Harvesting Process

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Abstract

The harvesting process consists in the mission to get the tree from the forest site to a wood processing mill. Forest harvesting refers to cutting and delivering trees in a productive, safe, economic, and ecological process. It includes the conversion of trees into merchantable raw material according to specific industrial or individual requirements and needs. In general, the wood passes through several processing steps before it can be transported. The most important operations are felling, delimbing, debarking, bucking, chipping, wood extraction, piling, loading, and wood transport. Depending on the qualitative demand, environmental and social restrictions, technological know-how, and access to technologies, some of the steps might be skipped. Also, the sequence of the processing may vary, going that far that the full tree is transported and processed at a central log yard. In the tropics, a variety of forest ecosystems can be found. From dry savanna to evergreen tropical rainforests, big differences exist in biodiversity, wood volume produced per area, soils, and climate. No matter what forest ecosystem is intended to be managed, they are all very sensitive and may be easily degraded or destroyed. On the other hand, there are many tropical regions with climatic conditions favorable to tree growth. It has to be differentiated between native tropical forests, generally managed in form of exploitation, and intensively managed forest plantations. While selective logging in native forests has to be done extremely careful considering many restrictions concerning mechanization of the harvesting process, in forest plantation in general, high volumes are produced in short rotations and harvested in fully mechanized clear-cuts, because soil disturbance can be corrected before new planting. Forest harvesting has the highest ecologic and economic impact of all forest operations. It has to be thoroughly planned and executed to avoid damages on the ecosystem and putting at risk sustainability issues of the forest-wood chain. Planning of harvesting occurs in several planning levels, starting from a macroscale considering the general issues like volumes and areas, forest access, or transport up to an individual microscale planning on the single stand. The base of all planning is detailed inventories, consisting of quantitative and qualitative data of natural resources, road systems, technologies available, and logistic capacity of the company or forest owner. With these databases and a geographical information system, powerful planning tools might be developed for optimizing harvesting and transport operations. One of the most important steps concerning harvesting is cost planning of machine and labor cost. In general, wood harvesting is a very labor- and machine-intensive activity. Depending on the wood utilization, in this planning step, the cost calculation often shows that the harvesting operation is too expensive and can’t be conducted in an economic feasible way. At least, the forest road system or other transport means have to be carefully evaluated and planned, too. Transport distance and infrastructure are key issues in harvesting planning. This chapter aims to give an overview about the important issues to consider for the harvest process and highlights how complex the overall harvesting operations are.

Keywords
Harvesting process • Harvesting operations • Harvesting planning • Forest plantation • Native forest • Wood transport

Introduction

Forest harvesting refers to cutting and delivering trees in a productive, safe, economic, and ecological way. It includes the conversion of trees into merchantable raw material according to specific industrial or individual requirements and needs. Wood harvesting has become an important science and operational factor all over the world in the last decades. In the framework of sustainable forest management, it is one of the key issues where the human impact on nature and forest ecosystems can be reduced (Dietz et al. 1984).

Specifically in tropical countries, the forest ecosystems are very sensitive to any kind of human intervention (Jordan 1985). In native tropical forest as well as in tropical and subtropical forest plantations, the principles of reduced impact logging (RIL) are regarded as the most critical factor for economic, ecologic, and social sustainability (Bacha and Rodriguez 2005; Boxmann et al. 1985). Most of the negative image of tropical forest management comes from inappropriate harvesting methods with catastrophic environmental impact. Conventional logging systems did not take into consideration any sustainability matter, since the objective was always to make fast money and move on to the next exploitation site. In a long term, careful planning of harvesting operations can reduce costs, avoid environmental degradation, improve the utilization of the natural resources, and prevent the injury to personnel (McEvoy 2004).

This chapter focuses on the harvesting process, which mainly consists of a critical evaluation of the natural conditions and the production target as well as definition of the single operational steps and the subsequent planning of the harvesting operations.

As already mentioned, the forest harvesting process is focused on providing processed wood at the forest road for further transporting. The harvesting process consists of several steps that have to be executed before the assortments are piled for transportation at forest road or other products (for instance, chips) are loaded (Machado 2014).

The main process steps in harvesting are:

- Felling – cutting down the trees
- Delimbing – cutting off the branches
- Debarking – taking off the bark from felled trees or stems
- Bucking – sectioning the stems of felled trees into transportable length according to the final use of the wood
- Hauling – off-road transport of whole trees or stem sections for further processing in the forest or further transportation
- Piling – preparing of the assortments for loading on a landing zone or forest road

For the planning process, the **infrastructure** and **logistics** are also of high importance, because they have direct impact on the technical and economic feasibility of the harvesting operation. The existing infrastructure and road system of a forest area determine in a wide range the technical possibilities of loading and further transport and therefore are included in this chapter.

Planning of the Harvesting Process

General Issues

Forests in the tropics are manifold and heterogeneous, due to the climatic and topographic variations found in the latitude of 21° south and north of the equator (Young and Giese 2003). There exist several classifications in literature, mainly based on the precipitation regime predominant in the region and if the forests are temporarily, always, or never flooded (Lamprecht 1986). For selection of the most adequate harvesting system, the quantity and distribution of the rainfall over the year and also the fact if the forests are partially or completely flooded throughout the year are of importance (Evans 2001).

Rainfall is influencing on the soil compression in the forest stands during harvesting operations, whether machines or animals are used. It also influences on trafficability of forest roads and has impacts on the choice of the wood transport in a general sense (Hakkila et al. 1992).

In wet evergreen forests (rainforests), restrictions may be given through the bearing load of the different soil types under humid and dry conditions. Under certain circumstances, it might be advisable to stop all harvesting or transport operations during this period. In seasonally wet forests, it might be useful to concentrate harvesting operations on dry seasons to reduce damages in the ecosystem. In dry and wet savanna forests, the choice of the appropriated harvesting system might be influenced by the high risk of forest fires. In temporarily or permanently flooded forests, harvesting and wood hauling and transport are determined by the flooding regime. Felling of the trees is easier when done under dry conditions, while for wood hauling or transport, the water can be used. There are innumerous combinations of factors that have to be considered in harvesting and transport planning besides the existing legal and technical restrictions (FAO 1993, 1999).

Native Forests

Logging operations in native forests are much more complex than in forest plantations. In primary tropical forests, there is a relatively low volume of merchantable wood per hectare available, forest structure is highly complex, and the ecosystem is extremely sensitive to all kinds of disturbance (Higuchi et al. 1994). In many cases, harvesting in such forests is a pure exploitation of the natural resources. Only where enrichment planting or other silvicultural measures are taking place, the forests become more homogeneous and provide higher increment of commercial volume per area unit (Higman et al. 2005).

In many tropical countries, the predominant use of the forest is linked to forest concessions, where the government allows the utilization of the wood of a given area, in change for a fee paid by the logging company. Depending on the rules and regulations, the monitoring, and controlling, the utilization of the natural resources is sustainable or not. Where logging companies have no restrictions to consider, the concession system may lead to a more devastating utilization of the forests, since the planning intensity on the management unit is low and the mentality is focused on a short-term profit system (Machfudh et al. 2001). The forest utilization is based on the so-called principles of “conventional logging.” Conventional logging is considered to be more impacting on the ecosystem, since it is based on a singular use of the forest. The intensity of the logging operations is high; wood volume extraction per hectare is beyond the sustainable productivity of the forests (Noack and Scharai-Rad 1992). Coordination between the teams responsible for felling and skidding is low or not existing; the forest workers are not trained and cause high damages during logging operations. The consequences are degradation of the forests, in the best case a succession leading to a secondary forest, and in the worst case a permanent devastation of the ecosystem (Chomitz and Gray 1996). The loss of forest cover increases the risk of fire; the insolation and the high quantity of dry biomass provide favorable conditions for burning the area. In many cases, the consequences are other types of land use, such as agriculture and cattle breeding, which might not be sustainable in a long term; in any case, a loss of biodiversity, soil fertility, and erosion have to be taken into account. Since the logging company in such a system has no long-term commitment concerning the forest area and local population, they are not interested in a sustainable use of the land. Starting from this situation, the principles of “reduced impact logging” have been developed (Dykstra and Heinrich 1996). The goal of these principles is to reduce negative ecological and social impact of industrial logging operations (Dykstra 2005). Damages on the remaining forest and the soil can be avoided by applying appropriated harvesting technologies (Sessions and Heinrich 1993). The reduction of unwanted by-fellings and damages caused on falling trees as well as training of the forest workers and machine operators improves the yield rate and therefore the economic output, besides providing the option of a long-term forest utilization over several rotation cycles (Sist et al. 2003; Sist and Nguyen-Thé 2002). One of the most important factors of reduced impact logging is the preharvest inventory. This inventory provides the data for the harvesting planning, including the selection of a low-impact harvesting system, training of staff and machine operators, opening of the forest roads and the skidding trails, volumes to be harvested, and rotation cycles. The postharvest assessment provides the necessary data for the controlling of the impact of the intervention (Supryatno and Becker 1998).

