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Chapter

Silvicultural Practices in Venezuelan Natural Forests: An Historical Perspective and Prospects of Sustainable Forest Management

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Abstract

More than four decades of cumulative silvicultural experience in Venezuelan forests represents a significant progress towards sustainable forest management in the tropics. Here, based on an extensive literature review, expert opinions and discussions with forestry stakeholders in the country, we offer a broad overview of the history and current state of silvicultural practices in Venezuela's natural production forests. Despite important research advances, several factors including institutional and policy limitations, along with the lack of sound technical guidelines have hampered a more positive influence of silvicultural research for sustainable forest management across the country's managed forests. On an industrial scale, after an often poorly planned selective logging, and despite increasing evidences against for, a strong prominence of assisted natural regeneration (i.e., enrichment planting) characterized the post-logging management compared to other approaches. With very few exceptions, using artificial regeneration did not produced the expected outcomes in terms of tree growth, expected timber yield and survival. Finally, amidst the current political and economic upheaval in Venezuela, a broad range of lessons and policy recommendations is proposed including the strengthening of research on silvicultural options for multiple use of forests and for climate change mitigation and adaptation.

Keywords: enrichment planting, forest policy, minimum harvest diameter, research, tropical forests, Venezuela

1. Introduction

Forests in their multiple forms and types are the dominant terrestrial ecosystems on Earth, covering about one third of the globe's land area [1]. Forests represent a fundamental component of world's carbon cycle, are the habitat for biodiversity and are important for the provision of a myriad of services from which people depends for their livelihoods. Distributed over different

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environmental and latitudinal gradients, forest ecosystems account for at least 75% of global terrestrial productivity (GPP) [2], with tropical forests (TFs) being disproportionally relevant compared to other forests-types in the temperate or boreal regions. For example, TFs store 200–300 Pg C, about a third as much as is held in the atmosphere [3, 4].

Globally, recent estimates indicate that the forest area under management plans, mostly for timber production, has increased since 2000 reaching close to 2.05 billion ha in 2020 [5]. However, this proportion remains largely unbalanced when compared across regions, and for example less than 20% of the total forested area of South America has some type of long-term management plan [5], while high rates of deforestation and degradation continue to threaten the stability of forests, particularly in the tropics [5–7]. In terms of forest management, more than 400 million hectares (ha) of natural tropical forests have been designated as production forests [8–10]. Moreover, nearly 40% of sawn wood traded annually in tropical regions has an origin in natural forests [11], often under a "selective logging" approach in which large trees of a relatively low number of tree species are harvested in rotation cycles of 30 years on average [9, 12, 13]. The dynamics driving how tropical forests respond, and ultimately recover to this type of intervention is a function of several ecological and socio-economic factors. Yet, the characteristics of the logging practices (i.e. intensity of harvest, conventional vs. reduced impact logging), the elapsed time before the next harvest, and the post-harvest interventions are all silvicultural decisions particularly relevant to facilitate the speed of the recovery and the features of the future forest [14, 15]. Thus, throughout this entire process, silviculture plays an important role by ideally outlining the 'best' system and a set of specific practices to facilitate long-term forest management.

As an applied discipline, silviculture traditionally has aimed at controlling the establishment, composition, structure, growth, and the role of trees within a forest to create a more predictable production system [16, 17]. While objectives of forest management have changed globally in the last two decades with an increasing relevance for conservation of biological diversity, carbon storage, and other ecosystem services, the design, planning and application of silvicultural practices is still very much oriented towards timber production that often reduce structural and biological complexity, and has become a prevalent driver of change in many tropical managed forests [18–21]. From the outset, tropical silviculture faces the challenge of reconciling timber production as a primary goal with long-term conservation of forest ecosystems, so thresholds of extraction intensity coupled with silvicultural treatments needs to be compatible with the maintenance of biodiversity and other ecosystem services, as well as the financial viability for all the actors involved [9]. Accomplishing this goal, while difficult, seems more feasible than a few decades ago, given that the levels of ecological knowledge of tropical forests has increased enormously in the last 20 years, which means that there has never been a sounder scientific basis from which to guide forest management in the tropics [22].

This chapter discusses the history of silvicultural practices in natural forests of Venezuela, a country with one of the longest history of forest management in the tropics [23, 24] (**Figure 1**). First, an outline of the context of Venezuelan forestry is presented, including an overview of forest extension, forest types and the characteristics of forest management in the country. A review of the main silvicultural systems historically applied with considerations of their effectiveness and impacts is shown to finalize the analysis with a general proposal of recommendations to improve how forests in Venezuela could be sustainably managed in the twenty-first century.

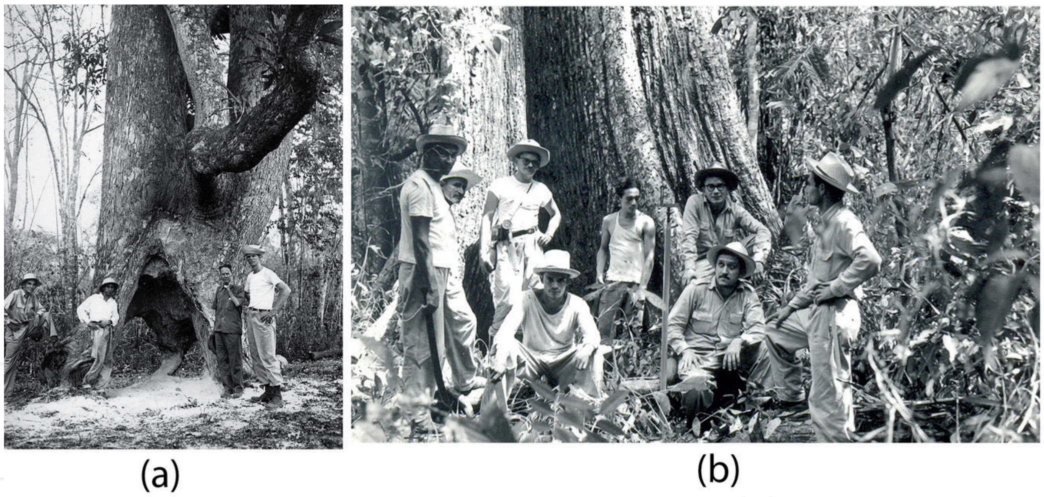

Figure 1.
(a) Early forest exploration in Turén Forest Reserve, Portuguesa state, Venezuela, circa 1965. Photo: Courtesy of Giorgio Tonella; (b) forestry students in early 1970s doing forest inventory in Caparo Forest Reserve, Barinas State. Photo: Lawrence Vincent.

2. A general description of Venezuela's forest cover

Venezuela has a total land area of about 916,445 km^2 with 45–50% of this area covered by different types of forests [25, 26]. The variation in forest cover in Venezuela in the last three decades has followed a similar trend as in many tropical countries with a notorious peak in forest loss during the early 1990s and a slightly declining trend in deforestation rates towards the end of the twentieth century [6]. Over a longer time period, Pacheco et al. [25] found that between 1920 and 2008 Venezuela had, on average, an annual rate of forest loss of 0.30% per year, with a net decrease of 26.4% in the national forest cover for the entire period. It is around the beginning of the 1950s that a sharp increase in deforestation especially in the Western Plains ecoregion occurred, an area that remained as one of the national hotspots of deforestation for a long time [27]. With the somewhat historical unbalanced distribution of Venezuelan population, largely concentrated to the northern portion of the country, from the 36% of forest cover that was estimated to exist in this region by the mid twentieth century, some estimates place this number to as low as 10% in recent decades [24, 28], leaving the vast region of the Guiana Shield to the south of the Orinoco river as the main forested area in the country.

According to recent estimates from the Food and Agriculture Organization of the United Nations (FAO) [29] 287,500 ha, on average, were lost every year in Venezuela between 1990 and 2000 (−0.6% year^{-1}), with a decrease in forest cover during the 2000–2010 decade of about 164,600 ha per year (−0.3% year^{-1}). Updated statistics from public available data in Global Forest Watch (**Figure 2**) (www.globalforestwatch.org) that uses information from the study of Hansen et al. [6] indicates that from 2001 to 2018, Venezuela lost 1.95 million ha of forests (average of 108,333 ha per year), while only gained 191,000 ha of tree cover. In recent years, the spike in deforestation to the southern region in the Guiana Shield has been mostly driven by illegal gold mining [24, 28, 30]. Forests of the Western plains have been mostly cleared for agricultural purposes with current standing forests in this region being located mostly within protected areas and other inaccessible areas [24, 30], while agriculture also appeared to be a main driver of forest loss in the Andean region [31].

