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Sustainable management of logged tropical forests in the Caribbean to ensure long-term productivity

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Sustainable management of logged tropical forests in the Caribbean to ensure long-term productivity

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Cover photo:
Forest worker marking a harvest tree in Suriname.
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FOREWORD

Lowland tropical forests around the Caribbean have been subjected to logging for centuries. The intensity of timber harvesting has varied from country to country and within countries between different management regimes. These selectively logged forests constitute an important resource that can continue to provide quality timber and ecosystem services if managed sustainably. In most cases, these forests are accessible, and still contain many valuable timber species despite modified species composition and structure.

To facilitate sustainable management of logged forests in the Caribbean, forest authorities of Belize, Guyana, Suriname, and Trinidad and Tobago, jointly with the Food and Agriculture Organization of the United Nations (FAO) and the University of Hamburg, World Forestry, as scientific partner, implemented the regional project "Ensuring Long-Term Productivity of Lowland Tropical Forests in the Caribbean". The project was financed by the German Federal Ministry of Food and Agriculture and implemented from September 2015 to December 2019.

The main objective of the project was to support sustainable management of logged forests to maintain productivity and prevent further degradation. For this purpose, extensive field studies were conducted in the project countries, which resulted in silvicultural recommendations presented in this publication. In addition, the project examined the economic feasibility and applicability of the silvicultural method of future crop tree release as an activity in support of REDD+.

Section 1 of this paper presents the overall context, including the global status of tropical forests, common harvesting practices, the practice of silviculture, and challenges to sustainable forest management in the tropics. Section 2 presents the findings of the field studies conducted under the project and discusses implications for forest management. Finally, the guidelines presented in Section 3 describe the planning process and measures to maintain and enhance the future crop of commercial trees in the forest. Although the project was implemented in the Caribbean, the results and guidelines are also relevant and can be replicated in other tropical regions. We hope that these guidelines will support forest managers and extensionists in improving the sustainability of logged forest management in the tropics.

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GUYANA
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SURINAME
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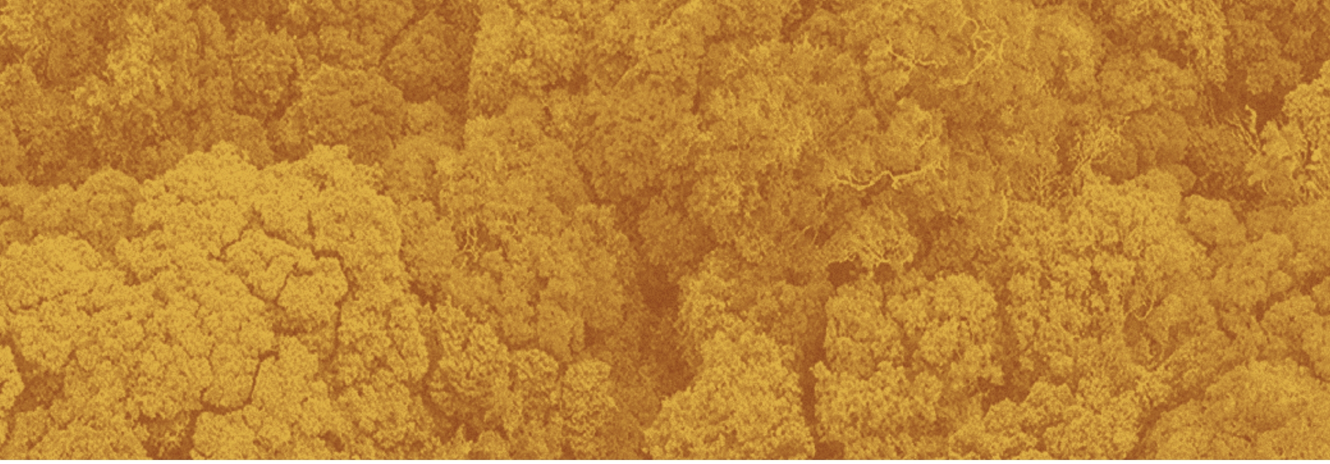
ACRONYMS AND ABBREVIATIONS

AGB	above-ground biomass
ANR	assisted natural regeneration
CBD	Convention on Biological Diversity
DBH	diameter at breast height
FAO	Food and Agricultural Organization of the United Nations
FCT	future crop tree
FSC	Forest Stewardship Council
GHG	greenhouse gas
ITTO	International Tropical Timber Organization
MAC	maximum allowable cut
MHD	minimum harvesting diameter
PEFC	Programme for the Endorsement of Forest Certification
RIL	reduced impact logging
REDD+	reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SFM	sustainable forest management
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests

KEY MESSAGES

1. In addition to the critical roles that tropical forests play in biodiversity conservation, the global carbon cycle, livelihood support and provision of other ecosystem services, the world's tropical forests are also of great importance from an economic viewpoint as production of wood remains the dominant primary objective of forest management in many countries.
2. About 2/3 of tropical forests have been affected by human activities, mainly through selective harvesting. Sustaining productivity of these logged forests can maintain forest management as a financially viable land use option, reducing the likelihood of conversion and maintaining the flow of diverse forest benefits.
3. The application of general sustainable forest management protocols for tropical production forests that set limits on harvesting (e.g. minimum felling diameter, annual allowable cut, fixed rotation period, etc.) does not necessarily ensure sustained productivity if the composition and management of the residual stand are not considered.
4. The ratio of number of harvested trees to the remaining future crop trees can provide a simple indicator of sustainability of harvest. If the current harvest exceeds the number of future crop trees, the harvest is not sustainable. As a rule of thumb, at least one, preferably two future crop trees per harvested tree should be retained for future use.
5. To ensure sustainability, it is important to select future crop trees from the same group of commercial species currently being harvested. Otherwise, the stand composition will shift from high-value timber species to those of less value, resulting in high grading of the forest.
6. From the current diameter of future crop trees and species-specific growth rates, it is possible to estimate the time when a sufficient number of trees will become harvestable. The commonly applied felling cycles for natural forest harvesting in the tropics are generally not sufficient to allow for the recovery of growing stock of commercial timber species.
7. Future crop tree release aims to expand the growing space of these trees and thereby accelerate their growth by removing competing trees nearby. This silvicultural operation incurs costs, which may not be recoverable through the increased growth of released future crop trees within the cutting cycle or the logging permit period. However, the economic feasibility depends on many factors that cannot be generalized or predicted with certainty. These factors include future timber price, growth rate of commercial timber species before and after release, choice of discount rate, costs associated with the release operation and future harvesting, etc.

8. Release of future crop trees enhances the productivity and value of the forest by directing biomass increment to high-value trees. However, the removal of competitors will result in temporary decline of forest carbon stock. This illustrates the potential trade-offs among the different forest management objectives as improved productivity may not lead to conservation or enhancement of forest carbon stocks within the desired timeframe.
9. Protection of future crop trees can be a simple and practical approach to preventing high grading and degradation of the forest growing stock. Even if it is not economically feasible to release future crop trees, it is still important to identify and mark these trees to ensure protection of trees that represent the future economic value of the forest. The importance of reduced impact logging to reduce unnecessary damage to the future crop trees and for sustainable forest management in general is stressed.



Canopy of an intact tropical forest in the Caribbean.

Part 1: **SUSTAINABLE MANAGEMENT OF TROPICAL PRODUCTION FORESTS**

1. RELEVANCE AND STATE OF TROPICAL FORESTS

With an area of 4.06 billion ha, forests cover about 31 percent of the global land area. Tropical forests account for 45 percent of the total forest area (FAO, 2020a). Forests are home to the greatest part of the world's terrestrial biodiversity, and tropical moist forests are known to be particularly diverse, containing about 60 percent of all plant species (FAO and UNEP, 2020). In addition to their diverse ecosystem services, forests provide the basis of life for a large number of people. It is estimated that 300 to 350 million forest-proximate people depend on forests for their subsistence and income, and 2.4 billion people rely on wood-based energy for cooking worldwide (Chao, 2012; FAO, 2014).

At the local level, communities benefit from access to forest products such as wood, medicines and fuelwood. At the regional level, forests provide important ecosystem services such as water regulation, soil stability, flood mitigation and improved air quality. At the global level, forests make an important contribution to economic development, biodiversity and climate regulation. Timber and processed forest products contribute more than USD 450 billion to the global economy each year, and the annual value of internationally traded forest products reached USD 248 billion in 2019. Tropical hardwood accounted for 24 percent of the global export value of industrial roundwood in 2019 (FAO, 2020b).

Forests contain large amounts of carbon and act both as a source and sink of carbon (Butarbutar *et al.,* 2019; FAO, 2020a). They thus play a key role in the global carbon cycle and climate change. The carbon stocks of tropical forests alone are estimated to be 306–324 billion tonnes, of which 49–53 percent are bound in tropical primary forests (Mackey *et al*., 2020). Primary forests cover 32 percent of tropical forest area (Morales-Hidalgo *et al.,* 2015). Each year, tropical forests sequester between 0.47 and 1.3 billion tonnes of carbon, which corresponds to 8–13 percent of global annual anthropogenic CO_2 emissions (Mackey *et al.,* 2020). On the other hand, deforestation in the tropics is responsible for 10–15 percent of anthropogenic carbon emissions (Houghton, 2013; Pearson *et al.,* 2014; Pearson *et al.,* 2017; Munang *et al.,* 2011)

Although the rate of deforestation has decreased over the past three decades, deforestation and forest degradation continue at an alarming rate (FAO, 2020a). Since 1990, an estimated 420 million ha of forest have disappeared through conversion to other land uses, with more than 90 percent of the deforestation occurring in the tropics. Between 1990 and 2010, over 15 million ha were deforested annually, which slowed to 11.8 million ha per year in 2010–2015, and further decreased to 10.2 million ha per year in 2015–2020

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Deforested tropical landscape.

(FAO, 2020a). Africa had the highest net loss of forest cover, with a loss of 3.94 million ha per year between 2010 and 2020, while South America experienced a decline in forest cover of 2.6 million ha per year during this period (FAO, 2020a).

Despite international attention and measures against deforestation and forest degradation, primary forests are declining rapidly due to ongoing land use interventions (Mackey *et al.,* 2015). Primary forests account for about one-third of the total tropical forest area, while the rest are forests that have been impacted by human activities to various degrees. Forest degradation is notoriously difficult to measure and monitor because it is difficult to detect subtle and temporary changes due to low-intensity forest use through remote sensing data. In an analysis conducted by FAO, 185 million ha of forest was degraded (using partial canopy cover loss as a proxy for forest degradation) between 2000 and 2012, of which 156 million ha was in the tropics (FAO, 2015). This illustrates the wide extent of forest degradation, which is affecting a disproportionately high percentage of tropical forests.

The primary driver of global forest loss is commercial agriculture, which accounts for 70–80 percent of forest conversion in Africa, around 70 percent in tropical and subtropical Asia, and over 90 percent in Latin America (Sandker *et al.,* 2017). Commercial logging is the main cause of forest degradation in Latin America and Southeast Asia, while firewood and charcoal production are the main causes of degradation in Africa. These direct drivers of deforestation, which are human activities at the local level, are shaped by indirect drivers including global population and economic growth and the associated increase in demand for primary raw materials, agricultural products, wood products and minerals (Kissinger *et al.,* 2012; Boucher *et al.,* 2011; Hosonuma *et al.,* 2012; Geist and Lambin, 2001).

Several international initiatives and programmes have been launched to combat deforestation and forest degradation. Within the framework of the United Nations Conference on Environment and Development (UNCED), 179 countries signed Agenda 21 and declared their intention to combat deforestation. Under the 2030 Agenda for Sustainable Development, target 15.2 aims to "promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally" by 2020. Forest certification systems such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) promote sustainable forest management (SFM) practices at the local level in order to prevent forest degradation. The Convention on Biological Diversity (CBD) adopted the strategic plan for biological diversity 2011–2020, which includes measures to reduce forest degradation. The United Nations Framework Convention on Climate Change (UNFCCC) developed a framework to guide activities in the forest sector that reduces emissions from deforestation and forest degradation, as well as the sustainable management of forests and the conservation and enhancement of forest carbon stocks in developing countries (REDD+). The New York Declaration on Forests, endorsed by over 200 governments, multinational companies, groups representing indigenous communities, and non-governmental organizations since 2014, aims to cut natural forest loss in half by 2020 and strives to end it by 2030. As well, driven by increased social and environmental awareness of consumers, an increasing number of private companies are voluntarily committing to eliminating deforestation from their supply chains.

2. TIMBER HARVESTING AND SUSTAINABLE FOREST MANAGEMENT IN THE TROPICS

Despite the increased recognition of the range of products and services provided by forests and the movement towards multi-purpose forest management, wood production remains the dominant forest management objective globally and in the tropics. More than 20 percent

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Primary tropical forest supporting high levels of biodiversity.

of humid tropical forests globally have been allocated to selective timber harvesting, and forests that have been selectively logged dominate secondary forests, which comprise two-thirds of the tropical forest area (Asner *et al.,* 2009).

Globally, tropical forests have the highest growing stock per unit area and encompass over half of the world's standing timber, including some highly valued species (FAO, 2020a; Thomas and Baltzer, 2002). As only a few species (or groups of species) have commercial value, tropical production forests are usually managed through selective logging to extract economically attractive trees for timber production (Asner *et al.,* 2005; Putz *et al.,* 2012; Blanc *et al.,* 2009; Blaser and ITTO, 2011). The removal rate and intensity are often controlled by a felling cycle, a diameter limit and an annual production quota (or annual allowable cut) (Fredericksen, 1998). Annual logging takes place in one or more compartments, which are then left to recover until the next harvest. Typical felling cycles in the tropics are between 15 and 40 years (Hawthorne *et al.,* 2011; Keller *et al.,* 2007) with typical harvesting intensities ranging from two to three trees per hectare (about 8 m^3) up to 120 m^3/hectare or more in dipterocarp forests of Southeast Asia (Armstrong and Inglis, 2000; Appanah and Weinland, 1990).