Comparison between reduced impact logging and conventional logging showed a considerable reduction in damages on the remaining forest (40–50 %) and less soil compaction. Technologies and machines used for harvesting are much better adapted to forest conditions (Huth et al. 2005). On a short-term observation, reduced impact logging is more expensive, if the damages on the forest ecosystem and the loss of productivity are not taken into account and only the operational costs are considered. Observing the full costs, including the better regeneration of the forests, improved growth and value of the remaining trees, and higher recovery rates, reduced impact logging is more competitive in an economic and social way (Holmes et al. 2002). The principles of reduced impact logging are nowadays constantly improved by research and newer technologies and frequently implemented in legislation and certification processes of native forest management (FAO 2003).

Planted Forests

The situation found in planted forests is much more controlled and minted by long-term strategic planning (van Bodegom et al. 2008). Unlike the case in many native tropical forests, the forest companies producing wood in planted forests are the owners of the land and pretend to maintain or even improve productivity of their land. The system is not based on exploitation of natural forests, but on a competitive production of renewable resources comparable to agricultural land use (Hillis and Brown 1984). To reach economic sustainability, the forests have to be managed and harvested after the best practices, applying newest technologies. Ecology and social aspects can be much better controlled in planted forests. On the one hand, the products based on wood grown in industrial plantations are sold on international markets that require ecologic and social correct production of the raw material used in the chain of custody. On the other hand, the forest companies are much easier to control and check by governmental authorities. Therefore, the principles of reduced impact logging, particularly intense planning, all wood production, and harvesting processes, have much longer to be implemented in forest plantation management (Nutto 2007).

In terms of harvesting planning and execution, planted forests offer many advantages compared to native forests. The volumes produced per management are much higher. While in native forests between 0.7 and 2.5 m^3/ha/year of commercial volume can be produced, in planted tropical forests this value ranges between 15 and 60 m^3/ha/year (Toit 2008). Besides the higher productivity, also the quality and dimension of the produced wood are more homogeneous. In monocultures, only one or two assortments of one species have to be produced in the harvesting process; in native forests the products are manifold with a low harvesting intensity per unit. In planted forests clear-cuts with volumes between 200 and 350 m^3/ha every 5–7 years are quite common; in native forests the limits range between 20 and 30 m^3/ha every 30 years in a selective logging process. In intensively managed forests, the expenses for infrastructure and logistics may be higher, since the return on the investment is shorter and higher. In planted forests, intense mechanization of harvesting is possible, since soil damages can be compensated by ripping, plowing, or fertilization. This is only possible in clear-cut systems, while target diameter logging of single trees does not allow such forest operations.

All these factors allow a more efficient management and planning of plantation forestry that differ in many ways from the native tropical forest exploitation.

Planning of Forest Harvesting Operations

Harvesting planning has to follow the three principles of sustainability: technically practicable, economically feasible, and environmentally acceptable. Only by considering these facts a harvesting operation can be successful at the long run. According to the FAO Code of Practice for Forest Harvesting in Asia-Pacific (1999), the objectives of the planning are (FAO 1999):

- To develop comprehensive strategic and operational planning mechanisms that ensure that forest values will be protected during harvesting
- To ensure responsible use of land and forest resources for the maximum benefit of all stakeholders
- To develop plans that take into account the socioeconomic and environmental impacts on the area
- To provide for efficient and environmentally responsible means of harvesting timber

Tropical forests in many cases show unique ecological factors that have to be considered in the planning. Climate, soils, species composition, and topography often are much more sensitive to handle than in temperate or boreal zones. On the other hand, also infrastructure and social conditions make careful planning of all operations necessary in order to provide acceptable working conditions for forest workers.

The edaphic factors in the tropics have to be considered as critical because of the wet conditions often found in these regions. **Soils** rich in clay and loam are highly susceptible to soil compaction under wet conditions; they offer low traction for wheel-based machines and are prone to erosion if exposed to rainfall. This leads to restrictions for harvesting, where operations are restricted to dry seasons or cost-intensive measures have to be taken in road construction. Pure sandy soils on the other hand are difficult for wheel-based machines if they are very dry, often making it necessary to irrigate for the machines not to get stuck. Both soil types lead to restrictions in the machine combinations that might be used and the period during the year where harvesting operations can be performed (Bygden et al. 2004; Fenner 1996; Heinimann 1997).

Topography in the tropics plays a more important role than in temperated zones. The terrain often consists in steep and short hills which make felling and off-road transport of wood more difficult. As a consequence, productivity is low, costs are very high, and the risk of erosion is omnipresent. In flat terrain, the problem often consists in poor water drainage, leading to seasonal restrictions of road-based harvesting systems.

High yearly **rainfall** in many cases is a limiting factor for harvesting operations. Strong and heavy seasonal precipitation throughout the years makes careful planning to a premise for successful felling and skidding necessary. Periodical restrictions intensify costs for forest operations and/or reduce productivity, while the offer of raw material for the wood industry may be restricted to a few months in the year. Very wet conditions are also difficult for wood storage in the field because of high risk of decomposition (bacteria, fungi) and increasing transport weight of soaked wood (Machado 2014).

Tropical forests in general are **rich in species,** which only are available in a low volume of wood per harvesting unit. The heterogeneous species composition in many cases makes the formation of assortments at harvesting operations extremely difficult. Continuous delivery of merchantable volumes for the wood industry can only be reached in cost-intensive bucking and classifying processes. At the felling, trees with big crowns often lead to unwanted by-fellings of other trees of the understory or future crop trees. Buttresses make difficult motor-manual felling operations and may lead to a high percentage of harvesting residues, resulting in low recovery rates. In tropical forest plantations, the figure is quite different. **Monocultures** provide high growth rates and homogeneous material in a continuous way, but they are associated with high environmental and economic risks. The harvesting operations on the other hand are easier to perform because of regular spacing, homogeneous diameters and tree heights, and similar assortments that may be produced. The trend here is clearly a completely mechanized harvesting of different machine combinations.

Road infrastructure in many tropical countries is a clearly limiting factor for forest management and harvesting operations. The remaining tropical forests in many cases are far away from the industrial centers and rarely connected to an acceptable road system. Roads are expensive to build, since construction material often has to be transported over hundreds of kilometers. Dirt roads on the other hand are very sensitive to heavy-load transport during rainy seasons. A solution that can be observed quite often is fluvial transport of wood, where the stems of the felled trees are joined to rafts and transported over the rivers. The trees are separated in "floaters" (trees with specific mass less than 1 g/cm^3) and "sinkers," which are species that do not float in the water. They have to be transported on top of the rafts. Other transport solutions are railroads, which are independent from rainfall but very expensive to build and not as flexible as roads in there projection (Leite 2001).

At least, availability of **labor** force and the living conditions that can be provided to the forest workers have to be considered in planning. The regions where harvesting operations are performed often are far away from the urban centers. The unskilled workers available in such regions (if any!) have to be trained and provided lodging and food. The workers in many cases show an extremely low productivity due to poor nutrition status and health problems induced by **disease** under humid and hot conditions of the tropical climate. In some regions, **social policy** and cost factors may have to be taken into account in the harvesting planning.

