Optimizing the results of HPRS

Harvesting with the protection of regeneration and of soils

Best practices guide

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Forest Engineering Research Institute of Canada (FERIC)

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9
☎ (514) 694–1140
(514) 694–4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4
☎ (604) 228–1555
(604) 228–0999
admin@vcr.feric.ca

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Best practices guide

Jean A. Plamondon
Eastern Division
Forest Engineering Research Institute of Canada

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Introduction

For many years now, Quebec has depended on natural regeneration to sustain its forests after harvesting operations. The Guide d'utilisation de la coupe avec protection de la regeneration (abattage mécanisé) (Canuel 1989), a guide on mechanized harvesting with the protection of regeneration (HPR), formed the basis for the practices currently applied in the majority of regeneration cuts performed in the province's public forests. To improve the protection of regeneration, particularly between trails, the HPR approach evolved to include provisions for the concentration of machine travel on the cutover in well-defined trails. The addition of a soil component ("harvesting with the protection of regeneration and soils", HPRS) thus aimed not only to improve the protection of regeneration by reducing coverage of the cut block by trails, but also to limit damage to the soil. This treatment is defined in the Règlement sur les normes d'intervention dans les forêts du domaine public (RNI), a standards guide that governs forestry operations in the public forest. Among the many objectives associated with sustainable development, preservation of the productive capacity of forest soils has become a primary concern. For this reason, goals related to the reduction of rutting will be integrated into the province's plans general d'aménagement forestier (PGAF; forest management plans) starting in 2008.

During the period covered by these changes, harvesting equipment underwent a remarkable evolution both in the nature of the harvesting systems and in terms of productivity. An extreme example of this evolution is the move from the Koehring shortwood harvester to the modern single-grip harvester and forwarder.

The desire to meet several environmental objectives, combined with the evolution of the machines being used and how they are used, necessitated an update to the current best practices that should be promoted during harvesting operations so as to optimize the results obtained with HPRS. To achieve this goal, the Forest Engineering

Research Institute of Canada (FERIC) undertook a joint program of applied research with financial support from Quebec's Ministère des Ressources Naturelles et de la Faune (MRNF, the provincial ministry responsible for natural resources and wildlife) and support from the forest industry.

This guide presents the main knowledge acquired about regeneration and soils with respect to the relevant characteristics of the most common harvesting equipment currently being used. Its goal is to provide useful information for those who are called upon to perform, supervise, or plan HPRS operations. The methods and practices described in this guide are not exhaustive because the diversity of operational contexts in Quebec's forests makes any generalizations risky. They should, however, help managers to develop their management plans by providing information that will help them to meet their objectives and adapt to the constraints associated with today's forestry operations, as well as to the range of site conditions they will encounter.

Context and challenges

The importance of natural advance regeneration

Monitoring of cuts performed since the 1960s has demonstrated that many stands could be regenerated naturally in a satisfactory manner (that is, to produce a stocking of 60% or better) after 15 years (Clemmer et al. 1978). More recently, this level of stocking has been observed in stands 30 years after harvesting (Laflèche et al. 2004, Ruel et al. 1998). The early harvesting methods were quite different from what they are today, and no particular attention was paid to the protection of regeneration during harvesting. The large quantity of research performed on natural regeneration of black spruce and fir stands supported the use of a silvicultural approach that relied on this form of natural regeneration to regenerate the stands. In fact, natural advance regeneration often grew faster than planted seedlings; in addition, it was typically taller, which gave it an advantage with respect to the competition. The contribution of tall regeneration (Figure 1) to the merchantable volume of second-growth stands has been recognized (Pothier 1996, Pothier et al. 1995), and justified additional care to protect this resource during harvesting. This was translated into a technique called harvesting with the protection of tall regeneration and of soils (HPTRS) in the provincial forest management manual.

Figure 1. Tall regeneration present immediately after HPRS.

In addition to the advantages in terms of improved fiber yield, relying on natural regeneration also ensures the maintenance of biodiversity by conserving the species present on each site and by using a natural process that

retains the local genetic resource. Rapid recovery of forest cover is also beneficial in terms of easing runoff from a site, for example by reducing the energy of the surface water. Last but not least, the presence of good-sized regeneration right after harvesting improves the visual quality of the landscape and improves public perceptions of the operation.

Classes of regeneration

Monitoring under Quebec's Règlement sur les normes d'intervention dans les forêts du domaine public (RNI) focuses on three classes of regeneration: that with a height of 5 cm or more, a diameter at stump height (dhs) of 2 cm or more, and a dhs of 6 to 9 cm.

This approach reveals whether the absence of regeneration after harvesting is attributable to a prior absence or due to its destruction during the operation, irrespective of the stocking before the operation (MRNFP 2004).

The importance of soil

In contrast with vegetation, which is easily visible, the eye sees almost nothing of a site's soil and it is difficult to appreciate the importance of soil for the forest ecosystem. Soil not only represents the physical support for growth of the vegetation, but also interacts with the vegetation in terms of nutrients, water, and gas exchange. Lastly, although a forest can regenerate in a few decades, the development of the soil's structure takes considerably longer, and thus the effects of soil disturbance may last much longer.

NOTE:

FERIC's guide to the prevention of soil damage in the Boreal and Acadian forests in eastern Canada (Sutherland 2005) discusses the question of soils in considerably more detail and suggests additional reading on the subject.

The most visible element of the soil, namely the organic layer, is composed of vegetation debris in various states of decomposition. In general, when the thickness of this layer reaches or exceeds 40 to 60 cm, the soil is described as an organic soil.

Under this more or less thick layer lies the mineral soil. Apart from the elements of stoniness (gravel, cobbles, stones, and boulders), the relative proportions of sand, silt, and clay that make up the soil define many of its physical characteristics.

The porosity of the soil represents the space between its constituent particles. This space can be occupied by air or water (Figure 2). Compaction of the soil by an applied weight can reduce or modify this porosity, thereby limiting movement of water and gas exchange within the soil and interfering with plant growth. The infiltration of precipitation may also be decreased, leading to the development of puddles. If the terrain is on a slope, gullying and soil erosion may occur.

The vulnerability of a soil to compaction depends on its texture, but can also vary widely as a function of its moisture content. For example, mineral soils with a medium or fine texture can have good resistance to compaction when dry, but become much more subject to compaction when wet.

