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OVERVIEW OF APPROACHES TO SUSTAIN FOREST PRODUCTIVITY DURING FOREST ROAD DEVELOPMENT AND TIMBER HARVESTING ACTIVITIES

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ABSTRACT.—Various approaches are available to minimize impacts on forest productivity during forest road building and timber harvesting activities. These approaches include a variety of practices and technologies. They include practices such as reducing road and trail development, using designated trails, and leaving slash at the stump on nutrient deficient sites. Technology options include low ground pressure machinery, tracked swing-to-tree feller-bunchers, small-scale equipment, and portable wetland and stream crossing structures. Increased application of these approaches will require additional research, training for foresters and loggers, and support for loggers.

Timber harvesting operations, including forest road building, can impact forest productivity by taking land area out of production, damaging residual trees and seedlings, removing nutrients from the site, and by compacting, rutting, and eroding the soil. Productive capacity is most dramatically reduced in heavily trafficked areas, such as access roads, landings, and main skid trails. Adjacent areas can also be affected by associated changes in the hydrology of the site. Severe nutrient depletion reduces soil fertility, directly affecting tree growth. Rutting and soil compaction and associated disturbances reduce soil porosity, physically damage roots, and restrict water and air movement through the soil. Accelerated soil erosion leads to the removal of surface soil material, depleting available soil nutrients and organic content. While some of these impacts are unavoidable consequences of timber harvesting operations, their frequency and extent can be significantly reduced.

There are several options for taking a "light-on-the-land" approach during forest road building and timber harvesting operations. This paper presents an overview of some of the approaches for sustaining forest productivity. Topics discussed include planning considerations, forest productivity guidelines, equipment options, including small-scale equipment, and facilitating the application of these approaches. Due to space limitations, all of the available approaches cannot be described here and extensive detail cannot be included.

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PLANNING CONSIDERATIONS

Pre-planning and an on-site evaluation are important tools for avoiding productivity impacts. Pre-planning includes identifying management goals and objectives and gathering information using aerial photographs, soil surveys, and topographic maps of the site. During the on-site evaluation, factors to consider include soil capabilities and limitations, slope (steepness and length), location of wetlands and stream crossings, adequacy of any existing infrastructure (forest roads, skid trails, and landings), need for additional infrastructure, preferred season(s) of operation, and appropriate methods of operation. Planning based on the predictable limitations and capabilities of a site will help the manager and operator maintain site productivity, reduce maintenance costs for infrastructure and equipment, and maximize operational efficiency.

An on-site evaluation should be conducted to locate and connect key control points and to identify the best operational approach. Key control points include the potential locations for site access, landings, stream and wetland crossings, and other project features. This will help limit erosion, sustain productivity, meet landowner objectives, improve safety, and reduce costs. Start by locating soils and topographic features that are best suited for roads, trails, and landings (e.g., well-drained soils, nearly level terrain, areas away from water) as well as areas that may limit operations (e.g., steep terrain, wet soils, advance regeneration). Select a safe, effective access point. Identify routes that avoid the need for crossing streams or wetlands, or, if necessary, that cross them at appropriate places. Finally, create a map with all control points marked and clearly identifying the most efficient routes for roads and trails.

Developing a written plan or detailed instructions is strongly recommended to minimize misunderstandings and to avoid conflict. Clearly delineating places of special concern, such as an area with advance regeneration, both within the plan and on the ground is valuable. Conducting an on-site meeting with the logger, landowner, and resource manager prior to moving equipment onto the site is the final step in good planning. This allows the plan to be communicated to the logger so that adjustments can be made based on the specific equipment and operational capabilities of the crew that will carry out the harvest. Before and during the harvest, a close working relationship between the sale administrator or landowner and the operator is essential to the effective implementation of the plan.

FOREST PRODUCTIVITY GUIDELINES

A certain amount of disturbance is inevitable when conducting management (forest road building and timber harvesting) activities. A critical component of mitigating impacts is careful advance consideration of existing management guidelines. To mitigate these impacts, most states and provinces have developed forestry Best Management Practices (BMP's) to protect water quality. While BMP's generally pertain to areas in close proximity to water, additional guidelines have been developed to protect other forest values, including soil productivity. Many managers and operators already do this because they recognize the operational and economic benefits of these practices (e.g., reduced costs of road, skid trail, and landing maintenance; increased number of operable days on-site; reduced cost of maintaining equipment).