The list above may not be complete and have to be evaluated by the planning team under each condition found in a specific region or country.

The intention is to highlight the possible problems and the more complex situation when harvesting planning is conducted in tropical countries.

Planning Levels

Harvesting planning consists of different **planning levels** (FAO 1999). In native tropical forests, a careful planning of all levels is even more important, because of the low volume of merchantable wood available per hectare and the huge areas necessary to work with commercially interesting volumes. There are three levels to consider:

- Long-term or strategic planning (1–30 years of the whole forest area)
- Operational plans (harvesting units)
- Task plans (specific tasks to solve)

Long-term or strategic planning has to be done over the whole area, considering all social, environmental, and economic aspects of the harvesting operations. In many cases, no maps are available and have to be produced by the logging company. Based on the maps and inventory data, areas with operational restrictions, reserved for biodiversity or conservation, have to be identified. Communities living in the forests or in the neighborhood have to be considered in the planning process. The areas identified for harvesting operations have to be evaluated after the sustainability criteria were set up by local or national legislation or (voluntary) certification companies. The size, location, and sequence of the future harvest areas have to be determined, and the harvesting schedules have to be performed, based on the wood types and harvesting volumes of each harvesting area. The next step is the planning of the access to the harvest areas, where options like forest roads, fluvial transport, or railroad have to be evaluated by the planning team. At least, monitoring standards have to be developed to ensure adequate management of the forest areas.

After the long-term planning follows an **operational planning**. The plans developed at this level have to be based on detailed information, in general coming from inventories and ground truth mapping. Important elements of operational planning are the determination of harvesting units which should follow topographic or other natural features, as well as the areas excluded from harvesting for different possible reasons. The plans in general contain a detailed description of different forest types, procedures of how trees are marked for felling and skidding, volumes of felled trees and diameter size classes, and the exact location of each tree. Based on this information, forest roads, landing zones, log yards, or skid trails may be planned minimizing negative impact on the environment.

Finally, the **task planning** has to be performed. In this important level, the staffs necessary to perform the harvesting operations are identified and planned. It follows directly the operational planning and considers features like the teams necessary for road construction and maintenance, machine operators, machine maintenance crews, monitoring staff, and many others.

Cost Planning

Harvest costing is very complex and depending on many operational factors. Economic and technical resources and legislation, to the point of the company philosophy, may influence on cost planning and real costs. In this chapter, only a general overview about costs and its planning is given.

General Issues on Cost Planning

The success of any business largely depends on the economic output. A planning of the costs of a harvesting operation is useful to avoid negative surprises on the total business. The factors that have to be considered in cost planning are (FAO 1992):

- Productivity of operational systems
- Machine and/or equipment costs
- Labor costs

To perform the calculation, deep knowledge of harvesting operations in a broader sense is necessary. The cost planning of modern harvesting systems depends on many additional operational factors as there are:

- Public road system available, water, and railway transport options
- Forest road system, influencing on:
  - Hauling distances and costs
  - Loss of productive area
  - Costs for environmental damages (or how to avoid these)
  - Costs for road construction and maintenance
  - Costs for other silvicultural activities

Following these restrictions, the selection of an appropriated harvesting system adapted to the environmental, operational, and social restrictions found in the planning region can be performed in a first step that includes checking if the technology to apply is available and sustainable in the target area and if skilled operators can be hired. In many tropical regions, there exists no adapted technology or there are some obstacles in importing machines and other goods. On the other hand, there are no skilled persons available on the labor market for operating machines or performing efficient operational planning. Second, the harvesting system chosen might not influence on overall production costs, since the final product has to be competitive at a national or even international level.

Planning of Machine Costs and Labor

In forest operations, many decisions have to be taken for highly specific and individual operational conditions. In most of the cases, no reliable productivity data are available for different steps in a process, such as productivity and performance of equipment and human labor. Cost estimation under these circumstances widely depends on expert guesses. Valuable data about productivity can be obtained by machine providers, but in general the real performance of machines or systems has to be calculated using specific factors for terrain, skills of operators, and effective machine hours. The latter depends on supply with spare and skills and equipment of the maintenance teams. In tropical countries, the supply chain management is not always given for all technologies, so machines because of a wearing part of a few dollar cost get stopped for several weeks, reducing the effective working hours and overall performance significantly.

Today, there exist many free machine cost calculators that are available for download on the Internet. Provided in the form of spreadsheets, they allow detailed machine cost calculations. Some of them also offer additional tools that allow comparison of the machine costs, including several options like buying, leasing, or renting machines.

In some tropical regions, forest operations widely depend on unskilled labor, since the educational systems do not provide the possibilities as it does in other parts of the world. In some cases, it is even difficult to get workers able to read or write at a level it is necessary for some harvesting operations. It may cause problems in efficient planning and controlling if a machine operator is not able to note fuel consumption or working hours. On animal skidding, people are not able to mark wood piles or to measure the volume of the wood piles at the forest road produced by them. All these facts may cause difficulties in the whole harvesting process that have to be considered in the planning stage.

For a cost calculation of, for instance, skidding with a pair of oxen, in a first place, the costs per animal have to be considered. In a next step, the “lifetime” where they can be used for skidding has to be defined. In general, the animals have to reach a minimum age where they can be used in the harvesting operation and a maximum age where they get a week for hard daily work. In a next step, it is important to define how many days an animal can work per year, taking into account the necessary recreation time for the hard physical work. Also the labor costs of the ox driver leading the animals through daily work have to be considered in the cost calculations. With these data depreciation, interest rates, taxes, pasture for the animals, food supplements, and veterinary services can be calculated at a solid base. Also the equipment needed for the animals like harness, chains, or sulky are of impact for cost calculation. At least, also the time and costs for the caretaking of the animals after work have to be taken into account, as there might be feeding, fence control, or construction of corral that have to be included. It might be mentioned at this place that in general one driver works with two pairs of animals, since the recreation, illness, and recovery time only permit a half-time occupation of the animals (Lihai et al. 1996). In many cost calculations, some of the variables are not considered, which leads to a nonsustainable use of the animals and also an underestimation of total costs.

For calculating machine rates, the technical specification of the equipment to be used is the first step. For felling or hauling, the size of the trees is the first restriction. The machines have to be planned to meet with the size and weight of the trees and assortments that might be produced during the harvesting process; if possible, the machine should have some reserves and not always work to the limit.

The purchasing costs of the machine, lifetime, fuel consumption, operators, helpers, and mechanics contribute to the labor costs. In machine cost calculation depreciation, interest costs, insurance, taxes, and all costs for consumption and maintenance are of importance, besides the definition of the working days per year and the number of shifts per day the company wants to work. These data have to be compared to productivity under specific working conditions and the prices that can be achieved for the given assortments. In general, the machines need some additional tools for working with harvesting operations, such as winches, cables, special blades, or grapple, among others.

Considerations for Harvesting Operations

For harvesting operations, it is essential to consider the impact of the operation on the environment. Since the premise is to accomplish with the sustainability of all human activities, specifically when managing natural resources, the facts listed below have to be taken into account when planning and executing harvesting operations.

Environmental Considerations

Harvesting operations in general not only show a “visual” impact on the environment but also may lead to severe damages of the ecosystem. The operations affect water, fauna, flora, soils, and other resources according to the utilization standards defined in the forest management plans. Mainly, the transport of wood in the stands (off-road) as on the forest and public roads has direct impact on the environment and has to be carefully planned to avoid negative impact as much as possible. The principles of reduced impact logging (RIL) were developed exactly for this purpose and adapted for tropical conditions. In most countries, these principles today can be found in local legislation and were also implemented in modern certification processes (Humphrey 2004). The operational restrictions linked to the RIL make harvesting expensive and have to be considered carefully in the planning process to meet with the economic sustainability of the forest managers (FAO 1995). Soil erosion, soil compaction, sedimentation in rivers and lakes, water temperature, and chemical pollution are only part of the manifold negative impacts that may be linked to harvest operations and which can be avoided by careful harvesting planning.