Many other parameters can be used to describe changes in soil properties: these include the bulk density, resistance to penetration, hydraulic conductivity, and shear resistance. However, estimation of these parameters requires a range of instruments and sometimes, complex procedures or even laboratory analyses that could only be expected in the context of experimental research. The measurement techniques thus become inconvenient, and perhaps even wholly impractical, when the goal is to provide an overall assessment. Since changes in many of these parameters accompany rut development

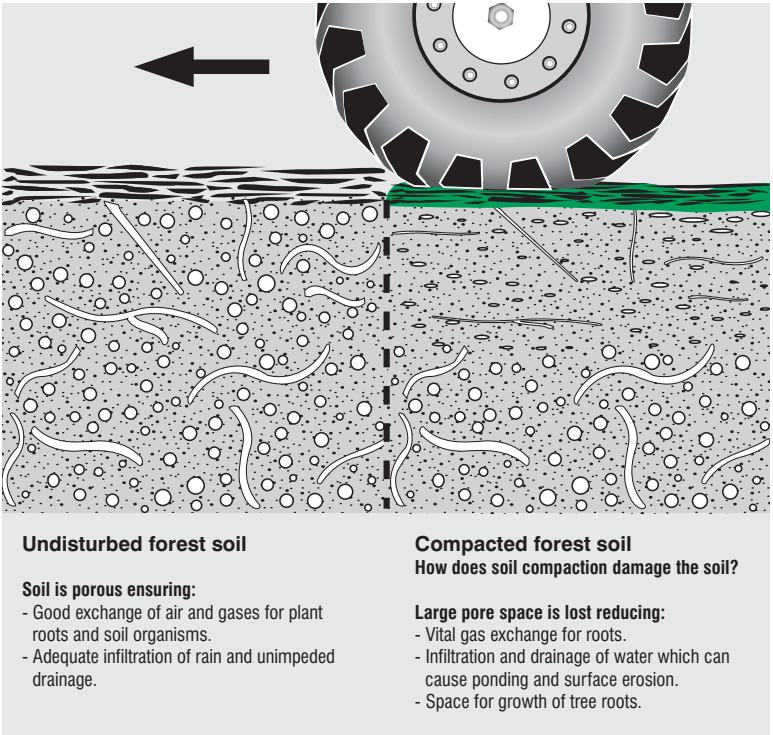


Figure 2. Effects of compaction on soil (from Sutherland 2005).

and since ruts are easily observable, it's logical to focus on rutting as an indicator of physical disturbance of the soil, as has been proposed by Schreiber and Jetté (1998). The phenomena leading to rutting and the resulting effects are complex (Brais 1994), and the presence of ruts does not directly relate to all the modifications of the soil properties, but monitoring ruts is more practical than other alternatives. As such, the reduction of rutting was one objective defined by Quebec within its objectives for site protection and obtaining value from the forest resource in public forests.

Impact of rutting

The impact of rutting on the long-term productivity of forest stands is poorly understood, and a multitude of other factors can also have an influence. Nonetheless, the presence of multiple, deep ruts on a site (Figure 3) can have the following consequences:

- modification of water movement within the soil, which can lead to a rise in the water table and possibly even flooding of the site (in particular, the movement of water in organic soils is more rapid in the first few centimeters, and decreases with increasing depth);
- loss of microsites for tree growth due to the presence of pools of water;
- alteration of local growing conditions on and near trails, plus damage to the roots of advance regeneration.

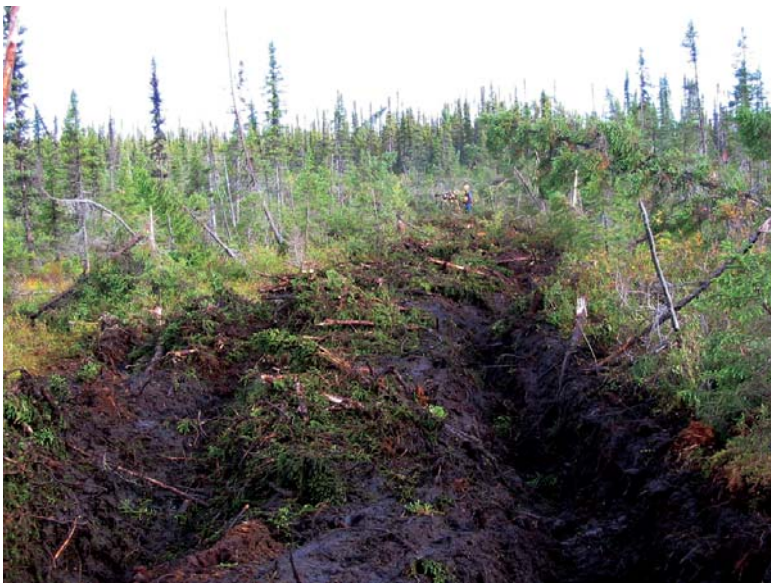


Figure 3. Deep ruts on a harvesting site.

Objectives related to the reduction of rutting

Quebec's guidelines for implementing the protection and value recovery objectives (MRNFP 2005) specifies the schedule that must be followed and the targets that must be attained to reduce rutting. In summary, the target is adapted to the regional context and specifies the proportion of harvesting situations that must show little rutting. The cutovers are considered to have little rutting if ruts deeper than 20 cm appear in less than 20% of the total length of trails.

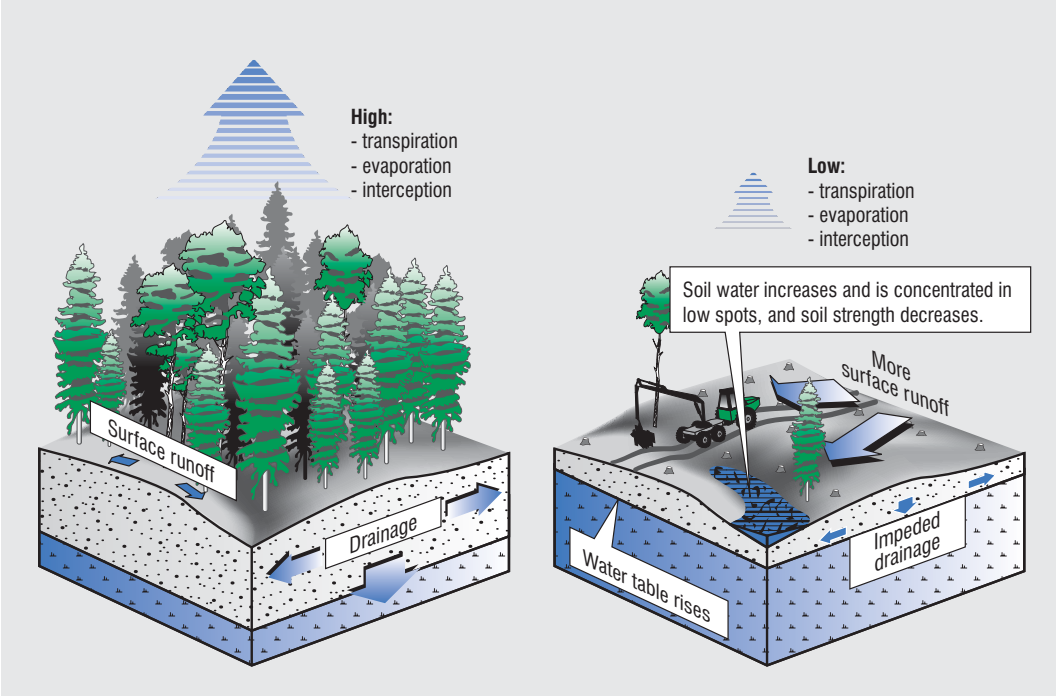
Soil moisture content and rutting

The soil's moisture content is a factor that greatly influences the success of efforts to prevent rutting. Outside large lowlands that remain wet throughout the year (which most companies try to harvest in the winter), soil moisture content fluctuates seasonally and in a highly variable manner that depends on local conditions. Spring is generally recognized as the season in which soil disturbance is most likely, and this most often leads to a cessation of operations. The fall, when evaporation is slower and rain is abundant, is typically a season of active forestry operations, with an associated risk of rutting (Schreiber et al. 2002). A given cut block will frequently comprise a range of soil conditions, each with specific textures, drainage characteristics, mean levels of the water table, and water percolation rates. After a rain, the bottom of a slope with poor drainage will be more vulnerable to rutting than the top of the slope.