Selective logging is performed either as conventional logging or as reduced impact logging (RIL). Conventional (unmanaged) logging usually makes little or no use of planning measures such as pre-harvest inventory or skid trail planning. Due to the lack of planning, conventional logging leads to considerable damage to the remaining stand (Boltz *et al.,* 2003; Rivero *et al.,* 2008). Marketable trees are identified and felled during harvesting in the forest and later searched for and extracted by skidders. Harvesting contractors are usually paid by piece rate, which leads to quick work with little care for the remaining stand. The skidding crews often lack the information needed to locate the felled trees quickly and precisely. This leads to a highly inefficient skidding process, commonly resulting

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Harvesting operation in an FSC-certified forest concession.

in unnecessary skidding damage to the remaining stand (Holmes *et al.,* 2002).

On the other hand, RIL involves intensively planned and carefully controlled implementation of timber harvesting operations to minimize environmental impacts on the forest stand and soils. RIL techniques were tested in the 1990s and are now standard best practice in tropical production forest management (van der Hout and van Leersum, 1998; Putz *et al.,* 2008; Holmes, 2020). RIL includes a number of measures, such as pre-harvest inventories, skid trail planning, cutting of lianas on harvest trees, protection of sensitive areas and buffer zones, use of directional felling, closure and rehabilitation of log landings and logging roads, post-harvest assessments, etc. (Dykstra, 2001, 2002; Sist, 2000).

Currently defined SFM protocols for production forests mandated by governments comprise static restrictions or limits on harvesting, including prohibition on felling certain trees (e.g., seed trees and species of conservation value), minimum felling diameter, maximum harvest intensity per unit area, and minimum distance between harvested trees. Little attention is being paid to the residual stand and the future crop trees that remain in the forest. The assumption is that there is enough natural regeneration of commercial trees in the forest to replace the harvested trees within the mandated felling cycle, which often does not hold true.

Considering the vast expanse of tropical forests allocated to selective logging worldwide, sustainable management of logged forests to maintain productivity and prevent further degradation is critical. If sustainably managed, these logged forests can continue to generate financial benefits and incentives for local communities and forest managers to maintain forest land use, along with many intangible benefits that forests provide.

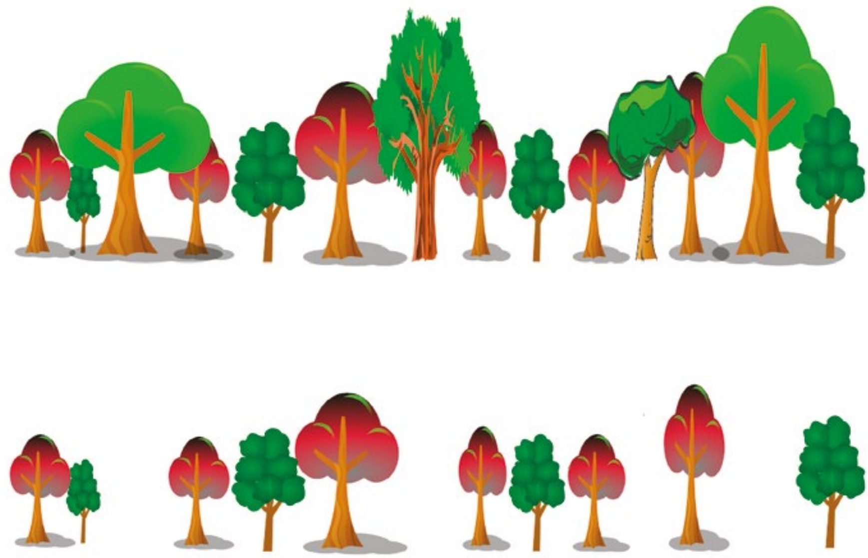
3. PRACTICE OF SILVICULTURE

Silviculture is defined as the theory and practice of controlling the establishment, composition, constitution and growth of forests (Ford-Robertson, 1971) to meet the diverse needs and values of landowners and society. It used to be generally assumed that tropical forests naturally and perpetually renewed themselves after harvesting to sustain productivity. However, it became apparent that most commercial timber species did not regenerate adequately on their own after harvesting, even if conducted at low intensity. In order to sustain production, carefully implemented harvesting operations with appropriate limits need to be combined with silvicultural treatments to enhance the abundance and growth of commercial timber species.

The main objective of silviculture applied in natural production forests is to enhance the growth and abundance of commercial timber species to improve the value of the forest stand. Research in tropical silviculture in recent decades has oscillated between two concepts: artificial regeneration (e.g. enrichment planting of seedlings of commercial timber species in canopy gaps); and natural regeneration by creating conditions conducive to the establishment and growth of natural regeneration of targeted species, for example through thinning (Bertault *et al.,* 1995; Putz, 2004).

In enrichment planting, forest stands are enriched with valuable tree species, which are planted after harvesting. However, planting of tree seedlings under closed canopy or in single tree canopy openings without constant maintenance and continued opening of the canopy has rarely been successful. Planted seedlings require long-term care to ensure establishment and continued growth (Schwartz *et al.,* 2013; Schwartz *et al.,* 2017; Navarro-Cerrillo *et al.,* 2011). Enrichment has frequently

Figure 1. Liberation of future crop trees (marked in red) by felling competitors



failed to achieve its objective where the requirements for careful planning and the considerable amount of maintenance work have not been met (Bertault *et al.,* 1995; dos Santos and Ferreira, 2020; Neves *et al.,* 2019).

The current paper is dedicated to improved management of production forests through natural regeneration and stand improvement, with the aim of promoting the growth of existing trees with the potential to produce high-value timber by reducing competition. The practice is generally termed thinning, which is a common tool of forest management all over the world. When applied in forest restoration, the approach is termed assisted natural regeneration (ANR), which aims to accelerate the growth of natural regeneration of preferred species by reducing competition from grasses and other weedy vegetation (Shono *et al.,* 2020). Future crop tree (FCT) release, which can be considered a form of thinning, refers to the elimination of competitors of selected smaller sized individuals of commercially valuable species (Figure 1). One rationale underlying FCT release is that dominant and co-dominant trees account for the largest share of total biomass growth in a forest stand (Smith, 1997; Dawkins, 1955; Wadsworth and Zweede, 2006; Wadsworth, 1997). Therefore, forest productivity can be improved significantly by helping smaller individuals of commercial tree species attain (co-)dominant positions in the canopy. It has been shown that individual tree measures, such as the selective removal of climbers and lianas, can lead to a substantial increase in the growth of targeted trees (Graaf *et al.,* 1999; Villegas *et al.,* 2009; Peña-Claros *et al.,* 2008; Wadsworth and Zweede, 2006; Mills *et al.,* 2019).

4. CHALLENGES RELATED TO SFM IN THE TROPICS

4.1 Understanding SFM

Over the past few decades, the concept of sustainability has increasingly been mainstreamed into tropical forest management. SFM is an approach to bringing environmental, socio-cultural and economic management goals into harmony with the forest principles adopted at the UNCED in 1992.

The United Nations Forum on Forests (UNFF) developed the non-legally binding instrument on all types of forests, which was adopted by the UN General Assembly in 2007 and specifies seven thematic elements of SFM as follows:

1. extent of forest resources
2. biological diversity
3. forest health and vitality
4. protective functions of forests
5. productive functions of forests
6. socio-economic functions
7. legal policy and institutional framework.

These seven thematic elements illustrate the complexity of SFM, which is one reason why there is not a single universally agreed definition of SFM. One of the most widely accepted definitions of SFM adopted by the UN General Assembly (Resolution A/RES/62/98) defines SFM as a "dynamic and evolving concept [that] aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations." According to the International Tropical Timber Organization (ITTO, 2005), SFM is "the process of managing forest to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment". According to the World Commission on Forests and Sustainable Development, SFM must be "a flexible concept that accepts changes in the mix of goods and services produced or maintained over long periods of time and according to changing values signalled by various stakeholders" and should be "seen as a process that can be continuously adapted according to changing values, resources, institutions and technologies" (Salim and Ullstein, 2000; Sist *et al.,* 2014). SFM aims not only to ensure the flow of goods and services, but also to keep forest processes intact, including the conservation of the range of functional species that provide these goods and services (Thompson *et al.,* 2014). SFM considers forests in terms of both time and space. SFM represents a balance between the conservation and production of forest goods and services for humans and must operate within the capacity of the forest to restore and maintain its functions (Sist *et al.,* 2014).

Although there are variations in the definition and interpretation of SFM, there is a consensus that the concept of SFM encompasses sustaining and maintaining the full range of products and services provided by forests for

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Logs being transported in Belize.

present and future generations through a flexible and adaptable approach.

Despite the recognition of the importance of SFM, production forests in the tropics are seldom managed with a long-term vision. Growing stock of commercial timber species declines substantially after a primary forest is harvested for the first time, and this does not recover to pre-harvest levels within a practical timeframe. Furthermore, management for long-term production is often not the most lucrative land use option (Putz *et al.,* 2012). As such, the general approach is to harvest revenue-generating high-value timber as quickly as possible, moving to lesser-value species in subsequent harvests, until the economic value of the forest is depleted.

4.2 Post-harvest recovery and rotation cycles

Where tropical forest management focuses mainly on timber production, the main objective is to sustain timber yield. After harvesting, the commercial growing stock is expected to recover over the felling cycle, which is typically 20 to 40 years (Putz *et al.,* 2012). The crucial question is whether the mandated rotation period is sufficient to allow this recovery to happen. Sustainability in timber production is achieved when the same amount of wood as harvested in each felling cycle is replenished over the rotation period. From an ecological and environmental point of view, SFM requires that the provision of forest goods and services does not decline over time. This means that forests should not be affected by interventions in their resilience, and should have the same structure, timber volume, biodiversity, biomass and ecological processes as before harvesting (although an exception may have to be made for the first time a primary forest is logged as it is unlikely that the forest can return to the original pristine conditions within a reasonable period) (Sist *et al.,* 2014).

However, a meta-analysis on the recovery of tropical forests after logging indicates that only 54 percent of the timber volume extracted from primary forests will be available for the next harvest, assuming that the number of harvested species increases over time. If the same species continue to be harvested, then only 35 percent of the original stock will be available for the second cut and yield will likely continue to decline thereafter (Putz *et al.,* 2012). Under the prevailing harvesting protocols, the current felling cycles are too short by a factor of at least two, and therefore would need to be lengthened to 50–100 years to sustain yields (Zimmerman and Kormos, 2012; Putz *et al.,* 2012).

4.3 Impact of selective logging and fixed harvest regulations

During selective logging, the most valuable tree species are removed in one or several harvesting operations. When the most valuable species in an area have been exhausted, the next group of valuable tree species are extracted. This shifting of biomass increment from high-value timber species to lower-value species (called high grading) reduces the economic value of the stand. The disappearance of certain timber species, which are often the dominant canopy trees, also has a negative ecological impact and impoverishes species diversity. The impact of selective logging on the forest depends mainly on the harvest intensity, measured by the number of trees harvested or cubic metres extracted per hectare. With increasing intensity of harvest, damage to the remaining stand increases (Zimmerman and Kormos, 2012).

Government protocols on SFM often mandate fixed limits on harvesting, such as minimum cutting cycle, minimum felling diameter, maximum harvest intensity, and retention of seed trees. Minimum cutting cycles of 25 to 35 years and minimum harvesting diameter of 50 cm are common. Various studies have investigated the sustainability of current cutting cycles and harvest intensities in tropical forests, and concluded that the prevailing management practices with static limits on harvesting are unlikely to be sustainable (Macpherson *et al.,* 2012; Piponiot *et al.,* 2019; ter Steege *et al.,* 2002; Huth and Ditzer, 2001; Kammesheidt *et al.,* 2001; Hall *et al.,* 2003; Sist *et al.,* 2003; Dauber *et al.,* 2005; Zimmerman and Kormos, 2012).

Reducing harvest intensity, for example by increasing minimum felling diameter, lowering annual allowable cut or retaining more large-diameter trees, would help sustain production. Leaving more marketable trees in the forest represents opportunity cost for the forest managers, and this would reduce the economic feasibility of operations. Furthermore, lower harvest intensity may not increase the regeneration of light-demanding timber species which dominate the tropical timber market. Higher harvesting intensity on the other hand would lead to larger and more frequent canopy gaps, promoting vigorous regeneration of pioneer species with no commercial value. Ideally, harvesting protocols should be designed for each harvested species, considering its life history, including regeneration ecology, growth rates, distribution and size composition. The challenge, however, is that such data are not readily available, even for the most valuable commercial timber species.

4.4 Effects of silvicultural treatments

Silvicultural treatments, including enrichment planting, removal of lianas, girdling of unwanted trees and liberation felling, have been tested and implemented in the tropics to increase the production of high-value timber.


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Marked future crop tree in Suriname.

Commercial timber species in tropical forests are often present in low densities and show clumped distribution patterns influenced by biophysical requirements for regeneration and habitat preference. In many cases, natural regeneration is inadequate, and silvicultural treatments are needed to ensure recruitment and regrowth of the harvested species after logging.

FCT release is mainly used in North America and Europe to positively influence the growth of selected crop trees identified in the early stages of stand development (Abetz, 1990; Abetz and Klädtke, 2002; Burschel and Huss, 2003). By eliminating crown competition from neighbouring trees, the FCTs are provided with more growing space. Release of FCTs directs limited resources, including light, water and soil nutrients, of a given forest site to a smaller number of selected trees. This accelerates the growth of FCTs and shortens the time until these trees reach the final harvesting diameter (Dawkins, 1955; Wadsworth and Zweede, 2006; Smith, 1997).

