Chapter 23
Review
Silviculture in Secondary Forests

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Abstract Secondary forests are forests regenerating through natural processes after significant reduction in the original vegetation at a point in time or over an extended period, and displaying a major difference in forest structure and/or canopy species composition with respect to nearby primary forests on similar sites. Despite their large extent, existing and potential benefits, secondary forests are mostly overlooked. The increasing area of secondary forests necessitates their professional management. If properly managed, secondary forests can provide important social and environmental benefits, contribute to poverty alleviation and reduce the pressure on the few remaining areas of primary forest. However, only suitable silvicultural treatments can restore and increase the commercial value of secondary forests. This chapter discusses the degradation processes leading to secondary forest formation, their structures, growth and yield and regeneration processes. Three insightful and demonstrative case studies were also presented to illustrate key points.

Keywords Secondary forests · Silvicultural systems and techniques · Degradation process · Succession · Regeneration · Biodiversity conservation

23.1 Introduction

23.1.1 Definitions

Secondary forests refer to woody vegetation regrowing on land after natural and/or human disturbance of the original forest. Even though human disturbances in form of logging and agricultural practises are generally more frequent (Oliver and Larson

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1990), natural disturbances such as fire and hurricanes also destroy primary forests to give way to secondary forests. Secondary forests are products of secondary succession. The concept of secondary succession relates to the observed sequence of vegetational change from dominance of early to later successional species on disturbed or cleared sites. A more detailed definition of secondary forests has been given by Chokkalingam and de Jong (2001), who define them as forests regenerating largely through natural processes after significant reduction in the original forest vegetation through tree extraction at a single point in time or over an extended period, and displaying a major difference in forest structure and/or canopy species composition with respect to nearby primary forests on similar sites. From this definition, the following vegetation types are not regarded as secondary forests:

- Forests subject to low-intensity selective logging, that is when management interventions are significantly below critical natural disturbance frequencies and intensities.
- Forests subject to low-intensity, small-scale extractive activities (e.g. for non-timber forest products).
- Forests affected by small-scale natural disturbance.
- Intensively managed plantations.
- Forests regenerated largely through planting.

The definition provided for secondary forests include several key components such as significant disturbance, largely natural re-growth, and difference in structure and/or composition from adjoining vegetation. The thresholds for many of these components need to be determined at regional or ecosystem levels. Some variations exist in the type of secondary forests across the globe. For instance, on the one hand, in West Africa, most secondary forests are young, corresponding to forest fallows or logged-over residual forests. On the other hand, most secondary forests in Central Africa are old forests and generally result from the very slow colonisation of savannas, to which the present climate is favourable. In Costa Rica, high deforestation rates for cattle raising during the 1970s, followed by pasture abandonment due to a drop in export meat prices one decadeclater (Butterfield 1994), resulted in the development of secondary forests, particularly in the wet, Caribbean lowlands. These forests are characterised by low number of canopy tree species but with high relative dominance (Guariguata and Finegan 1997).

23.1.2 Degradation Processes

In the absence of human or natural disturbance, primary forests remain intact with the ability to regenerate and close gaps left whenever any ageing tree falls. However, when forest degradation processes set in, forest cover is reduced and such forests become secondary forests.

Several factors lead to forest degradation. These include land cultivation for agriculture, logging activities (which are often without due sustained yield principles), conversion of natural forests into plantations (usually monocultures) and other land-use types, implementation of developmental projects (i.e. construction of infrastructural facilities), forest fires, and intensive animal grazing. While some of the land-use types lead to permanent forest loss, others (such as intensive commercial logging) lead to forest degradation. The degradation process sets in because the forest is hardly allowed to recover before another felling cycle commences. This incessant nature of the exploitation activities has often led to a drastic reduction in the quantity and quality of timber obtained from such forests.

23.1.3 Structures, Growth and Yields in Secondary Forests

Like any other tropical forest ecosystem, secondary forests display multi-storey complex structures with relatively high tree species composition (Chokkalingam et al. 2000). By the nature of their formation, secondary forests differ from primary forests in structure, tree species composition and age class range, although there may be old secondary forests whose structure may resemble that of primary forests. Thus, the most determining factors that differentiate the two categories of forests are structure and species composition: a primary forest presents in general more tree species per hectare at a given age, while age class and diameter distribution is more varied; whereas in a secondary forest the number of tree species per hectare is usually limited to a few, and the age class and diameter distribution tends to be more homogeneous. For example, Onyekwelu et al. (2008) reported 51 tree species per hectare in a primary forest in Nigeria as against 31 for an adjacent secondary forest.