In Venezuela, the effects of deforestation and forest degradation in terms of carbon released have not been officially quantified. Lack of standardized methods for monitoring forest cover, the undermining of institutional capacities, and a

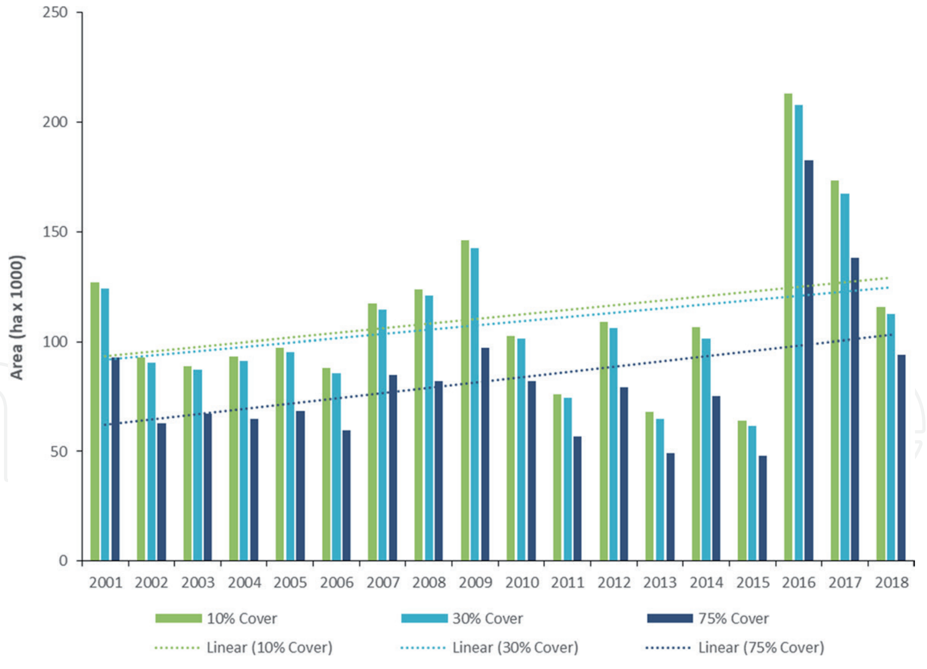

Figure 2.
Total annual forest cover loss (in thousands of hectares per year) in Venezuela for the 2001–2018 period using different proportions of forest canopy cover. Each category includes a linear trend. The figure was built using public data available from the global forest watch (www.globalforestwatch.org).

dramatic decline in professional training, among other factors, helps explaining this situation. However, reviewing the literature in this topic we find few studies that have shown that carbon emissions due to deforestation and forest degradation in Venezuela can be significant. Most of these studies have been conducted at global or pantropical scales and includes a reference for Venezuela. For example, Harris et al. [32] estimated that, between 2000 and 2005, about 9 Tg C year^{-1} (units are 10^{12} grams of carbon per year) were lost due to deforestation in Venezuela. This estimation might have represented between 9 and 28% of national emissions during the last decade [30]. Additionally, Pearson et al. [33] found for the 2005–2010 period that close to 10% of Venezuelan carbon emissions came from forest degradation, including selective logging, wood fuel harvest, fires and grazing as the main factors.

3. Environmental setting and forest-types in Venezuela

Located in the northern portion of South America, slightly above the equator, like much of the tropical region, Venezuela is largely subjected to the influence of the intertropical convergence zone (ITCZ), which affects rainfall patterns and results in the existence of wet and dry seasons in comparison to the cold and warm seasons of higher latitudes. ITCZ's position, structure, and migration influence the ocean-atmosphere and land-atmosphere interactions on a local scale, the circulation of the tropical oceans on a basin scale, and a number of features of the Earth's climate on a global scale [34]. Land form and relief, or the physiographical features in the land in Venezuela, largely expressed by the existence of three major mountain systems and different types of plains and savannas are a major driver of the seasonal and geographical patterns in rainfall in Venezuela at local and regional scales [35]. At least two major gradients in the distribution of precipitation in the country have been described: one from the Northeastern Atlantic to the Andes in the west, and a second one from the Caribbean Sea to the southern Amazonian flatlands. Annual precipitation in Venezuela ranges from less than 400 mm per year in some of the driest portions of the country up to about 4500 mm year^{-1}, which along with its seasonal distribution influence the type and characteristics of the vegetation [35].

From the standpoint of temperature, though much less variable than precipitation, there are important differences at regional scales, mostly as a response of elevation and latitude. With an elevation range from sea level up to close to 5000 m in the peaks of the Andean mountains, temperature varies accordingly [36]. Consequently, a highly diverse vegetation can be found across the country, where up to 18 different types have been identified with lowland evergreen forests largely dominating the nation's landscapes [35]. Other important formations include the cloud forests restricted to a rather narrow elevation gradient in different mountainous areas of the country, palm-dominated and swamp forests in the Orinoco Delta, mangroves, riparian and semi-deciduous forests across much of the savanna and the plains, and different expressions of shrub-like vegetation, grasslands and savannas. In fact, savannas might account for close to 25% of the country's land area with major continuous savannas located in the central Orinoco Plains (*Llanos*) limited by the Andean and Coastal Mountains to the west and north, respectively, and with a second large savanna in the Guiana Plateau (*Gran Sabana*) in the southeast of the country [37].

4. Management of natural forests in Venezuela

4.1 General overview

Venezuela is a tropical country having made one of the longest and continuous effort towards natural forest management (NFM), especially under long-term concession tracts in Tropical America. During the 1970s, the introduction of a forest concession system represented a significant advancement towards NFM at a regional level [24, 38, 39]. The first private concessions were allocated in 1970 and were probably the first known attempt to formally develop long-term management plans in the tropics, including silvicultural practices as a core component. By 1992, almost 3.2 million ha were allocated in more than 30 forest management units (FMUs) and had management plans approved by the national government [40]. In 1995, the national government planned a significant increase in the area under forestry concessions to 10 million ha over 5 years but the country's adoption of new policies and the rising criticism to forest management strategies prevented this from happening [24]. This process led to a significant decline in timber production coming from FMUs. For instance, in 1987 almost 40% of the national round wood production came from natural managed forests [40], while this proportion dropped to only 7% 20 years later [41], shifting the demand for timber products essentially to plantations. Albeit the lack of good quality indicators that has characterized the last decade in terms of forest statistics nationwide, the last available official data from 2018 indicates that only 2.5% of the wood legally consumed in the country came from FMUs in an estimated area of 246,313 ha of forests with formal management plans [42] (**Table 1**).

Several analyses of the forest management model applied in Venezuela have highlighted critical limitations in multiple aspects of the management process, including planning deficiencies, inadequate policies, and overall an insufficient application of sustainable management guidelines during forest operations. While some of the reasons behind this situation may fall outside the specific realms of forest management activities, there is consensus that forest management practices have not contributed to guarantee the long-term permanence of production forests nationwide [40, 43–45]. In a 2011 pantropical assessment led by the International Tropical Timber Organization (ITTO) [8], after almost four decades of NFM in

Description[a]	**Total area (ha)**	**Relative proportion of the total area (%)**
Areas under special administration (n = 382)[b]	67,883,078[c]	—
Natural forest production areas	11,183,202	16.5%
Forest reserves (n = 10)	6,742,047	9.9%
Forest lots (n = 4)	967,093	1.4%
Forest areas under protection (n = 43)	3,473,702	5.2%
Area with approved forest management plans	246,313	2.2%[d]
Area of forest plantations for wood production[e]	557,324	—
Wood production	Volume (m^3)	Relative proportion of total volume (%)
National roundwood production in 2017 (m^3)[e]	496,748	—
National roundwood production outside Forest Reserves in 2017 (m^3)	484,429	97.5%
National roundwood production inside Forest Reserves in 2017 (m^3)	12,319	2.5%

[a]*Modified from the last available official forest statistic report from 2018 [42]. Production forests are classified as category VI as per the International Union of Conservation of Nature (IUCN) guidelines to label protected areas with sustainable use of natural resources.*
[b]*Venezuela has a complex system of natural protected areas (NPAs). These are managed for specific purposes according to special laws and were designated as* "áreas de administración especial" *– ABRAE (Areas under Special Administration), which includes up to 25 different categories including National Parks, Natural monuments, wildlife refuge, among others. More info on Venezuela's protected areas can be found elsewhere (e.g. [24, 28]).*
[c]*Includes overlapping in some protected areas which implies the net area protected is lower.*
[d]*Relative proportion is given based on the total forest production area of 11,183,202 ha.*
[e]*Planted forests are not part of the ABRAE system. This area is based on 2014 data from the official government report [46] submitted to the 2015 Global Forest Resource Assessment program from FAO (http://www.fao.org/forest-resources-assessment/en/). Includes timber production from forest plantations mainly of exotics species such as Caribbean Pine (*Pinus caribaea*), Eucalyptus (*Eucalyptus sp.*) and Teak (*Tectona grandis*).*

Table 1.
General overview of the forest sector in Venezuela.