Heterogeneous sites that include local wet areas, such as the source areas of intermittent streams, represent a challenge in operational planning. They must be recognized before operations begin, and if the estimated risk of rutting is serious, machine travel should be planned so as to minimize the potential damage.

Another factor to consider is the loss in evapotranspiration resulting from the decreased forest cover that remains after harvesting (Figure 4). This loss can lead to a rise in the water table that, combined with a reduction in the water percolation rate, can decrease the bearing capacity of the soil, increase rutting, and flood parts of the site. The wood harvested in such areas must thus be extracted quickly after felling.

Figure 4. The impact of forest stand removal and harvesting activity on the water content of soil (from Sutherland 2005).



Basic concepts of machine–terrain interactions

The nominal ground pressure on the soil is a commonly used indicator of the ability of equipment to travel on soft terrain. This value can be obtained by dividing the estimated axle weight by the footprint area of standard tires or bogies[1]. The addition of tracks to forestry machines offers well-understood advantages in terms of its reduction of bearing pressure (Figure 5) and its increase of machine mobility and operator comfort.

It's important to keep in mind that this calculation describes a static situation and that during real operations, dynamic forces must be added to this total, thereby modifying the behavior of the drive train and its effects on the soil.

The degree of symmetry of an articulated machine will have an impact on the traces it leaves on the ground during turns. A machine whose axles are equidistant from the point of articulation of the frame will turn within its own path, whereas a machine with

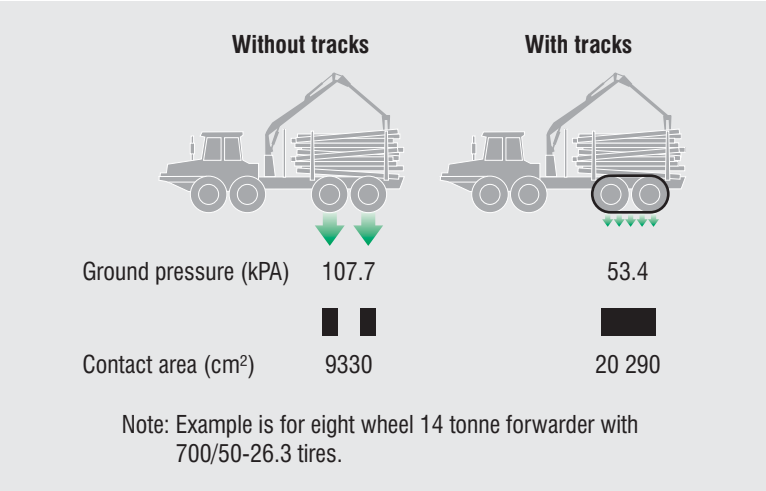


Figure 5. Impact of adding tracks to bogies on the contact area and on the ground pressure of a loaded forwarder (from Sutherland 2005).

1. Assuming a mean penetration into the soil equal to 15% of the wheel's radius.

unevenly spaced axles will off-track during turns. Off-tracking can destroy additional regeneration, and this is clearly undesirable.

Tracks, whether they are rigid like those of feller-bunchers or flexible like the bogies of a forwarder, cannot turn without exerting a shearing force on the soil (Figure 6). This shearing can lead to light disturbance if the shearing is superficial, or more serious disturbance if the shearing penetrates more deeply, breaking (for example) the root mat that contributes to the soil's bearing capacity. It's thus important to travel in a straight line as much as possible, without abrupt turns, when using tracked machines.

Figure 6 shows the initial position of three elements of a track (in blue). When the machine turns, these elements must slide and skid to reach their final position (in red), thus exerting a shearing force on the soil.

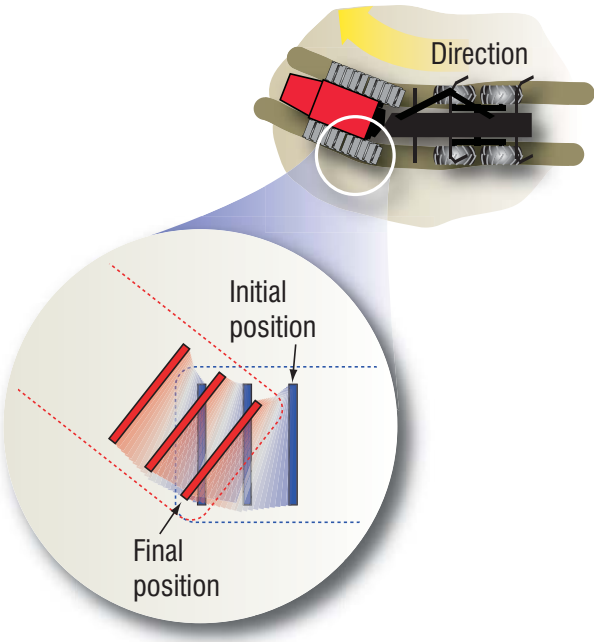


Figure 6. Shearing exerted by a track during a turn.

Harvesting systems

HPRS harvesting operations in Quebec's softwood forest are, for all practical purposes, fully mechanized. Full-tree harvesting, in which the trees are delimbed at roadside, remains the most popular. However, cut-to-length harvesting, in which the trees are delimbed and slashed on the cutover, has become significantly more common since the 1990s (Figure 7). In this mode of harvesting, there are two main alternatives: one with a single-grip harvester and one in which a processor handles trees felled and piled by a feller-buncher. The latter process is frequently referred to as three-machine cut-to-length harvesting, with the forwarder being the third machine. The tree-length system, which is only common in single-tree selection cuts, is nonetheless occasionally used in regeneration cuts. It involves felling and delimbing on the cutover, but maintains the full length of the stem during extraction to roadside.

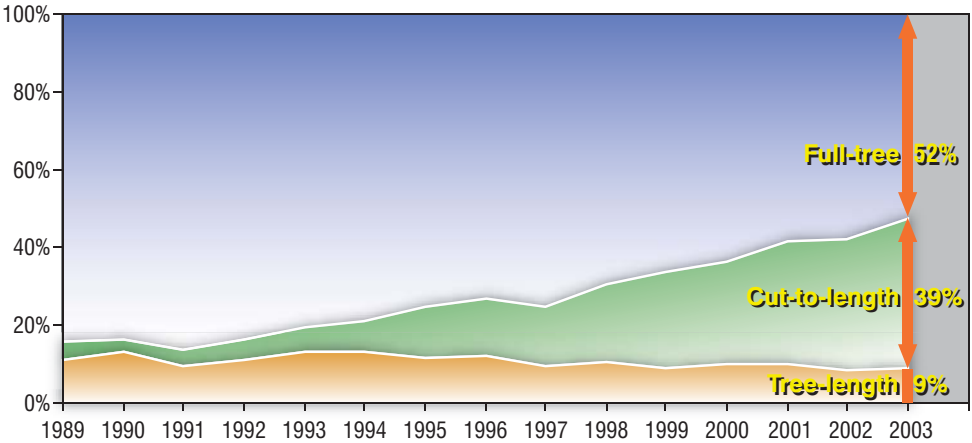


Figure 7. Proportions of the various harvesting systems used in Quebec's public forests (adapted from Claveau 1995, 1997, 2001, and 2005).