Soil Erosion

Before and during harvesting operations, the soil of the area is partially exposed by road construction, landing zones, skidding trails, and the removal of trees. The impact of tropical rainfall and wind on exposed soil can lead to severe erosion problems, where part of the soil is transported according to the external forces and gravity acting on the particles. The negative impact can be reduced by careful planning of the harvesting operations. A crucial point is the construction of access roads and landing zones. Location, size, surface sealing, inclination, and water draining may be considered to reduce erosion. The selection of harvesting systems, wheel- or track-based machines, location of the skidding trails, and skidding performance of operations have to be checked for reducing negative impact. Depending on the climate, considering the season may also be an important restriction, as it is already stated in the forest legislation of many tropical countries. At least, also the postharvest activities have to be planned. Replanting of sensitive zones and closing of roads with water bars are only a few options that are available to reduce erosion.

Protection of Waterbodies

Closely linked to the erosion problems of harvesting operations are the negative environmental impacts of forest management on waterbodies. Streams, rivers, and lakes are often a source of drinking water, used for transport and irrigation, or a source for industrial cooling processes. Besides this, they are essential for nature conservation, especially for wildlife. One of the main concerns of harvesting planning therefore should be waterbody protection. In local and regional legislation and many certification rules, the issue is taken into account with rigorous restriction for forest management nearby rivers, lakes, and water reservoirs. The most important issues for defining the restrictions are:

- Soil type and slope of the terrain (erosion risk)
- Local communities living at and from the waterbodies
- Climate, specifically intensity of rainfall
- Specific use of the waterbody, like functions as water reservoir, fluvial transport, and irrigation in agriculture

These factors decide the protection intensity and size of the buffer zones around waterbodies that have to be respected and if they are excluded from any kind of management or road construction. Bridges, landing zones, haven, or access roads to rivers need special permissions and have to be built according to rules of lowest impact.

Keeping a minimum distance from the waterbodies in general already solves a lot of the problems related to erosion and sedimentation. Additional measures that may be taken are careful selection of road location, no skidding trails close to rivers, as well as uphill felling and skidding. Again, the season of the year where harvesting operations take place has to be carefully planned, avoiding month of high precipitation. Respecting the buffer zones also solves the risk of water pollution by chemicals like machine and hydraulic oils.

Soil Compaction

Depending on the felling and skidding operations planned for a specific harvesting project, soil compaction may occur in a more or less intensive way. Wheel- and track-based machines may cause compacting of the soil structure, leading to less porosity and reducing water and gas exchange of the soil with the environment (Hofmann 1988). Higher water runoff, reduced tree growth because of disturbed root development, and difficulties in natural regeneration may be a consequence. The negative impact may be reduced if the harvesting system is planned according to the climatic and edaphic conditions. Track crawlers show less compaction than wheel-based machines, dry soils compact less than humid ones, and also there is also the option of using cable winch to push the stems out of the stand (Mendes 2013). Also the layout of skidding trails considering sensitive zones already in the operational planning may reduce negative impact of harvesting operations.

Wood Utilization

The waste of natural resources is commonly agreed as not acceptable in any kind of production process. Harvesting residues have to be regarded as very critical regarding this aspect, because from the total harvested volume, a high proportion of biomass remains in the forest. In tropical forests, the commercial volume of a felled tree in general is very high. Crown slash, high stumps, forgotten logs, and unwanted by-fellings increase the volume of not used biomass. Harvesting planning can reduce the volume of wasted wood and increase the economic return in a significant way (Gebremariam et al. 2009).

In conventional logging systems, staff responsible for felling operation were not trained properly. High stumps and damages and losses during felling by poor felling techniques were prevalent. Lianas linking tree crowns and leading to unwanted by-fellings today are cut during the inventory which can reduce unwanted by-felling substantially. The felled trees often were not found or forgotten due to poor coordination between the felling and skidding teams. Many hollow trees rotten inside were equally felled, without any merchantable wood. New inventory method and modern equipment like GPS and geographical information systems allow a much more efficient planning of all processes linked with harvesting, which allow to improve the utilization of the wood harvested (Holmes et al. 2002).

Forest Roads and Wood Transport

Harvesting operations are closely linked to staff and wood transport. On the one hand, the forest workers, logistic crews, service personnel, machines, and equipment have to be transported to the forest areas; on the other hand, the harvested wood must be transported for further processing. Forests, depending on its production goal and utilization, have to be managed in more or less intense intervals, where the access to the stands has to be guaranteed. Therefore, basic parameters have to be given here, at least as far as harvesting planning and operations are concerned. Basic information about modern intelligent transport system (ITS) in developing countries is provided by the World Bank (Yokota 2004a, b, c, d; Yokota and Weiland 2004a, b; DNER 1999).

Forest Roads

Forest roads are a basic requirement for sustainable forest management (Dietz et al. 1984; Machado 2014). Only in pure exploitation systems or for the use of wood of indigenous groups, under certain circumstances, forest roads are dispensable. In modern harvesting planning and systems, the access to the forest stands is always a key factor. There are several quantitative and qualitative parameters that describe the quality of forest road systems (Anderson and Nelson 2004). One of the most important is forest ***road density (RD)***, expressed in meters per hectare of managed area.

$$\boldsymbol{RD\ (m/ha) = Road\ Length(m)/Managed\ Forest\ Area(ha).}$$

Another important parameter for calculating harvesting costs and productivity is the **mean distance of extraction (MDE).**

$$\mathbf{MDE = DS/2\ (a) \qquad MDE = DS/4\ (b)}$$

where:

DS = depth of the stand perpendicular to the forest road.

Equation (a) is used if the access to the stand starting from the road is only single sided, while (b) is applied if the road offers the option to haul wood from both sides.

Another value often used to classify a forest road system is the **average distance between forest roads (ADR).**

$$\mathbf{ADR = 10,000\ (m^2)/MDE.}$$

The values presented are merely theoretical and only may be applied in a flat terrain with a 100 % orthogonal road system. In many cases, this is not reflecting reality, and so a series of correction factors are being applied to adapt the theoretical values. One correction factor frequently applied is the index developed by Backmund (**E%**). The index reflects the proportion of forest area with access to the total managed area. In the ideal case, this value is close to 100 %. In some cases, the index exceeds 100 %, when a dense forest road system leads to a high percentage of overlapping of area with access. There also exist several correction factors for slope and non-orthogonal road systems, which can be found in literature and have to be

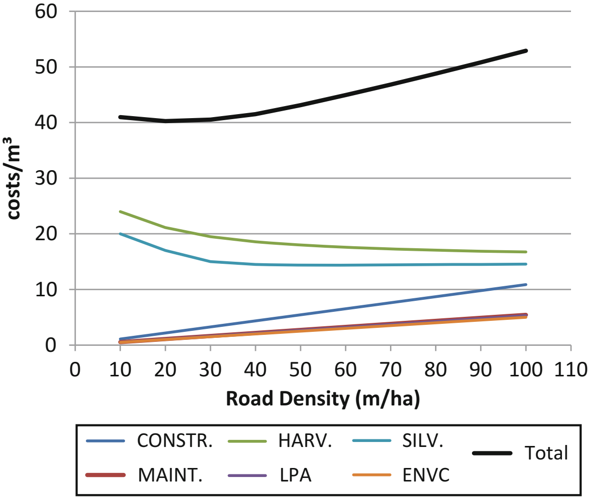

Fig. 1 Optimized density of forest roads (*Constr*. construction costs, *Maint*. costs for road maintenance, *Harv*. harvesting costs, *LPA* loss of productive area, *Silv*. costs for silvicultural operations, *ENVC* environmental costs, such as recovery of erosion damages or sedimentation in waterbodies). Source: Leif Nutto

considered when planning forest road construction or when evaluating an existing system (Dietz et al. 1984).

In greenfield projects, the planning of the forest road system has still to be done before forest operations can take place. In this case, the planning can be done based on a cost optimization calculating productivity of different harvesting systems based on a given road system. One objective of harvesting and access planning is to determine optimal road network under different logging practices, considering all types of relevant costs (Naghdi and Limaei 2009).