The structure of secondary forest varies greatly. However, they are simple when compared to matured forests. The characteristics that typify secondary forests include: high total stem diversity but low density of trees greater than 10 cm dbh, low basal area, short trees with small diameter, low timber volume and high leaf area indices (Brown and Lugo 1990). The structural characteristics change with age, with the rate of change affected by climate and soil type. For example, as age increases, the stand-weighted wood specific gravity of secondary forests increases (Saldarriage et al. 1986; Weaver 1986). When very young the abundance of saplings and climbers generally gives secondary forests a dense tangled appearance, which makes them difficult to penetrate (Blay 2002). However, after some years (especially on abandoned cultivated land), cohorts of trees of remarkably regular structure emerge, consisting mainly of a single fast-growing species such as *Musanga cecropioides* (in Africa). Those trees, which are dominant for a single generation, are mostly light-demanding and short-living species. They are later replaced by a mixture of less fast-growing, more shade-tolerant and longer-living trees, some of which are pioneer and some primary forest species (Blay 2002). In contrast, the secondary forest vegetation developing after logging, at least during its earlier stages, is very irregular in structure. Damaged survivors from the former forest are scattered among climber tangles and patches of "razor grass" (*Scleria* spp.), and dense stands of saplings may be present (Blay 2002). Secondary forests are generally characterised (depending on its level of degradation) by a less developed canopy structure and smaller trees when compared to primary forests. Due to the lack of a full canopy, more light will reach the floor, supporting vigorous ground vegetation.

The growth of trees in secondary forest is highly variable, too, with large differences between species, tree sizes, sites, and even between the same sizes of individual trees of the same species growing in the same site. In contrast, growth of individuals during successive periods is much less variable. Although trees that are growing fast continue to do so, the slow-growing individuals continue to grow slowly.

The productivity of secondary forests may vary in relation to factors such as site conditions (in particular topsoil and humus conditions), time since settlement and, more specifically, the number of crop–fallow cycles at a particular site, the type and intensity of land-use during the cropping stage, and the prevalence of disturbances such as accidental burning during the fallow stage (Blay 2002; ITTO 2002). Other factors that may influence the growth and yield of secondary forests include: the age of the stand, density, secondary forest type, etc., which is clearly evident from the data published by Brown and Lugo (1990) presented on Table 23.1. As succession progresses, total stem density tends to decrease and the stand increases in height, basal area and volume. The first 15 years of succession are characterised by rapid biomass accumulation up to 100 tonne ha^{-1} (Brown and Lugo 1990). The relative amount of woody biomass also increases rapidly during the first 15–20 years, followed by a steady but slower rate until maturity (Blay 2002). There are indications that volume growth is higher in advanced secondary forest than in young secondary forest, which may be attributed to the presence of bigger individual trees in advanced secondary forests. Weaver and Birdsey (1990) reported a significantly higher mean volume growth rate of 6.9 m^3 ha^{-1} $year^{-1}$ in an advanced secondary forest in Puerto Rico than the 2.0 m^3 ha^{-1} $year^{-1}$ in young secondary forest. However, within a specified time scale, growth is sometimes more active in young secondary forest, for example while growth increased by an average of 50% within a 5-year period in young secondary, advanced secondary forest increased by only 18% within the same period (Weaver and Birdsey 1990).

Gomide et al. (1997) reported a decreasing trend in growth parameters of a secondary forest in Amapa, Brazil. For example, during the first period of observation, the average diameter growth rate of 1.93 cm $year^{-1}$ was recorded, which decreased to 0.34 cm $year^{-1}$ after 2 years. Basal area increment changed from about 6 m^2 ha^{-1} $year^{-1}$ to 1 m^3 ha^{-1} $year^{-1}$ within 10-year period. This decreasing trend was attributed to canopy closure, competition and the progressive decline in pioneers in the forest (Gomide et al. 1997). An average volume growth of 3.5 m^3 ha^{-1} $year^{-1}$ in 14 years was reported for the secondary forest in Amapa, Brazil.

Table 23.1 Structural and growth characteristics of secondary forests

Age (years)	Min. dbh measured (cm)	Basal area (m^2 ha^{-1})	Density (No. ha^{-1})	Canopy height (m)	Mean Dbh (cm)	LAI
Tropical wet forest						
4.5 (Poor soil)	All stems	4.3	4,060	6	–	–
4.5 (Rich soil)	All stems	16.3	3,867	12.2	–	–
9.5	All stems	12.7	2,200	11.5	–	–
15	–	26.9–37.1	400–610	–	20–25	–
Tropical moist forest						
10	10	12.8	342	10	–	5.8
20	10	16.9	461	–	–	6.9
35	10	18.6	495	18–19	–	6.6
60	10	24.5	441	–	–	5.6
80	10	24.0	604	–	–	6.4
Mature	10	38.4	570	25–35	–	7.5
2	–	–	–	7.2	6	7.5
2	–	–	–	8	12	6.9
4	–	–	–	10	13.8	11.6
6	–	–	–	12	17.6	16.5
Tropical dry forest						
8	3.2	11.8	2,038	25	–	–
3	1.0	–	512	2.5	1.8	–
7	1.0	–	2,270	4.7	4.6	–
10	1.0	–	2,670	5.8	7.2	–
Late secondary	1.0	–	2,260	10.4	20	–
Sub-tropical wet forest						
6	10	7.2	1,334	10	–	–
20	10	28.5	1,234	25	–	–
21	10	27.8	2,436	19	–	–
50	10	33.8	1,593	24	–	–

Source: Brown and Lugo 1990

23.1.4 Biodiversity

Most human-modified areas in the tropics, such as secondary forests, were largely considered hostile to biodiversity. However, a series of studies done in the last few years have painted a very different picture. Secondary forests play vital function and are becoming increasingly important in conserving biodiversity because they currently constitute a large proportion of tropical forest cover. One of the most notorious characteristics of secondary forests is the high biodiversity heterogeneity between stands only short distances apart, both in the canopy and in the understorey. This has been mainly attributed to phenological variations of colonising species at the moment of land abandonment (fallow period), the type of regeneration (re-sprouts versus seeds), past land-use type as well as the presence of different species of remnant trees, which can influence species composition (Brown and Lugo 1990; Blay 2002).