Relevant characteristics of the harvesting systems and related recommendations

The remainder of this section reviews the relevant characteristics and recommendations that apply to each of these harvesting systems and to the machines used therein. Some recommendations are specific, whereas others are common to all the systems. In each case, communication is a key success factor. The supervisor and the operators of the various machines should together review the objectives to ensure that each clearly understands what must be done and the needs of the subsequent phases. For example, some sections in a cut block could be felled so as to direct the extraction phase towards sections of the site with a better bearing capacity.

As well, the supervisor and the operators must be aware of the possible actions to take when problems arise. Of course, once the wood has been felled, it must be extracted, but in the case of a local wet spot, for example, traffic could be directed onto an adjacent trail with better bearing capacity to reduce the risk of machines getting stuck in the softer ground.

Full-tree harvesting

Feller-bunchers

The feller-buncher is a highly specialized machine that has become highly productive in recent years. Continuous-rotation saw heads are now widely preferred for their speed, but the large saw disk (1.6 m) requires considerable space. In addition, the motion of the head and the cut direction must always be done along the axis of the boom, which limits the choice of head movements the operator can use to avoid residual stems that should be protected. For some years, most felling heads have provided full lateral tilt, thereby improving the flexibility of movement, particularly while placing felled trees on the ground.

The following general principles can improve the results of HPRS operations using feller-bunchers:

- use the machine's full boom reach;
- pile at a sharp angle with respect to the trail;
- concentrate the bunches in the smallest possible area;
- adjust the bunch volume to the operating conditions;
- avoid sweeping or crushing tall regeneration;
- evaluate the angle of approach to account for tall regeneration;
- recover any dropped stems;
- agree on what to do when problems arise;
- pay attention to the layout of the cut block.

Use the machine's full boom reach. This practice aims to maximize the total width of the felling corridors. Wide corridors maximize the area of protected leave strips after extraction; in these strips, advance regeneration receives better protection because there is no machine travel. "Full reach" means between 95 and 100% of the distance permitted by the maximum extension of the boom. The degree of success in attaining this objective can be measured by comparing a value equal to twice the distance from the machine's point of rotation to the end of the saw when the boom is at full extension (i.e.,

twice the felling radius) with the average distance between the trails (center to center). CAUTION: In particularly sensitive terrain, it may be wise to avoid concentrating wood extraction excessively, which can result from applying this technique.

Most manufacturers now offer equipment with a reach of up to 10 m (Figure 8). However, lighter heads must be used to maintain machine stability at full boom extension.

Pile at a sharp angle with respect to the trail. Pile trees at an angle of 20 to 30° to the trail, with the butts facing the landing, to facilitate the extraction of bunches during skidding. This simplifies a grapple skidder's work, while limiting sweeping of the regeneration. It also limits the sweeping that can occur during loading of a clambunk skidder.

Concentrate the bunches in the smallest possible area. To achieve this, use heads with full lateral inclination ("full-tilt" heads), which can increase bunch size by piling bundles of trees collected from a larger distance without requiring the machine to move. However,

Figure 8. An extended-reach boom on a feller-buncher.

when this is done, operators must avoid mowing of tall regeneration. When extraction will be done by a grapple skidder, bunch size should match the loading and extraction capacity of the machine.

Adjust the bunch volume to the operating conditions. The optimal load volume for grapple skidders can vary as a function of the soil's bearing capacity. Evaluate the ideal balance between the damage to regeneration that results from additional maneuvers and the need to reduce the load in difficult terrain.

Avoid sweeping or crushing tall regeneration. It is more difficult to protect tall regeneration (i.e., diameter at stump height > 2 cm) than smaller trees, and thus, to maintain stocking at an acceptable level. When laying down felled trees, operators should attempt to account for the presence of tall regeneration by taking advantage of stand openings for the construction of bunches. Operators must consider all of the area that will be affected by the bunches, since tall regeneration located within 1 m of a bunch is most susceptible to damage during extraction by the skidder.

Figure 9 presents an example of damage to tall regeneration, with the squares showing that the proportion of damage is higher (in red) closer to the bunch.

Figure 9. Destruction and survival of tall regeneration near bunched trees.

Evaluate the angle of approach to account for tall regeneration. When the approach of the felling head to the target tree is blocked by tall regeneration, the operator should evaluate whether it would be better to approach the tree from another position. The operator should resist the temptation to improve visibility by crushing or cutting the regeneration.

Recover any dropped stems with the feller-buncher. Recovery of dropped stems by the skidder requires the skidder to leave the trail, even for skidders equipped with a recovery grapple on the side of the blade.

Agree on what to do when problems arise. After preliminary site reconnaissance by the supervisor, the feller-buncher operator often develops a better sense of the local site conditions and should alert the skidder operator to the presence of any problem areas. Everyone should agree on what measures to take when problems arise—call on the radio, switch to another block, and so on (Figure 10).

Figure 10. A problem area of a site revealed during the felling phase.

Pay attention to the layout of the cut block. Blocks with an irregular shape and rough terrain can lead to crossing of trails and increased traffic in certain areas, in addition to increasing extraction distances and leading to congestion at roadside. Sometimes it's necessary to consider whether it would be beneficial to begin felling elsewhere than along the block boundaries that have been flagged. This can provide better spacing and branching of trails and fewer cross-overs, or can even avoid the need for excessive slopes for subsequent extraction trails in steep terrain.

When the feller-buncher is working ahead of cable skidders, bunching stems in the return trail rather than in the leave strip will limit the damage to regeneration. This technique is not appropriate with grapple skidders and clambunk skidders, which would have to leave the trails and travel around the bunches to collect a full load.

Skidders

Two main types of skidders are used in mechanized full-tree operations in softwood forests: grapple skidders and clambunk skidders. These are by far the most common solutions, with cable skidders being used primarily when access to the site is extremely difficult, such as on steep slopes.

Irrespective of the type of skidder, the manner in which the machine is driven will have an impact on the soil. Operators should learn to accelerate gradually and smoothly rather than starting and stopping abruptly. There should also be good communication between machine operators. Skidder operators should work closely with feller-buncher operators to ensure, for example, that the skidder can travel on the trail without difficulty and that the wood has been piled so that it can be easily loaded.

Grapple skidder

Still widely used, grapple skidders offer poorer results than other skidders in terms of the protection of regeneration (Gingras et al. 1991). Because movements of the grapple's arch only occur in line with the machine's axis, the frame must be pivoted to pivot the grapple during loading, which requires the machine to leave the extraction trail. However, grapple skidders can produce satisfactory results with appropriate work techniques and in terrain with a good bearing capacity (Figure 11).

Figure 11. A grapple skidder approaching a landing where delimbing is occurring.

In terms of protection of regeneration, keeping the machine within the trail is the key to success. The operator should consider traveling backwards in the first 50 to 75 m of an extraction trail to avoid the need to turn around. Some machines now offer a rotating seat that makes it much easier to travel long distances facing backwards.

Over longer distances, the machine should travel forward, but turn around only at appropriate locations—that is, where the soil is firm and where there is little regeneration. The number of these locations should be minimized, and operators should strive to avoid destroying the regeneration in and around the turnarounds.