In Fig. 1, a mathematical optimization of the forest road density is calculated by considering possible cost units of a forest road system. Where the black curve (total) shows a minimum, from an economic point of view, the optimal road density is given. The figure may change under varying environmental or technical conditions (Naghdi et al. 2012).

Figure 1 shows the close interactions between the different cost units linked with forest operations, influencing in all planning levels (Martini and Barbosa 1988).

But not only the quantitative assessment of a forest road system is of importance. The quality influences on a variety of operational factors, such as trafficability throughout the year, maximum load under wet conditions, or slope of the roads. There exist numerous classification systems for forest roads, using terms such as main haul road, primary haul road, secondary haul road, skidding road, or skidding trail. The classification determines the type of vehicle that can be used on the road type and if it is a permanent or seasonal road. The road width and the quality standard of construction are influenced by the wood volumes to be transported, the transport system chosen, and the ascending slope of the roads or the construction materials available in the region (Hruza 2003; Heralt 2002).

Some of the parameters presented above are more of theoretical value and have to be cross-checked with the operational requirements. The wood volumes harvested often have to be piled at the forest roads for further transporting.

Depending on the road type and the road density, there might not be enough space available to pile the whole harvesting volume. In such cases, intermediate log yards or specific landing zones have to be planned together with the road system.

Wood Transport

Wood transport can be done in many ways, depending on the resources available in the region and the value, volumes, and specification of the wood (Machado et al. 2000). The transport of the raw material (in general roundwood) to units for further processing or consumption is underlying some restrictions. Roundwood is in general of high volume, high weight, and low value. These facts are reducing the transport radius significantly, since the transport costs may by far exceed the value of the raw material. The transport distance on the other hand is influenced by the transport means, where almost 100 % is transported by waterway, railroad, or road haulage (Kirby et al. 1986). The cheapest way to transport wood, also allowing longer transport distances, is by waterway, followed by railroad and trucks (Uasuf 2010). The biggest problem of nonroad-based transport is, in many cases, the fact of broken transport chains, where the load has to change the means of transport. Only in under rare conditions the wood transported by waterway or railroad can be directly loaded at the forest side and be brought directly to the processing industry. In many cases, the roundwood has to be transported to the waterways or a railway station by truck, to be unloaded, loaded again to the new means of transport (ship, train), unloaded in a harbor or railway station, and transported again by truck to the final destination. In such cases, the logistic effort is enormous and very expensive, compensating possible financial advantages of a cheaper transport by ship or train.

Road Transport

The most important transport today is road based using different kinds of trucks as transport means. The main argument for a road transport of roundwood is the flexibility of the system, enabling the direct transport from the forest side to the processing mill with an acceptable logistic effort. The contribution of the transport costs on the total costs of pulpwood in Brazil delivered at the mill varies between 35 % and 65 % for transport distances between 50 and 200 km (Salmeron 1984). For logs of tropical hardwoods coming from native forests, the value per m^3 is much higher, so the share of the transport costs should be lower. But while in pulpmills almost 100 % of the wood can be utilized, the recovery rate on high-value products from logs of native forests in many cases does not exceed 20 % (Maderna 2002). Wood defects and old processing technologies are critical in many saw- and veneer mills working with tropical wood from native forests. Longer-distance transports are highly recommendable to be performed with already converted wood or the final product, where value was already aggregated. High weight and volume compared to low value of the roundwood suggest the use of larger transportation units (road trains) or at least the multiple product transport, such as roundwood, chips, or charcoal in the same truck. This turns out to be problematic, since

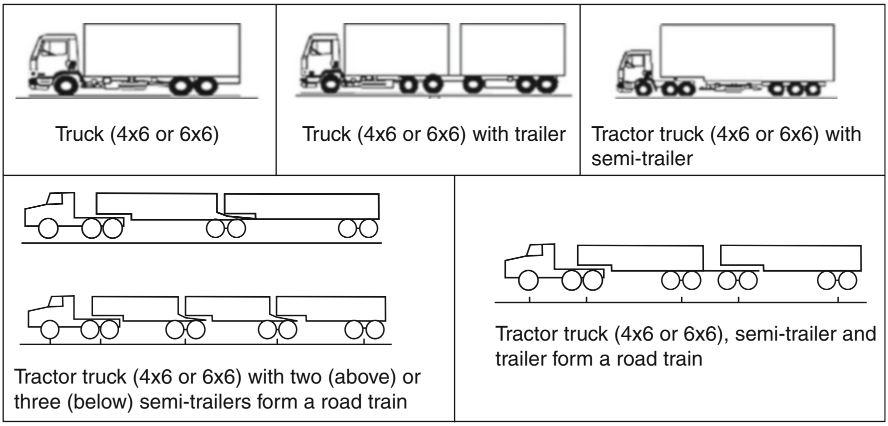

Fig. 2 Different types of trucks for roundwood transport. Source: Leif Nutto

roundwood transport with its specific requirements does not facilitate the transport of other products.

Another problem for roundwood transport is the fact that forest roads in general are unpaved and under high traffic volume, wet conditions or in steeper terrain, need a permanent maintenance input. The trucks or tractor trucks need to be adapted to all terrain conditions, which turns the machines and the maintenance more expensive. Depending on the road quality, assortments, and volumes to transport, a series of different trucks may be used for transport. Normal trucks, trucks with trailer, tractor trucks with semitrailer, or multiple semitrailers (road trains) may be used for economic and efficient wood transport (Fig. 2).

In tropical forest plantations managed in short rotations, with high wood volumes to transport, the forest road network, infrastructure, and logistics are well developed and allow the use of bigger transport units, if local legislation allows such trucks on public roads (Oliveira 2004). The net load of such trucks reaches up to more than 50 t, reaching the cross weight of the vehicle more than 70 t. In bigger forest plantation companies with more than 75,000 ha of managed forests, the transport of wood with road trains may be restricted to private-owned forest roads. To guarantee a safe transport with such long and heavy vehicles, the quality criteria of the forest roads are more restrictive: slopes should not exceed 8 %, road width should be adequate, and the bearing layer of the road must be adequate. The increased costs for the road construction and the maintenance must be compensated by the reduced costs for transport (Fig. 3).

Transport by Railway

As mentioned before, railway transport is cheaper than road-based transport. Railway transport is also independent from seasonal weather conditions and can also be used in full extent in rainy season. The problem is the relatively high initial investment of the railway constructions, the locomotive, and the wagons.

Fig. 3 Pulpwood transport with road train (*left*) and stem transport coming from native forest harvesting in the Amazon (*right*). Source: Gustavo Castro / Leif Nutto

A long-term-based depreciation allowance is necessary to develop a profitable business plan for the use of railway, including a high transport volume all over the year. In most cases, where in tropical countries a successful wood transport by railway takes place, the transport is done in cooperation with an already existing railway company (Fig. 4).

Rarely, the railways pass in managed forest areas and offer a synergy effect for the use in wood transport. To build a railway, only used for transportation of wood rarely is competitive to road-based transport. Therefore, in most tropical countries, road-based transport is the predominant form of wood transportation.

Waterway Transport

Unlike railway transport of wood, waterways are more often used for wood transport in tropical countries. Rivers and streams in tropical countries often are the only alternative to bring harvested wood in an economical feasible way to processing units.

In the first place, the roundwood to be transported by water has to be classified as “floaters” or “sinkers.” The term “floaters” is used for stemwood that, with a certain

Fig. 4 Railway transport of pulpwood from tropical plantations. Source: Gustavo Castro

moisture content, is still floating, while the wood density (including wood moisture content) of “sinkers” is above 1 g/cm^3. In tropical forests, many species have to be classified as sinkers and cannot be used for timber floating or rafting. Timber rafting is a transport of roundwood where the stems are tied together into rafts and pulled or drifted across a waterbody, while timber floating is a more uncontrolled process where the stems follow the current of rivers and streams. Timber rafting is a cheap and frequently applied transportation method in the tropics, especially where rivers and streams of bigger size are available, like in the Amazon Region, in Congo Basin, or in Malaysia and India. Rafts can be small or huge, reaching length of more than 600 m, width of 50 m, and stacking heights of 2 m.