Most secondary forests differ in floristic composition from primary forests. It is generally believed that secondary forests always have fewer tree species per unit area than primary forest, but this is not necessarily so, especially in comparison with fairly old secondary forests. Although secondary forests contain often less canopy (tree) species diversity than primary forest, they could be the sources of important timber species and other species used for carving and the manufacture of household items (Blay 2002). Some economic tree species found in secondary forests include *Triplochiton scleroxylon, Ceiba pentandra, Daniella ogea, Lophira alata, Milicia excelsa, Nauclea diderrichii, Terminalia ivorensis, Terminalia superba, Alstonia boonei*, etc.

Since the occurrence and distribution of tropical forests are largely explained by geophysical characteristics, and the quantity and seasonality of rainfall, the composition and species population sizes of secondary forests are determined in part by species tolerance of prevailing environmental conditions, particularly rainfall and soils, and in part by local site history (Swaine and Hall 1983). Generally, the tree species that dominate secondary forests are apparently unable to regenerate under their own shade, as suggested by the absence of small size classes in stem-diameter distributions, changes in tree species composition across a forest chronosequence, and by monitoring tree recruitment over long periods (Guariguata 2000). During the early stage of secondary succession, the number of species per hectare increases rapidly but slows down after a few years. It is noteworthy that semi-deciduous and deciduous tree species characteristic of seasonal climates are often common in secondary rainforest. In West Africa, for example, *M. excelsa* and other mixed semi-deciduous forest trees often occur in clearings and young secondary rainforest. *Bombacaceae* are also often found in old and middle-aged secondary forests (Budowski 1970). Similarly, in a large sample of secondary forests in Costa Rica, 90% of tree species found in old-growth forest areas were represented by either seedlings, small trees, or large trees, with the number of species increasing with age of the forest, allowing biodiversity to recover faster than many expected (Hance 2009). Various factors influencing the recovery of species composition in secondary forests have been identified, among which are: stem coppicing and root sprouting mechanisms, seed availability, nature of disturbance, etc. (Uhl and Clark 1983; Murphy and Lugo 1986; Brown and Lugo 1990).

Unlike tree species, the understorey species assemblages in secondary forests are more diverse, richer, and have a higher density than the understorey assemblage in primary forests. Understorey plant species assemblages may have different patterns of diversity than tree species because of variable responses to different abiotic factors. Furthermore, the canopies of secondary forests may be more open than in primary forests, allowing higher levels of light to the forest floor, which may result in understorey species assemblages of higher diversity than adjacent primary (Laska 1997). In a study that compared the floristic composition, species diversity, richness, and density of three common families of understorey shrubs between two secondary growth forests (12- and 25 years old) and an adjacent primary forest in Costa Rica, Laska (1997) encountered 22 species (47%) occurring in secondary growth forests only, one species occurring in old-growth forest only and 24 species (51%) in both types of forest. The secondary forest understories were found to have higher species diversity, higher species richness and density than the primary forest.

23.2 Regeneration in Secondary Forests

The regeneration of secondary forests follows a wave of succession that usually occurs in forest openings following disturbances from fallen trees, forest clearing under shifting cultivation, use of heavy machinery and various natural disasters such as floods, hurricanes, wind-throws and die-back, etc. Swaine and Whitemore (1988) recognised two categories in secondary forest succession process: pioneer and secondary species. Pioneer species typically germinate, establish, grow and mature relatively quickly in the clearings and breaks created by the death of dominant trees. Many of the primary species regenerate by seedlings and young plants already on the forest floor, root suckers and rhizomes, seed in the soil and seeds with a very short seed dormancy that happen to be in fruit during disturbance of the area (Richards 1966). Early pioneer species are often fast-growing, short-lived "weedy trees". At the other extreme, many climax species are designed to tolerate resource scarcity. Their seeds are able to germinate in the dark forest understorey and seedlings can tolerate canopy shade for long periods, until disturbance creates an opportunity for growth. Shade-tolerant species reach their peak rates of photosynthesis at much lower light levels than their counterparts (Riddock et al. 1991). Eventually, the late pioneers are replaced by late successional vegetation that is diverse in architectural form and long-lived. The mature forest is the ecological unit that has reached its maximum diversity and number of species by containing all stages of the forest mosaic.