Skidder and feller-buncher operators should agree on the optimal bunch size. Where possible, forming bunches equal in size to a full skidder load will eliminate the additional maneuvers required during extraction (so long as the bearing capacity of the terrain is

not a limiting factor) because this avoids the need to drop trees at the side of the trail to consolidate multiple bunches during a trip. Conversely, it also avoids the need to divide too-large bunches. In both cases, this reduces the risk of destroying regeneration beside the trails and piles.

Limit the size of the extraction cone as much as possible (a maximum of 30 m from the road). This can present a challenge for the skidder when approaching the landing because of the need to form piles of well-aligned stems for the delimber and occasional space constraints at roadside. Nonetheless, good planning of felling in the block will avoid unnecessarily complicating the skidder's work by creating bottlenecks. Hot logging (integrating the skidder's work with the delimber's work) can also help keep trails from fanning out near the landing. Hot logging involves delimbing each skidder load as soon as it arrives at roadside rather than building a large cold deck from which the delimber supplies itself. This approach avoids the problems of congestion at the landing and the detours that the congestion requires.

Grapple mounted on a pivoting boom (swing boom)

For several years, grapple skidders mounted on a pivoting boom (a "swing boom") have been used in western Canada. This type of device adds considerable freedom of movement for the grapple, and allows operators to load a pile without requiring the machine to leave the trail (Figure 12). This can offer an advantage in terms of protecting regeneration.

Figure 12. A grapple skidder with a swing boom performing loading. (The model illustrated here has six-wheel drive and the rear bogies are equipped with tracks.)

Clambunk skidder

The clambunk skidder is the other type of equipment most commonly used in full-tree systems. This skidder loads itself by placing the bases of trees in its clambunk using a loader (Figure 13), which can reduce the amount of damage to regeneration that would be caused by sweeping. This also eliminates the need for maneuvers outside the extraction trail, which are likely to damage the regeneration.

Figure 13. A clambunk skidder with a 14-tonne capacity performing loading.

A rotating seat allows the operator to more easily travel backwards while unloaded to collect a new load, thereby keeping travel within the trail.

Since most clambunk skidders have eight drive wheels equipped with tracks, it is important to travel in a straight line and avoid sharp turns that would cause shearing of the soil.

The clambunk skidder's work is less affected than that of a grapple skidder by smaller bunches of trees. However, feller-buncher operators should still try to maximize bunch size to reduce the space occupied by the bunches and the associated damage to advance regeneration.

Piling trees at a sharp angle to the trail will limit the sweeping of tall regeneration that can occur when the bunches must be balanced on the load already held in the bunk during loading. With small bunches, it is preferable to load the trees by resting them on the bunk, then to pull them into line by advancing the machine.

Cut-to-length harvesting

It's generally recognized that cut-to-length harvesting offers an advantage in terms of improved protection of regeneration. However, the system itself does not guarantee successful protection of regeneration nor better results than with other equipment. Conscientious operators and good communication between supervisors and operators are still required.

Single-grip harvesters

The use of single-grip harvesters has expanded greatly during the past 15 years. The carrier can be equipped with rigid tracks (like an excavator) or wheels (common for European models). Their reach can easily attain 10 m since the single-grip heads are lighter than feller-buncher heads and can generally only handle a single tree at a time. Movement of the head and cutting are performed along the axis of the boom, but the head can also pivot around its vertical axis to allow cutting of a tree from the side. The booms employed by these machines can be articulated or telescoping (Figure 14).

Figure 14. A single-grip harvester with a telescoping boom.

The following general operating principles can improve the results of HPRS with single-grip harvesters:

- use the machine's full boom reach;
- concentrate the piles of logs;
- consider the ideal positioning of the cut;
- place the tops at 90° to the trail;
- avoid piling the logs on visible regeneration;
- accumulate trees for processing;
- move the head towards the trail as the tree falls;
- pay particular attention to the presence of tall regeneration.

Use the machine's full boom reach. This practice aims to maximize the total width of the felling corridors. Wide corridors maximize the area of the protected leave strips after extraction, where the best protection of advance regeneration occurs. "Full reach" means between 95 and 100% of the distance permitted by the maximum extension of the boom. The success in attaining this objective can be measured by comparing a value equal to twice the distance from the harvester's[2] pivot point and the center of the head when the boom is at full extension (i.e., twice the felling radius) with the average distance between the trails (center to center).

Concentrate the piles of logs. Limit the area occupied by the piles and arrange the piles so they are easy to reach with the forwarder's grapple. This recommendation can become difficult to implement as the number of products to be sorted increases.

Consider the ideal positioning of the cut. When visibility of the base of the tree is poor, consider the possibility of cutting the stem from the side rather than crushing or cutting vegetation and regeneration that gets in the way.

2. Or the distance from the gear that pivots the base of the boom if this gear is not mounted on the harvester's turret.

Place the tops at 90° to the trail. Process the trees so as to drop the tops and delimbing debris at 90° to the trail and ahead of the machine. This is a good way to limit rut development and maintain equipment mobility (Figure 15).

NOTE:

This practice is to be avoided where the regeneration is marginal and where the site will require site preparation; in that case, dispersal of the debris would be preferable.

Avoid piling the logs on visible regeneration. Whenever possible, avoid piling logs on visible regeneration. Instead, use areas covered with shrubs (for example, kalmia and Labrador tea), where there is typically little or no regeneration. Remember that every stem of regeneration may contribute to the development of the future stand.

Accumulate trees for processing. When the felling head permits the processing of several stems at a time, two trees falling at the same time can cause less damage to the regeneration than two separate falls.

Figure 15. Tops placed at an angle of 90° with respect to the trail.

Move the head towards the trail as the tree falls. This approach can decrease the area of ground that is swept by the tree and its branches.

Pay particular attention to the presence of tall regeneration. It is more difficult to maintain the stocking of tall regeneration than that of shorter regeneration. Avoid unnecessary cutting of the regeneration (Figure 16). Watch where the logs will drop from the head during processing so as to prevent them from damaging regeneration near that point. Keep the head near the ground during processing to better control the point where the logs will fall and to prevent them from rolling away.

Figure 16. A stem of tall regeneration that has been cut.

Shortwood forwarders

Shortwood forwarders are available in several configurations, ranging from four to eight wheels (Figure 17). Eight-wheeled forwarders offer a better weight distribution; in addition, the use of bogies on the front wheels improves operator comfort during travel. Remember that the front part of the machine, with the engine and the cab, represents a significant weight.

Figure 17. A typical shortwood forwarder.

The following general operating principles can improve the results of HPRS with forwarders:

- travel backwards unloaded toward the back of the block;
- restrict travel to trails;
- promote travel in a straight line;
- cross sensitive areas with a reduced load;
- avoid turning around on the cutover;
- avoid striking tall regeneration while loading logs;
- practice driving in a way that minimizes the impact on the soil;
- ensure good communication between operators.

Travel backwards unloaded toward the back of the block. By moving to the back of the block before beginning the extraction, it is possible to observe the distribution of products and volumes and better plan the loading strategy so as to limit the total number of trips. At the same time, it becomes possible to identify areas that could be at risk of rutting.

Restrict travel to the trails. Concentrating traffic within the trail can avoid widening of the trail.

Promote travel in a straight line as much as possible. It's important to note that tracks increase mobility of the equipment and reduce ground pressure, but that changes of direction will lead to shearing of the soil. These disturbances are even more pronounced when the machine's bogies are not symmetrical or equidistant from the articulation point.