Types of guidelines to consider for sustaining forest productivity during forest road building and timber harvesting are noted below. Consult the specific BMP's and other management guidelines in each state or province for more information.

General Practices: *Location of Fueling and Maintenance Areas, Prevention and Cleanup of Spills*

Forest Roads: *Design Considerations, Alignment and Location, Excavation, Drainage, Stabilization of Disturbed Areas, Maintenance, Closure*

Timber Harvesting: *Design Considerations, Skidding and Skid Trails, Minimization of Rutting, Management of Slash, Post-operational Activities*

TIMBER HARVESTING EQUIPMENT OPTIONS

Timber harvesting equipment options include machinery for felling, extraction, and processing. Of these, extraction causes most of the negative site impacts during timber harvesting activities. Ground-based equipment is most commonly used because it has a definite productive and economic advantage over alternative systems. However, ground-based systems also have the greatest potential for site disturbance, impacts to residual vegetation, and associated degradation of forest productivity because they must traffic the site.

Felling Equipment

Rubber-tired felling machines are generally faster moving and have lower initial and operating costs than other alternatives. However, these machines generally have fixed heads that require them to drive to each tree to be felled. The need to drive to each tree and to move rapidly to maintain production increases the incidence and severity of site and stand disturbances.

Excavators have commonly been adapted for use as felling machinery. The inherent stability of tracked excavators, the long reach of the boom that minimizes the need to move the machine to each tree to be felled, and the low ground pressures exerted by these machines greatly reduce their impacts on a site while overcoming some of the productivity limitations of other tracked machines. An inherent problem with this machinery is the wide tail or back end of the rotating platform that extends outside of the tracks, making it difficult to operate in narrow corridors. Recent developments have led to "zero tail swing" machinery where the entire rotating platform is able to stay within the width of the tracks.

Advances in forwarder technology have led to the development of harvesters that use the forwarder chassis for mobility and a harvester head attached to the boom for felling and processing functions. The trafficability of this chassis, particularly those versions that have double-axle bogie wheel assemblies either on just the rear axles or on both front and rear axles, is extremely good. The low ground pressure, low speed, and high load capacity of this equipment combination make it especially well-suited to harvesting operations on sensitive sites.

Extraction Equipment

Before the development of rubber-tired skidders, tracked machines were the most commonly used ground skidding equipment. Lower ground pressure, increased traction, and reduced site disturbance are still advantages of tracked machines. Disadvantages include lower productivity and higher operating and maintenance costs.

Rubber-tired skidders with conventional-size tires are currently the most popular option for timber extraction because of their proven flexibility, performance, productivity, and lower purchase price and operating costs. However, these vehicles tend to cause frequent rutting and site damage. Low ground pressure vehicles are generally recommended for operating in sensitive areas. Skidders equipped with wide or dual tires or tire tracks provide better flotation and improved traction. Use of dual tires is increasing because they are less expensive than wide tires and because operators can easily remove the outer tires when soil conditions are dry enough to operate without the dual tires.

Grapple skidders are used more frequently than cable skidders because they are more productive when operating conditions are favorable. Their advantage comes from the operator not having to get off the machine to secure the load. Grapple skidders also tend to come in much larger sizes, which leads to greater production rates under the proper operating conditions. They are not recommended for use on steep slopes because of concerns associated with stability and operator safety.

Cable skidders have significant advantages on difficult sites because they can be kept out of sensitive areas by winching the wood to the machine. This feature can be used to limit the area trafficked, thereby reducing impacts. A cable skidder can also drop its load when it bogs down in difficult conditions, move ahead, and winch the load through the difficult area. Cable skidders tend to be narrower than grapple skidders, making them more maneuverable and reducing impacts to residual trees. They are also better suited to staying on designated trails and working in steeper terrain.

Combination cable/grapple skidders are now available that include both a grapple and cable. On these skidders, the cable is used when operating on sensitive areas while higher productivity is achieved when the grapple can be employed.

Forwarding may be a good alternative to use of a skidder where site disturbance is a major concern. It eliminates site disturbance from the wood dragging on the ground, a cleaner product is delivered to the landing, and landing size requirements are relatively small. On the negative side, a forwarder can create greater ground pressure, which increases the potential for soil compaction and rutting. This effect is somewhat offset by the forwarder's ability to move the same volume of wood in fewer trips because of larger average load size.