Venezuela, of the approximately 12 million ha of production forests, a very low proportion of close to 0.03% was considered as being sustainably managed. Moreover, Venezuela is one of the few tropical countries with no certified forest management operations in natural forests. In addition, although a modest progress has been made to establish a more inclusive approach to include local communities in the application and benefits of forest management, the few community-based cases that did exist have resulted in deforestation and degradation of forests [44, 47]. Also, there is no detailed information on the distribution of formal and informal employment in the Venezuelan forestry sector to quantify the social impact generated by this activity. Available data indicates that forestry's contribution to national gross domestic product (GDP) was between 0.5 and 1% in 2005 according to Carrero and Andrade [48], but historical economic trends suggest that this proportion is likely to have considerably reduced in recent years.

In recent years, with the enactment of the new *Forests and Forest Management Law* in 2008, later revised in 2013, a policy shift began with regards to how forest management should be planned and applied in Venezuela. Perhaps, the most novel aspect of this process was the creation in 2010 of a public government-based forest company (*Empresa Nacional Forestal* – National Forest Company). Broadly, the general objective is to promote the "*…sustainable production of forest goods and services, through the planning and management of the forest heritage (…) aimed at promoting the direct participation of local communities and other organizations…*" [49]. In practice, along with government agencies, this company currently oversees the guidelines for developing new forest management plans while slowly substituted the model of private concessions previously in place. At present, the company supervises the management for all production forests in the country and has an active management operation in the Imataca Forest Reserve in Eastern Venezuela. In addition, with the support of FAO, a 5-year project started in 2016 aiming at connecting multiple components (e.g. Reduced Impact Logging, ecological restoration, silviculture, research) to support the development of sustainable forest management guidelines at national scale.[1] The impacts of this initiative are yet to be assessed.

4.2 Historical perspective of silvicultural practices in Venezuela's production forests

With the beginning of major development projects in the second half of the twentieth century, it became clear that a significant area of forests in the country represented, on one hand, environments of high ecological value that had to be preserved and that is how the main foundations of the national system of protected areas (ABRAE) were laid. On the other, some of these areas also showed characteristics that made them important resources for the development of local and regional economies across the country and a significant component for a forest-based productive sector (**Figure 3**).[2]

As in many tropical countries, the beginnings of forestry in Venezuela were influenced by practices extrapolated mostly from experiences applied in European temperate forests [20, 50, 51], especially on topics related to methods to promote the regeneration of the harvested forest. In its early days, the forestry practice in Venezuela was grounded on the conceptual premise of the so-called "experimental management" through two variations upon different intensities in the prescription of silvicultural treatments [52]. This concept of experimental management was based on the need to manage production forests, even under conditions of lack of enough sound scientific information being available. Thus, conducting forest management as an "experiment" implied the existence of a set of guidelines in which there is a research program in place to test various silvicultural alternatives while management is simultaneously applied on a commercial scale [53].

In practice, this approach was later defined as a combination between active and passive management approaches [24, 54], and was influential during the early days of forest policy and management in the Forest Reserves of the Western Plains region (i.e. Ticoporo, Caparo, San Camilo – **Figure 3**). From the theoretical stand point, passive management meant that forests were managed via seemingly very low intensity treatments, on the assumption of natural and spontaneous production without silvicultural treatments, while timber harvest was properly regulated in intensity and environmental impacts [52, 54]. Generally speaking, this approach and its guidelines fit well with sustainable forest management practices that have been promoted based on reduced impact logging (RIL) in many tropical regions [45, 55–57]. However, as has been widely documented (e.g. [23, 24, 43, 44, 58]), its implementation was poorly executed often with negative environmental effects [45, 59, 60]. Secondly, the active management approach was characterized for concentrating intensive practices over relatively small areas. The main objective was the "improvement" of the forest composition mostly through directing the intervention towards species with high commercial value and with low natural abundance or that were completely absent in the forest stand. These practices ranged from relatively low-intensity practices (e.g. assisted natural

[1] http://www.fao.org/venezuela/programas-y-proyectos/lista-de-proyectos/es/

[2] http://sigot.geoportalsb.gob.ve/abrae_web/index.php

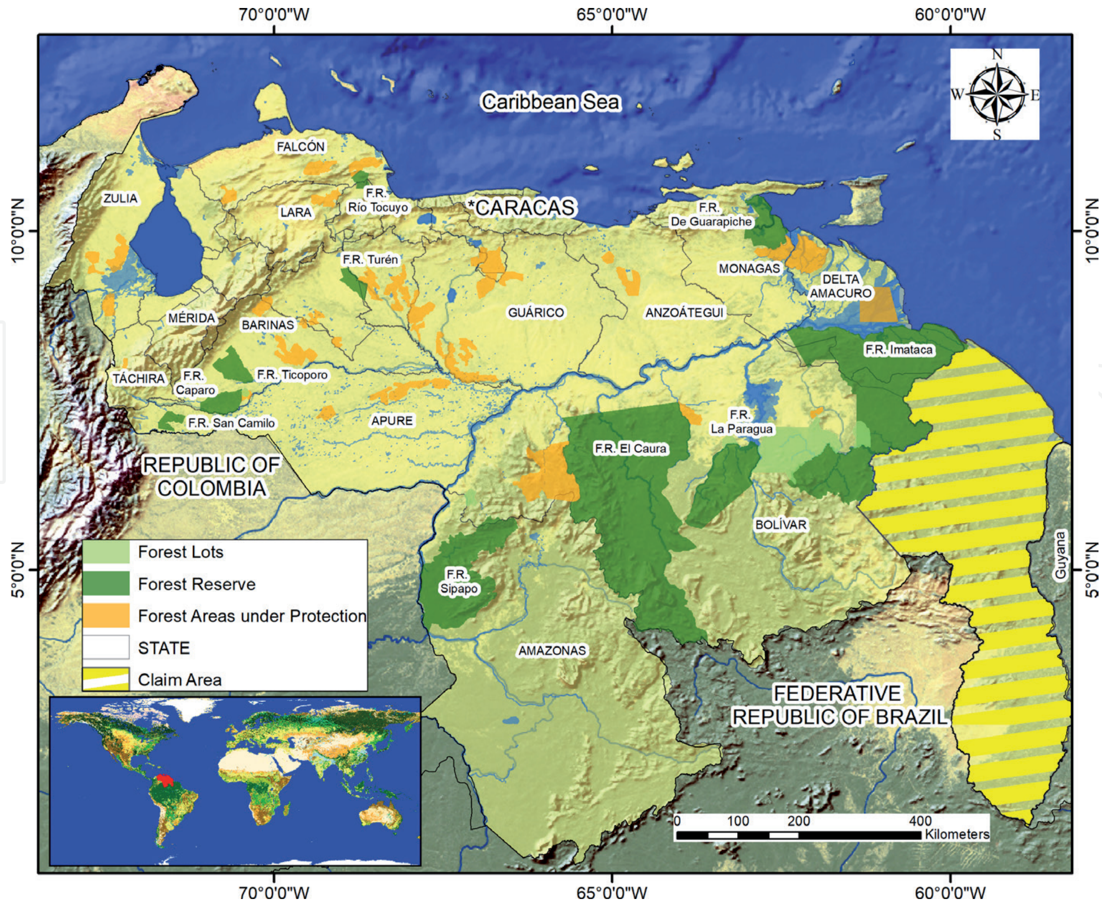

Figure 3.
General distribution of natural production forests in Venezuela. There are legal differences in terms of how forest reserves and lots are administered, but along with the group of 39 Forest areas under protection these are all public-managed areas. In 2018, El Caura *Forest Reserve in the Guiana Shield region, with more than 5 million ha officially became the 44th National Park. Therefore, the total area shown in* ***Table 2*** *excludes this reserve. Map elaborated by Carlos Pacheco based on publicly available data of Venezuela's protected areas.*

regeneration) to more intensive options including a total forest conversion of the selectively logged forest to fast-growing plantations mostly with exotic species [23, 52, 54].

Although no specific rules were set to determine how each approach should be spatially applied, Vincent [61] proposed that the selection and designation of the active management areas should be carried out in each annual compartment or, preferably, by sets of compartments only in the "best" sites (i.e. high productivity, mostly flat with relatively good drained soils). For instance, in the units of the Western Plains where this approach was implemented, active management was executed in close to 10% of the total managed area. The rest of the annual compartment, typically in areas on average of about 2000 ha in 25–30 years cutting cycles, was managed under the passive approach using selective logging upon a group of previously set minimum harvesting diameters (MHDs) for commercial timber species, and the marking and mapping of future commercial trees including those designated for seed production.

As has been documented in different analysis focusing on the tropics (e.g. [21, 22]), silvicultural practices applied in the management of Venezuela's production forests had the fundamental objective of solving the "problem" of a relatively low regeneration of many commercial species and, when possible, to secure sustained volumes of timber within cutting cycles typically of 25–30 years, although 40-year cycles were common in management plans for less productive forests of the Guiana Shield. Many of these practices have been strongly criticized [23, 24, 44, 62], because they frequently ignored the importance of pre-harvest planning operations and the complex ecology and dynamics of tropical forests. Thus, these practices generally neither increased the productivity of the system nor contributed to its sustainability [24].