The stimulation of tree growth by release treatments in temperate forests has been confirmed by numerous studies (e.g. Hein *et al.,* 2007a; Hein *et al.,* 2008; Hein *et al.,* 2007b; Herbstritt *et al.,* 2006; Mäkinen and Isomäki, 2004). Several studies examined the effect of silvicultural treatments in tropical forests, where growth increases of 20 to 60 percent were observed (Wadsworth and Zweede, 2006; Villegas *et al.*, 2009; Peña-Claros *et al.*, 2008; Kuusipalo *et al.*, 1997; Werger 2011). Graaf *et al.* (1999) had carried out silvicultural treatments in Suriname since 1965. They reduced the basal area of non-marketable tree species from 20 m^2/ha to 6 m^2/ha and the total basal area to 10 m^2/ha. The effects of these treatments lasted for less than 10 years and even with short cutting cycles of 20 to 30 years, the treatments were only effective if they were repeated. The mortality rate increased as the intensity of the treatments increased. David *et al.* (2019) found that the magnitude of the liberation effect on the remaining stand depends strongly on the tree species. Studies on the effect of logging and crown liberation on the population dynamics of tree seedlings show that canopy release favours the recruitment of light-demanding pioneer species rather than promoting the regrowth of the desired timber stock (Zimmerman and Kormos, 2012; Kuusipalo *et al.*, 1996).

5. SUSTAINABLE FOREST MANAGEMENT AND REDD+

Reducing emissions from deforestation and forest degradation, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stocks (REDD+), is an essential part of the global efforts to mitigate climate change. The aim of REDD+ is to encourage developing countries to contribute to climate-change mitigation by: 1) reducing greenhouse gas (GHG) emissions by slowing, halting and reversing forest loss and degradation; and 2) increasing removals of GHGs from the atmosphere through the conservation, management and expansion of forests (UNFCCC, 2020).

Countries are adopting diverse approaches to finance their REDD+ mitigation actions through public and private finance, both market- and non-market-based (FAO, 2018). Results-based payments are the final phase in REDD+ where developing countries receive financial rewards for measured, reported and verified REDD+ results (UNFCCC, 2020).

The aim of SFM is to maintain and enhance the multiple values of forests over generations. It is, therefore, fundamentally important for REDD+; in many countries it will be an essential means for achieving the objectives of curbing emissions from deforestation and forest degradation and conserving, managing and enhancing forest carbon stocks. REDD+ offers opportunities for restoring forests where they have been lost or degraded and thereby bringing more land under SFM. REDD+ may also generate additional revenue to broaden the financial base for forest conservation and sustainable management, increase the benefits deriving from forests and trees, and encourage the wider uptake of SFM (FAO, 2020c).

The following five REDD+ activities have been globally agreed to contribute to forest-related mitigation actions:

1. reducing emissions from deforestation;
2. reducing emissions from forest degradation;
3. the conservation of forest carbon stocks;
4. the sustainable management of forests; and
5. the enhancement of forest carbon stocks.

These five activities can best be implemented through a package of coordinated policies and measures defined by each country and included in national strategies and action plans.

For sustainable management of forests, examples of REDD+ policies and measures may include:

- bringing more forests under sustainable management;

- implementing payment schemes for the environmental services rendered by forests;
- strengthening community forest management; or
- obtaining forest certification.

Despite the obvious synergies between SFM and REDD+ objectives, only a few countries have included sustainable management of forests under their national REDD+ activities due to complexities in measuring increases in forest carbon stocks and sequestration due to improved forest management practices as measured against forest reference (emission) levels (FAO, 2020d).

This paper assess the potential impact of silvicultural practices, specifically FCT release treatment, to improve productivity of logged forests while conserving and enhancing forest carbon stocks. The evaluation of carbon benefits of different forest management practices needs to consider: species-specific growth rates and response to treatments, carbon sequestration in above- and below-ground biomass; emissions due to forest operations; emissions related to harvesting of trees; and the duration of forest management cycle.

FCT release will shift the growth increment from non-commercial trees to high-value timber species, improving productivity and sustainability of yield. In addition, such silvicultural treatments might strengthen the financial basis of forest management to prevent conversion to other land uses. However, the principal objective of REDD+ is to reduce GHG emissions, and carbon is valued at the same price regardless of the composition of trees that comprise forest biomass. There is a need to better understand the trade-offs among different forest management objectives, the impact of silviculture treatments on carbon emissions and absorption, and the synergies between REDD+ and SFM, both of which are multifaceted.

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Landscape dominated by degraded forests in Trinidad and Tobago.

Measuring diameter of a large tree above the buttress in Suriname.

Part 2: **THE CARIBBEAN CASE STUDIES**

Lowland tropical rain forests covered much of the Caribbean countries prior to the arrival of Europeans in the 15th century. Colonization of the New World by Europeans brought significant changes to the Caribbean, and many of the countries were heavily deforested for commercial agriculture. There was also intensive exploitation of timber resources starting in the 18th century. In the past half century, conversion for agriculture – both commercial and subsistence – urban development, mining, timber harvesting, fuelwood collection, etc., have continued to drive deforestation and degradation of forests. In recent decades, forest cover has stabilized in many countries, and there is increased recognition of the importance of forests for watershed protection, biodiversity, recreation and resilience. The current forest extent, condition and level of production vary widely among the countries.

Even though the ecological integrity of these previously harvested forests has been substantially affected, the forests still constitute a valuable resource. In most cases, these forests are located in relatively accessible areas and still contain several tree species that provide valuable timber despite their modified species composition. Intensive forest management can offer much needed employment opportunities in rural areas and can contribute significantly to the reduction of poverty and hunger. Apart from subsistence agriculture, forestry and forest-related activities represent the only income opportunities in many hinterland communities in the case study countries.

Forest management practices in the Caribbean have been driven by the need to generate and maximize short-term revenues. Intensive forest management, including silvicultural interventions, is likely to be more expensive than conventional forest exploitation. In order to make economic sense, the additional costs of implementing improved forest management must be balanced by increase in productivity and potential payments for ecosystem services including carbon.

To guide the sustainable use and management of these often-neglected forest resources, the project "Ensuring

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A large tree in a tropical forest in Suriname.

Long-Term Productivity of Lowland Tropical Forests in the Caribbean" sought to address the following questions:

1. Do the logged-over forests contain sufficient timber resources to sustain further harvesting?
2. Can silvicultural treatments increase the productivity of these forests? If so, what are the expected costs and benefits of these interventions?
3. What is the impact of these silvicultural treatments on forest carbon stocks, and is there a scope for obtaining additional revenues from carbon financial mechanisms?

1. APPROACH AND METHODOLOGY

Four countries were selected to investigate the sustainability of silvicultural interventions to improve forest management in lowland tropical forests in the Caribbean: Belize, Guyana, Suriname, and Trinidad and Tobago. The climate of these countries is tropical and characterized by pronounced dry and rainy seasons. While Belize and Trinidad and Tobago have a dry season from January to May, Guyana and Suriname have two rainy seasons, from February to April and from August to November, with dry seasons in between. In Belize and Trinidad and Tobago, forests are also threatened by hurricanes.

In all four countries, forests have been managed and timber harvested commercially since the mid-19th century. However, there are considerable differences among the project countries in the current extent and condition of their forests. In countries with low population density, namely Guyana and Suriname, large tracts of forest remain mostly untouched, as logging operations have only affected certain designated areas. On the other hand, on the island of Trinidad, with a high population density and a high demand for agricultural land, most of the original forest cover has been removed and the remaining forests are severely degraded. Forests in Belize have been heavily exploited in the past, mostly for mahogany. Of the four project countries, Belize is the only country that is currently experiencing relatively high rates of deforestation, mostly due to agricultural expansion. There are significant levels of forest production in Guyana and Suriname, where forest products constitute an important export commodity, while there is limited forest harvesting in Belize and Trinidad and Tobago (Table 1).

In the four project countries, a total of ten 100-ha test sites were established for an extensive forest inventory (Table 2). The participating national forest authorities were responsible for the site selection based on specific interests and context of the country.

Table 1. Status of forests and forest production in the project countries

Country	Forest area (1 000 ha) and cover	Forest area change 2000–2020 (1 000 ha)	Carbon stock (tonnes/ha)	Total roundwood production in 2019 (m^3)	Value of forest products exported in 2019 (1 000 USD)
Belize	1 277 (56%)	-182 (-12.5%)	123	167 000	3 715
Guyana	18 415 (94%)	-149 (-0.8%)	396	1 137 022	39 583
Suriname	15 196 (97%)	-146 (-0.9%)	220	1 170 981	88 372
Trinidad and Tobago	228 (45%)	-8 (-0.4%)	53	197 259	2 302

Source: FAO, 2020a and FAOSTAT.

Table 2. Study sites and tenure types

Country	Site	Silvicultural System/Logging Type	Ownership	Tenure Type	Cutting Cycle
Belize	Rio Bravo 305	Polycyclic/controlled selective logging based on minimum harvesting diameter (MHD) and maximum allowable cut (MAC) from yield model	Private forest	Privately managed	40 years
	Rio Bravo 102				
	Quiche Ha	Polycyclic/conventional selective logging	State forest	Community managed with annual cutting permits	1 year
Guyana	Great Falls	Polycyclic/conventional selective logging based on MHD			
	Orealla				
	Ituni				
Suriname	Mapane	Polycyclic/controlled selective logging based on MHD and fixed MAC	State forest	Large-scale concession	30 years
	Kabo	Polycyclic/semi-controlled selective logging based on MHD and fixed MAC			
Trinidad and Tobago	Rio Claro	Polycyclic/conventional selective logging based on MHD with individual tree sale	State forest	Periodic block system	30 years
	Cats Hill				

©Kenichi Shono/FAO

An abandoned steam engine used for hauling logs in Rio Bravo Conservation Area, Belize.

In all test sites, logging was practised at least once within the past 30 years and planned to be carried out again within the project period, and the participation of concessionaires, forest owners or communities with granted tenure was secured. The test sites do not cover the entire range of forest types and conditions that exist in the project countries, but represent the key common forest tenure types found in the Caribbean region, which are:

1. large-scale concession managed forest
2. periodic block system
3. privately-owned forest
4. community-managed forest.

Box 1 Forest tenure types covered by the study sites

Large-scale concession

The management of large-scale concessions included in this study is based on annual cutting areas of 100 ha with pre-harvest inventory, planned skidding and directional felling. The concessionaire prepares a management plan, which is approved by the national forest authority prior to harvesting. Harvesting follows guidelines published by the respective forest authority which include maximum allowable cut per hectare (normally between 20 and 25 m^3/ha) with a rotation period of 30 years, minimum distance of 10 m between harvested trees, protection of soil, water and conservation values, block alignment and the maximum area of roads to be constructed in a felling compartment (Blaser and ITTO, 2011). The restrictions listed above were gradually introduced over the last 20 to 40 years. In the past, there were fewer restrictions on harvesting, but only large-diameter trees of a few selected species were marketable and the rest remained untouched in the forest. Hardly any trees under the diameter of 60 cm were felled regardless of the stipulated minimum cutting diameter. In this way, an economic cutting limit often replaced the regulatory limit. As a result, these stands still remain relatively well stocked.

Periodic block system

The periodic block system is a polycyclic selective timber harvesting system. At least one block per year is opened and the trees within the block are sold over a period of two years. After two years the block is closed and allowed to regenerate without interventions for a period of 30 years. The trees for sale are selected and marked by forest officers following guidelines for tree selection. So-called replacement trees are required for each harvest tree selected. Harvest and replacement trees need to be of the same species. There is no pre-harvest inventory. Skid trails are not pre-planned, but are created by the logging crew in an unplanned manner during harvest operations. Although the amount of timber that can be removed from a block during a 30-year cycle is fixed, there are blocks with clear signs of overuse, which means trees not designated for utilization have been felled (Ramnarine *et al.*, 2002).

Privately-owned forest

The privately-owned forests in this study have been heavily harvested in the past. The forest areas were exploited from the middle of the 19th century until 1982 under a logging concession licence (Shono and Snook, 2006). Logging was mainly concentrated on mahogany without any management prescriptions. Minimum cutting diameter was introduced only in 1992. The first forest inventory was conducted in 1975 and showed that the commercial species volume had dropped to 36 m^3/ha (PFB, 2016). Since 1988 the area has been managed by a non-governmental organization, which uses a yield model developed based on the data of a network of national permanent sample plots for the selection of harvest trees. Before logging, the forest owner has to apply for a cutting permit by presenting an annual plan of operations to the respective national forest authorities. A pre-harvest inventory is mandatory, skid trails need to be pre-planned, and a post-harvest inventory is executed after logging. The cutting cycle is 40 years (PFB, 2016).

Community-managed forest

The communities participating in this study log their forest on an annual basis. The forest is state-owned but managed by a community and harvested through conventional logging. Cutting permits, called state forest permits, are granted on an annual basis. The permit holder is not required to present a management plan or to conduct pre-harvest activities such as pre-harvest inventory or skid trail planning (Blaser and ITTO, 2011). Required measures for sustainable management of the forest are written in a national code of practice, which was adopted by a forests act in 2009 (Parliament of Guyana, 2009).