The rate of regeneration in secondary forest appears variable based on the stage (age) of forest growth. Jin et al. (2005) showed that the appearance rate of regeneration species during the restoration period of a secondary forest was very low during the initial 10 years, but was markedly higher after 15 years and had only little change afterwards. The stocking density of regeneration species increased gradually along with the restoration of secondary forest, it could reach 7,500 trees per hectare, with little change at later stage (Jin et al. 2005). Enrichment planting is perhaps the most popular and appropriate method of artificially regenerating secondary forests (Piotto 2007). It is employed to increase the stocking of valuable tree species. Other secondary forest regeneration methods include: refining and liberation thinning, post-abandonment, etc. Where enrichment planting is adopted, native or exotic species could be used. However, priority should be given to the appropriate native tree species, which are well known and adaptable to the area.

23.3 Silvicultural Systems and Techniques

Fundamentally, the silvicultural treatments used to stimulate the production of commercial timber species in tropical primary forests may also be applicable in the regeneration and tending of secondary forests. Experience has shown that young secondary forests are more receptive to silvicultural manipulations than primary forests because of their manageable tree size and rapid growth response

(Müller 2002). The silvicultural strategy adopted must consider tree species composition and structure of the forest. Specifically, information on the extent, location, condition, conversion processes, current and potential uses of secondary forest is necessary. Silviculture in secondary forests should be based in the first instance on existing natural regeneration (ITTO 2002) because new germination or planting of seedlings is more difficult to handle compared to tending the seedlings already present. Thus, one of the most important tasks is the assessment of existing natural regeneration. Since many important timber species are rarely found in secondary forests, the economic value of secondary forests can be increased through strategies that facilitate the growth of economic tree species (Piotto 2007). The basic questions for determining the silvicultural techniques of secondary forests are presented in Table 23.2.

The silvicultural techniques ultimately chosen will depend heavily on the priorities and objectives of the forest owner, the costs and benefits associated with the strategy as well as the economic, social, and environmental values of the land resources in their current and desired future states. The major systems used in secondary forests include enrichment planting within existing stands, refining and liberation thinning, post-abandoned secondary forest, assisted natural regeneration (ANR) and plantation establishment after clear-cutting.

Table 23.2 The four basic silvicultural questions for determining the management strategy for secondary forests

Silvicultural questions	Management strategy
What are the present stand and site conditions?	• Stand: species composition, structure, health, age, regeneration capacity, etc. • Site conditions: edaphic, hydrologic, etc. • Socio-economic context: Who uses the forest, what for, what kind of impact?
What are the stand and site histories?	• Determine the cause(s) of degradation: for example was the area under shifting cultivation? If yes, what intensity? Is the stand a logged-over forest? Did forest fire occur?
How would the site develop in the absence of planned management interventions?	• What will happen to the stand if there is no management? For example, ecologically (succession, etc.) and socially (conversion into other land-use, etc.)

What management strategies are needed to achieve a particular outcome (restoration, secondary forest management, rehabilitation)? Depending on who manages the forest, the question of who plans, who harvests and who monitors will influence how this will be done	• Participatory and adaptive management planning for the particular forest stand or the degraded site: silvicultural options, collaborative use management, multiple-use management
	  • Define objective
	  • Specify methods
	  • Specify monitoring of forest development, and adopt, if necessary, the strategy and the course of action

Source: ITTO 2002

23.3.1 Enrichment Planting

Enrichment planting is one of the major silvicultural methods used in the management of secondary forests and perhaps the most popular and appropriate (Piotto 2007). It is employed to increase the stocking of valuable tree species in degraded or secondary forest, where regeneration of the required species is scanty, partially successful or completely absent, without removing the trees already present (Montagnini and Jordan 2005; Piotto 2007). Enrichment planting is defined as a technique for promoting artificial regeneration of forests in which seedlings of preferred timber trees are planted in the understorey of existing logged-over forests and then given preferential treatment to encourage their growth (Lamprecht 1989). The use of enrichment planting requires canopy manipulation to optimise the growth and survival of the planted trees. The practise is influenced by the ability of the species to survive as young seedlings under existing natural forest stands.

Necessary conditions for successful enrichment planting include the provision of adequate light conditions, proper supervision, and follow-up maintenance (especially canopy opening treatments). In the tropics, enrichment planting has declined because of several reasons, which include (a) planting work is difficult to supervise; (b) seedlings have to be regularly released from regrowth; (c) a regular supply of seedlings is needed and (d) it is costly (labour demanding). Failures have been mainly attributed to the poor or improper selection of species and planting stock. In addition, lack of adherence to sound planting and tending practises, that is, insufficient overstorey opening prior to planting and insufficient follow-up tending operations also lead to some setbacks. In spite of the failures, enrichment planting still has the advantage of mimicking natural gap dynamics and protecting the soil by maintaining vegetation on site. According to Montagnini et al. (1997), the system can be successfully used to increase the value of secondary forests and prevent their conversion to other land uses, thus reducing deforestation. Enrichment planting is an important land-use strategy in the context of the current international attempt to curb deforestation and forest degradation in developing countries (Paquette et al. 2009). If managed successfully, enrichment planting presents an interesting opportunity for carbon sequestration in the tropics.