While they are not frequently used, cable yarding systems are a viable possibility on steep slopes and on other sensitive sites. The main advantage of this system is that heavy machines do not traverse the site and the need for skid trails is reduced or eliminated.

Processing Equipment

Most mechanical processing equipment is designed to work at the landing. However, full-tree skidding can increase site and residual stand disturbance and also results in nutrients being taken away from the stump area. Grapple skidders can redistribute the slash across the site, although placement of that material may be uneven. Tree-length and shortwood systems, including cut-to-length harvesters (CTL), leave branches and tops at the stump. A significant advantage of CTL harvesters for working in sensitive areas is their ability to deposit the delimbing residue in front of the machine and thus build a slash mat for travel. This capability retains the nutrients in the slash on site and can greatly reduce site disturbance and rutting.

Harvesting Systems

The three harvesting systems are the full-tree, tree-length, and shortwood systems. The full-tree system consists of feller-bunchers; skidders; processing equipment such as delimbers, slashers, and whole-tree chippers; haul trucks; and support equipment. General advantages of full-tree systems include (Gingras 1994):

- They can efficiently handle a variety of tree sizes.
- The individual machines are mechanically simpler, which leads to less down time and higher mechanical availability, requires less skilled operators, less training, and quicker attainment of maximum productivity.
- Owning and operating costs are generally lowest on a per unit basis because less labor is required per unit of production and overall production levels are high.

The tree-length system consists of chain saw fellers or feller-bunchers, delimbers/toppers, skidders, slashers, haul trucks, and support equipment. General advantages of these systems are much the same as for full-tree systems with these added advantages:

- Limbs and tops are left in the stump area, reducing nutrient removal.
- It is well-suited to clearcutting.
- It may be applied during partial cutting where skid trails are wide and straight enough because trees are delimbed and topped at the stump.

The shortwood system consists of processing the tree into final product lengths at the stump and then forwarding those products to the roadside. There is increasing interest in cut-to-length equipment, which consists of pairs of harvesters and forwarders matched to their productive capacity. General advantages of the cut-to-length approach to shortwood harvesting include (Richardson and Makkonen 1994):

- It can work efficiently in small tracts because there are only two machines to move between jobs.
- Minimal landing space is required.
- It is well-suited to partial cutting because it processes

the harvested trees to shortwood lengths at the stump, minimizing damage to the residual stand and reducing nutrient removal.
- Skid trails do not have to be created and the trails used can be narrow and meandering.
- The equipment works well in wet areas and on sensitive sites because of its capability to work on a slash mat it produces as it moves through the stand.
- Forwarders can work economically over longer distances because of the larger loads they can carry, reducing the needed road network.
- The system facilitates product sorting and merchandising.

SMALL-SCALE LOGGING

There is a variety of equipment that can be considered small for harvesting timber. Small machinery may be narrower, shorter, or lighter than "normal"-size equipment. Small harvesting machines have several silvicultural advantages over conventional-size equipment. Their smaller size, lighter weight, and greater maneuverability generally cause less soil compaction, soil displacement, and damage to residual vegetation. This results in better regeneration and tree growth. Also, small equipment costs less to purchase and operate than large equipment, making it more affordable to most operators. Small equipment is also easier and cheaper to transport between sites, making it more economically viable to harvest small parcels.

The main disadvantages of small equipment are the smaller maximum tree size that can be handled and the smaller load size, which make these machines less productive than large machines. They are still a viable option for many contractors and harvesting situations. Small equipment is well-suited to thinnings where space limitations exclude large machines and minimizing damage to residual trees is of primary importance. They are also well-suited to harvesting sensitive sites because of the lower impacts to the stand and soil.

For felling machines, under 80 horse power is generally considered small. Small felling machines are usually small excavator-type carriers on tracks with a rotating platform and hydraulic boom allowing the machine to stay on a trail and reach out to cut trees. Some machines are incorporating zero tail swing in the carrier to minimize trail width and residual tree damage as the machine swings in tight stands. The associated small felling or harvesting heads on these machines typically handle a maximum tree size of about 15 inches. Ground pressure is usually less than 7 pounds/square inch (psi).

Timber extraction machinery under 75 horse power is generally considered small. Small extraction equipment includes all-terrain vehicles, farm tractors, and small skidders and forwarders. Horse and mule skidding is also considered a small-scale skidding method. Loaded ground pressure of small extraction systems is generally less than about 10 psi.