Figure 2. Study site design

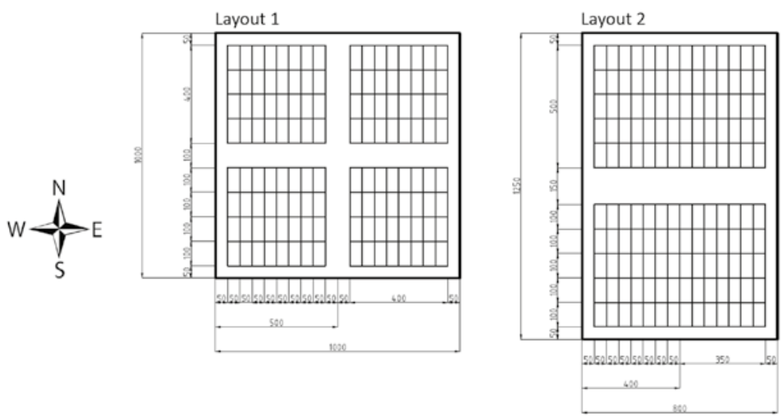


Figure 2 presents the layout of the study sites, which follows a randomized block design. With the exception of one site in Suriname, all study sites were established according to Layout 1. Study sites arranged according to Layout 1 cover an area of 1 x 1 km. In each 1 x 1 km site, four blocks containing 32 plots of 50 x 100 m (0.5 ha) were established. The individual blocks and the entire 1 x 1 km site are surrounded by a buffer-zone to avoid influences from neighbouring stands. In Suriname, a modified block design had to be used for one site due to the concessionaire's pre-set logging area alignment. This site follows Layout 2 and has a size of 0.8 x 1.25 km. Two blocks are located within this site, which contain 140 sample plots with a size of 0.5 ha each. The entire case study covers an area of 10 km^2 or 1 000 ha.

On each site, a forest stock assessment (pre-harvest inventory) was implemented, and the following characteristics collected for all trees with a diameter at breast height (DBH) ≥ 25cm:

- DBH
- position (GPS coordinates)
- log grade
- species
- standing volume
- harvestable timber volume

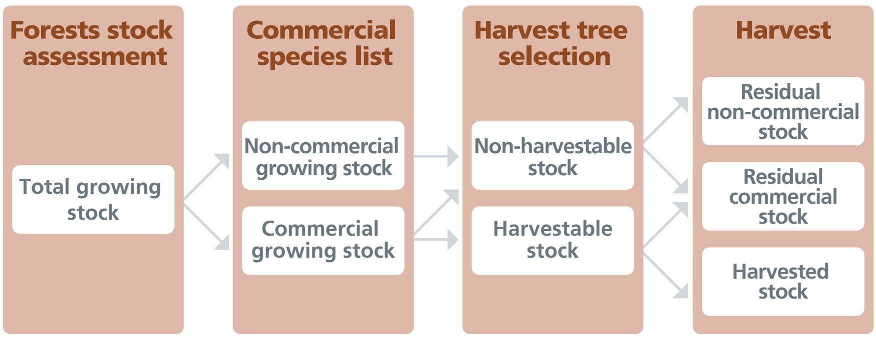
In total more than 80 000 trees were recorded over 1 000 ha.

2. CATEGORIZATION OF COMMERCIAL TIMBER STOCK

All trees in the test sites were classified as either commercial or non-commercial species according to national species classification systems. Figure 3 illustrates the categorization of the total forest growing stock from the time of initial stock assessment to harvest.

The class "commercial species" was further categorized into the following classes based on marketability of the species:
Class A: species with the highest market value
Class B: less-valuable species, but with a high market acceptance
Class C: marketable species, but with lower demand and value
Class D: commercial species with weak marketability

Figure 3. Categorization of forest growing stock from stock assessment to harvest stage



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Log landing in a forest concession in Suriname.

In addition, the commercial trees were evaluated according to their stem quality. For this purpose, four log grade categories were used (Table 3).

Based on this classification scheme, harvestable trees were selected for felling and removed from the stand. In the large concessions, only trees of species class A and log grade 1 were harvested. In the periodic block systems, species classes A and B with log grade 1 and 2 were harvested. In the private and community forests, trees in species classes A, B, C and D and log grade 1 and 2 were selected for harvest. From the remaining commercial trees, potential FCTs were identified, some of which were determined to require release treatment. The corresponding numbers of trees harvested and FCTs are shown for the four test sites in Table 4.

Table 4 clearly shows that the study sites differ in densities and average diameters of commercial and non-commercial trees. As a result, there are substantial differences in the number of trees harvested and trees that could be selected as potential FCTs. The effect of past forest management is obvious and will affect the potential future harvesting volumes.

Impact of past management practices is also evident from the abundance and spatial distribution of commercial and non-commercial trees. As an example, tree distribution maps of two test

Table 3. Log grade categories

Options	Category	Description
High quality	1	Straight tree without visible damage due to fire, pests, diseases, animals, etc.
Medium quality	2	Tree with few defects or damage due to fire, pests, diseases, animals, etc.
Poor quality	3	Tree with several defects or damage due to fire, pests, diseases, animals, etc.
Dead or dying standing tree	0	A tree is dead when none of its aboveground parts are alive (leaves, buds, cambium). A tree is dying if it shows damage that will surely lead to death.

Table 4. Selection of harvest trees and future crop trees

	Large-scale concessions		Periodic Block System		Privately-owned forest		Community-managed forest	
	No./ha	Avg. DBH (cm)	No./ha	Avg. DBH (cm)	No./ha	Avg. DBH (cm)	No./ha	Avg. DBH (cm)
Trees with DBH ≥25 cm (commercial and non-commercial species)	125	41.6	118	42.1	92	36.1	113	37.9
Harvestable trees	33	61.7	34	62.7	13	56.4	5	54.2
Harvested trees	8	63.2	4	74.1	5	56.6	4	45.6
Remaining commercial trees	81	42.2	69	44.6	48	36.6	10	37
Selected FCTs	7	36.8	22	35.7	3	36.7	6	31.6
Number of FCTs requiring release treatment	3	36.2	3	39.1	3	36.6	1	32.2

sites are presented in Figure 4. On the maps on the right, there are enough commercial trees available for future use. On the maps on the left, only a few commercial trees are available for future use as many of the marketable trees have been removed in previous harvest operations and the forest stands are dominated by non-commercial tree species.

This condition clearly illustrates the problems that arise from the use of logging codes that specify static limits on harvesting without taking into account the species and size class composition of the residual stand after harvesting. Under these logging codes, it is assumed that the defined period of time between harvests will be sufficient to allow the remaining stand to regrow and replenish the harvested growing stock. Our data clearly show that adherence to rigid harvesting limits does not necessarily ensure sustainable yield of commercial timber in the future. If such harvesting rules are applied to stands that have previously undergone extensive use, they can lead to overuse and further degradation. In some of our test sites, particularly the community-managed forests, adequate numbers of commercial trees were not available to ensure sustained harvest.

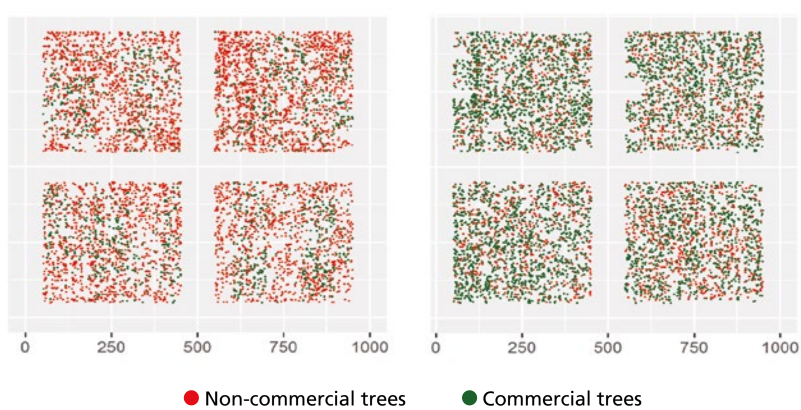
It is important to highlight that only those trees that are currently present in the forest can be expected to grow into harvestable size class during the rotation period of 30–40 years. To ensure viable future harvest, there needs to be minimum of one, preferably two, FCTs available in the stand, clearly marked and protected, for every tree harvested.

3. SUSTAINABILITY OF LOGGED FOREST MANAGEMENT

3.1 Felling cycle and recovery of timber volume

Gräfe *et al.,* (2020a) analysed the sustainability of timber production in the test sites presented above by estimating the projected recovery time of forest timber volume after harvesting and its expected condition 30–40 years after logging. In order to predict the future state, assumptions on the forest growth rate had to be made. Due to the high variability of tropical

Figure 4. Spatial distribution of commercial and non-commercial trees in the test sites



forests, growth estimates are associated with considerable errors. Therefore, increment values from studies of comparable forests were consulted and three DBH increment scenarios (1.6 mm/year, 2.7 mm/year and 4.5 mm/year) were defined and applied across all trees above 25 cm DBH. Under the assumption of low growth rate of 1.6 mm/year, none of the forest stands reached the initial total volume within the felling cycle of 30–40 years. Assuming the high growth rate of 4.5 mm/year, all except the community-managed forests reached the initial total volume within one felling cycle.

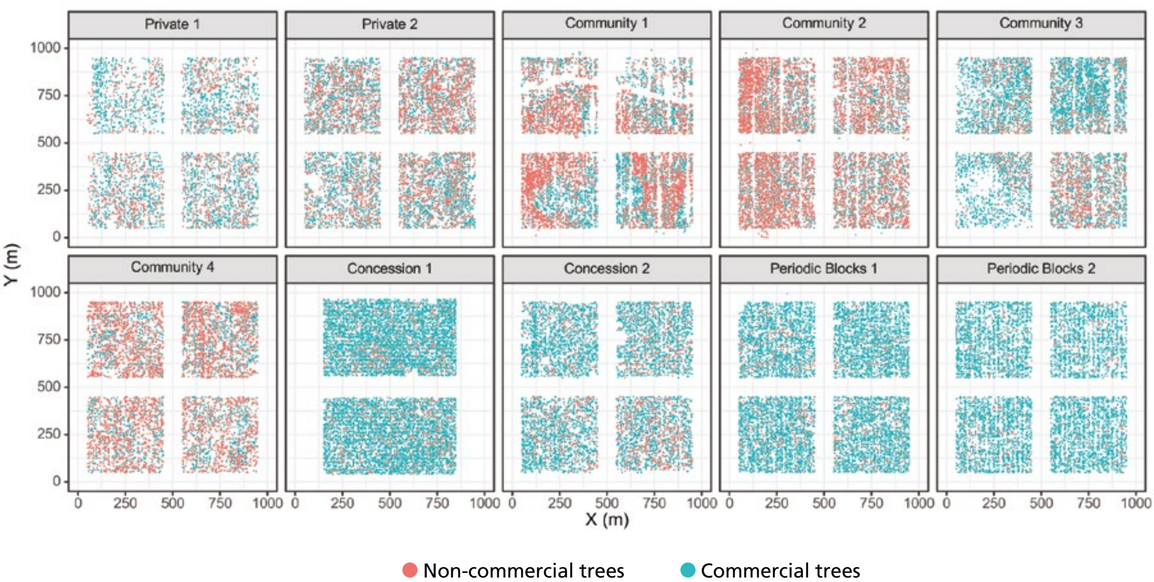
As expected, the choice of assumed growth rate and the current composition of the stand had a large influence on the estimated time needed for recovery of timber volume. The current condition of the forest should be used as a reference point to avoid further degradation through harvesting.

Logged-over forest in Belize.

3.2 Current condition of forest stands under different tenure types

There are clear differences in the initial conditions of the investigated forest stands managed under different tenure types. Figure 5 presents the abundance and spatial distribution of commercial and non-commercial trees of all test sites by tenure type. It is evident that in three of the four test sites under community management, a very limited number of commercial trees were

Figure 5. Spatial distribution map of the test sites



present. The test sites under large concessions and periodic blocks had a higher percentage of commercial trees. The privately-owned forest had an intermediate level of commercial trees.

Trees to be felled were determined based on the pre-harvest inventory data. Figure 6 shows the distribution of the volume of grade 1 and 2 commercial tree species by DBH classes for the four tenure types. Volumes used in the current harvest are presented in red for each diameter class, and blue represents the volume of the residual stand. The initial volumes and the proportion of marketable volumes were highest in the large concessions and periodic block system. Significantly lower volumes were measured in the community and private forests. The differences are largely a result of the preceding exploitation of the stands in addition to site-specific or geographical influences. The previous harvests in the large-scale concession only focused on large diameter trees of 2 to 3 species because there was no market for the smaller trees.

The spatial distribution of commercial trees of the residual stand and trees harvested are presented in Figure 7. Again, it is apparent that only a small number of harvestable trees are available in the community-managed and privately-owned forests.

The difference in the number of potential harvest trees becomes even more evident if only trees assigned to log grades 1 and 2 are considered (Figure 8). The community forests are almost depleted of harvestable trees of high quality. In two of the four sites under community management, practically no trees will be available for harvest in the future, making sustainable production impossible without active interventions to restore commercial timber stock. Also, in the other two sites under community and private management, only a small number of commercial trees in log grades 1 and 2 are available, which substantially limits future timber utilization potential. In contrast, previous use in the sites managed under large concessions and periodic block system has not led to overuse. In these forests, a sufficient number of trees are available for future harvesting.