Due to the relative management complexity of enrichment planting, basic information about the species ecology is fundamental in selecting potential species and predicting their response to silvicultural treatments. Since trees are planted under a measure of shade, the species adopted are mainly shade tolerant species. Also pioneer and late successional species are used. Important silvicultural characteristics for species ideal for enrichment planting include: produce timber of high value, low crown diameter, regular flowering and fruiting, wide ecological range, fast growth rate, tolerance to moisture stress, good natural stem form, free of pests and diseases, drought resistance and ability to grow in low-nutrient soils (ITTO 2002).

The experience with enrichment plantings in secondary forests has generally been more favourable than in primary forests. Enrichment plantings have generally yielded promising results when applied in young secondary forests (Müller 2002), because of their manageable tree size and rapid growth response. However, enrichment plantings tend to be costly and labour-intensive. When high timber productivity is a major objective, a monocyclic system that relies on creating a future, even-aged stand by opening the middle and upper canopies shortly before tree harvesting is perhaps the most appropriate (Müller 2002). This strategy is required for pioneer/light-demanding species that need almost complete canopy removal to stimulate seed germination and sustain seedling growth and survival.

23.3.2 Refining and Liberation Thinning

Refining and liberation thinning are important in the initial stage to demonstrate measurable effects from secondary forest restoration, management and rehabilitation efforts (ITTO 2002). They also reduce the time in which a merchantable crop of timber and NWFP will become available. However, the operations of refining and liberation thinning are costly and only yield distant future returns. Refining refers to the elimination of undesirable trees, climbers, shrubs and other plants that will inhibit site occupation by desirable trees while liberation thinning refers to the cutting that relieves young seedlings, saplings and trees in the sub-canopy layer from overhead competition (ITTO 2002). Refining allocates growing space to the potential final-crop trees at the expense of others. One major setback of this method is that refining can jeopardise species diversity in secondary forests and may endanger the ecological integrity of the stand, thus care must be taken to prevent biodiversity loss (Grieser 1997). In the past, this method was used to eliminate tree species that were then thought to be “useless”, some of which were later discovered to be of high economic importance. Thus, the method is constrained by the limited knowledge of the usefulness of many secondary forest tree species and the continual discovery of use for species that were once considered “useless”. To minimise wastage, a reasonable compromise is to leave sub-canopy species and tree regeneration layers of the canopy as intact as possible, while removing only those trees and climbers that overtop the desired trees (ITTO 2002). Liberation thinning stimulates growth, since tree growth is directly related to the formation of a healthy and dense crown.

23.3.3 Assisted Natural Regeneration

ANR is an alternative and low cost approach to the restoration of native forest biodiversity and productivity. It is a simple, inexpensive and effective method for accelerating and enhancing the regeneration and establishment of secondary forest and shrub vegetation by protecting and nurturing the mother trees and their wildlings inherently present in the area (Ganz and Durst 2003; FAO 2010). The method entails assisting the natural processes of regeneration and planting new trees when necessary. The ANR aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g. fire, grazing, and wood harvesting). Seedlings are, in particular, protected from undergrowth and extremely flammable plants such as Imperata grass (FAO 2010). It also aims to strike a balance between high-cost restoration planting to restore biodiversity to small areas and the establishment of commercial plantations over large areas to restore productivity (Shono et al. 2007). ANR offers significant cost advantages because the costs associated with propagating, raising, and planting seedlings are eliminated or reduced. Some of the processes involved in ANR methods include: cutting or pressing the weeds around existing naturally established seedlings, protecting the area from fire and interplanting with desired species if necessary. ANR differs from natural regeneration, which allows some human intervention but precludes tree planting.

According to Shono et al. (2007), ANR is most suitable for restoring secondary forests where some level of natural succession is in progress. As a first condition, sufficient tree regeneration must be present so that their growth can be accelerated. Seedlings of pioneer tree species are often found among and below the weedy vegetation even on a seemingly weed-dominated land. The minimum required number of pre-existing seedlings to implement ANR depends on the acceptable length of time for the forest to be restored and site-specific conditions that influence the rate of forest recovery. As a general reference, a density range of 200–800 seedlings (>15 cm in height; counting clumps in 1 m^2 as one seedling) per hectare has been suggested for ANR reforestation, and it has been estimated that at least 700 seedlings per hectare are needed during the early treatment period to achieve canopy closure within 3 years (Jensen and Pfeifer 1989; Shono et al. 2007). To ensure further successional development, remnant forest should be in proximity so that there would be sufficient input of seeds. Most importantly, it must be possible to prevent further disturbances such as fire, grazing and illegal logging because the success of ANR ultimately depends on the continued protection of the site.

Various steps are involved in the implementation of ANR, among which are (see Jensen and Pfeifer 1989; Cohen et al. 1995; Friday et al. 1999; Shono et al. 2006 for more details):

1. Marking woody regeneration;
2. Liberation and tending of woody regeneration;
3. Suppressing weedy vegetation;
4. Protection from disturbance;
5. Maintenance and enrichment planting.

