	Small medium canopy openings (80-250 m^2) in sheltered mid-slopes
S.megistophylla	Dipterocarpaceae	Canopy	Shade intolerant	Large canopy openings (>400 m^2) in sheltered bottom slopes and seepage ways
S. trapezifolia	Dipterocarpaceae	Canopy	Shade intolerant	Medium to large canopy openings (200-400 m^2) in mid to lower slopes
S. worthingtonii	Dipterocarpaceae	Canopy	Very shade tolerant	Small medium canopy openings (80-250 m^2) in sheltered upper slopes and ridges
Syzygium firmum	Myrtaceae	Sub canopy	Shade tolerant	Valley to midslope sites
S. makul	Myrtaceae	Canopy	Moderately	shade tolerant Valley to midslope sites
S. operculatum	Myrtaceae	Sub canopy	shade intolerant	Large openings in stream banks
S. rubicundum	Myrtaceae	Canopy	shade intolerant	Large openings in midslopes

Conclusions

The rain forest restoration can only be achieved if both researchers and managers have clear concepts about what they are restoring for and why (Ashton *et al.*, 2001). The differing forest dynamic principles we have explored would enable managers to understand the core issues in restoration practices such as degradation processes and environmental heterogeneity and provide logic and techniques for rain forest restoration. This information will allow the managers to identify the factors in species-site interactions on the basis of severity of disturbance. Because, depending on the type and severity of disturbance, the size of the canopy opening would vary and thus, the shade, soil moisture and soil nutrients. Since, no species is adapted to all kinds of disturbances (Ashton *et al*., 2001) tree seedling ecology (shade and drought tolerance and nutrient requirement) should be known in any application of rain forest restoration practices (Singhakumara *et al*., 2003).

Shade, soil moisture, and soil nutrients, all vary depending upon the size of the canopy gaps and with the altitude and topographic variation in the rain forest environment (Ediriweera *et al.*, 2008). Therefore, different species have to be used for different sites. For southwest Sri Lanka, we provide a list of canopy and sub canopy tree species (Table 1) that can be used in restoration practices. As an example, for disturbances that create large canopy gap sites in the valley, more shade intolerant species should be planted (eg. *Shorea megistophylla*, Fig. 1). Similarly, in the forest understory and in the gap edges, more shade tolerant species should be planted (eg. *Shorea worthingtonii*, Ashton 1995, Fig. 1). In this article, we mainly focused on the use of canopy and sub canopy tree species for restoration practices. Because, once the forest canopy is established, understory and groundstory species can easily be established.

Finally, with the expanding human population, the demand for land is growing. Therefore, rain forest restoration for a single-objective (eg. for biodiversity) is likely to be less attractive in the future. Silvicultural restoration will have to offer a wider range of ecological, social, and industrial benefits. Managers, therefore, need to address more than one objective and then adjust the relative importance of these alternatives during the lifetime of a restored land.

References

Aber, J.D. (1987), *Restored forests and the identification of critical factors in species-site interactions*: In: Jordan W.R., Gilpin M.E., Aber J.D. (Eds.), Restoration Ecology: A Synthetic Approach to Ecological Research, Cambridge University Press, Cambridge, UK, pp. 241-250.

Ashton, P.M.S. (1992), *Establishment and early growth of advance regeneration of canopy trees in moist mixed-species broadleaf forest*, In: Kelly M.D., Larson B.C., Oliver C.D. (eds.), The Ecology and Silviculture of Mixed-Species Forests, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 101-125.

Ashton, P.M.S. (1995), *Seedling growth of co-occurring Shorea species in the simulated light environments of a rain forest*, Forest Ecology and Management, 72: 1-12.

Ashton, P.S. (1998), *Niche specificity among tropical trees: a question of scales*, In: Newbery D.M., Brown N.D., Prins H.T.T. (Eds.), Dynamics of tropical communities, Blackwell Scientific, Oxford, pp.491-514.

Ashton, P.M.S., Gunatilleke, C.V.S., Singhakumara, B.M.P., Gunatilleke, I.A.U.N. (2001), *Restoration pathways for rain forest in southwest Sri Lanka: a review of concepts and models*, Forest Ecology and Management, 154: 409-430.

Ashton, P.M.S., Gunatilleke, C.V.S., Gunatilleke, I.A.U.N. (1995), *Seedling survival and growth of four Shorea species in a Sri Lankan rain forest*, Journal of Tropical Ecology, 11: 263-279.

Ashton, P.M.S., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., Singhakumara, B.M.P. (2000), *Ecology and silviculture of mixed dipterocarp forest of the southwest hill region, Sri Lanka*, Unpublished manuscript.

Ashton, P.M.S., Peters C. (1999). Even-aged silviculture in tropical rain forests of Asia: lessons learned and myths perpetuated. *Journal of Forestry*, 97: 14-19.

Ashton, P.M.S., Singhakumara, B.M.P., Gamage, H.K. (2006), *Interaction between light an drought affect performance of Asian tropical tree species that have differing topographic affinities*, Forest Ecology and Management, 221: 42-51.

Ediriweera, S., Singhakumara, B.M.P., Ashton, P.M.S. (2008), *Variation in canopy structure, light and soil nutrition across elevation of a Sri Lankan rain forest*, Forest Ecology and Management 256: 1339-1349.

Gamage, H.K.; Ashton, P.M.S.; Singhakumara, B.M.P. (2003), *Leaf structure of Syzygium spp. (Myrtaceae) in relation to site affinity within a tropical rain forest*, Botanical Journal of Linnean's Society 141: 365-377.

Gunatilleke, I.A.U.N, Ashton, P.M.S., Gunatilleke, C.V.S., Ashton, P.S. (1996), *An overview of seed and seedling ecology of Shorea (section Doona) Dipterocarpaceae*, Biodiversity and the dynamics of Ecosystems 1: 81-102.

Gunatilleke, C.V.S., Gunatilleke, I.A.U.N. (1985), *Phytosociology of Sinharaja-a contribution to rain forest conservation in Sri Lanka*, Biodiversity Conservation 31: 21-40.

Gunatilleke, I.A.U.N., Gunatilleke, C.V.S. (1991), *Threatened woody endemics of the wet lowlands of Sri Lnaka and their conservation*, Biological Conservation, 31: 21-40.

Lamb, D. (1998), *Large-scale ecological restoration of degraded tropical forest lands: The potential role of timber plantations*, Restoration Ecology, 6: 271-279.

Lee, D.W., Baskaran, K., Mansor, M. Mohamad, H. Yap, S.K. (1996), *Irradiance and spectral quality affect Asian tropical rain forest tree seedling development*, Ecology, 77: 568-580.

Richards, P.W. (1996), *The Tropical Rain Forest*, Second edition, Cambridge University press, Cambridge.

Singhakumara, B.M.P., Gamage, H.K., Ashton, P.M.S. (2003), *Comparative growth of four Syzygium species within simulated shade environments of a Sri Lankan rain forest*, Forest Ecology and Management 174: 511 – 520.

Whitmore, T.C. (1990), *An Introduction to Tropical Rain Forests,* Clarendon Press, Oxford, UK.