Figure 6. Volume distribution of harvest trees and commercial residual trees by DBH classes

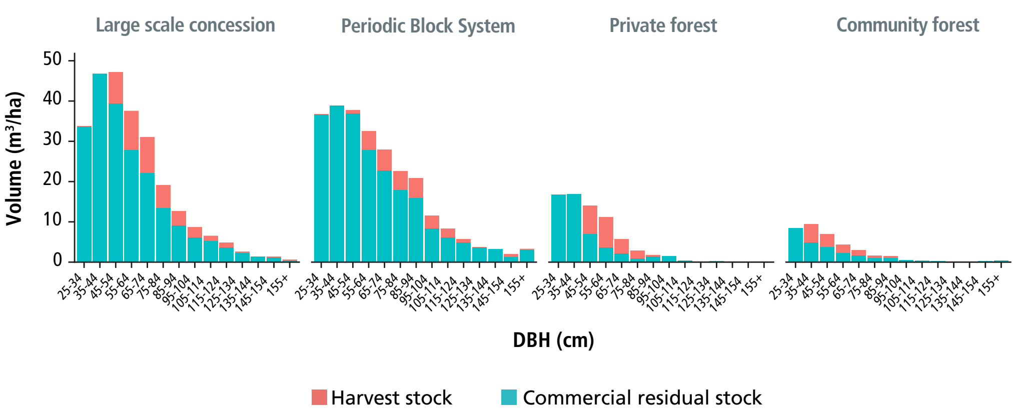


Figure 7. Spatial distribution of commercial trees in the test sites

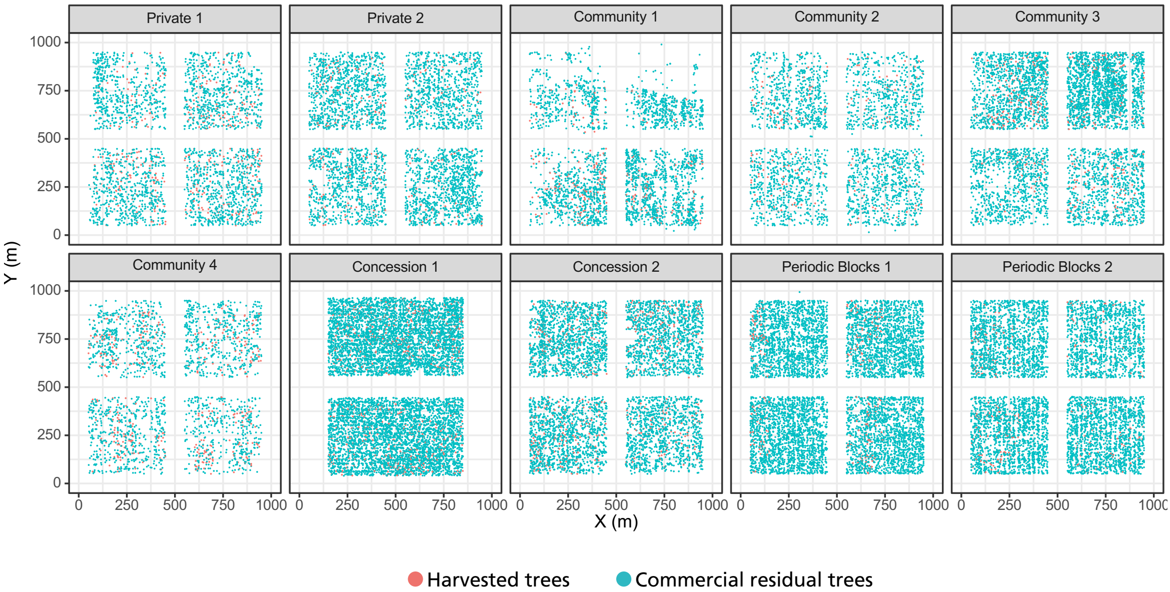
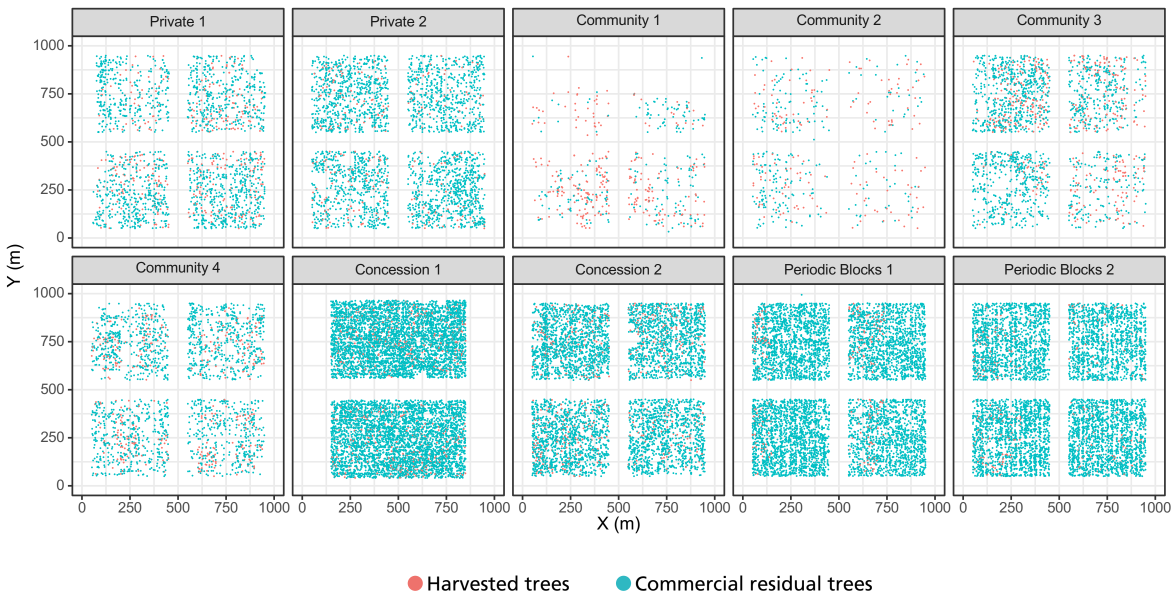


Figure 8. Spatial distribution of commercial trees with log grades 1 and 2



3.3 Impacts of past management and logging codes on sustainability

The large concessions are currently managed under a set of strict rules and a code of practice in which maximum logging volumes and felling cycles are clearly defined. This has not always been the case historically, but because of low harvest intensities in the past and rather long timespans without harvesting, the forest stands are relatively well-stocked. These forests can therefore support sustainable timber production into the future. However, it is questionable whether these general specifications of logging codes will ensure sustainable production of forests when applied across forest stands with very different stocking levels, historical use and site conditions.

Allowable cut should be defined in relation to the estimated volume increment of the forest stand, which depends on the site and stock conditions (species composition and population structure). Post-harvest recovery of timber volume over time is illustrated in Figure 9. The residual stand can reach the pre-harvest growing stock level within the specified felling cycle only if harvest intensity is low enough to leave behind sufficient stock of commercial species that can sustain growth. If the residual stand does not contain sufficient growing stock, harvest intensity must be reduced and recovery periods substantially lengthened.

Stand volume growth simulation presented in Figure 10 models the volume increment of commercial trees after harvesting and recovery time required under different annual diameter growth rate scenarios (1.6 mm/year; 2.7 mm/year; 4.5 mm/year) with assumed mortality rate of 1 percent (Gräfe *et al.,* 2020b). This analysis clearly shows that a general definition of maximum harvest volumes and intervention periods, as stipulated in logging codes, only ensures sustainable timber yield for well-stocked forests with relatively high growth rates of commercial trees. In other words, adherence to logging codes alone do not guarantee sustainable use. In order to ensure sustainability, harvesting intensity and frequency, as well as the growth rates, abundance and diameter structure of the commercial timber species, must be considered together.

Figure 9. Recovery of commercial timber volume after harvesting

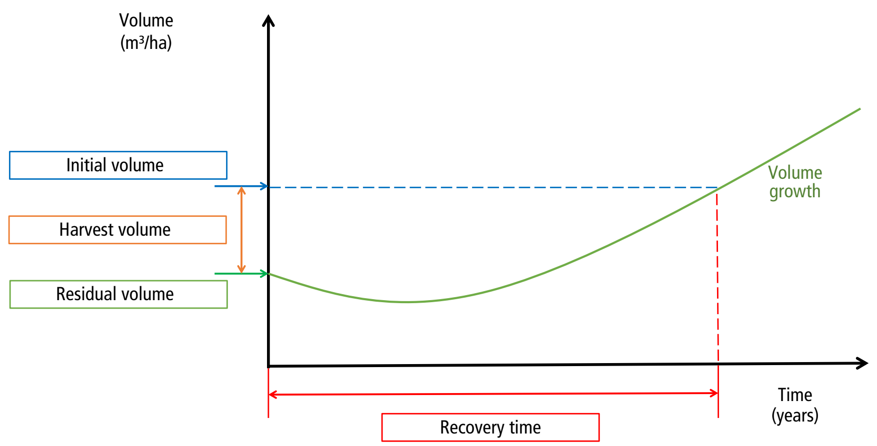
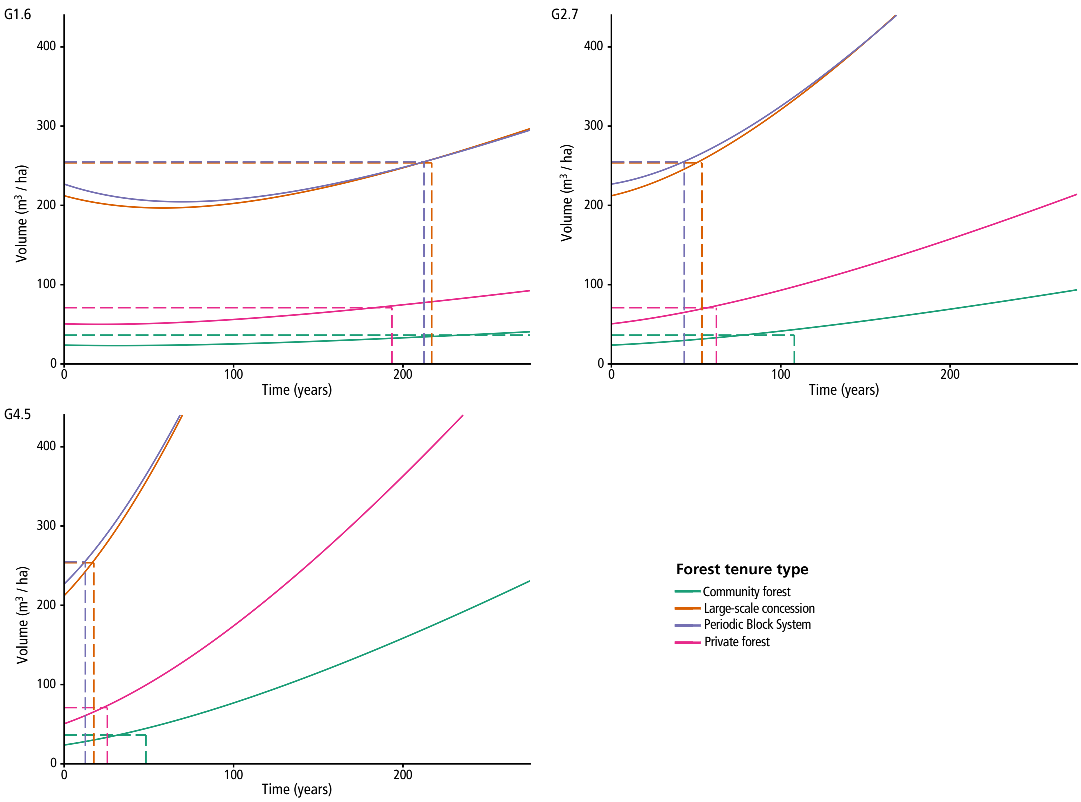


Figure 10. Volume growth of commercial trees under different diameter increment scenarios



Note: Dashed lines show the initial volume before harvesting and the time needed for the residual stand to reach the initial level again

Based on the result of these analyses, the felling cycle of 30 years commonly practised in the Caribbean will not ensure sustainable timber yield, considering the targeted harvesting of a few high-value species that typically exist in low densities with relative lack of regeneration. In contrast to the large-scale concessions studied, the management of community forests has been, and still is, largely unregulated. In the past, this has led to substantial logging, facilitated by the availability of access infrastructure created by large-scale concessions. As a result, these community forests contain significantly lower volume and fewer numbers of commercial timber species comprising mostly small-diameter individuals compared to large-scale concessions and periodic block system stands. Uncontrolled harvesting activities have degraded the community forest stands to a state from which they cannot naturally recover within practical time horizons. Available data do not give a clear indication of how much time without harvesting would be needed to ensure the recovery of the stands. What is clear is that the current management of these stands is not sustainable. These results indicate that community-based forest management in itself does not necessarily guarantee sustainability, in contradiction to some studies which consider community-based forest management to be a key instrument in assuring forest sustainability (Jafari *et al.,* 2018; Baral *et al.,* 2018; Ojha *et al.,* 2008).

Until 1988, the privately-owned forests analysed in this study were also subjected to uncontrolled use, aggravated by damage caused by hurricanes. A change in ownership resulted in change of management objective and practice, and the forest is now managed under strict guidelines. Despite the previously unregulated use and periodic disturbances by hurricanes, stocking volume has doubled in the last 30 years under current management. This is a result of successful application of adaptive management, which adjusts harvest volumes for individual stands based on pre-harvest inventory data. The long-term sustainability of this management practice remains to be proven through permanent sample plot data and careful monitoring.

3.4 Selection and protection of future crop trees

The ratio of harvested trees to the number of high-quality trees of the same group of species remaining in the residual stand is a good indicator of sustainability of current harvest. In Table 4, it is shown that the number of remaining commercial trees well exceeds the number of harvested trees in large-scale concessions, periodic block systems and privately-managed forest. Harvestable trees left for the next cutting cycle, together with the good quality trees expected to grow into higher diameter classes, will form the future harvest stock.

To ensure sustainability, it is important to select FCTs from the same list of species currently being harvested. Otherwise, the stand increment will shift from high-value timber to timber from less-desirable species. Even if the total timber volume from the previous harvest is being replenished, the management practice cannot be considered sustainable if the economic value and ecological integrity of the forest are being compromised. The harvest can be sustainable only if the same (or at least the group of) species remain present in the stand. This is important not only to ensure continued timber production but also for sustainability of the ecosystem.

The difference between the minimum cutting diameter and the current size of FCTs dictates how long a stand must be left to regrow until the next harvest. If forest inventory data exist, it would be ideal to develop specific growth models for each commercial species to estimate sustainable yield. MYRLIN, which stands for Methods of Yield Regulation with Limited Information, is a set of simple software tools designed to assist in yield regulation for natural tropical forest. FAO is currently working to improve the MYRLIN model, and the original version is available at www.myrlin.org. In selective logging systems, the high-value tree species represent the commercial value of the stand. Hence, their protection and development should be given priority.