The construction method of rafts depends on the watercourse the stemwood should be transported. Smaller and curved rivers are more difficult for rafting, while big streams allow even to chain several rafts together. The main difference in building the rafts was the shape given to the stems forming a raft. Most common are the V-bowed rafts, being easier to handle, while square-bowed ones got more often stuck or stems to fall apart.

Rafting today in most countries and on most streams and rivers is regulated by law, specifically in regions where waterways form the main system of transport. Rafts are difficult to handle and form dangerous obstacles for ships and boats.

Fig. 5 Rafting of wood in the Amazon region. Source: Jorge Malinovski

In general length and total size of rafts, time and hours of rafting and sections of rivers and streams are restricted by law in many tropical countries (Fig. 5).

Sinkers may be transported loaded on the rafts or transported by ferryboats or ships. The cheap transport of roundwood by waterway allows longer distances between the raw material source (forest) and the wood think (processing mills). There are also cases reported where a pulpmill in tropical countries transports the wood by maritime transport (ferryboat) over 270 km, reaching a yearly volume of more than two million m^3 of roundwood.

Case Studies: Practical Examples for Harvesting Planning in a Tropical Rainforest and a Forest Plantation

After discussing the different issues involving the harvesting process, two examples are given. The first example is based on a harvesting process of a company owning 500,000 ha of native forests in the Amazon region. The second example is based on the harvesting process of a pulpwood-producing company in the tropical region of Brazil.

Case Study 1: Example for a Native Forest Management Planning

In the following example, the operational steps in the different planning levels are shown for a native forest management area. In a first step, the whole area has to be evaluated for manageable zones (Fig. 6). The lighter green zones are classified as areas where no management is planned. That could be natural reserves (according to legislation), areas of indigenous or local communities, or sensitive areas (protection, no access). The important question is, how many management units are

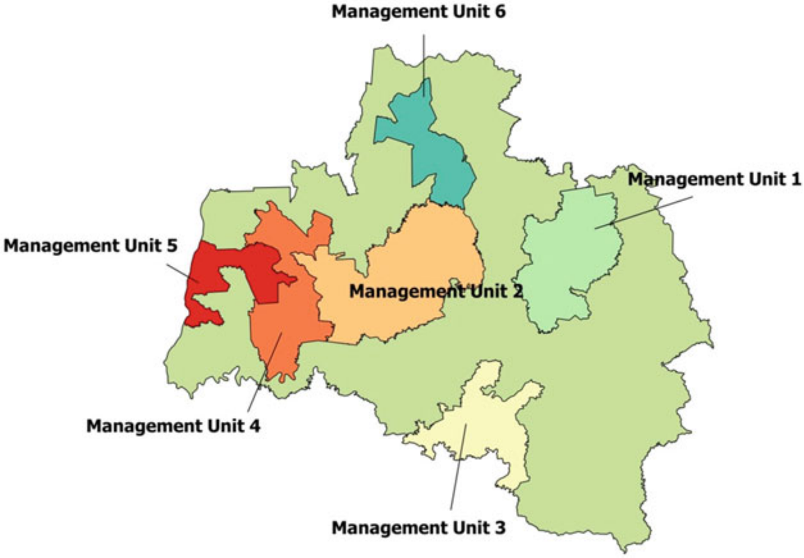

Fig. 6 Example for a long-term planning, subdividing the manageable area in management units and protected areas (Source: the authors). Source: Leif Nutto

necessary for a reasonable planning? Therefore, the following facts have to be taken into account during the planning:

- What is the yearly annual increment of marketable wood volume? In tropical rainforests, these values vary between 0.7 m^3 ha^{-1} $year^{-1}$ (i.e., poor soils in Amazonian rainforests) and 2.5 m^3*$ha^{-1*}$$year^{-1}$ (i.e., dipterocarp forest in Asia). *These important data form the base of any sustainable management plan and have to be evaluated for each individual case by inventory and expert estimations!*
- What is the minimum volume to harvest per ha in an economic feasible operation? This value may vary between 25 and 35 m^3 ha^{-1}, in a system with motor-manual felling and use of a skidder for hauling (partially mechanized harvesting system). *This value has to be estimated by labor and machine cost calculations!*
- The premise is to manage the forest in a sustainable way. That means not to take more wood out of the forest than the ecosystem is able to replace. If the yearly annual increment of marketable volume of a tropical forest is assumed to be 1 m^3*ha^{-}1*$year^{-1}$ and an optimized operational harvesting volume is about 35 m^3*ha^{-1}, it would be necessary to wait 35 years until the next harvesting operation at this area can be done. *The calculation of the rotation cycle therefore is important for the long-term planning!*
- That leads to the next planning step: the division of a management unit into annual harvesting units (Fig. 6). According to the productivity of the harvesting operation (felling and skidding), the annual harvesting units have to be set on a number that

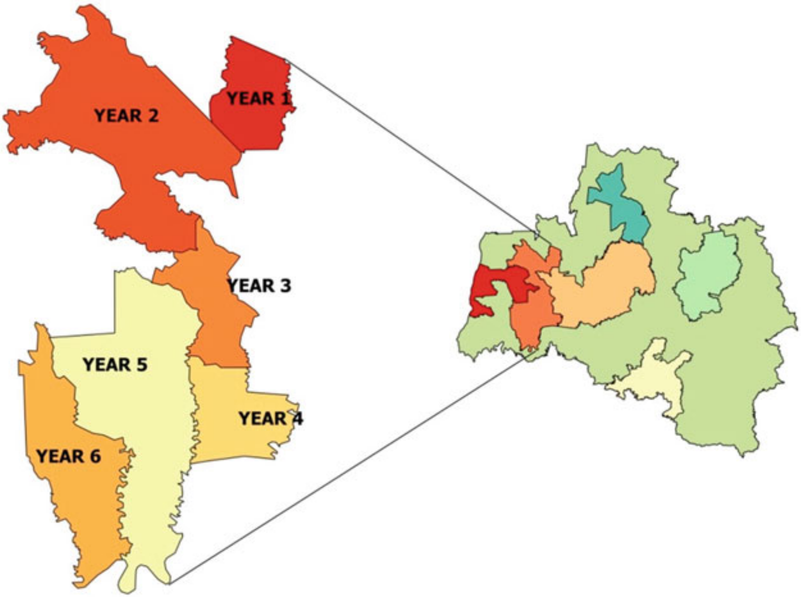

Fig. 7 Subdividing a management unit into annual harvesting units. Source: Leif Nutto

matches with the estimated rotation cycle. Each management unit therefore has to be divided into six annual harvesting units. Six annual harvesting units per management unit lead to 36 units to be harvested on an annual base. This number matches more or less with the estimated rotation cycle of 35 years. When all units are harvested, the operations can return to the first harvesting unit.

The process shown in Fig. 7 is leading to the operational planning. A yearly harvesting unit, depending on its size, cannot be handled in an operational way. A more schematic planning is necessary. This is reached by laying a grid over the area to be managed. In Fig. 8, a 4 by 4 km grid is used splitting the annual harvesting unit in blocks of 1,600 ha, a size that could be handled by one forest engineer. The maps already contain the information of the inventory data like restricted areas (buffer zones around rivers) and location, species, diameter, commercial height, and other information of the trees to be harvested in the block.