Within the Forest Management Research Program that began in 1970 in the Caparo Forest Reserve in the Western Plains region, a great deal of effort was put into the understanding of the basic ecology of many forest species with timber value. Looking for effective and efficient systems, not only basic information on the ecology of the species was collected (i.e. phenology, reproduction, dispersal strategies, growth), but also a large number of these potential species was part of multiple experiments in which different planting and management conditions were tested, including open-field trials and enrichment planting in strips with different variations [63]. This is probably one of the most successful aspects of the Research Program, that is producing a baseline of applicable information on the ecology and management of several species in the Western Plains. The use of teak (*Tectona grandis*), an exotic species deserves a special mention as this species optimally acclimatized and resulted in highly productive stands specially in well-drained sites [24]. Teak plantations were often established in open field conditions in deforested areas, but several logging companies used teak after full conversion of logged forests as part of their "active" management plans [23].

Since 1970, and fundamentally since the creation of the Graduate Center for Forest and Environmental Studies (CEFAP) in 1968, a large cumulative experience in tropical silviculture exist, but with a limited application at the operational and commercial scales. Much of this experience is sustained on a research program that included multiple silvicultural trials and experiments that, for reasons analyzed later in this chapter, were not fully applied on a larger scale. As documented by Putz and Ruslandi [56] for the tropical region, between plantation conversion and single-tree selection using RIL, there is a wide variety of silvicultural interventions that tropical foresters can apply but these are rarely used outside of experimental plots. Silvicultural methods such as shelterwoods, group selection and others all have received considerable attention from research, but with a few exceptions, most have not been formally adopted at industrial or commercial scales. In the next sections, some of the most prominent silvicultural practices are described.

4.3 Common silvicultural systems and practices

An extensive literature review was conducted to compile and characterize the most common silvicultural systems used in Venezuela's production forests (**Table 2**). This process included peer-reviewed studies, but most of all was based on the analysis of numerous official reports from the national forest agencies, a review of different management plans from private companies and the results from surveys distributed widely among different stakeholders linked to forest management in Venezuela. The reader will find that the topic of plantation forestry has been purposely ignored (but see [24] for more information), while others such as the use of non-timber forest products (NTFP) and its management lacked of sufficient information to offer a comprehensive analysis. Nevertheless, the following section is by far the most updated review of the history and characteristics of silvicultural practices applied in natural production forests in Venezuela.

4.3.1 Minimum harvest diameters (MHDs)

Probably the oldest and most widespread management system applied in the tropics. After a pre-harvest inventory, a minimum harvest diameter is established to determine mature commercial trees and is the basis of the polycyclic management, a selection approach where, in theory, the objective is to control overexploitation of the forests by harvesting a relatively low number of commercial trees [64]. It is essentially a system based on natural forest production where the only direct intervention is selective harvesting repeated within moderately short cutting cycles [65]. It is a highly selective

Silvicultural system[a]	Reasons for its implementation	Region or area of the country where it is applied or may be applicable and main species used
Direct transformation (clearcutting): system that involves the complete replacement at once of the logged uneven-aged forest by another regular and homogeneous stand, established by even-aged plantation and usually with fast growing species.	• Forests poor in abundance of commercially valuable species (young or mature; logged or unlogged); • As a market need, to produce wood for homogeneous products; • Hardly applied today for environmental reasons.	• Used to be part of the "Active management" scheme applied in the Western Plains by using species such as *Tectona grandis, Gmelina arborea,* and other exotic species; • Applicable in the context of fast-growing plantations.
Enrichment in transversal strips: system of indirect transformation by introducing artificial regeneration *via* strip planting after selective logging mostly to increase commercial stocking of stands. Aims at maintaining the uneven-aged condition of the forest (**Figure 5**).	• Young or mature forests poor in abundance of commercial species; • Rich or relatively rich forests in which commercial species have limited natural regeneration; • Introduction of one or more species at special demand of an ecological, industrial or market nature;	• **Western Plains**: A local version of this system known as "Método Caimital" was developed with positive results. Species used: *Bombacopsis quinata, Cordia apurensis, Handroanthus rosea, Swietenia macrophylla, Cedrela odorata*; • **Guiana Shield**: Mureillo *Erisma uncinatum, Carapa guianensis, Tabebuia serratifolia*; • **Orinoco Delta:** *Euterpe oleracea*;
Modified selection thinning: system that seeks to transform a stand with an irregular structure and heterogeneous composition (e.g. 40–70 species/ha) to a more regular and less diverse stand (e.g. 20–30 species/ha).	• Suitable for the permanent treatment of mature natural forests where most of the species are shade tolerant with good natural regeneration; • System suitable for forests located on land with moderate to strong slopes prone to erosion that also meet the above;	• Applicable to irregular and heterogeneous forests. A large area of forests in the country meet these conditions, but no information is known about its practical application;
Strip clearcuttings: regeneration system applied to natural tropical forests to transform their heterogeneous structure to a more regular and less diverse structure.	• It has been suggested for primary or secondary forests (young or mature) where commercial species are predominately shade-intolerant species with abundant low-weight seeds; • It could be used for relatively regular and homogeneous forests where natural regeneration is high (e.g. Mangroves);	• In the early 1970s this system was applied in a management plan for flooded forests of the Orinoco Delta (Guarapiche Forest Reserve – **Figure 3**) dominated mainly by *Rhizophora mangle.*
Enhanced natural regeneration in strips: indirect transformation system to promote the establishment of the natural regeneration of valuable species (usually scarce) in previously open strips.	• Mature forests relatively rich in commercial species with limited natural regeneration to ensure long-term production;	• Applied at research scale in Caparo Forest Reserve ("Metodo Limba-Caparo) in the Western Plains with promising results for two important commercial species: *Cedrela odorata* and *Handroanthus rosea.*

Silvicultural system[a]	Reasons for its implementation	Region or area of the country where it is applied or may be applicable and main species used
Minimum Harvest Diameter (MHDs): the most widely applied system and is based only in natural forest production and is considered a "passive" approach (see Section 4.3.1 for further details).	• Its application is justified on the basis of the maintenance of enough crop trees to ensure a sustainable harvest under polycyclic schemes; • Typically accompanied by intermediate treatments to reduce competition on crop tress.	• Widely applied in the forest management of the Western Plains and today in the Guiana Shield. • If logging is the unique treatment, it is often not considered a formal silvicultural system.

Table adapted from [65] with inputs from [64, 66].
[a]This grouping of silvicultural systems is presented based on practical experiences, results of applied research or based on the analysis of the ecological conditions of forests that would make a particular system applicable. In all cases, wood production is the overall major objective.

Table 2.
Silvicultural systems applied or potentially applicable in Venezuela's production forests.

management system in terms of the spectrum of commercial species and the relatively low number of trees logged that is common in many tropical managed forests (1–20 trees per ha -[67]). Under these conditions, it was expected that with a proper planning with minimum standards for cutting and transportation activities, the impacts on the forest stand would be low and facilitate a consistent flow of timber in the next cutting cycles [20, 51, 64]. This system was the fundamental basis of the first forest harvesting permits granted in Venezuela more than 40 years ago [23], and remained relatively unaltered even at times when research evidences made clear that major modifications to this approach were urgent in support of long-term sustainable management [44, 68–70].

Most frequently, these MHDs are set by national authorities, and depending on the species groups and their commercial value, values are typically within the range of 30 up to 70 cm or more in diameter at breast height (DBH) [64]. However, these limits are mostly set to accommodate processing technologies and market demands, rather than the biology and persistence of the harvested species, limiting the possibility to provide ecologically sustainable forest management [71]. Remarkably high numbers of species that are common in many tropical differ in growth requirements, growth rates, marketability, ecological roles and other relevant traits. Thus, simple silvicultural guidelines such as fixed MHDs or cutting cycles are unlikely to be satisfactory [13]. In Venezuela's case, the lack of sound ecological information on growth patterns of commercial species, density and structure, along with limited long-term information has been highlighted as a major limitation [23, 24, 69, 72]. A relatively new official regulation related to MHDs enacted in 2009 [73] aimed at solving, at least partly, the lack of data on species growth by expanding the information on the number of species with MHDs. However, if no improvement is made to the overall process of forest planning, including the urgent implementation of reduced impact logging, and a rethinking of cutting cycles the negative perception towards timber harvest is likely to persist (**Figure 4**).