Identifying and marking FCTs in the forest makes them visible to the forest manager and workers, and helps to focus attention on the future of the stand. The chainsaw operator can easily recognize them and try to save them from felling damage. The skidder operator can haul logs around them and protect them from being damaged by skidding. The marking of FCTs has an educational benefit for those working in the forest and will help to spread the message that a forest should be managed as a renewable resource and not as a quarry.

Marking a harvest tree in Suriname.

Within the scope of this project, funds were provided to cover the additional resources required to undertake the selection and marking FCTs. It started with the enumeration and mapping of all trees above 25 cm DBH, followed by preselection of FCTs based on the survey results, and concluded with field verification. For the field verification and final selection of FCTs, a team of three people needed an eight-hour working day to assess between 60 and 75 FCTs.

The identification and marking of FCTs represents an additional effort beyond normal logging operations. However, most codes of practice for forest harvesting require stock assessment and preparation of a stock map. A typical stock map only shows the trees to be harvested and their locations. To introduce the FCT concept, it is recommended to identify and mark one or two FCTs for each tree to be harvested.

The selection and identification of FCTs in the field will always be susceptible to a certain level of subjectivity. Nevertheless, those involved in logging operations can quickly learn to recognize suitable FCTs in the forest. Marking FCTs in the field will help to protect them during the harvest. Recoding and comparing the numbers and diameters of the trees to be harvested to the FCTs serves as an easy-to-use indicator to determine the sustainability of harvest. This is recommended as a standard practice for sustainable management of logged forests to maintain productivity and prevent further degradation.

4. ECONOMIC VIABILITY OF FUTURE CROP TREE RELEASE IN LOGGED FORESTS

An FCT is a tree that exhibits desirable quality characteristics to produce high-value timber and has the vitality to remain competitive for many years. FCT release is a silvicultural treatment aimed at increasing the growth rate of selected FCTs by expanding their growing space. This is achieved by reducing crown competition through the removal of competitor trees with crowns overtopping or touching those of FCTs (Figure 11). Such removals can be realized by girdling, applying arboricides or felling. Since girdling does not always lead to mortality of the treated trees and arboricides can be harmful to the environment, removal by felling was selected for this study. The competitors were felled by directional felling to avoid damaging the FCTs. The need for removing competitor trees was carefully considered to avoid unnecessary costs and minimize excessive canopy openings. Excessive canopy openings can lead to strong light exposure of the trunk and stimulate the formation of epicormic branches, increase the risk of storm damage, and promote the emergence of light-demanding pioneer vegetation. Removing only those competitors that limit light availably to the FCTs ensures that the additional growing space made available is quickly occupied by the FCTs, resulting in quick reclosure of the canopy to reduce the above-mentioned risks (Miller *et al.,* 2007).

The aim of the investigated silvicultural liberation treatment is to increase commercial timber production. However, the application of the treatment, including the cost of marking future crop and competing trees, incurs additional costs, which need to be amortized by additional revenues resulting from the increased timber production in order for the treatment to be profitable (Figure 12).

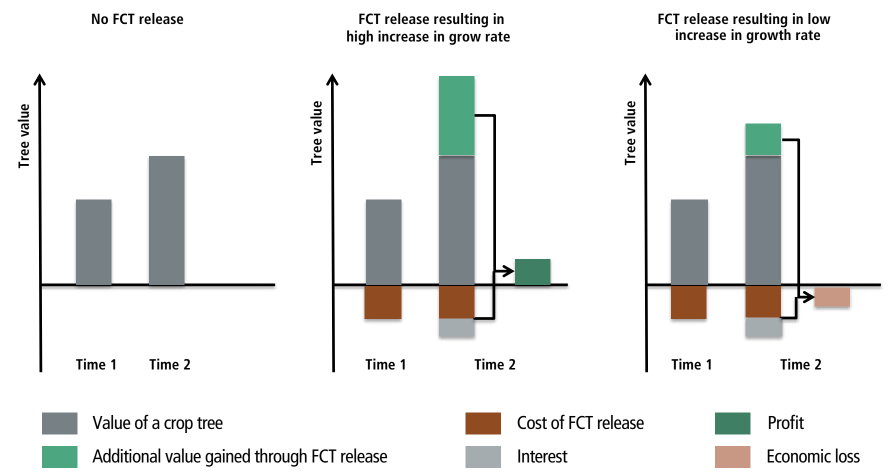
Gräfe *et al.,* (2020b) examined the economic feasibility of FCT release treatments based on empirical data collected from the test sites in Belize, Guyana, Suriname, and Trinidad and Tobago. A reverse approach based on net present values was used to determine the timber price and the additional growth needed to cover treatment costs.

In this study, silvicultural treatments were carried out parallel to regular timber harvesting, which removed half of the potential competitors at no additional cost. On average, about the same number of FCTs were identified as harvest trees, and only about half of the FCTs required removal of competitor trees in addition to regular harvesting to achieve a release. Without the regular harvesting, the number of competitors to be removed would have doubled. In a study in Amazonia for example, Wadsworth and Zweede (2006) removed on average around three competitors per FCT to achieve a sufficient release. In the study conducted by Gräfe *et al.* (2020b), an assumption of three competitors to be removed per FCT would have led to a doubling of treatment costs.

Figure 11. FCTs (with red canopies) and competing trees

Only the three FCTs on the right need to be released by removing the competitors.

Figure 12. Economic gains and losses through FCT release



Combining the treatment with regular timber harvesting or applying the treatment immediately after harvesting as a post-harvest measure can reduce the treatment cost.

The timber prices that must be achieved for the released FCTs to break even financially were in some cases above the prevailing Free On Board (FOB) timber prices in the region. Treatment in these cases would only be profitable if they focused exclusively on high-quality trees that could achieve high prices in the timber market. From the financial perspective, there are relatively high risks associated with investment in silvicultural treatments. Besides the general risks of biological production, the profitability of silvicultural treatments is dependent on future timber prices and the assumed discount rate. The choice of discount rate also reflects the uncertainties regarding expected costs, revenues and growth rates of trees. In addition, the origin and cost of the capital required for the treatments and the possibility of alternative investment opportunities may further influence the choice of discount rate.

For the silvicultural release treatments to be economically viable, the FCTs must respond to the release with increased growth and accumulate the required additional volume within the current felling cycle. Furthermore, the FCTs must be marketable and valuable at the time of future harvest, and the treatment and harvesting costs must be kept as low as possible.

To evaluate the profitability of a treatment, robust information on the abundance and population structure of commercial tree species, future timber prices, and harvesting and treatment costs is required. In addition, species-specific growth rates and the species-specific response to treatment must be known or estimated with certain accuracy for the particular site. For the growth rates, available data from growth studies and silvicultural experiments at comparable sites can be used.

In summary, liberating FCTs is a sound idea in principle, but under the current economic conditions, it is seldom profitable. However, in this study, only half of the selected FCTs required liberation beyond regular harvesting as

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Harvest tree surrounded by natural regeneration of commercial tree species.

the harvest tree and its "replacement" were often found growing in close proximity. This underscores the importance of identifying and protecting FCTs during felling operation using RIL practices, including directional felling.

5. IMPACT OF FUTURE CROP TREE RELEASE ON FOREST CARBON STOCKS

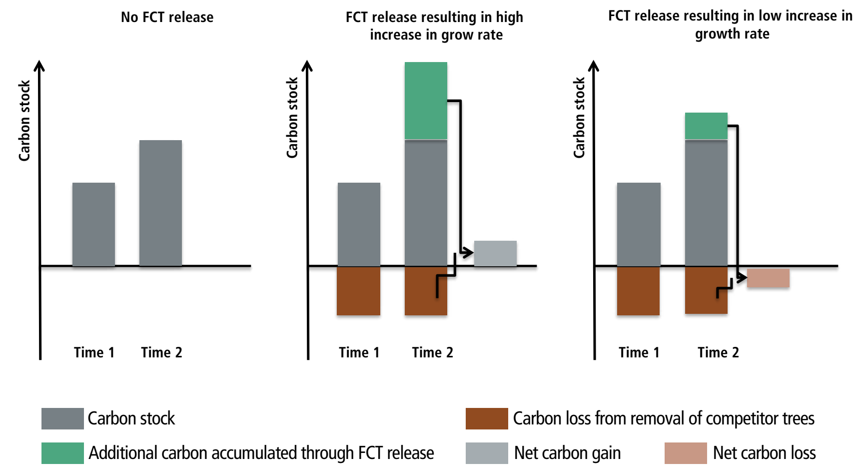
One of the aims of this study was to assess the potential applicability of FCT release to enhance productivity and reduce degradation as a REDD+ activity. The release of FCTs through the felling of competitor trees is intended to increase the growth of selected trees and thus enhance both productivity and carbon sequestration. On the other hand, the felling of competitor trees leads to a temporary reduction of forest carbon stocks. Net emission reductions would be achieved only at the point when the additional carbon sequestered by the accelerated growth of released trees exceeds the carbon loss from thinning (Figure 13).

Gräfe and Köhl (2020) estimated the time needed for the released trees to compensate for the carbon loss caused by the felling of competitor trees (most of which were left on the forest floor to decay) through increased growth of FCTs. Based on the data from the ten test sites in Belize, Guyana, Suriname, and Trinidad and Tobago, it was determined that it would take an average of 130 years or more to compensate for the carbon loss caused by the felling of the competitor trees with the assumed baseline diameter growth rate of 2.7 mm/year and a 30 percent increase in the annual growth rate of released FCTs (Figure 14).

Time required for recovery of biomass after thinning depends on a number of factors and assumptions, including the baseline growth rate of the released and removed trees, additional growth due to the release treatment, number of competitor trees removed, the comparative sizes of the removed trees versus the released FCTs, and how long the effect of release would last. Furthermore, partial opening of the canopy will not only benefit the targeted crop trees but also encourage natural regeneration and the growth of other suppressed trees in the understorey.

A study in tropical forests of Australia showed that 55 years are required for

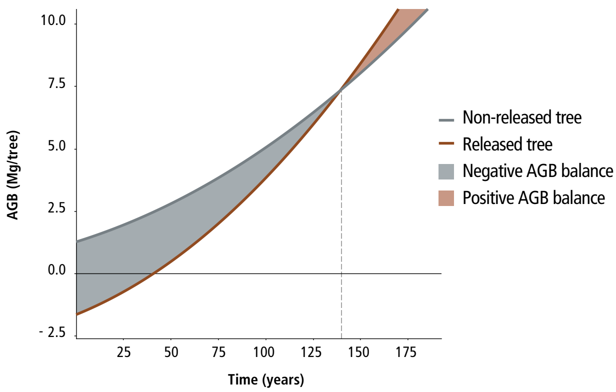
Figure 13. Carbon gains and losses from FCT release



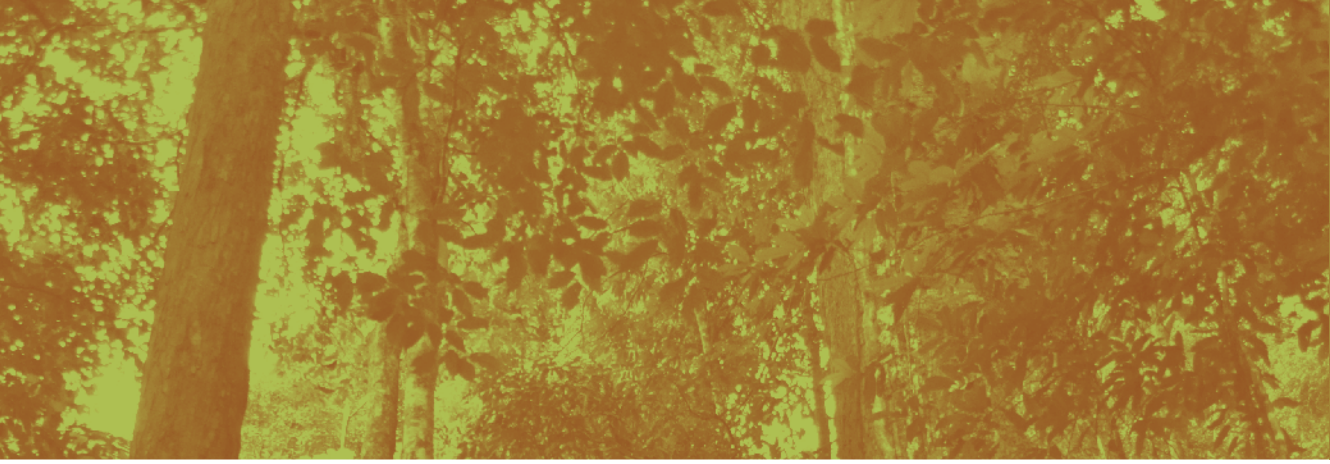
recovery of biomass after logging, which increases to 77 years for logging combined with thinning (Hu *et al.*, 2020). Even if we make an optimistic estimate using the higher end of values available in various studies as assumptions, it would still take 40 years for the additional biomass increment in the released FCTs to compensate for the removal of competitor trees provided that only one competitor trees, is removed per FCT. The estimate will be more than twice as long, at 85 years, if two competitor trees are removed for each released FCT.

Despite the dependency of the estimated time required for biomass recovery from silvicultural release treatment on various assumptions, it is apparent that even the most optimistic estimates are not compatible with the current REDD+ commitment periods (Nationally Determined Contributions are renewed every five years) or the typical duration of voluntary land use carbon projects. Limited availability of long-term monitoring data on how various forest management activities

Figure 14. Above-ground biomass (AGB) accumulation break-even point of a released and a non-released tree



impact forest carbon balance constrains the inclusion of specific SFM practices under national REDD+ strategies.
In this case, it was determined that releasing FCTs to increase the future value of the forest would not guarantee REDD+ results that could be financially rewarded, particularly within the timeframe of one harvesting rotation.