A method that has potential for lowering overall stand and site impacts during extraction is bunching wood to trails with small equipment prior to extraction with a large forwarder. This minimizes impacts over most of the area and concentrates heavy forwarder traffic on widely spaced trails while maximizing forwarder efficiency.

Many factors are increasing the level of interest of foresters, loggers, and landowners in small-scale logging technology. These factors include creating employment opportunities, increasing flexibility and maneuverability during thinning operations, extending production seasons, and potentially lowering the impacts of harvesting on sites and residual vegetation.

TEMPORARY AND PORTABLE WETLAND AND STREAM CROSSINGS

Variety of reusable temporary[2] or portable wetland and stream crossing options can help meet the increasing demand for environmentally sustainable forest management in an economically acceptable manner. These options include both commercial and homemade devices that are either transported to or built on-site. Increased use of these options can help minimize the cost of protecting our water and wetland resources. They can also provide cost savings because they are reusable and they may provide several operational benefits. A comprehensive review of options is presented in Blinn *et al.* (1999).

While the initial price of a reusable temporary option may exceed the cost of a currently used alternative (e.g., fill for a wetland crossing), the fact that it is reusable may make it the lowest cost option in the long term. Also, some temporary options are more effective at reducing environmental impacts than options most frequently used today.

All crossing options are most effective with a proper foundation. Temporary wetland crossing options function best with a geotextile under them. Geotextiles allow water to drain through them, provide additional support, and separate the options from the native soil, making removal easier. A non-woven fabric is recommended because it is less slippery than woven fabrics, reducing movement of the crossing option during use. Also, it will

[2]*For purposes of this paper, a temporary crossing is one that is used for a maximum of three (3) years before it is removed*

not continue to tear as easily as a woven fabric if it becomes punctured. Despite this, it is important to limit the number of high spots (e.g., rocks, stumps) to reduce the potential of puncturing during use. Care should also be taken to avoid damaging the root or slash mat in the area of the crossing. The mat will provide additional support during use and can speed revegetation of the site following removal of the crossing option.

Temporary and Portable Wetland Crossings

Wood mats, wood panels, expanded metal grating, and polyvinyl chloride (PVC) and high-density polyethylene (HDPE) pipe mats are some of the temporary wetland crossing options that serve as alternatives or supplements to crossing wetlands during frozen or dry conditions. The options can be applied to the surface of a wetland soil, including a wet spot on a haul road, to stabilize it for short crossing distances. While we define "short" as being less than 200 feet, the distance may depend on the initial cost to purchase or construct the selected option, the value of whatever is to be accessed, and the costs associated with other travel route options. Although a very long distance could be crossed with the options discussed here, their initial costs may be prohibitive for such applications. The ability to use some of the options several times makes them more viable, especially those with a higher initial cost.

Most of the wetland crossing options are best suited to be used in conjunction with hauling and forwarding activities and not for use during skidding. If they are used during skidding operations, the options will wear faster and may move out of position when timber is dragged over the crossing. The options should not be placed on areas that have firm high spots (e.g., stumps) or large rocks to reduce the chance that they will break during use. They will work the best on road sections with straight alignments, grades up to 4%, and no cross slope. Steeper grades, cross slope, or curves may result in loss of traction or lateral movement of the option outside of the planned travel area.

The width of an option needed for any particular crossing will differ according to site characteristics, soil strength, anticipated loads, and installation and removal equipment available. On very weak soils that have a low bearing strength (e.g., muck, peat), the options may need to be wider than what is used on other soils. The additional size is needed to spread the weight over a larger surface area. Additional crossing width may be needed at road intersections and curves to provide necessary maneuvering room for vehicles.

Examples: *Wood Mats, Wood Panels, Expanded Metal Grating, and PVC and HDPE Pipe Mats and Plastic Road*

Temporary and Portable Stream Crossing Options

Stream crossing options include fords, culverts, PVC and HDPE pipe bundles, and bridges. It is important to follow the proper permitting process when installing and using a stream crossing. Contact the local hydrologist to determine whether a permit is required. The permit may specify the type of crossing as well as when it can be installed and/or used. Properly designed and installed temporary structures can greatly reduce costs and make it easier to meet the concerns of regulatory agencies.

Engineering input from a licensed engineer into the design of many stream crossing options is recommended. However, engineering design information for some of the alternatives is limited, and the additional costs for an engineered design may be considered exorbitant for a temporary crossing. Caution is necessary when using any crossing that has not been engineered and/or that has not been inspected between and during uses.