23.3.4 Plantation Establishment

Another silvicultural strategy for managing secondary forest to overcome degradation, while ensuring financial returns is the establishment of commercial tree plantations (Lamb 1998). Few secondary forests will recover unaided, thus there has been increasing interest in using industrial plantation to increase biodiversity in the landscape (Lamb 1998). Numerous studies have demonstrated the catalytic effect of plantations in fostering the regeneration of native forest species in the understorey. The need to integrate biodiversity conservation in commercial plantations is becoming increasingly important, and plantation trials involving high-value native trees and species mixtures are underway in many countries. The use of plantation as a silvicultural strategy for regeneration in secondary forest is often referred to as restoration or ecological rehabilitation plantation. This type of plantation differs from commercial industrial plantation in that trees are invariably planted with uniform distribution of trees in industrial plantations, while in ecological rehabilitation plantation, the trees are planted in clumps or some other configuration that will be more effective in producing the desired conditions for ecosystem development (Evans and Turnbull 2004). For restoration planting, the primary objective will be ecological in nature, whereas for rehabilitation planting, the objective is increasing the structural complexity and biodiversity of the plantation, in addition to the potential for making economic return.

Because the practises used for restoration and rehabilitation plantation depend very much on the nature of the degradation at a specific site, the results can be variable. Thus, there is a need of criteria and indicators to judge whether the plantation is achieving its objectives (Evans and Turnbull 2004). Due to differences in forest type, environmental conditions, time since planting began, it is not possible to have a universal set of criteria and indicators. Potential indicators for assessing the success of restoration plantation are suggested by Lamb (1993), like the presence of a litter layer, and a flora and fauna close to the original state of the undisturbed or untouched forest ecosystem.

For the management of severely degraded secondary forests, the common practise is to establish plantations after clear-cutting. Areas that are poorly stocked and could take very long to naturally regenerate are usually developed into plantations. This method usually leads to land-use change from natural forest to forest monoculture or mixed plantation. The advantage of this method is that it is used to salvage the secondary forest, by preventing them from being converted to agricultural land or other land-use forms and thus ensuring that the land remains under forest cover. In many tropical countries, forest plantations are usually established within forest reserves by completely clearing degraded or secondary natural forests (Chen et al. 2004; Evans and Turnbull 2004; Onyekwelu et al. 2006). This practise usually results in land-use change from degraded natural forests to plantation forests. Chen et al. (2004) reported that about 50,000 ha of the hoop pine plantations in southeast Queensland, Australia were established on previous natural forest land. In Nigeria, virtually all the existing forest plantations, especially those within the tropical rainforest zone of southwestern Nigeria, were established on lands that once carried degraded natural forests. For a more extensive appraisal of silvicultural strategies and techniques in rehabilitation, we refer to Weber et al. (Chap. 30).

23.3.5 Post-abandonment Secondary Forest

Post-abandonment secondary forest is an unconventional secondary forest management method that is most widely used in secondary forest regeneration and management. In post-abandonment secondary forests, the forests are left to restore themselves without any deliberate human intervention or rehabilitation measures. This is attributed to the ability of secondary forests to recover and eventually return to their original "species rich" situation, even after significant degradation. Post-abandonment secondary forest is defined as a process whereby the forests are deliberately allowed to regenerate largely through natural processes after total abandonment of alternative land-use on formerly forested lands (Chokkalingam et al. 2000). This unconventional secondary forest management method has been practised in developing countries, where systematic management of natural forest is not common. The level of success for post-abandonment as a management strategy for secondary forests will require that all forms of degradation activities (e.g. timber exploitation, fuelwood and NWFP collection, fire, encroachment by farmers) must cease or be reduced to the barest minimum. If this is not done, the forest may not be able to recover. The management challenge in these forests is to maintain a certain species composition and structure in the long term and to guarantee the regeneration of the desired species.

23.4 Users and Uses

Secondary forests are becoming the predominant forest types in many tropical countries, thus they are gradually having to provide the productive (in terms of both wood and non-wood forest products) and environmental functions of primary, old-growth forests. Moreover, the relative close proximity and accessibility of secondary forests to human settlements have made them readily available as a source of wood products, such as timber, construction wood, fuelwood and charcoal, carving wood, etc. Secondary forests are used by a wide array of people including the forest dwellers, forest adjacent households, commercial producers and users of forest products, nature lovers and ecotourists. Thus if properly managed, secondary forests can provide a wide variety of goods and services to society, especially to local communities that depend on them. The main users are the sedentary group (forest adjacent households) who rely on various components of the forest all year round for their subsistence. The secondary forests provide not only wood products but also a wide range of goods and services to the local users including medicinal plants, honey, thatching grass, fodder, saplings, seeds, cultural/ceremonial sites and food (vegetables, fruits, game meat). In addition to these benefits, secondary forests also play significant roles in soil and water conservation as well as carbon sequestration. In some tropical countries, secondary forests play a very important economic role as the source of wood raw materials for some export products.