Tropical logging concession with large commercial trees remaining.

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Part 3: **GUIDELINES FOR LOGGED FOREST MANAGEMENT IN THE CARIBBEAN**

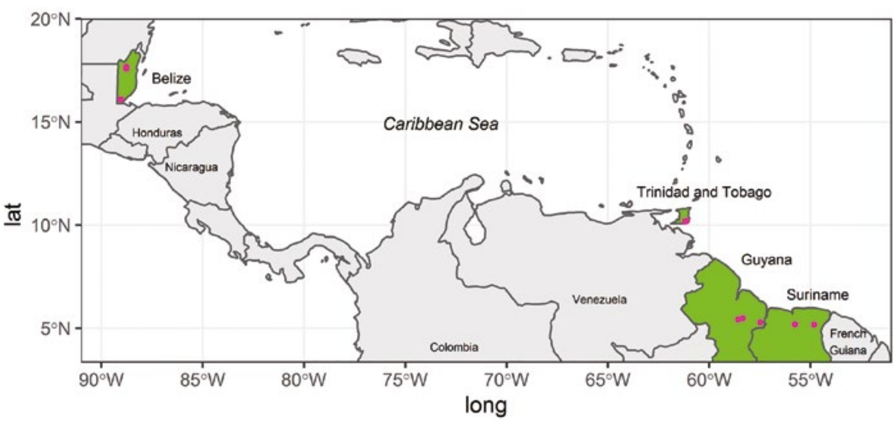
1. BACKGROUND

Lowland tropical forests around the Caribbean have been subjected to logging activities for centuries. The intensity of historical and current timber harvesting varies from country to country and, within countries, between different management regimes.
These forests constitute an important renewable forest resource, which can continue to provide quality timber and maintain the flow of ecosystem services if managed sustainably.

To support sustainable management of production forests in the Caribbean, the forest authorities of Belize, Guyana, Trinidad and Tobago, and Suriname, together with FAO and the University of Hamburg, World Forestry, Germany, have implemented the regional project "Ensuring Long-Term Productivity of Lowland Tropical Forests in the Caribbean."

Under the project, experiments were carried out on test sites covering an area of 1 000 ha to evaluate the sustainability of current forest harvesting practices, explore measures to prevent further degradation of these forests, and assess the viability of silvicultural treatments to enhance forest productivity. The results of these experiments were discussed

Figure 15. Project countries (green) and study sites (magenta)



Source: Gräfe and Köhl, 2020.

in several workshops by all partners involved. The present guidelines bring together the scientific findings and practical experience from the project to provide an easy-to-use reference for the planning and implementation of sustainable management of logged forests with a focus on maintaining future yield of commercial timber.

These guidelines focus on the fact that the trees currently growing in the forest stand are the future harvest trees and thus represent the future value of the forest, which should be protected in the course of forest management practice. The guidelines introduce the future crop tree (FCT) concept, which focuses on individual trees of commercially valuable species with good stem qualities to be harvested in future cutting cycles, and propose measures to protect them.

2. APPLICABILITY AND USE OF THIS GUIDELINE

These guidelines provide practical advice to forest managers for managing logged forests sustainably, which can be applied under wide-ranging circumstances. In most of these logged forests, previous harvesting has removed trees of the highest quality and value, typically leaving behind trees of potential commercial value but of smaller than marketable sizes at the time of harvest, or below the legally defined minimum cutting diameter.

The present guidelines recommend a silvicultural approach to safeguard the long-term production potential of logged forest and to support restoration activities where needed.

These guidelines are not intended as a guide for implementing reduced impact logging (RIL) or to address all aspects of SFM. For these questions, interested readers are referred to publications listed in the further reading section.

3. FUTURE CROP TREE CONCEPT

When planning and carrying out timber harvest, the viability of the next harvest must always be taken into consideration. This means that, in addition to current harvesting, measures must be taken to ensure that there are trees that can be harvested again in the future. At the centre of the silvicultral approach presented in these guidelines are valuable tree species, of good quality and vitality, but with stem diameters that are too small to be harvested today. These trees, referred to as FCTs, represent the future harvest and thus form the basis for the future value of the stand.

Summary of measures to protect FCTs:

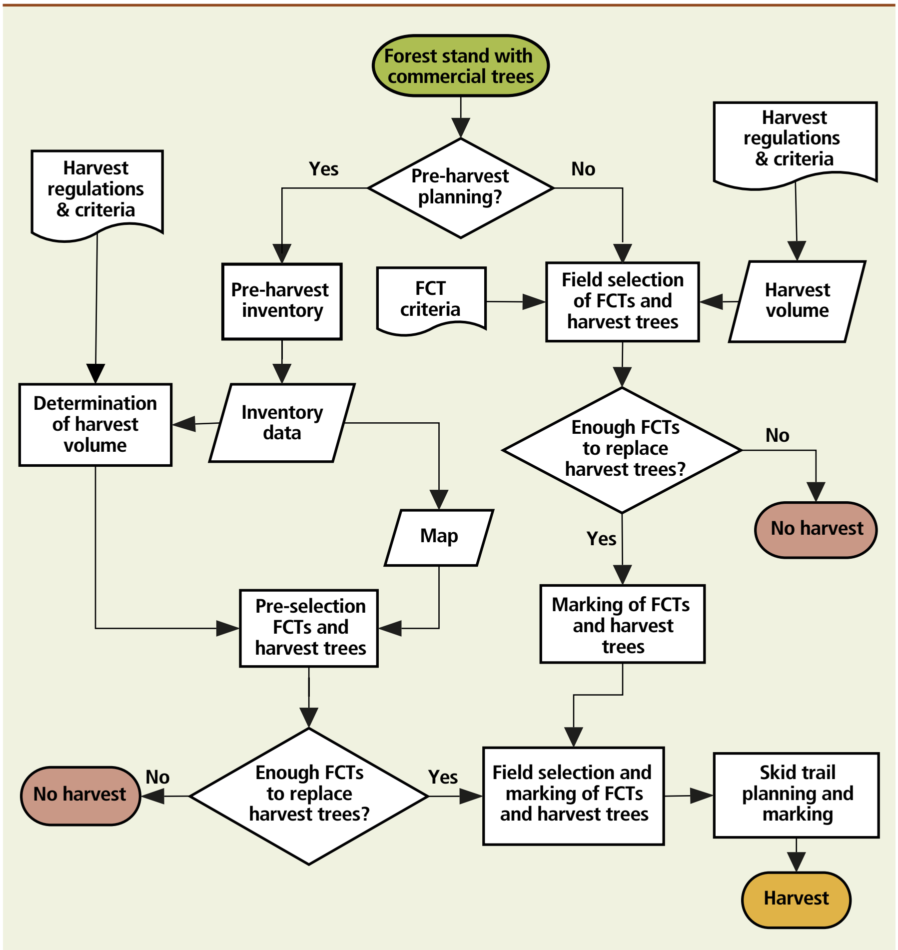
- Selection of a sufficient number of suitable trees as FCTs (based on size, vitality, log quality, and canopy social class)
- Permanent and clearly visible marking of FCTs
- Pre-harvest skid trail planning
- Direction felling
- Awareness raising and training of field crew

4. HARVESTING AND SILVICULTURAL OPERATION PROCESS

The following diagram (Figure 16) shows the decision-making process for the silvicultural practice presented here. It starts with a formerly logged forest that still contains marketable tree species. The new logging operation should be planned in advance so that it can be carried out as effectively and efficiently as possible. An important basis of pre-harvest planning is the pre-harvest inventory. Such an inventory provides the forest manager with an accurate and comprehensive understanding of the forest stand. The inventory results can be used to determine the harvestable tree volume and the composition of the remaining stand, thereby enabling forest manages to assess in advance whether logging would be profitable and whether enough trees would still be available after harvesting to grow into harvestable size class for the next felling cycle. The pre-harvest inventory data can also be used to create a tree position map, which simplifies orientation in the forest and enables the planning of skid trails.

If no pre-harvest planning occurs, the operation begins directly in the forest, with selection of which trees to harvest. In addition to the selection of trees for immediate harvest, the current guidelines recommend selection of trees for future harvesting which will help maintain the value of the forest stand over the long term. In order to ensure similar levels of future harvests, the number of harvested trees should not exceed the number of trees marked as FCTs. If there are not enough suitable FCTs, harvesting should be delayed until such time as a sufficient number of FCTs is available.

Figure 16. Harvesting and silvicultural operation process flow




©Michael Köhl

Mobile data logger being used in pre-harvest inventory, Suriname.

5. PRE-HARVEST PLANNING

Pre-harvest planning can help reduce the impact of harvesting on the forest. For example, skidding damage can be reduced by skid trail planning. Pre-harvest inventory data enable advance planning, and thus support efficient and smooth harvesting operations.

5.1 Pre-harvest inventory

Before harvesting, information on the current state of the forest should be collected through a pre-harvest inventory. The results of the pre-harvest inventory provide information on the spatial and diameter distribution of commercial tree species, their abundance, log qualities, standing volume, and site features. Rigorous intervention planning is only possible with the help of a complete pre-harvest inventory. Pre-harvest inventory makes it possible to determine the appropriate harvest intensity, the expected volume and the log qualities. It therefore serves as the basis for all further decisions.

5.1.1 Parameters measured in pre-harvest inventory

Usually, a pre-harvest inventory involves a 100 percent inventory of all trees that meet the species and size criteria over the entire management area. To keep the amount of work (and thus the costs) as low as possible, only commercial tree species are recorded. This should include current usable volume as well as the future commercial stand. Thus, the diameter threshold should be determined in such a way that trees expected to reach harvestable sizes in the next cutting cycle or two are also recorded. A practical example would be a diameter threshold of 25 cm.

In order to obtain useful results, the following parameters should be collected for each tree inventoried:

- Tree species
- Diameter (DBH)
- Log length
- Log quality
- Social class (crown class/position)
- Tree position (GPS coordinates)

In addition to the parameters mentioned above, site features such as water courses and ridges should be recorded. These features are important for the identification of areas to be conserved, buffer zones around them, and the planning of skid trails.

TREE SPECIES

For production purposes, tree species are categorized as either commercial or non-commercial species depending on their marketability. Commercial tree species are further divided into classes according to their market value. As high-value timber species become scarce, the market turns to lower-value species and lesser-known species, resulting in some species that previously had no commercial value becoming commercial tree species.

The inventory should always include all current commercial tree species. Recording of non-commercial tree species is not recommended due to the considerable additional effort involved.

LOG QUALITY

In order to estimate qualities and value of commercial timber, a uniform log grading system should be defined. Tree stems can be evaluated for quality according the defined log classification scheme, an example of which is presented in Table 5 below.

SOCIAL CLASS (Crown Class or Position)

Natural forests consist of trees of varied sizes and shapes whose canopies occupy different social classes. The larger, taller trees are those that have won

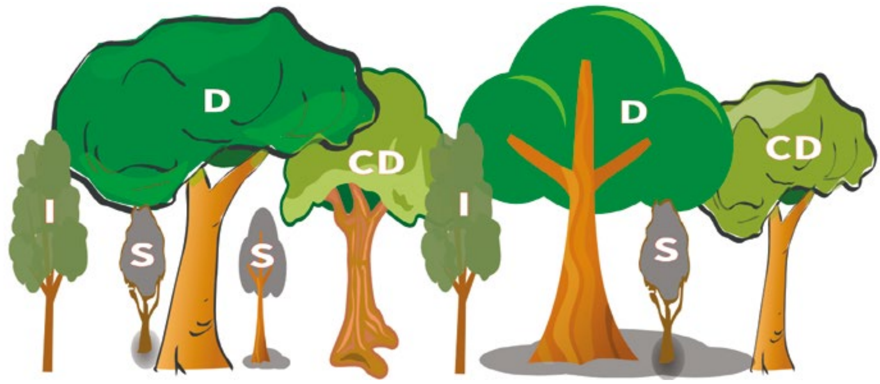
Table 5. Log grade classification

Options	Description	Log grade
High quality	Straight tree without visible damage due to fire, pests, diseases, animals, etc.	1
Medium quality	Tree with few defects or little damage due to fire, pests, diseases, animals, etc. Still merchantable.	2
Poor quality	Tree with several defects or much damage due to fire, pests, diseases, animals. Not merchantable due to defects.	3
Dead or dying standing tree	A tree is dead when none of its parts are alive (leaves, buds, cambium) at 1.3 m or above. A tree is dying if it shows damage that will surely lead to death. Not merchantable.	-

Table 6. Description canopy social classes

Canopy social class	Description
Dominant (D)	Crown extends above the general canopy layer; crown well developed and large; tree diameter usually among the largest in the stand
Co-dominant (CD)	Crown within and forming the main canopy of the stand; crown well developed, but only medium size and crowded at the sides; tree diameter among the upper range of those present, but not the largest
Intermediate (I)	Crown extends somewhat into the lower part of the main canopy; crown narrow and short, with limited leaf surface area; tree diameter in the middle to lower range of those present, but not necessarily the smallest
Suppressed (S)	Crown entirely below the main canopy and covered by the branches of taller trees; no direct sunlight; crown small, often lopsided, flat-topped and sparse; tree diameter among the smallest in the stand

Figure 17. Social classes of trees in a forest stand



D = dominant; CD = co-dominant; I = intermediate; S = suppressed

the competition for sunlight in the canopy. They are known as dominant or co-dominant trees. Trees that are overtopped by dominant or co-dominant trees are intermediate or suppressed and receive little direct sunlight (Figure 17).