4.3.2 Post-logging silvicultural treatments

In many tropical managed forests, a group of standard practices are often applied after selective logging to reduce competition for future harvestable trees. These intermediate treatments might include *refining*, that is, the elimination of undesirable tree species or sick or damaged material, to the extent only that the

Figure 4.
General conditions of current logging practices in Venezuela's production forests in the Guiana shield. Unplanned road systems are major drivers of forest degradation. By using a RIL approach, the extension and size of logging roads is considerably lower compared to conventional harvesting which ultimately reduces the environmental impacts [55]. Photo: Emilio Vilanova.

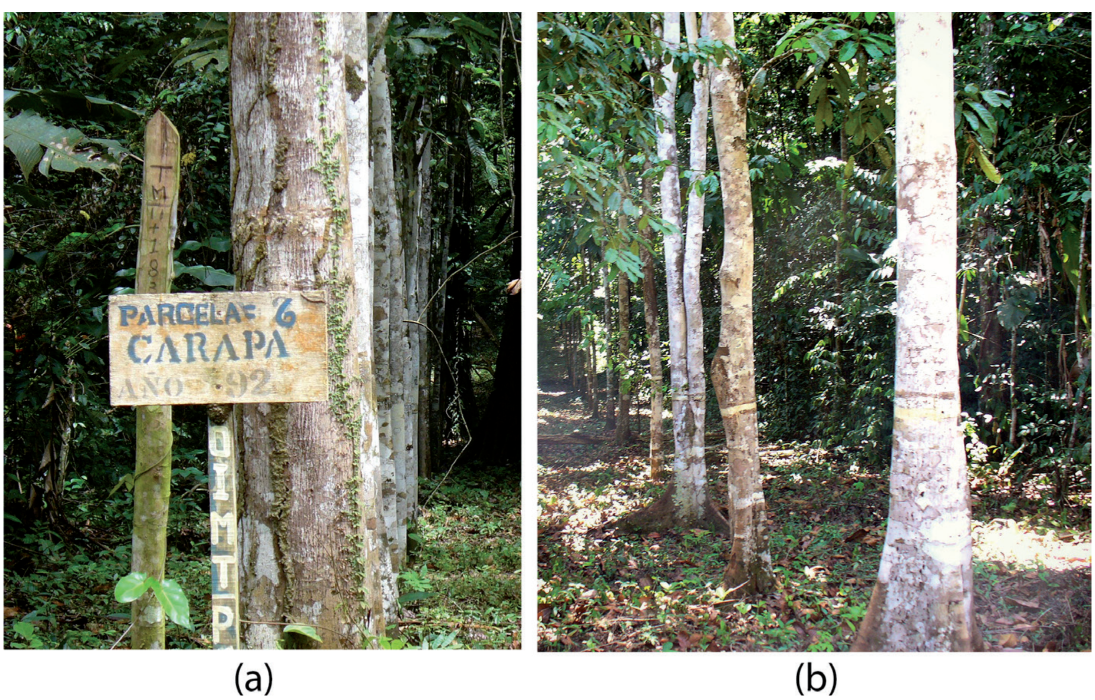

Figure 5.
Two examples of enrichment planting in strips in the Venezuelan Guiana shield. In less than 10% of the logged stands, strips of 5–6 m in width separated by 40–50 m are opened via clearcutting to establish artificial regeneration of commercial species. In these two examples, the main species planted is Carapa guianensis *(Meliaceae). Photos: Emilio Vilanova.*

structural stability of the stand is not weakened [64]. Also, *liberation* or the favoring of all valuable individuals (juveniles, candidates) through the elimination of competitors can be part of the silvicultural prescription. In practice, these activities can comprise cutting of vines and/or climbers – even before logging as a step for RIL – and the elimination of undesirable trees that might delay the establishment of regeneration of commercial species after harvest [66]. It is expected that with a periodical repetition and adequate monitoring, these practices would serve as complementary practices within the MHDs system. This approach has been known in Venezuela as *Management of the remnant stand* and was used mostly to improve growing conditions of the advanced regeneration of commercial species with diameters above 15 cm [74]. In some cases, to reduce multiple re-entries, girdling and occasionally poisoning of undesired trees with an arboricide were used [52]. However, although there are positive examples with regards to improving stand growth [e.g. 22], in the few cases where information was available from management plans in Venezuela, girdling often did not helped killing all selected trees and the use of chemicals in highly sensitive ecosystems was later discouraged and ultimately banned by government agencies overseeing these operations.

4.3.3 Natural and artificial regeneration enhancement systems

Results from early assessments that were carried out as part of the Forest Management Research Program of the Western Plains, and to some extent in the Guiana Shield region as well, led to the conclusion that in order to secure a sustained production of timber over multiple cutting cycles, natural regeneration of commercial species was limited [52]. It was suggested that this was a direct response of the predominately shade-intolerant condition of most commercial species, its reproductive biology and other limiting factors such as dispersion and germination in both undisturbed and logged stands, which drove the plan for practices aiming at the enhancement or improvement of regeneration [63]. Consequently, several alternatives were tested, from "simple" interventions such as the creation of small gaps or canopy openings to promote rapid colonization of natural regeneration of commercial species, to more intensive practices such as strip clearcutting, prescribed burning, and planting (see **Table 2**). For example, a modified version of the well-known uneven-aged system Shelterwood [56, 66] was applied in an experimental setting in the Western Plains and was described as a "promising" system [23, 52, 70] but the lack of an adequate financial analysis prevented this system for its potential application at the management scale [70].

Another variant of enrichment planting where the intensity of intervention was higher was the method known as "Limba-Caparo Method" [52, 63] and was considered as one of the few successful experiences for this type of system [70]. It is a type of plantation in strips where, once the commercial species are extracted via selective logging, often highly abundant palms, lianas and other minor competing vegetation with a diameter below 10 cm are removed to later facilitate the use of prescribed burning to facilitate establishment of natural regeneration. A synthesis of enrichment planting experiments indicates that this method was successful in promoting regeneration of an important local species (i.e. *Handroanthus rosea*) with rapid growth, high survival and adaptability to various environmental conditions, particularly in some flooded zones where growth of other valuable species is limited [63]. While this system was labeled as promising, the complexity behind the initial treatments, along with concerns for the use of fire in semi-dry forests and the potential impacts on biodiversity were major limitations for the application at larger scales.

Although several variants of this system were tested, it was the simpler versions of enrichment practices with artificial regeneration the ones that were predominately adopted at industrial scales. In fact, these ultimately became a requirement for the approval of many forest management plans in the country's production forests. It was considered a relatively simple approach yet with high environmental impacts [75] especially in highly sensitive ecosystems such as the Guiana Shield. Between 1987 and 2010 a total of 41,460 ha of enrichment strips were planted in Venezuela's production forests [76]. Furthermore, poor adaptability of many of the species used and lack of a solid monitoring plan led to very low growth rates and low survival [62] (**Table 3**). From the commercial standpoint, one of the few economic analyses conducted in Venezuela about the

Species	Survival (%)	Height growth (m/year)	Diameter growth (cm/year)
Jacaranda copaia	40.0	1.1	1.36
Parkia nitida	79.4	0.8	1.23
Loxopterygium sagotii	66.2	0.9	1.16
Ceiba pentandra	42.2	0.5	1.13
Simarouba amara	75.6	1.1	1.07
Spondias mombin	97.5	1.0	0.98
Cordia spp.	62.3	0.6	0.92
Terminalia amazonia	64.8	0.5	0.89
Swietenia macrophylla	54.7	0.5	0.84
Enterolobium cyclocarpum	26.0	0.4	0.82
Cedrela odorata	62.2	0.6	0.75
Handroanthus rosea	29.0	0.4	0.69
Gmelina arborea	100.0	1.0	0.68
Pera glabrata	42.6	0.8	0.65
Carapa guianensis	74.3	0.6	0.64
Caesalpinia coriaria	77.1	0.3	0.62
Handroanthus serratifolia	83.3	0.5	0.62
Anacardium giganteum	93.5	0.8	0.62
Hymenaea courbaril	84.6	0.6	0.58
Erisma uncinatum	47.2	0.5	0.54
Cattostema comune	43.0	0.5	0.48
Manilkara bidentata	69.4	0.4	0.48
Diplotropis purpurea	29.2	0.3	—
Mouriri huberi	12.5	0.1	—
Anacardium excelsum	33.3	0.2	—
Platymiscium pinnatum	—	0.8	—
Samanea saman	41.1	0.3	—
Tectona grandis	25.0	0.1	—
Peltogyne porphyrocardia	63.1	0.4	—
Mean	**66.7**	**0.60**	**0.80**

Table adapted from [13].

Table 3.
Results from multiple assessments of enrichment planting practices applied in managed forests of the Venezuelan Guiana shield region.

use of enrichment planting indicate that, even in scenarios of relatively high prices for timber, the net benefit–cost ratio (BCR) was very low, amidst the initial high costs of establishment and long cutting cycles needed to obtain reasonable wood volumes [74]. For many of these reasons, this practice has been officially abandoned, at least as a requirement for the approval of management plans since 2010. Nevertheless, as has been documented in other tropical regions, in recent years there has been a reawakening interest for the use of enrichment planting in a context of restoration of degraded and secondary forests [13, 63, 77] where this approach seems more feasible.