Cross sensitive areas with a reduced load. Operators can complete loading of a full load once they have crossed such areas during the return trip. This practice reduces pressure on the soil of the sensitive area (Figure 18).

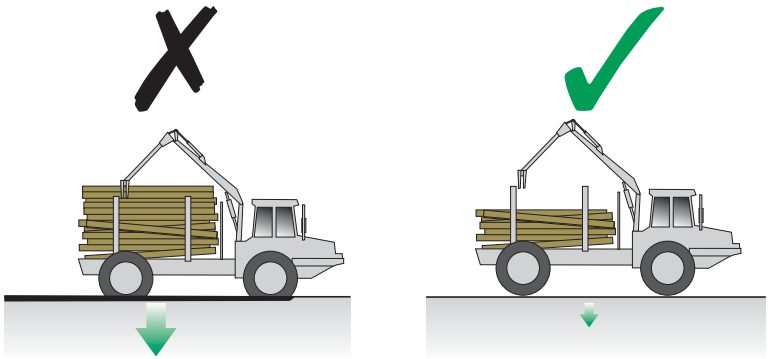


Figure 18. Reduction of payload in sensitive zones (from Sutherland 2005).

Avoid turning around on the cutover. A load, even when incomplete, greatly restricts visibility towards the rear, thereby increasing the risk of crushing regeneration during maneuvers.

Avoid striking tall regeneration while loading logs. It can be more difficult to attain this objective when tall regeneration is abundant and when the logs to be loaded are long (5 to 7 m).

Practice driving in a way that minimizes the impact on the soil. Operators should accelerate slowly and smoothly rather than starting and stopping abruptly.

Ensure good communication between operators. Forwarder operators should work with the harvester operator to ensure, for example, that the forwarder can easily use the harvester's trail and that the wood is piled so as to facilitate loading.

Processors (cut-to-length with three machines)

The use of a processor (Figure 19) leads to additional machine traffic on the cutover. To limit the risk of disturbance entailed by this additional traffic, the processor must travel only in the trails created by the feller-buncher[3].

Figure 19. A processor working on felled trees.

3. The general operating principles for a feller-buncher working in front of a processor are the same as those in full-tree harvesting, with the exception of the angle at which the stems are piled, which should be at 90° to the trail.

The following general operating principles can improve the results of HPRS with processors:

- create the most concentrated and accessible piles that you can;
- pay attention to the head's movement;
- pay attention to the trajectory of the processed logs;
- concentrate the debris and tops in the trail during processing.

Create the most concentrated and accessible piles that you can. Delimb above the trail and create the most concentrated piles you can that are accessible to the forwarder's grapple. To accomplish this, keep the head near the ground during processing to prevent the logs from bouncing or rolling after they fall. Favor locations that are free of regeneration for piling the logs.

Pay attention to the head's movement. Paying attention to the head's movements will minimize the frequency of hitting and damaging regeneration.

Pay attention to the trajectory of the processed logs. The end of the log can wound tall regeneration by striking it during processing.

Concentrate the debris and tops in the trail during processing and leave the tops at 90° to the trail. This is a good way to limit the development of rutting and to maintain the mobility of equipment, particularly in wet areas.

Tree-length harvesting

In the context of a regeneration cut (as opposed to a single-tree selection cut), the tree-length system can be considered as an extension to cut-to-length harvesting, with the stems left at their full length and subsequently forwarded rather than being skidded along the ground (Figure 20). As in cut-to-length harvesting, the system configurations can use either two or three machines.

The operating principles are thus the same as in cut-to-length harvesting, but with increased emphasis on reducing the handling of tree-length stems on the cutover. Because of their length, these stems can cause accidental sweeping of tall regeneration.

The use of stroke delimbers on the trails of the cutover is possible, although somewhat difficult. The debris left on the trail will, however, be oriented parallel with the trail, which is less effective for limiting rutting than debris deposited at an angle of 90°.

Figure 20. A tree-length forwarder.

Choice of practices

Coverage of the site by trails and protection of regeneration

Based on article 89 of Quebec's RNI, the manager is given a choice:

- a maximum coverage of the site by trails of 33%, accompanied by minimum standards for the protection of regeneration (see sidebar); or
- a maximum coverage of the site by trails of 25%, with no criteria for the protection of regeneration.

To make the best choice, ask the following questions: Would the regeneration be protected better by cutting closer to the machine? If so, would this advantage compensate for a relatively larger area occupied by the bunches, which represent zones where the regeneration would be subjected to considerable damage?

Criteria that must be met for the protection of regeneration with coverage of the site by trails between 25 and 33%.

Objective

≥ 80% of pre-harvest stocking before harvesting for regeneration 5 cm tall and taller

≥ 55% of pre-harvest stocking before harvesting for saplings 2 cm or larger in dhs

≥ 35% of pre-harvest stocking before harvesting for saplings 6 cm or larger in dhs

The protection rate for regeneration is established by evaluating the proportion of stocking accounted for by stems free from mortal wounds.

Maximizing the width of the felling corridors to reduce coverage of the site by trails remains a valuable approach to obtain regenerated cutovers and probably involves lower costs for subsequent monitoring of the work. However, where you expect to encounter difficult conditions such as wet soils, you should emphasize maximum protection of the regeneration, which will provide a larger margin for error in terms of coverage of the site by trails (33%). The abundance of advance regeneration should also be considered, since sites where it is less abundant are often more difficult to protect.

Contractors concerned by the delays caused by working at the full extension of the boom should consider using a telescoping boom (cut-to-length), whose action is faster than that of articulated booms.

Use of ghost trails

Developed for use in commercial thinning, harvesting on ghost trails (also known as "two-in-one" harvesting) was mostly applied when the reach of feller-bunchers was still relatively short. This method is not a good choice when the stocking of tall regeneration reaches or exceeds 15%. Since the full width of the felling trail is included in estimating the coverage of the site by trails, this method only offers the advantage of having one trail in two equal in width to that of the feller-buncher—that is, the ghost trails are not widened as a result of travel by the extraction equipment. The presence of residuals, poor visibility, or rougher terrain conditions also complicates the application of this method, and there is a possibility of excessive concentration of traffic in the extraction trails if the site is subject to rutting.

Return of debris to the cutover to mitigate rutting (full-tree)

Integration of the extraction and delimbing phases in hot logging operations, in which delimbing of a full skidder load occurs before the next load enters the landing, offers an opportunity to return debris to softer areas of the trails, and thus offers an increased possibility of preventing rutting (Figure 21).

Figure 21. A skidder returning debris to the cutover.

However, the results of one study (Plamondon and Desrochers 2005) suggested that the total length of rutting in the extraction trails may not decrease. In effect, the difficulty of arranging the debris optimally—and particularly, the difficulty of arranging tops perpendicular to the trail—limits the effectiveness of this approach. This method nonetheless helps to maintain equipment mobility, and the fact that it concentrates the debris at selected locations can certainly provide some benefits.

Good planning by skidder operators allows them to hold the debris in reserve against future need if they expect to encounter problems in subsequent trails. This point can be important on sites where the quantity of debris is low.