Forest land can be categorised into various uses depending on the nature of goods and services they provide. The species growing in secondary forests often have multi-purpose functions, which is an important feature to be taken into account for its management. Secondary forest use boosts local economy and provides tangible benefits to those who live in and around the forests. FAO estimates that 80% of the people in the developing world relies on NTFPs (mostly from secondary forests) for some purpose in their everyday life, thus the local communities are the principal users of secondary forests. For example, plants for medicinal uses are important components of secondary forests, thus their abundance and distribution, especially in the understorey, plays important role in rural health care delivery. The categorisation may be based on such factors as provision of food and economic empowerment for rural dwellers, maintenance of environment, provision of opportunity for recreation activities, habitat for wildlife, watershed protection, general conservation including minimisation of soil erosion and the production of wood for various uses. For each category of use, it might be subdivided, or combined to be used in the same area of forest land.

Building on the important uses of secondary forest, ITTO (2002) and Müller (2002) identified the following benefits of secondary forests:

- Fallow within shifting cultivation systems, which are often an integral component of small farmers' agricultural systems for the regeneration of soil fertility and the containment of pests and diseases.
- Fuelwood and charcoal, which are the primary energy sources for many rural people in tropical regions, are important secondary forest products.
- Non-timber forest products (NTFPs) (e.g. bamboo, rattan, edible fruits, nuts, leaves, medicinal plants, game, etc.), which are harvested for their economic, social and nutritional importance.
- Wood for local needs (house-building, posts) and for sale (sawn wood, veneer wood, industrial wood).
- Environmental services such as protection of soil erosion; regulation of water regime and reduce water loss.
- Through run-off on hillsides; fixation and storage of significant amounts of carbon, thus contributing to mitigation of global warming; refuges for biodiversity and biological corridors in fragmented/agricultural landscapes; contributing to reducing fire risk; and conservation of genetic resources.
- The use of secondary forests may reduce pressure on primary forests, thus reducing deforestation rates. However, this only applies if the products from the secondary forests are suitable for the same uses as those derived from primary forests, if the financial rewards are comparable, and if economic conditions do not encourage the simultaneous use of both types of forest.
- Recreational activities.

23.5 Conclusions

One of the daunting challenges is the sustainability of the utilisation of the vast resources from secondary forests. Consequently, appropriate management options that take into account the peculiarities of secondary forests and the needs of people who depend on their resources must to be identified and implemented. The selected management strategies should be based on a sound analysis of the general social, economic, institutional, and ecological context. Hence, the particular ecological and socioeconomic criteria and indicators adopted should be linked to site-specific objectives and goals (ITTO 2002).

References

Blay D (2002) Tropical secondary forest management in humid Africa: reality and perspectives. Proceedings of workshop on tropical secondary forest management in Africa: reality and perspectives, Nairobi, Kenya, 9–13 Dec 2002

Brown S, Lugo AE (1990) Tropical secondary forests. J Trop Ecol 6(1):1–32

Budowski G (1970) The distinction between old secondary and climax species in tropical Central American lowland forest. Trop Ecol 11:44–48

Butterfield NJ (1994) Burgess Shale-type fossils from a Lower Cambrian shallow-shelf sequence in northwestern Canada. Nature 369:477–479

Chen CR, Xu ZH, Mathers NJ (2004) Soil carbon pools in adjacent natural and plantation forests of subtropical Australia. Soil Sci Soc Am J 68:282–291

Chokkalingam U, De Jong W (2001) Secondary forest: a working definition and typology. Int For Rev 3:19–26

Chokkalingam U, De Jong W, Smith J, Sabogal C (2000) Tropical secondary forests in Asia: introduction and synthesis. Paper prepared for the "Tropical secondary forests in Asia: reality and perspectives' workshop", Samarinda, Indonesia, Center for International Forestry Research, Bogor, Indonesia, 10–14 Apr 2000

Cohen AL, Singhakumara BMP, Ashton PMS (1995) Releasing rain forest succession: a case study in the *Dicranopteris linearis* fernlands of Sri Lanka. Restor Ecol 3:261–270

Evans J, Turnbull JW (2004) Plantation Forestry in the Tropics, 3rd edn. Oxford University Press, Oxford, p 467

FAO (2010) Assisted natural regeneration of forests. http://www.fao.org/forestry/anr/en. Accessed 1 Feb 2010

Friday K, Drilling E, Garrity DP (1999) Imperata grassland rehabilitation using agroforestry and assisted natural regeneration. International Center for Research on Agroforestry, Southeast Asia Regional Research Programme, Bogor, Indonesia

Ganz DJ, Durst PB (2003) Assisted natural regeneration: an overview. In: Dugan PC, Durst PB, Ganz DJ, McKenzie PJ (eds) Advancing assisted natural regeneration (ANR) in Asia and the Pacific. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand, pp 1–4

Gomide GA, Sanquetta CO, Da Silva JN (1997) Dynamics of a tropical secondary forest in Amapa, Brazil. In: Guariguata MR, Finegan B (eds) Proceedings of the Conference on Ecology and Management of Tropical Secondary Forest: Science, People, and Policy, Turrialba, Costa Rica, 10–12 Nov 1997