Starting from this information, the operational harvesting planning can be performed. The 4 × 4 km blocks again are subdivided into smaller units of 10 ha. In general, they have the form of a 400 m × 250 m rectangle. From the primary road, secondary roads are planned with a distance of 250 m between the roads (Fig. 9). Starting from the secondary roads, the skidding trails are designed manually by the responsible engineer, including information about:

- Felling direction
- Number of sections of the stem estimated per tree

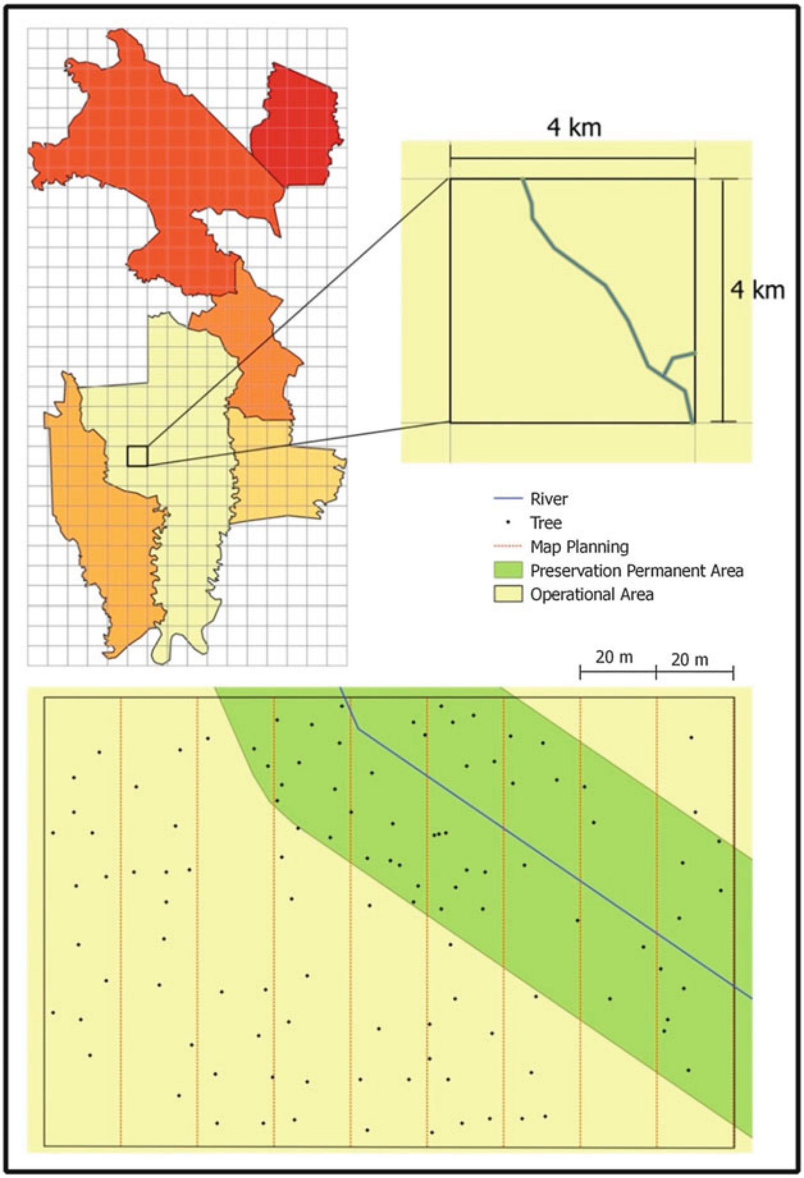

Fig. 8 Operational planning of the harvesting by laying a 4 by 4 km grid over the annual harvesting units (1,600 ha for each block). Source: Leif Nutto

- Skidding trails (if grapple skidder is used), considering ecological and operational restrictions
- Calculation of the commercial wood volume harvested (to cross-check with inventory data)

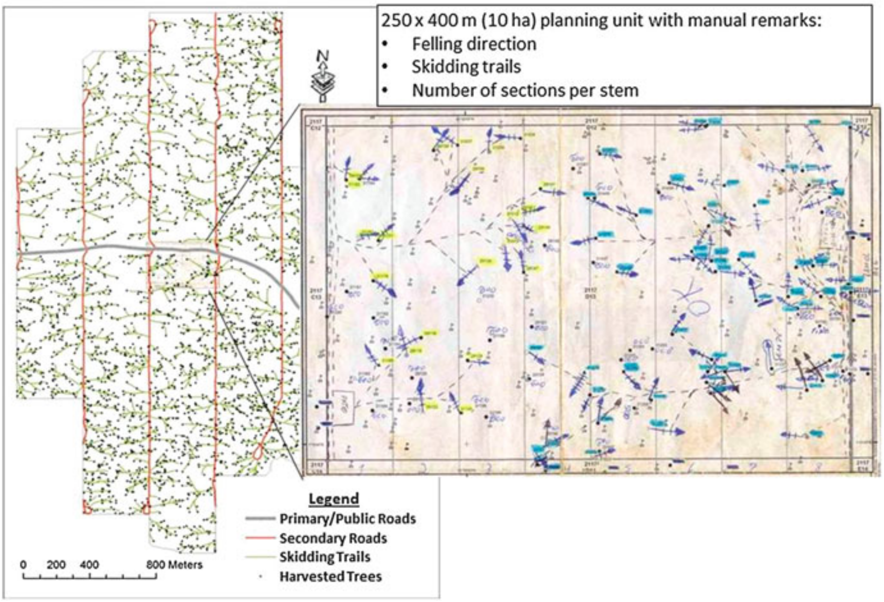

Fig. 9 Operational planning of felling and skidding of the trees (Source: the authors). Source: Leif Nutto

The map with the manual remarks is available to the harvesting team and the chain saw operators as well as for the skidding crew, providing detailed information for each 10 ha unit.

According to the volumes harvested and skidded per unit, landing zones have to be planned. In the given example, about 300 m^3 of roundwood is harvested in a 10 ha block. Depending on loading and transport capacity, size and number of the landing zones may vary in the planning. Transport capacity has to be planned after the transport means available (type of trucks), road quality, and local restrictions and regulations. In the best case, no truck is in a waiting queue, and also the loader is working at full capacity. Harvesting and skidding as well as wood transport in native tropical forests should not be planned during nighttime. Most of the operations are extremely dangerous, the harvesting systems used are risky compared to fully mechanized ones, and the forest roads are dangerous to drive with bad visibility.

Example for the Planning of the Harvesting Volume of a Sawmill

In this chapter, an example is given for planning of the harvesting units in relation to area, and wood volume for a sawmill is given. We assume that a sawmill is consuming 100,000 m^3 of roundwood per year. The wood is planned to come from a native tropical rainforest with an annual increment of merchantable wood of 1.2 m^3*ha^{-1}. The local legislation claims that buffer zones around waterbodies are kept, summing up to 50 % of the total area in the given example.

Calculation:

- 100,000 m^3 of roundwood is needed, with an annual increment of merchantable wood volume of 1.2 m^3*ha^{-1}; about 83,333 ha (100,000/1.2) of managed area would be necessary to provide the wood volume for the sawmill.
- Since only 50 % of the forest area in the target area can be managed (legislation), a total area of about 167,000 ha (2*83,333) would be necessary.
- The harvesting team needs a volume of 30 m^3*ha^{-1}, an annual increment of merchantable wood volume of 1.2 m^3*ha^{-1}; the rotation cycle would be 25 years (30/1.2).
- The target forest area of the example, according to infrastructure, growth rate, and terrain, makes it reasonable to split up the total area in five management units. The average size of each unit would be 16,667 ha (83,333/5); the management units may be subdivided in five annual harvesting units with a size of 3,333 ha each (16,667/5).
- One harvesting unit would be able to provide 100,000 m^3 of roundwood per year (3,333*30), enough to feed the sawmill. The system itself may be considered as sustainable, since the rotation cycles of 25 years allow the forest ecosystem to replace the wood harvested in the operations.

This example of course is very limited for general application, since the forest type, growth rate, local legislation, and environmental conditions are very specific. But for a rough harvesting planning of the area of a tropical rainforest needed to feed a virtual sawmill with 100,000 m^3 of roundwood, it gives a good example (167,000 ha). In an intensively managed tropical eucalypt plantation, the area needed to produce the same volume of roundwood under the same legal conditions would be less than 15 % of the area given in this example.

Case Study 2: Planning of a Harvesting Operation in a Tropical Forest Plantation

In tropical forest plantations, the information base and the operational conditions for harvesting planning in general are favorable as compared to native forests. In most cases, the final harvesting operations are done as clear-cut in even aged, homogeneous stands. Under these conditions, highly productive, fully mechanized operations can be planned.