Keep in mind the following key points for the application of this method:

- ensure good communication with the feller-buncher operator to help the skidder operator plan and manage the debris (the felling operation should not get too far ahead of the extraction operation);
- arrange the debris on both sides of the trail, with the tops at 90° to the trail;
- avoid excessive use of the articulation of the skidder frame, which can lead to shearing of the soil.

Winter operations

Even when the operations occur during the winter, the soil may not always be frozen beneath the layer of snow, and this can lead to rutting problems. Packing of the snow cover by repeated passes by the skidder decreases the insulation provided by the layer of snow. Partial extraction in the most sensitive part of the trail will have a similar effect. After a very cold night, the frost will penetrate the soil and improve its bearing capacity.

In rough terrain

In HPRS, rough terrain or steep slopes don't inevitably lead to poor results, but both factors can certainly make the operations more difficult (Figure 22) because the trail networks are dictated less by a need for systematic spacing than by the configuration of the terrain itself.

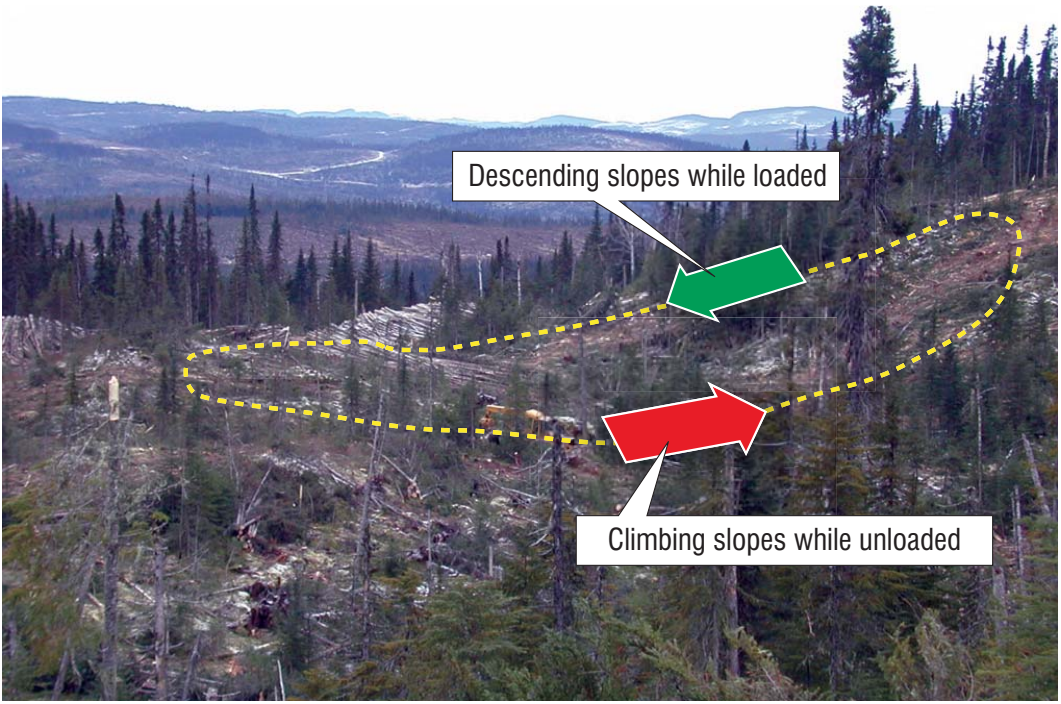
Increased numbers of trail crossings and of secondary trails can lead to a marked increase in coverage of the site by trails. Good reconnaissance of the site before harvesting will improve planning of the approach in difficult blocks. Good communication between the harvester and skidder operators is required to permit adequate

Figure 22. A feller-buncher working in rough terrain.

planning of the operation. Consequently, the felling work should not get too far ahead of the extraction work. Immediate extraction of wood, or extraction after a short delay, can also offer an opportunity to exploit an unanticipated but favorable route when laying out the cut block.

When the skidder is unable to climb certain slopes, the use of return trails (Figure 23) can improve both the protection of the soil and the productivity of the equipment. The additional branching of trails created by this technique must, however, be tightly controlled to prevent an unacceptable increase in coverage of the site by trails.

Figure 23. Return-trail skidding.



Rutting on long, even slopes is likely to cause erosion because it increases the speed and volume of runoff water (Figure 24). Operators should thus place snags or other debris on the trails to create obstacles that interrupt flowing water or should use curved trails that create barriers to an uninterrupted flow of runoff (MRN 1998). During the planning of extraction trails, one should also keep in mind that downhill extraction is more likely to reduce disturbance.

Last but not least, attaining the 25% threshold for coverage of the site by trails can prove difficult in rough terrain. A better strategy might thus consist of aiming for maximum protection of tall regeneration and taking advantage of the larger maximum trail coverage (33%) permitted by this approach.

Figure 24. Rutting on a slope where channeling of runoff water has occurred.

Develop knowledge appropriate to the local context

In general, it is easier to obtain good results in stands where advance regeneration is abundant. In stands that are not as well regenerated, it may be necessary to develop operator experience by asking them about the prevailing conditions on the site, with an emphasis on teaching them to keep an eye on the regeneration. For example, does the presence of shrubs (e.g., Labrador tea and kalmia) often suggest a total absence of regeneration, thereby permitting the piling of wood at these locations? Periodic verification should increase the ability of workers to recognize such favorable conditions.

Don't forget that under these conditions, each stem of tall regeneration is important and every effort should be made to protect these stems.

Specialized equipment

Many types of specialized equipment for harvesting in soft terrain have been studied. Economic realities have always dictated the viability of such equipment. Choosing specialized equipment poses the dilemma of finding the right balance between flexibility and specialization so the equipment can meet the specific objectives of HPRS. For example, skidders with extra-wide tires are relatively common in northeastern Ontario, but in that region, these machines work almost exclusively on soft soils. The use of wide tires gives the skidder a low ground pressure, which can be an attractive way to reduce rutting, but it also increases trail width.

Cable yarding in flat terrain (Figure 25) is another technique that has been evaluated (Meek 1997, Plamondon 1998). However, the approach is expensive and its limited area of application requires careful planning to ensure the availability of suitable sites throughout the year.

Figure 25. Cable yarding in flat terrain.

Figure 26. A tracked skidder equipped with a grapple mounted on a swing boom.

Skidders with rigid tracks pose a comparable problem. The tracks of the model illustrated in Figure 26 are 90 cm wide, which provides high flotation in soft terrain, but their use must be confined to such terrain. The torsional forces applied on the tracks by stones and other forms of rough terrain will cause problems for the drive train.

Mixed teams

It is possible to consider "multiple-type" extraction alternatives where a team approach would reduce disturbance by using the most appropriate equipment at each location.

For example, the combination of a clambunk skidder and a grapple skidder would allow each machine to work in its preferred niche: the grapple skidder for short distances and the clambunk skidder for longer distances (Kosicki 2002) or on sites with lower trafficability.

It's important to remember that when several skidders work on the same site, the operation should be planned so that their paths never cross.

Planning and monitoring aids

What new tools could help us meet our objectives?

Aids for general planning

Companies that regularly harvest large areas of wet or poorly drained sites tend to plan their harvesting for the winter season because of the increased mobility of their equipment, the reduced costs of road construction, and (more recently) reduced soil disturbance. For the same reasons, they reserve harvesting of pine stands for traditionally unfavorable periods such as during the fall rains.