5. Overcoming the barriers and limitations of silviculture

In this chapter we have tried to synthetize some of the most important aspects of the silvicultural practices applied in Venezuela's natural production forests. Details on past and current practices and their impacts were offered with the idea of facilitating a much needed discussion about the compatibility of silviculture for enhanced timber production with the maintenance of other ecosystem services offered by tropical managed forests [18, 22]. In doing so, we made a thorough review of the available literature, most of which came in the form of gray literature produced by government agencies, academic institutions, forest companies and other sources. This last section aims at identifying relevant lessons learned over the course of 40+ years including a set of major recommendations to improve how silviculture could be applied in natural tropical forests in Venezuela.

5.1 The role of scientific research

The main product of more than four decades of silvicultural experience in Venezuela is perhaps the existence of an enormous amount of information available on the main silvicultural practices applied or with potential to be applied to natural forests in the country. Most, if not all, this information came from a pioneer effort starting during the early 1970s in support of the idea that natural tropical forests can be sustainably managed and reduce the risk of deforestation. Important elements on the basic ecology of commercial tree species and how these could be managed occupied a major proportion of this process. Yet, the capacity to fully influence forest management at industrial scales was limited.

Adequate communication has proven to be an urgent capacity that many scientists are acquiring as a matter to (successfully) transmit sound scientific information to the public and decision makers [78]. Despite this, a weak connection between science, policy and decision-making has been cited multiple times as a major limitation for sustainable management of tropical forests [13]. In terms of silviculture for instance, a limited adoption of some of the recommended systems at commercial scales can be attributed to some extent to failures of researchers to appropriately design their studies, or because some of these interventions are cost prohibitive and these implications are not properly considered during research, which ultimately reflects a failure to communicate their results effectively [13]. This requires an effort to invest resources in training and capacity development into novel approaches to further improve how scientists disseminate the results of research. This is particularly relevant in the context of the current complex political and economic crisis in Venezuela where research institutions are being disproportionally affected [79].

Another element linked to how silvicultural research is conducted has to do with the need to adapt to the recent shifts in the conditions and requirements for sustainable use of tropical forests. While timber production can - and should -continue being an objective in the management of production forests, the contribution of other elements such as non-timber forest products or ecosystems services including biodiversity conservation and mitigation of climate change must be part of any research agenda for a twenty-first century silviculture. Furthermore, research on topics beyond logging practices is needed to assure both sustainability and that these other values are not underestimated and unnecessarily compromised where timber production is the principal goal of management [13].

5.2 A need for better monitoring

Appropriate technical procedures for monitoring the process of forest management are critical to decision-making. While this goes beyond silvicultural practices, many of the treatments applied in Venezuela's production forests were insufficiently monitored or never monitored at all. The implications of this might be two-fold. On one hand, the absence of standard guidelines for monitoring could have severely limited the real potential for some of the most promising practices (e.g. "Caimital" enrichment system) or, on the other, could have helped in abandoning more quickly those that clearly showed negative results (e.g. forest conversion of logged forests). For a country with a silvicultural research program that started more than four decades ago, and with one of the oldest forestry schools in the tropics, it is remarkable that not a single formal process of forest monitoring has been part of the national forest policy. Examples such as the guidelines developed by the International Tropical Timber Organization (ITTO) [80] have been largely underestimated and can serve as a guide for the adoption of criteria and indicators for monitoring forest management including silvicultural practices.

5.3 Amplifying the objectives of silviculture

The need for a different perspective in silvicultural practices was previously addressed in item 5.1 when analyzing the role of scientific research. However, from the standpoint of policy and decision making, it is important to reinforce the idea that if we want to preserve the vast amount of production forests still available, a new vision of silviculture should be adopted. In many tropical regions, logged forests often retain substantial biodiversity, carbon and timber stocks [18]. Thus, increasing the overall value of production forests in the tropics compared to other more intensive land-uses often highly profitable and linked to deforestation [81] is not only a matter of applying reduced impact logging practices – although urgently needed in Venezuela [45]. It also requires major modifications to integrate the great diversity of products that can be obtained from these ecosystems. In this process, at least in the short and medium terms, updating forest education curriculum programs at different levels and directly connected to applied forestry practices can contribute to the formulation of new strategies for diversifying forest management [82]. Assessments of non-timber forest products to design silvicultural practices [83], use of silviculture for ecological restoration [64], or simply improving harvesting practices as a tool to mitigate climate change and conserve biological diversity [84] are all important steps towards a more inclusive practice of forest management.

6. Final remarks and conclusions

Venezuela has now more than 40 years of experience in the development of forestry practices for the country's forests, plantations and other forest lands, a long-term valued effort for the forestry sector in the tropical region and in Latin

America. The development of a conceptual and practical model for the management of the country's natural forests and the establishment of a significant area of forest plantations are all remarkable actions. However, available information reviewed here clearly indicates that the objectives originally set out primarily to increase forest productivity were not achieved. In addition, the negative environmental effects of timber harvest have been significant, and the overall role of management as has been applied up to now in the country's production forests should be questioned. While multiple drivers interacted, the total loss of most production forests in the Western Plains, the reduction in recent years of the area with formal management plans, and the limited participation of local communities in the practice and benefits of forest management, among others, indicate the urgent need to reformulate how Venezuelan forests have been managed.

While further analysis is required for additional technical details about the characteristics of the silvicultural practices applied in Venezuela, the main goal of this chapter was, first of all, to provide an historical perspective for one of the countries with the richest, yet largely unknown, silvicultural experience in the tropical region. Secondly, understanding the historical reasons that led to the design and implementation of the different forest management strategies in much of the country's forests, helps identifying the benefits, advantages and the limitations to improve the practice of silviculture in Venezuela's natural production forests. Despite the loss of some of the most productive ecosystems in the Western Plains, the existence of an important resource base for forest production, especially in the Guiana Shield region from which a large proportion of rural populations depends, represents a great opportunity for improving forest management based on principles of multiple use of forests.

Finally, the institutional and political changes that started in the early 2000s have undoubtedly impacted how forests resources have been managed in the last 20 years. From the concession model in the late 1990s, dominated by private companies often poorly managed with a very low degree of compliance to sustainable management guidelines, management of natural production forests slowly shifted towards a heavily government-dominated system. This transition included a general revision of how silviculture should be applied but the expected outcomes for a new and more sustainable model are far from being clear. Furthermore, the ongoing political and socioeconomic crisis in the country is putting at risk the long-term stability of many natural production forests. We firmly believe that these changes, if widely discussed and agreed upon by all actors involved in forest management, can facilitate the adoption of better practices and thus increase the strategic value of forests as tools for the sustainable development of the country.

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Conflict of interest

The author declares no conflict of interest.

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References

[1] FAO. The State of the World's Forests. Rome: FAO; 2018. p. 118

[2] Beer C, Reichstein M, Tomelleri E, Ciais P, Jung M, Carvalhais N, et al. Terrestrial gross carbon dioxide uptake: Global distribution and covariation with climate. Science. 2010;**329**(5993):834-838

[3] Mitchard ETA. The tropical forest carbon cycle and climate change. Nature. 2018;**559**(7715):527-534. DOI: 10.1038/s41586-018-0300-2

[4] Le QC, Andrew RM, Canadell JG, Sitch S, Korsbakken JI, Peters GP, et al. Global carbon budget. Earth System Science Data. 2016;**2016**:605-649

[5] FAO-UNEP. The State of the World's Forests 2020 [Internet]. Rome: Food and Agriculture Organization of the United Nations; 2020. p. 139. Available from: http://www.fao.org/documents/card/en/c/ca8642en

[6] Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, et al. High-resolution global maps of 21st-century forest cover change. Science. 2013;**342**(6160):850-853

[7] Baccini A, Walker W, Carvalho L, Farina M, Houghton RA. Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science. 2017;**358**(6360):230-234

[8] Blaser J, Sarre A, Poore D, Johnson S. Status of Tropical Forest Management 2011. Yokohama, Japan: ITTO Technical Series; 2011

[9] Petrokofsky G, Sist P, Blanc L, Doucet JL, Finegan B, Gourlet-Fleury S, et al. Comparative effectiveness of silvicultural interventions for increasing timber production and sustaining conservation values in natural tropical production forests. A systematic review protocol. Environmental Evidence. 2015;**4**(1):1-7

[10] Sist P, Rutishauser E, Peña-Claros M, Shenkin A, Hérault B, Blanc L, et al. The tropical managed forests observatory: A research network addressing the future of tropical logged forests. Applied Vegetation Science. 2015;**18**(1):171-174

[11] Piponiot C, Rutishauser E, Derroire G, Putz FE, Sist P, West TAP, et al. Optimal strategies for ecosystem services provision in Amazonian production forests. Environmental Research Letters. 2019;**14**(6):64014. DOI: 10.1088/1748-9326/ab195e