The example taken is based on the forest operation for feeding a pulpmill producing two million tons of pulp, using residual biomass for bioenergy generation. For producing the pulp, a conversion factor of 3.8 m^3 of wood is necessary. The total wood volume for 1 year necessary is about 7.6 million m^3 of wood, resulting in a daily demand of about 21,000 m^3 a day (assuming the mill is working 365 days). The average growth per hectare is about 45 m^3/year (wood diameter > 4 cm) in rotation cycles of 6 years. The standing volume of a hectare therefore is

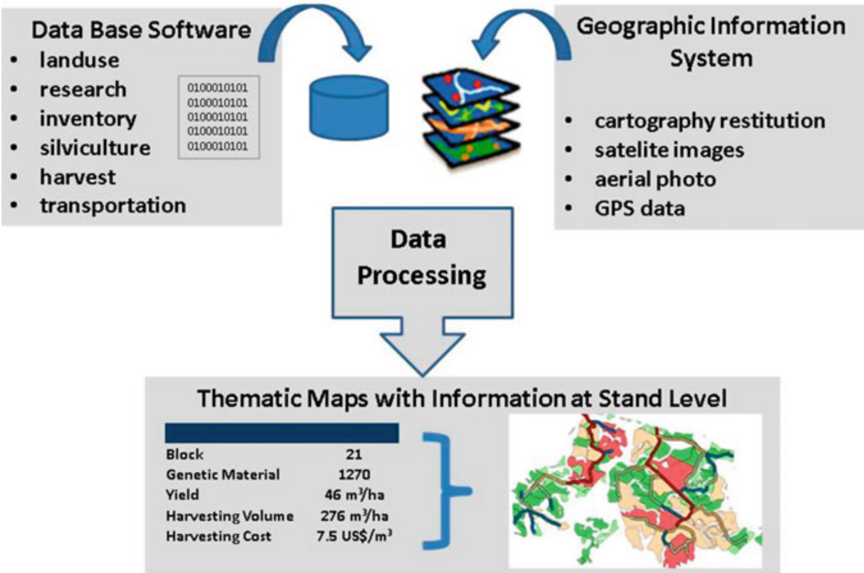

Fig. 10 Tools and data information necessary for macroscale planning. Source: Leif Nutto

270 m^3, resulting in an annual harvesting area of 28,150 ha or a daily area to be harvested of slightly more than 77 ha.

The harvesting process for such high wood volumes has to be carefully planned. The volumes have to be harvested, transported to the forest road, processed into assortments, and be piled for further transport. In general, pulpmills need a continuous feed with raw material, so that there is a log yard with a wood volume for 10–14 days, summing up to a wood storage of 210,000–294,000 m^3 that has to be maintained at this level. If trucks of the type of road train with 50 t (62.5 m^3) net load is used, 336 vehicles have to be loaded and unloaded every day.

Inventory data have to be collected and updated constantly at stand level and transferred to a central database. The data have to be linked with a geographical information system (GIS) to provide thematic maps with location, age class, volumes, diameters, and tree heights. When areas are selected for harvesting, specific preharvesting inventories are made to provide quantitative and qualitative data about the wood to be harvested.

In the macroscale planning, the harvesting projects are specified according to the harvestable volumes. In general, several stands in a given region are selected to aggregate harvesting volumes that allow the effective use of machines (Fig. 10).

Definition of the Harvesting System

Once the regions and the stands were selected with the help of the data provided by the database and GIS system, the microscale planning at field level can be started. Engineers of different areas take the thematic maps to the forests and start with

Fig. 11 Thematic map for microscale planning, containing all details like restricted area, water bodies, forest roads, contour lines, landing zones for wood piles, slope of roads, and terrain. Source: Cenibra

planning the details. Therefore, thematic maps are generated, and the forest engineers and technicians do the planning in the field. In a first step, the decision about the assortments to be produced has to be taken. In this case study, the idea is to use the full tree, all wood with more than 4 cm of diameter as pulpwood (roundwood of 6 m length), and the crown slash as residues for bioenergy production in the form of chipped material.

The next step is to check the terrain for slope, restriction zones, and the road system. Therefore, the maps from the macroscale planning are taken to the field, and information necessary is added by hand, for later transfer in the database of the company (Fig. 11).

According to slope and other terrain conditions, the harvesting system is defined. For a full-tree utilization, the highest productivity is reached with a feller buncher that makes bundles of 10–20 trees for later skidding with a clambunk skidder. The feller reaches a machine availability of 80 % and is able to fell 135 m^3/h; that means 2 h of work to fell the trees of 1 ha. The operation is planned to be done in three shifts, resulting in a daily volume of cut trees of 3,240 m^3. To cut the 21.000 m^3 necessary for the daily supply of the pulpmill, in total, 6.5 fellers have to work in the harvesting operation. After felling, the trees are left for drying in the field for 14 days, since the still-green leaves help to dry the wood through the process of evapotranspiration.

After the drying period of the full tree in the field, the activity of the skidders is planned. Under the conditions found in this case study, a skidder reaches a good productivity of 50 m^3/h. For the 21.000 m^3 on a daily base and a three-shift system of 24 h, about 17.5 skidders have to work on the area to deliver the tree bundles to the forest road. At the forest road, the full trees are piled for further processing with a processor head, doing the steps delimbing and bucking. A processor head is able to process the trees with a productivity of 60 m^3/h. Working 24 h, about 14.5 machines are necessary to cut the wood to length and to remove the branches. The assortments are prepared ready for loading at the forest road; the remaining crown slash is already pre-concentrated and can be used to directly feed the chippers. Of course the landing zones have to be planned carefully before starting harvesting operations. For the 6.5 fellers, the 17.5 skidders, and the 14.5 processors, the whole maintenance and supply chain has to be calculated: fuel consumption, spare parts, and preventive maintenance, among others. The machines have to be transported to the harvesting area by special trucks at the right time. Being most of the machines oversized, special permits for public road transport are necessary and have to be solicited. For the wood transport of 21.000 m^3 a day, road trains with 60 m^3 net load are used. The density of the wood is about 800 kg/m^3 at the day of transport. In 24 h, 350 fully loaded trucks have to reach the pulpmill and to be unloaded to keep a permanent stock in the log yard. The crown slash is about 5 % of the tree volume, being there 1,200 m^3 of crown slash to be chipped per day. Depending on the dimension of the chipper used, the material can be processed in 60–80 chipping hours per day.

In the presented case study, close to 40 machines are operated in a three-shift system, resulting in 120 machine operators a day. There are also the maintenance and supply teams, supervisors and monitors, and other staff necessary in the operations. A sophisticated logistics is necessary to cope with the daily needs of about 160 persons in the forests. Mobile headquarters, restaurants, water, storages, fuel tanks, and also toilets are necessary, to have acceptable working conditions for the personnel.

When the number and specifications of the machines are identified in the harvesting planning, technicians define and mark the danger zones. There might be steeper parts in the terrain where the machines cannot operate, swamps, protection zones, and other areas restricted to operations. The road system has to be completed where areas with no access are identified, closed forest roads might have to be reopened, gravel has to be replaced or completed, and the slopes of the roads have to be checked for the suitability with the selected transport system. All critical zones have to be marked in the field and on the maps to include the new information in the database.

Final Conclusions

The case studies are presented from different points of view. The case study for native forests is more focused on a holistic view of a company managing a big area of primary forest managed in a sustainable exploitation system. The case study of a pulpmill also enters a little bit in the field of harvesting systems, machine productivity, and personnel planning. Both case studies are not including all the planning steps because of the complex nature of harvesting processes. The high number of harvesting technologies and systems available; the impact of social, environmental, and technical restrictions; knowledge; training and capacity available at each single project; and at least financial resources make harvesting processes one of the most difficult to handle operations in the wood and forest industry. Hence, it becomes clear that well-trained and experienced personnel is required to plan the harvesting process in tropical forests, no matter if planted or native forests are pretended to be managed. To meet with the requirements of sustainability in forest harvesting operations, to implement reduced impact logging, and to cope with the local legislation, no “standard procedure” for the harvesting process can be applied. An individual evaluation of each single project is necessary to find the best solution.

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