Apart from these obvious situations, there are many sites whose vulnerability to rutting can vary among seasons or that include localized problem areas that are not sufficiently widespread to define the overall characteristics of the site.

In these cases, knowledge of the terrain acquired through the experience of the supervisory personnel is invaluable. This information can, however, be difficult to integrate within planning at different scales. Tools that allow managers to systematize the results obtained (for example, for rutting) can offer a basis on which to unite this knowledge.

MRNF has developed a matrix that shows the vulnerability of various stands to rutting (Grondin et al. 2005) in terms of the ecosite characteristics, and this matrix represents a good baseline tool. MRNF also offers software for assigning a rutting vulnerability level to ecosite polygons (MRNF 2005); once adapted to the local context, this tool will help to categorize sites based on their vulnerability.

More advanced methods can be use to refine the analysis of terrain and even to plan the operations as a function of other objectives.

Figure 27. Overlaying the results for rutting (cross-hatching) on a map of ecosites (green boundaries) on an orthophoto. (Adapted from Lacroix 2005.)

For example, Lacroix (2005) developed spreadsheet software with linear programming functions to plan operations so as to limit, among other things, rutting. The software used data from surveys of rutting levels and the specified harvest season in its calculations (Figure 27).

This or a similar approach could also be adapted to a company's planning system. It could then be supplemented by adding other potentially important variables such as the precipitation within a given period or even the maximum extraction distance in the block. Nonetheless, any model, however sophisticated it may be, should be validated by means of careful photo interpretation and thorough field verification (ground-truthing).

Aids for monitoring operations (trail occupancy)

GPS-based monitoring: reality or science fiction?

Since its introduction in forestry, global positioning system (GPS) technology has been evaluated in many applications, whether using real-time differential correction or post-processing. In some cases, the technology was quickly adopted, as in the case of monitoring mechanized silvicultural work. GPS-based tracking would appear to be a promising solution to monitor machine traffic during forestry

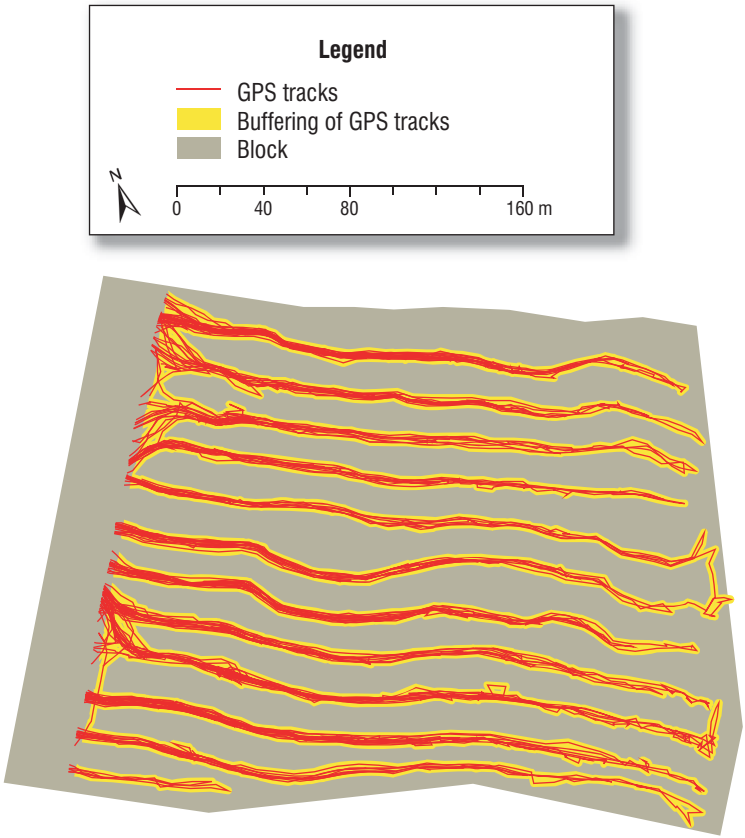


Figure 28. Results of monitoring of a forwarder using a GPS-based tracking system.

operations in Quebec's public forests. Early trials (Ryans 2000) illustrated the problems associated with random positioning errors that accumulated between passes. The arrival of receivers capable of using the Wide Area Augmentation System (WAAS) and the resulting accuracy has improved the results (Tran and Plamondon 2005) (Figure 28).

The complete portrait of the site that is obtained is one of the most attractive characteristics of an approach based on machine tracking. Whereas conventional detection of switching between trails depends on probability-based sampling using transects, a GPS tracking approach records all machine travel. It can also detect areas where the extraction cones exceeded the prescribed distance of 30 m.

As is often the case with new technologies, the implementation challenge lies in efficient processing of the collected information to obtain the maximum benefits without unduly increasing the workload.

In this context, the automated data analysis permitted by GPS tracking of machines would allow managers to intervene rapidly when problems arise rather than being unable to respond until weeks or even months later. Promising research results, combined with ongoing improvements to GPS receivers, make it possible to envision the implementation of such systems in the mid-term. Between now and then, a simple visual inspection of the tracking files can provide a good idea of the status of an operation. Irrespective of the technology used, technology alone cannot replace good interactions between supervisors, planners, and machine operators.

Elements of a control system

Once improved annual planning has been achieved, it's the responsibility of the actors involved in the field operations to ensure successful execution of the plan. What measures can be implemented to help them meet the plan's objectives? The understanding of all participants in the process cannot be taken for granted, so any such measures must address the need to create and gradually improve that understanding. A single meeting at the start of the operating season will not suffice. Here are some key ideas that should be implemented to create a control system that will ensure the success of HPRS operations:

- Provide rapid feedback on the results that were obtained by detecting problems while they're still "fresh". This can reveal the causes of the problems, and lead to joint development and application of the necessary corrections (Figure 29).
- Encourage a bottom-up flow of information (from the operator to the supervisor) to improve monitoring of the operations as they happen and encourage immediate correction of problems.

Figure 29. Feedback during the monitoring of operations.

Problems often appear to be obvious after they have occurred, but predicting them before they occur is far more difficult.

- Plan for the unexpected. For example, in case of periods of unexpectedly high rainfall, designate an alternative drier block near the planned operation. Would it be possible to harvest difficult areas during the day and reserve the easier terrain for night work? Would it be realistic to come back later when the conditions will be more favorable?
- Document the different solutions that have been implemented and how well they succeeded. This is an essential tool for creating a "corporate memory" that allows managers to learn from their errors and their successes.

From one season to the next, the knowledge that is gained should be reviewed:

- Was the equipment adequate?
- Are there incentives to ensure meeting the objectives? Are they effective?
- Are there any training needs?
- Is it possible to predict any unusual periods during which operations must cease? Who will cover the resulting costs?
- Could we imagine new work methods?
- Is our approach to documenting the activities effective? Is the information used to improve performance?

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Forest Engineering Research Institute of Canada (FERIC)

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC
H9R 3J9
(514) 694-1140
(514) 694-4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC
V6T 1Z4
(604) 228-1555
(604) 228-0999
admin@vcr.feric.ca

Web site: www.feric.ca

Ministère des Ressources naturelles et de la Faune (MRNF)

Ressources naturelles et Faune
Québec

Web site:
http://www.mrnfp.gouv.qc.ca/accueil.jsp