Examples: *Fords, Culverts, PVC and HDPE Pipe Bundles, and Bridges*

Bridges are the preferred option of water resource managers because they have the least potential for impacting a stream. By spanning the stream, bridges keep fill and equipment out of the water body to the greatest degree of any stream crossing option. There are designs for a wide range of span lengths and load capacities (e.g., pickup trucks, skidders and forwarders, or loaded semi-tractor trailers). Bridges that can be easily moved from one area of the site to the next using the available on-site equipment offer the most flexibility. Bridging options include ice, timber, used railroad cars or flatbed truck trailers, steel, or pre-stressed concrete.

Little site preparation is normally required when installing a temporary bridge. To provide stable, level support, it is recommended that bridges be installed on a log, railroad tie, or other similar abutment material on each side of a stream. This also facilitates removal during the winter and minimizes disturbance to the streambank.

Some bridge designs are open in the middle, or have holes or gaps in the traffic surface. While these designs may be less expensive or easier to install, they also allow dirt and debris to fall into the stream. As a result, some jurisdictions may not permit use of these designs. Also, movement of individual bridge panels may occur during use if they are not adequately connected. For structures where a gap exists in the traffic surface, it is recommended that a decking material (e.g., plywood, lumber) be added to close this space.

It is recommended that a licensed engineer review the design of any bridge that is fabricated from locally available materials to insure that it will be safe and is adequate for the intended use. However, that review may be difficult to obtain and/or costly in some cases. Construction specifications have not been established for some materials (i.e., hardwood lumber) and others may be converted to a use for which they were not originally designed (e.g., flatbed truck trailers). Many materials or structures have had substantial wear and tear prior to their use as a bridge structure (i.e., railroad flat cars, flatbed truck trailers, concrete panels) that may have significantly reduced their strength or limited their remaining service life.

FACILITATING APPLICATION OF LIGHT-ON-THE-LAND APPROACHES

Use of some light-on-the-land approaches is not new. States have had water quality Best Management Practices for several years, and equipment is constantly evolving to meet the ever-changing demands. However, the rate of adoption of these approaches could be expedited through additional research, appropriate training of foresters and timber harvesters, and support for timber harvesters to facilitate their continued adoption of new practices and technologies.

There is little research information available that has quantified the reduced impacts of using light-on-the-land approaches, when and where those approaches are most appropriate and inappropriate, or their effect on the productivity and costs of logging businesses. Until this information is available, it is difficult to know which approaches are best for a given site, what equipment is most likely to be needed in the future, and how this will impact the productivity and profitability of a logging business.

Foresters, logging business owners, and logging crew members need training to help them implement forest management guidelines that sustain forest productivity. Joint field-based training can bring out a variety of perspectives and ensure that all groups get the same training. That training needs research-based information that quantifies why and where forest productivity impacts may occur. Foresters also need to understand equipment limitations when designing and administering timber sales.

Operating light-on-the-land machinery may require more educated operators to run and maintain the more complex equipment. Due to the current economic boom, there is a shortage of available skilled labor which makes it difficult for businesses to hire and retain quality personnel. Operators also need to understand why it is important for them to apply light-on-the-land approaches when using their light-on-the-land machinery. Timber productivity may be compromised if that machinery is not operated with light-on-the-land approaches.

Light-on-the-land approaches can impact a loggers' safety, efficiency, operating costs, and their ability to remain competitive. While light-on-the-land machinery may be smaller or operate slower than traditional machinery, there may be very little reduction in purchase price as compared to conventional equipment. Requiring an operator to do more pre-planning, to operate slower, to be more cautious, and to use expensive machinery that has lower production levels is not a recipe for their long-term success. Maintaining a healthy, viable logging industry is also key to sustaining forest productivity.

CONCLUSIONS AND IMPLICATIONS

As our knowledge of forest productivity has increased, various forest management guidelines and equipment options have been developed to provide light-on-the-land approaches to sustain productivity. When harvesting plans are developed, the selection of light-on-the-land approaches needs to provide flexibility and the opportunity for logger input. Just as no single silvicultural prescription can be applied to every timber sale, all sites do not require the same amount of planning, number or diversity of operating restrictions, or specialized equipment to sustain forest productivity. Harvest plans need to be flexible enough to protect forest productivity while still allowing the logger to maintain an economically viable enterprise.

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