The social class of a tree within the canopy largely determines its growth rate. Dominant and co-dominant trees produce the bulk of the growth increment in a forest. Many of the harvest trees will be selected from the dominant class, whereas most of the FCTs will be found in the co-dominant or strong intermediate class. The assessment and recording of social class of a tree during pre-harvest inventory is necessary to enable preselection of FCTs.

5.1.2 Analysis of the inventory data set

Pre-harvest inventory will produce an extensive data set, mostly consisting of individual tree data. The data set must then be analysed accordingly to derive useful information about the forest. From the individual tree data, parameters such as log volume per tree can be calculated. From these individual tree parameters, the stand parameters can then be calculated to obtain values per hectare or for the relevant forest stand.

INDIVIDUAL TREE VOLUME AND LOG VOLUME

Log volume is the usable stem volume (or the commercial volume) of a tree, which is a part of the total tree volume. The log volume is important for determining the commercial volume to be extracted. The log volume can be calculated from diameter or basal area, log length, and form factor as shown in the formula below. The form factor is estimated, taken from literature or determined from measurements on lying stems.

$$V_{log} = \pi * \frac{dbh^2}{4} * L * F$$

where: V_{log} = Log volume in m³
DBH = in metres
L = Log length in metres
F = Form factor (e.g. 0.6)

In order to determine the total volume of a tree, the total height is necessary in addition to the diameter or the basal area and the form factor. However, the total height is often difficult to determine in tropical forests where crown tops are rarely visible.

In the literature, there are different equations which can be used to estimate volume using only the diameter (e.g. Alder and van Kuijk, 2009):

$$V = 0.0005107 * dbh^{2.2055}$$

VOLUME PER HARVEST AREA

The sum of all individual tree volumes gives the volume for the entire forest stand.

VOLUME PER HECTARE

Forest stand parameters are calculated on per-unit area (usually in ha) basis to produce a comparable reference value. The sum of individual tree values (e.g. log volume or number of stems) is divided by the area of the forest stand to calculate the average per-hectare values as shown in example below.

5.2 **Mapping**

A map of all recorded trees can be created using tree positions recorded with a GPS unit during the inventory. If the inventory data were recorded in or have been converted into digital format, they can be linked as attributes to trees on the map. Other site features can also be integrated into the map, for example, to visualize buffer zones or to plan skid trails. If there is minimum distance regulation between harvest trees, these can be placed as circular buffer zones around the harvest trees, making it immediately clear which trees cannot be harvested. Using a geographic information system (GIS) software, maps can be analysed and designed as required. These maps also enable the field crews to work more effectively and efficiently in the forest. Figures 19 and 20 show an example of such a tree location map.

Harvest area = 50 ha
Volume per harvest area = 1 500 m^3 (sum of individual tree volumes)
Volume per hectare = volume per harvest area / harvest area
= 1 500 m^3 / 50 ha = 30 m^3 per ha

When evaluating the stand, it is important to consider the stand volume in relation to species classes, log grades and diameter classes. This allows for determination of the current harvestable volume, volume of the residual stand after harvest, and future harvest volume by applying selected harvest criteria (e.g. MCD ≥ 50 cm, log grade 1, species class A).

5.1.3 Stand structure and ecological state

Inventory parameters such as tree species, diameter and social class can be analysed to understand the population structure, abundance, distribution, diversity and health of commercial timber species, which often play key roles in maintaining forest ecological processes.

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Evaluation of a commercial timber stand.

5.3 Preselection of future crop trees and harvest trees

The present guidelines aim to support the long-term preservation of the economic value of the forest. This can be achieved through the careful selection and protection of FCTs. To ensure sustainability, only as much should be taken from the forest as can be replenished within the felling cycle. In other words, the number of harvested trees should never exceed the number of FCTs. Considering natural mortality and increased mortality as a result of logging, the ideal ratio of FCTs to harvest trees is 2:1 (i.e. harvest half as many trees as are identified as FCTs).

5.3.1 Characteristics of a future crop tree

The FCT concept focuses on what will be available for harvest in the future, in either the next or the subsequent cutting cycles. Desirable characteristics of an FCP are described below.

SPECIES

FCTs should be of species with high commercial value in the current timber market. Most countries have a classification system to categorize commercial timber species into different classes depending on their commercial value and merchantability. FCTs should be listed among the highest- or higher-value species. It should also be kept in mind that market value and demand for timber species may change in the future, particularly as high-value timber species become scarcer, and accordingly species can move from a lower to a higher value classification.

CROWN POSITION/SOCIAL CLASS

FCTs must be able to compete successfully with other trees in the forest after logging intervention to grow into harvestable size class during the rotation period. Therefore, FCTs should have canopies in the dominant, co-dominant, or strong intermediate crown position.

STEM FORM AND LOG QUALITY

The stems of FCTs should be straight, without forks, and free of defects and visible damages.

VITALITY AND HEALTH

FCTs should be of good health and vitality, free of visible diseases.

DISTRIBUTION

FCTs should not all be concentrated in the "good quality" area of the forest. Ideally, FCTs should be evenly distributed across the forest stand, although their relative quality may differ, i.e. the "good quality" area of the forest may have FCTs with longer log lengths, larger diameters and more dominant canopy positions.

5.3.2 Preselection of future crop trees

If pre-harvest inventory has been carried out, an initial preselection of FCT candidates can be made based on the inventory data. The recorded data are filtered according to FCT criteria. Upper diameter limit of FCTs should be below the minimum cutting diameter so that potential harvest trees are not considered in the FCT preselection. With a minimum cutting diameter of 50 cm, the diameter range for FCT selection would be 25 to 49 cm. The result of preselection should be digitized on a map.

5.3.3 Preselection of harvest trees

As mentioned above, the number of harvest trees will be determined by the number of identified FCTs. A ratio of 2:1 (FCT: harvest tree) is recommended as some of the preselected FCTs may need to be excluded upon verification in the field. Harvest trees should be identified in the same stand as the FCTs.

Figure 18. Example of harvest and future crop tree pre-selection

Harvest tree criteria:
- DBH ≥ 60 cm
- Species class A or B
- Log grade 1 or 2

FCT criteria:
- DBH ≥ 25 cm
- Species class A or B
- Log quality 1 or 2
- Canopy social class: dominant or co-dominant

Tree No	Species class	DBH (cm)	Canopy social Class	Log grade	Pre-selection result	Justification for the selection
1	C	30	Suppressed	1		
2	A	50	Co-dominant	1	Future crop	Valuable species with very good log quality, but diameter too small for harvest currently. Canopy social class is co-dominant. Qualifies as FCT.
3	A	30	Suppressed	2		
4	B	35	Intermediate	3		
5	C	30	Suppressed	2		
6	A	60	Dominant	1	Harvest	Fulfils all criteria for a harvest tree.
7	A	25	Suppressed	1		
8	C	40	Intermediate	2		
9	A	45	Co-dominant	3		
10	C	30	Suppressed	2		
11	A	40	Intermediate	1		
12	B	25	Suppressed	2		
13	B	60	Dominant	1	Future crop	This tree would qualify as a harvest tree. However, to keep the ratio of FCT:Harvest tree of 2:1, it is pre-selected as an FCT.
14	A	30	Suppressed	1		

5.4 **Field selection and marking of future crop trees**

The final selection of FCTs and harvest trees takes place in the forest. To ensure long-term sustainability of yield and the use of the entire forest area, it is important that FCTs are located in the same harvesting block as the trees to be removed. Compensating harvest trees with FCTs from a better-stocked area of the forest may not provide the same benefit.

5.4.1 Field selection after preselection

Each tree preselected as an FCT based on inventory data is visited in the field to verify that the actual conditions match the selection criteria (i.e. species, crown position, vitality and form). A ratio of at least 1:1, preferably 2:1, of FCTs to harvest trees should be maintained after the final determination.

©Sebastian Gräfe

Field selection and verification of a harvest tree (left) and a future crop tree (right) in the forest.

©Sebastian Gräfe

Harvest tree marked with red "x" and future crop tree marked with single white circle in Suriname.

5.4.2 Field selection without preselection

If pre-harvest inventory has not been carried out, FCTs are identified directly in the field. The selection takes place together with the selection of harvest trees. Whenever a tree is selected for harvesting, at least one, preferably two, FCTs should be identified in the same stand.

5.4.3 Marking of selected trees

FCTs should be marked at the same time the final selection is made in the field. The marking should be permanent and clearly visible from all sides. Marking FCTs in the forest makes them visible to the forest manager and field crew so that they can avoid damaging the FCTs. It also draws their attention to and raises awareness of sustainability, as the future economic value of the forest becomes clearly visible in the form of FCTs.

5.5 **Skid trail planning**

After the preselection of FCTs and harvest trees has been completed, a pre-harvest planning of skid trails should be carried out. In order to avoid skidding damage to the FCTs, skid trails should be routed around the FCTs at some distance, preferably with some buffer trees between the skid trail and the FCT.

Figure 19 shows a forest stock map with skid trails planned without consideration of FCT protection. On the other hand, Figure 20 presents the same forest stock map with optimized skid trail layout. In this map, care has been taken to ensure that the skid trails are located as far away from the FCTs as possible. Nevertheless, all harvest trees need to be reached and the total skid trail length should be kept as short as possible to minimize soil disturbance and other impacts to the residual stand.

6. FIELD MEASURES TO PROTECT AND ENHANCE FUTURE CROP TREES

Forest managers and workers must be made aware of the importance of FCTs, and all work in the forest should be carried out with care to avoid causing any unnecessary damage or negative impacts to the FCTs.

Sound implementation of RIL and compliance with national and regional codes of practice for forest harvesting can reduce environmental impacts of harvesting operations, and measures such as directional felling and pre-planning of skid trails are standard best practice. Recommendations presented here are additional considerations to ensure protection of marked FCTs.

6.1 **Directional felling**

Felling damage caused by trees falling to the ground or hangers (or hung-up trees) on the FCTs must be avoided through directional felling so that the harvest trees fall away from the FCTs.

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Skid road (left) and skid trail (right) in Suriname.

Figure 19. Forest stock map with normal skid trail planning

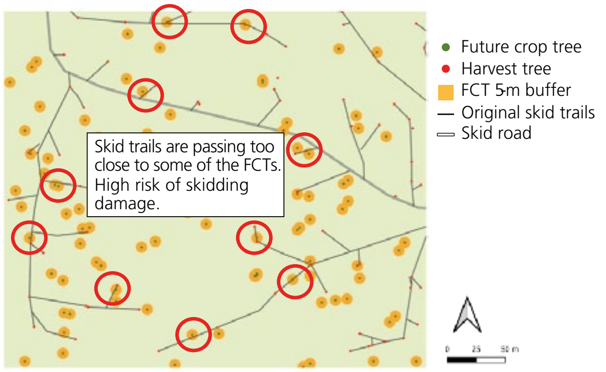
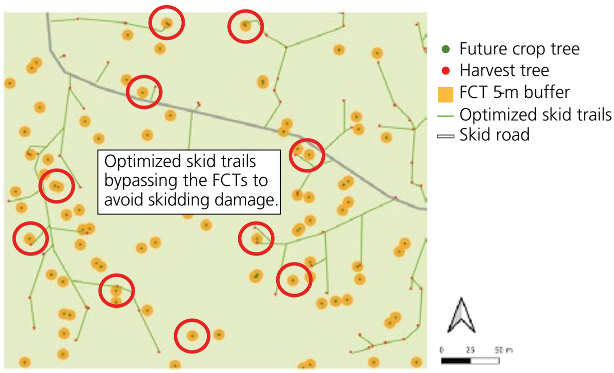


Figure 20. Forest stock map with optimized skid trail planning



Consistent and sound application of this technique requires appropriate training and sensitization of the chainsaw operators including on occupational safety and environmental awareness.

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White marking on the stem indicating the felling direction.

6.2 Skidding

Skidders should bypass the FCTs amply (5 metres or more) to avoid skidding damage to the trunk and roots. In order to minimize the risk of skidding damage, the skid trails should be planned at a sufficient distance from the FCTs. Planned skid trails should be clearly marked in the field, and the skidder driver must be instructed to strictly follow the marked skid trail route.

6.3 Silvicultural treatments

Following the identification, marking and protection of FCTs, the next logical step is the liberation or the release of FCTs. By removing their main competitors, FCTs are given more growing space in the canopy, which in turn stimulates their growth. Many FCTs can be liberated as a result of regular felling of harvest trees. However, there are usually many trees left which could benefit from such a release treatment.

Felling the competitors in combination with an ongoing harvest is a practical way of implementing the

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A skidder working in the forest.


©Sebastian Gräfe

Skidding damage on a residual tree.

treatment. However, as this entails additional effort, time and cost, which may or may not be compensated through the increased yield of commercial timber in the future, most concession holders would not be inclined to invest in this silvicultural treatment. Even if such an investment could potentially be economically profitable in cases where timber prices are high and labour costs are low, the time horizon may be perceived to be too long and the associated risks too high to make it a sensible investment. There are, however, certain scenarios under which such an investment in silvicultural release could make sense. One example would be the case of mahogany in Belize.

Another possible scenario for investing in the liberation of FCTs is in economically impoverished forests as an alternative to enrichment planting. Compared to the investment required to plant and maintain tree seedlings under the canopy of a degraded forest, it is far more economical to actively search for trees with the potential to produce high-value commercial timber and to liberate them. These trees, although small now and suppressed under the canopy of other trees, managed to establish naturally in the forest. They have survived the phase of highest mortality and were able to occupy sufficient growing space to survive. Most likely, these trees will respond positively to the availability of additional growing space and will grow faster if their competitors are removed. Even if FCTs are only found every 15 m to 20 m on average, it would still mean that there are 25 to 45 FCTs per hectare. Although these numbers may appear low, this amount of FCTs would restore the original productivity of most natural forest to a level prior to the beginning of selective logging.

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