[12] Piponiot C, Rödig E, Putz FE, Rutishauser E, Sist P, Ascarrunz N, et al. Can timber provision from Amazonian natural forests be sustainable? Environmental Research Letters. 2019;**14**(12):124090. DOI: 10.1088/1748-9326/ab5eb1

[13] Putz FE, Romero C. Futures of tropical production forests. In: Futures of Tropical Production Forests. Occasional Paper 143. Bogor, Indonesia: Center for International Forestry Research (CIFOR); 2015. p. 51. DOI: 10.17528/cifor/005766

[14] Hérault B, Piponiot C. Key drivers of ecosystem recovery after disturbance in a neotropical forest: Long-term lessons from the Paracou experiment, French Guiana. Forest Ecosystems. 2018;**5**(1):1-15

[15] Rutishauser E, Hérault B, Baraloto C, Blanc L, Descroix L, Sotta ED, et al. Rapid tree carbon stock recovery in managed Amazonian forests. Current Biology. 2015;**25**(18): R787-R788. DOI: 10.1016/j.cub.2015.07.034

[16] Puettmann KJ, Coates KD, Messier C. A Critique of Silviculture: Managing for Complexity. Washington D.C: Island Press; 2009. p. 207

[17] Fahey RT, Alveshere BC, Burton JI, D'Amato AW, Dickinson YL, Keeton WS, et al. Shifting conceptions of complexity in forest management and silviculture. Forest Ecology and Management. 2018;**421**(January):59-71

[18] Putz FE, Zuidema PA, Synnott T, Peña-Claros M, Pinard MA, Sheil D, et al. Sustaining conservation values in selectively logged tropical forests: The attained and the attainable. Conservation Letters. 2012;**5**(4):296-303

[19] Yguel B, Piponiot C, Mirabel A, Dourdain A, Hérault B, Gourlet-Fleury S, et al. Beyond species richness and biomass: Impact of selective logging and silvicultural treatments on the functional composition of a neotropical forest. Forest Ecology and Management. 2019;**433**(November 2018):528-534. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0378112718314944

[20] Dawkins H, Phillip M. Tropical Moist Forest Silviculture and Management: A History of Successes and Failures. Cambridge, UK: University Press; 1998. p. 351

[21] Weber M. Review: New aspects in tropical Silviculture. In: Gunter S, Weber M, Stimm B, Mosandl R, editors. Silviculture in the Tropics. Berlin Heidelberg: Springer-Verlag; 2011. pp. 63-89

[22] Finegan B. 21st century viewpoint on tropical Silviculture. In: Pancel L, Kohl M, editors. Tropical Forestry Handbook. 2nd ed. Berlin: Springer-Verlag Berlin Heidelberg; 2016. pp. 1605-1638

[23] Kammesheidt L, Lezama AT, Franco W, Plonczak M. History of logging and silvicultural treatments in the western Venezuelan plain forests and the prospect for sustainable forest management. Forest Ecology and Management. 2001;**148**(1-3):1-20

[24] Torres-lezama A, Ramírez-Angulo H, Vilanova E, Rodrigo B. Forest resources in Venezuela: Current status and prospects for sustainable management. Bois et Forets des Tropiques. 2008;**295**(295):21-34

[25] Pacheco C, Aguado I, Mollicone D. Las causas de la deforestacion en venezuela: un estudio restrospectivo. BioLlania. 2011;**5110**(10):281-292

[26] FAO. State of the World's Forests 2016. Forests and agriculture: land-use challenges and opportunities [Internet]. Vol. 45, State of the World'S Forests Forests and Agriculture: Land-Use Challenges and Opportunities. 2016. pp. 1-107. Available from: http://ccafs.cgiar.org/news/press-releases/agriculture-and-food-production-contribute-29-percent-global-greenhouse-gas

[27] Pacheco CE, Aguado MI, Mollicone D. Identification and characterization of deforestation hot spots in Venezuela using MODIS satellite images. Acta Amazonica. 2014;**44**(2):185-196. Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0044-59672014000200004&lng=en&tlng=en

[28] Bevilacqua M, Cárdenas L, Flores AL, Hernández L, Lares E, Mansutti A, et al. The State of Venezuela's Forests. A Case Study of the Guayana Region. A world Resources Institute Report. Caracas, Venezuela: Fundación Polar; 2002. p. 132. Available from: http://pdf.wri.org/gfw_venezuela.pdf

[29] Food and Agriculture Organization of the United Nations, FAO. Global Forest resources assessment 2015.

Desk reference. Desk Reference. 2015;**2005**:244

[30] Pacheco-angulo C, Vilanova E, Aguado I, Monjardin S. Carbon emissions from deforestation and degradation in a forest reserve in Venezuela between 1990 and 2015. Forests. 2017;**8**:291. DOI: 10.3390/f8080291

[31] Aide TM, Grau HR, Graesser J, Andrade-Nuñez MJ, Aráoz E, Barros AP, et al. Woody vegetation dynamics in the tropical and subtropical Andes from 2001 to 2014: Satellite image interpretation and expert validation. Global Change Biology. 2019;**25**(6):2112-2126. DOI: 10.1111/gcb.14618

[32] Harris NL, Brown S, Hagen SC, Saatchi SS, Petrova S, Salas W, et al. Baseline map of carbon emissions from deforestation in tropical regions. Science. 2012;**336**(6088):1573-1576

[33] Pearson TRH, Brown S, Murray L, Sidman G. Greenhouse gas emissions from tropical forest degradation: An underestimated source. Carbon Balance and Management. 2017;**12**(1):3. DOI: 10.1186/s13021-017-0072-2

[34] Waliser DE, Jiang X. In: North GR, Pyle J, editors. Tropical Meteorology and Climate | Intertropical Convergence Zone. Oxford: Academic Press; 2015. pp. 121-131. Available from: http://www.sciencedirect.com/science/article/pii/B9780123822253004175

[35] Huber O, Oliveira-Miranda M. Ambientes terrestres de Venezuela. In: Rodríguez J, Rojas-Suárez F, Hernández D, editors. Libro Rojo de los Ecosistemas Terrestres de Venezuela. Caracas: PROVITA, Shell Venezuela, Lenovo Venezuela; 2010. pp. 29-89

[36] Arismendi J. Presentación geográfica de las formas de relieve. In: Fundación Empresas Polar. Caracas, Venezuela: GeoVenezuela, Tomo 2; 2007. pp. 128-183

[37] Baruch Z. Vegetation–environment relationships and classification of the seasonal savannas in Venezuela. Flora - Morphology Distribution Functional Ecology of Plants. 2005;**200**(1):49-64. Available from: http://www.sciencedirect.com/science/article/pii/S036725300500006X

[38] Dourojeanni M. El futuro de los bosques de América Latina. In: Keipi K, editor. Políticas forestales en América Latina. Washington D.C.: Banco Interamericano de Desarrollo (BID); 2000. pp. 89-104

[39] Kammesheidt L. Some autecological characteristics of early to late successional tree species in Venezuela. Acta Oecologica. 2000;**21**(1):37-48. Available from: https://www.sciencedirect.com/science/article/pii/S1146609X00001089

[40] Centeno J. Estrategia para el desarrollo forestal en Venezuela. Caracas, Venezuela: Fondo Nacional de Investigación Forestal; 1995. p. 83

[41] del Ambiente M. Anuario de Estadísticas Forestales 2007. Caracas, Venezuela: Ministerio del Ambiente-Venezuela; 2008

[42] MINEC. Anuario Estadísticas Forestales 2017. Caracas, Venezuela: Ministerio del Poder Popular para el Ambiente y el Ecosocialismo-Venezuela; 2018

[43] Aicher C. Los efectos del conocimiento forestal en la política forestal venezolana. In: SEFUT Working Paper No. 14. Freiburg, Germany: Albert-Ludwigs-Universität Freiburg; 2005. p. 39. Available from: https://freidok.uni-freiburg.de/fedora/objects/freidok:1747/datastreams/FILE1/content

[44] Lozada JR. Situación actual y perspectivas del manejo de recursos

forestales en Venezuela. Revista Forestal Venezolana. 2007;**51**(2):195-218

[45] Vilanova E, Ramírez-Angulo H, Ramírez G, Torres-Lezama A. Compliance with sustainable forest management guidelines in three timber concessions in the Venezuelan Guayana: Analysis and implications. Forest Policy and Economics. 2012;**17**:3-12

[46] Food and Agriculture Organization of the United Nations. Evaluación de los Recursos Forestales Mundiales 2015 - Informe Nacional Venezuela [Internet]. 2014. Available from: http://www.fao.org/3/a-az372s.pdf

[47] Rojas-López J. Regulación ambiental y colonización agraria en reservas de bosque. El drama de Ticoporo, estado Barinas-Venezuela. Revista Geográfica Venezolana. 2007;**48**(1):129-141