Grieser AJ (1997) Timber production and biodiversity conservation in tropical rain forests. Cambridge University Press, Cambridge, UK, p 225

Guariguata MR (2000) Seed and seedling ecology of tree species in neotropical secondary forests: management implications. Ecol Appl 10(1):145–154

Guariguata MR, Finegan B (1997) Ecology and Management of Tropical Secondary Forests: Science, People and Policy. Proceedings of a Conference on Ecology and Management of Tropical Secondary Forests held at CATIE, Costa Rica, November 10–12, 1997, CATIE/ CIFOR

Hance J (2009) Secondary forest should become new conservation initiative. http://news.mongabay.com/2009/0118-hance_secondaryforest.html. Accessed 23 May 2010

ITTO (2002) ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. ITTO Policy Development Series No. 13. ITTO, Yokohama

Jensen CL, Pfeifer S (1989) Assisted natural regeneration: a new reforestation approach for DENR? Report to USAID, Manila, and Philippines, Department of Environment and Natural Resources, Manila, Philippines

Jin Y, Don K, Ho S, Zhou L (2005) Quantitative dynamics on natural regeneration of secondary forest during the restoration period in Changbai Mountain area. J Nanj For Univ (Natural Sciences Edition) 29(5):65–68

Lamb D (1993) Restoration of degraded forest ecosystems for nature conservation. In: Mortitz C, Kikkawa J (eds) Conservation biology in Australia and Oceania. Surrey Beatty, Chipping Norton, UK, pp 101–114

Lamb D (1998) Large-scale ecological restoration of degraded tropical forest lands: the potential role of timber plantations. Restor Ecol 6:271–279

Lamprecht H (1989) Silviculture in the tropics. TZ-Verlagsgesellschaft GmbH, Rossdorf, p 296

Laska MS (1997) Structure of understory shrub assemblages in adjacent secondary and old growth tropical wet forests, Costa Rica. Biotropica 29(1):29–37

Montagnini F, Jordan CF (2005) Tropical forest ecology. The basis for conservation and management. Springer, Berlin, p 293

Montagnini F, Eibl E, Grance L, Maiocco D, Nozzi D (1997) Enrichment planting in degraded forests of the Paranaense region of Misiones, Argentina. For Ecol Manag 99(1&2):237–246

Müller E (2002) Making secondary forests visible. ITTO Trop For Update 12(4):16–18

Murphy PG, Lugo AE (1986) Ecology of tropical dry forest. Annu Rev Ecol Syst 17:67–88

Oliver CD, Larson BC (1990) Forest stand dynamics. McGraw-Hill, New York, p 419

Onyekwelu JC, Mosandl R, Stimm B (2006) Productivity, site evaluation and state of nutrition of *Gmelina arborea* plantations in Oluwa and Omo forest reserves, Nigeria. For Ecol Manag 229:214–227

Onyekwelu JC, Mosandl R, Stimm B (2008) Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in South-western Nigeria. J Trop For Sci 20(3): 193–204

Paquette A, Hawryshyn J, Vyta Senikas A, Potvin C (2009) Enrichment planting in secondary forests: a promising clean development mechanism to increase terrestrial carbon sinks. Ecol Soc 14(1):31, http://www.ecologyandsociety.org/vol14/iss1/art31/

Piotto D (2007) Growth of native tree species planted in open pasture, young secondary forest and mature forest in humid tropical Costa Rica. J Trop For Sci 19(2):86–96

Richards PW (1966) The tropical rain forest, 2nd edn. Cambridge University Press, Cambridge, UK

Riddock I, Grace J, Fasehun FE, Riddoch B, Ladipo DO (1991) Photosynthesis and successional status of seedlings in a tropical semi-deciduos rain forest in Nigeria. J Ecol 79:491–503

Saldarriage JG, West DC, Thorp ML (1986) Forest succession in the upper Rio Negro of Colombia and Venezuela. Environmental Science Division Publication No. 2694 (ORNL/TM. 9712). Oak Ridge National labouratory, Oak Ridge, TN

Shono K, Davies SJ, Chua YK (2006) Regeneration of native plant species in restored forests on degraded lands in Singapore. For Ecol Manag 237:574–582

Shono K, Cadaweng EA, Durst PB (2007) Application of Assisted Natural Regeneration to Restore Degraded Tropical Forestlands. Restor Ecol 15(4):620–626

Swaine MD, Hall JB (1983) Early succession in cleared forest land in Ghana. J Ecol 71:601–27

Swaine MD, Whitemore TC (1988) On the definition of ecological species groups in tropical rain forests. Vegetation 75:81–86
Uhl C, Clark K (1983) Seed ecology of selected Amazon Basin successional species emphasizing forest seed banks, seed longevity and seed germination triggers. Bot Gaz 144:419–425
Weaver PL (1986) Hurricane damage and recovery in the montane forest of the Luquillo mountains of Puerto Rico. Can J Sci 22:53–70
Weaver PL, Birdsey RA (1990) Growth of secondary forest in Puerto Rico between 1980 and 1985. Turrialba 40(1):12–22