[48] Carrero GO, Andrade V. La contribución de las actividades del sector primario y secundario de la cadena forestal al PIB de Venezuela en los últimos 50 años y su relación con algunas variables macroeconómicas. Revista Forestal Venezolana. 2005;**49**(1):39-47

[49] de Venezuela RB. Ley de Bosques. Caracas, Venezuela: Asamblea Nacional; 2013. Gaceta Oficial No. 403.780

[50] Dawkins H. The Management of Natural Tropical High-Forest with Special Reference to Uganda. Oxford, UK: Imperial Forestry Institute, University of Oxford, Oxford, UK; 1958

[51] Lamprecht H. Silvicultura en los trópicos: Los ecosistemas forestales en los bosques tropicales y sus especies arbóreas -posibilidades y métodos para un aprovechamiento sostenido. Germany: Eschborn; 1990

[52] Vincent L, Rodriguez-Poveda L, Noguera O, Arends E, Lozada J. Evolución histórica, y desarrollos recientes de la silvicultura del Bosque Tropical Alto en América. In: Informe del Seminario-Taller "Experiencias prácticas y prioridades de Investigación en Silvicultura de Bosques Naturales en América Tropical." Pucallpa, Perú. Venezuela: Centro de Estudios Forestales y Ambientales de Postgrado; 1996

[53] Vincent L. A tropical forest minimum impact management system. Bois et Forets des Tropiques. 2004;**279**(1):88-90

[54] Plonczak M, Rodriguez-Poveda L. Conceptos, fundamentos y métodos del manejo forestal en Venezuela. Revista Forestal Venezolana. 2002;**46**(1):83-90

[55] Bicknell JE, Struebig MJ, Davies ZG. Reconciling timber extraction with biodiversity conservation in tropical forests using reduced-impact logging. Journal of Applied Ecology. 2015;**52**(2):379-388

[56] Putz FE. Ruslandi. Intensification of tropical silviculture. Journal of Tropical Forest Science. 2015;**27**(3):285-288

[57] Huth A, Kammesheidt L, Koehler P. Sustainable timber harvesting in Venezuela: A modelling approach. Journal of Applied Ecology. 2001;**38**(4):756-770

[58] Noguera LO, Pacheco AC, Plonczak Ratschiller M, Jeréz RM, Moret A, Quevedo RA, et al. Planificación de la explotación de impacto reducido como base para un manejo forestal sustentable en un sector de la Guayana venezolana. Rev For Venez. 2008;**51**(1):67-78

[59] Lozada JR, Arends E. Impactos ambientales del aprovechamiento forestal en Venezuela. Interciencia. 1998;**23**(2):74-83

[60] Vilanova-Torre E, Ramírez-Angulo H, Torres-Lezama A. Carbon storage in the aboveground biomass as indicator of logging impact in the Imataca Forest reserve, Venezuela. Interciencia. 2010;**35**(9):659-665

[61] Vincent L. Métodos cuantitativos de planificación silvicultural. Mérida, Venezuela: Centro de Estudios Forestales y Ambientales de Postgrado, Universidad de Los Andes; 1993. p. 237

[62] Lozada JR, Moreno J, Suescun R. Plantaciones de enriquecimiento. Experiencias en 4 unidades de manejo forestal de la Guayana venezolana. Interciencia. 2003;**28**(10):568-575

[63] Jerez-Rico M, Quevedo A, Moret AY, Plonczak M, Garay V, Silva JD, et al. Regeneración natural inducida y plantaciones forestales con especies nativas: potencial y limitaciones para la recuperación de bosques tropicales degradados en los llanos occidentales de Venezuela. In: Herrera F, Herrera I, editors. La Restauración Ecológica en Venezuela: Fundamentos y experiencias. Caracas, Venezuela: Instituto Venezolano de Investigaciones Científicas (IVIC); 2011. pp. 35-60

[64] Pancel L. Technical orientation of Silviculture in the tropics. In: Pancel L, Köhl M, editors. Tropical Forestry Handbook. 2nd ed. Berlin, Germany: Springer-Verlag Berlin Heidelberg; 2016. pp. 1639-1691

[65] Finol H. Sistemas silviculturales aplicados y aplicables al manejo de bosques tropicales en Venezuela. Venezuela: Mérida; 1983

[66] Ashton MS, Kelty M. The Practice of Silviculture: Applied Forest Ecology. 10th ed. Oxford, UK: John Wiley & Sons, Ltd; 2018. p. 776

[67] Burivalova Z, Şekercioğlu ÇH, Koh LP. Thresholds of logging intensity to maintain tropical forest biodiversity. Current Biology. 2014;**24**(16):1893-1898

[68] Ramirez-Angulo H, Ablan M, Torres-Lezama A, Acevedo MF. Simulación de la dinámica de un bosque tropical en los llanos occidentales de venezuela. Interciencia. 2006;**31**(2):101-109

[69] D'Jesus A, Torres Lezama A, Ramírez Angulo H. Consecuencias de la explotación maderera sobre el crecimiento y el rendimiento sostenible de un bosque húmedo deciduo en los llanos occidentales de Venezuela. Revista Forestal Venezolana. 2001;**45**:133-143

[70] Torres-Lezama A. La cuidada movilización de los recursos forestales. La industria forestal. In: Pantin A, Reyes A, Quintero A, Montero R, Cunill-Grau P, Márquez A, et al., editors. Geo Venezuela. Caracas, Venezuela: Fundación Empresas Polar; 2007. pp. 382-439

[71] Sist P, Fimbel R, Sheil D, Nasi R, Chevallier MH. Towards sustainable management of mixed dipterocarp forests of Southeast Asia: Moving beyond minimum diameter cutting limits. Environmental Conservation. 2003;**30**(4):364-374

[72] Kammesheidt L. Stand structure and spatial pattern of commercial species in logged and unlogged Venezuelan forest. Forest Ecology and Management. 1998;**109**(1-3):163-174

[73] de Venezuela RB. Norma técnica forestal sobre diámetros mínimos de cortabilidad. Caracas, Venezuela: Asamblea Nacional; 2009. Resolución No. 0000030

[74] Noguera LO, Carrero GO, Plonczak M, Jerez M, Kool G. Evaluación técnica y financiera de la silvicultura desarrollada en un bosque natural de la Guayana venezolana. Bois et Forets des Tropiques. 2007;**290**(4):81-91

[75] Ochoa GJ. Análisis preliminar de los efectos del aprovechamiento de maderas sobre la composición y estructura de bosques en la guayana venezolana. Interciencia. 1998;**23**(4):197-207

[76] Instituto Forestal Latinoamericano (IFLA). Evaluación del sistema silvicultural plantaciones en fajas de enriquecimiento (PFE) en las reservas forestales Imataca, San Pedro y Dorado Tumeremo, estado Bolívar. Mérida, Venezuela: Instituto Forestal Latinoamericano; 2010

[77] Hardt Ferreira dos Santos VA, Modolo GS, Ferreira MJ. How do silvicultural treatments alter the microclimate in a Central Amazon secondary forest? A focus on light changes. Journal of Environmental Management. 2020;**254**(October 2019):109816. Available from: https://www.sciencedirect.com/science/article/pii/S0301479719315348?dgcid=author

[78] Kappel K, Holmen SJ. Why science communication, and does it work? A taxonomy of science communication aims and a survey of the empirical evidence. Frontiers in Communication. 2019;**4**:55. Available from: https://www.frontiersin.org/article/10.3389/fcomm.2019.00055

[79] Paniz-Mondolfi AE, Rodríguez-Morales AJ. Venezuelan science in dire straits. Science. 2014;**346**(6209):559. Available from: http://science.sciencemag.org/content/346/6209/559.abstract

[80] International Tropical Timber Organization - ITTO. Criteria and indicators for the sustainable management of tropical forests. ITTO Policy Development Series No. 21. [Internet]. 2016. pp. 1-84. Available from: https://www.itto.int/direct/topics/topics_pdf_download/topics_id=4872&no=1&disp=inline

[81] Nepstad D, McGrath D, Stickler C, Alencar A, Azevedo A, Swette B, et al. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. Science. 2014;**344**(6188):1118-1123

[82] Guariguata M, Evans K. Advancing tropical forestry curricula through non-timber Forest products. International Forestry Review. 2010;**12**(4):418-426. Available from: http://www.jstor.org/stable/24309824

[83] Sist P, Sablayrolles P, Barthelon S, Sousa-Ota L, Kibler JF, Ruschel A, et al. The contribution of multiple use forest management to small farmers' annual incomes in the eastern Amazon. Forests. 2014;**5**(7):1508-1531

[84] Griscom BW, Goodman RC, Burivalova Z, Putz FE. Carbon and biodiversity impacts of intensive versus extensive tropical forestry. Conservation Letters. 2018;**11**(1):1-16