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AN OVERVIEW OF FOREST SOIL REHABILITATION IN THE BC INTERIOR

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ABSTRACT

Interest in forest soil rehabilitation has increased during the 1990's as a result of requirements within the Forest Practices Code (FPC) and because of recent investments made by Forest Renewal BC. Our understanding of what is required to successfully restore productivity to degraded forest soils is limited because (1) few research projects were initiated during the past decade, (2) the range of site types studied so far is limited, and (3) many of the questions we ask about these projects require information on long-term tree growth response, which can only be collected as fast as the trees grow.

This paper outlines the history of forest soil rehabilitation in BC, discusses growth-limiting conditions that need to be overcome for success, and describes three groups of techniques for restoring productivity, including tillage, topsoil replacement, and reforestation / revegetation. This paper summarizes the results of a problem analysis carried out during 1996 to examine existing information and assess the need for new information to improve the results and cost-effectiveness of soil rehabilitation efforts.

INTRODUCTION AND HISTORICAL PERSPECTIVE

Forest soil rehabilitation, as the term is used in the Forest Practices Code (FPC), refers to activities aimed at restoring soil productivity, <u>with the objective of re-establishing a productive forest ecosystem on a site that has suffered degradation.</u> Soil rehabilitation is an important part of the soil conservation program aimed at protecting the productive capacity of forest soils in BC. In response to concerns raised by soil scientists and foresters, research was initiated in the 1980's to understand the causes of forest soil degradation and to develop techniques for preventing it.

In 1986, a workshop held at the University of BC (Still and Lousier, eds. 1988) highlighted the growing awareness among forest land managers of the need for soil conservation. Utzig and Walmsley (1988) outlined the high cost to the economy that resulted from forest soil degradation. By 1990, a framework of soil conservation measures was in effect throughout BC restricting the amount of soil disturbance during forest operations, and specifying measures for soil rehabilitation where needed. These efforts recognized that preventing soil degradation is usually the most cost effective approach to soil conservation.

Forest soil rehabilitation usually requires activities beyond those aimed at restoring drainage, controlling erosion or stabilizing slopes (i.e. techniques for road deactivation as described by Chatwin et al. 1994; Carr, 1980; Moore, 1994). Successful soil rehabilitation requires that sites be stable, free of erosion, and have natural drainage patterns restored, so deactivation can be considered the first step to be taken on all sites where restoring soil productivity is planned.

According to Carr (1983), the Cariboo Regional Policy was the first policy requiring landing rehabilitation in British Columbia. The Cariboo Regional Policy specified:

1. ripping or scarification of landings to a depth of 30 cm, if deemed necessary,
2. burning of slash piles, and
3. respreading of topsoil and ash piles on the landing.

Mitchell (1982) noted several shortcomings in implementation of the Policy, including excessive site disturbance associated with landings, lack of topsoil conservation, ineffective scarification and decompaction, and poor performance of planted trees. Based on Mitchell's recommendations, a new landing policy was drafted for the Cariboo Region. In subsequent years, several forest regions and districts developed guidelines and policies regarding rehabilitation of landings and skid roads (e.g. Prince George Forest Region, 1986), but many of the concerns expressed in Mitchell's (1982) report remained valid.

During the 1980's, the results of rehabilitation work were mixed. The objectives of landing rehabilitation were not always clearly stated. Efforts to produce commercial forests were often secondary to those aimed at controlling erosion or maintaining grazing sites for cattle. As a result, many landings were decompacted and grass seeded, but a much smaller number were planted to trees. Even where trees were planted, little follow up work was conducted to evaluate survival and growth.

The regional and district policies and procedures, along with follow-up documents, (including Timber Harvesting Branch, 1993 and Vancouver Circular Letter, 1994) provided the background that led to the soil conservation requirements in the FPC. The FPC Act, Regulations and Guidebooks provide comprehensive, province-wide standards for soil conservation, which supersede most of the regional and district policies, except where more detail is needed than what is provided in the FPC. Even before the FPC was fully implemented, the amount of land being degraded each year as a result of forestry operations was declining. Key provisions in the FPC are:

1. Permanent access (roads and landings) is limited to what is necessary for the harvest, usually less than seven percent of the area.

2. All temporary access structures (roads, landings and trails not required for the long-term management of the area) are required to be rehabilitated to restore soil productivity.
3. Dispersed soil disturbance in the net area to be reforested is limited to what is necessary for the harvest, usually less than 5 percent for coastal sites, and less than 10 percent for interior sites, although on many sites the allowable level is lower.

Beginning in 1995, Forest Renewal BC has provided funding for rehabilitating areas that have been degraded or are at risk as a result of past forestry practices. The amount of soil rehabilitation work occurring in BC has increased substantially as a result of the funds available from FRBC.

Landing rehabilitation during the 1980's and early 1990's was carried out in a difficult climate, with rehabilitation practitioners facing widespread skepticism about the benefits of restoring soil productivity relative to the costs. Currently, however, many foresters and soil scientists are more optimistic about the potential productivity of rehabilitated sites, partly because of the renewed commitment to restore the forest, which has allowed modern rehabilitation projects to make use of site-specific techniques that may have been considered impractical only 10 years ago.

ALLEVIATING GROWTH-LIMITING CONDITIONS ON DEGRADED SOILS

Soil degradation occurs when machine traffic, or other types of disturbance, alter soil properties in such a way that site productivity is reduced (Smith, 1988). Two major groups of processes become dysfunctional in degraded soils, and must be restored to achieve successful rehabilitation.

Restoring soil physical processes

Soil physical processes such as infiltration and transport of soil water and air are strongly controlled by the characteristics of the pore system, including porosity and the pore size distribution. The pore system is adversely affected by compaction and puddling. Soil physical properties also affect the soil thermal regime and the resistance of soil to plant root growth. On many sites, alleviating compaction, and restoring the pore system is the most important requirement for restoring soil productivity

Ranges of growth-limiting values for soil strength (penetration resistance), bulk density, and aeration porosity are presented in Table 1. These growth-limiting values provide targets for soil conditions that need to be created by rehabilitation in order to restore productivity.

On landings seven years after rehabilitation, Kranabetter and Denham (1995) found that aeration porosity and bulk density were significantly correlated with height and increment of lodgepole pine. Aeration porosity values near 20 percent were associated with reduced height growth in lodgepole pine.

Table 1. Limiting physical conditions for root growth in forest soils.

Soil strength (kPa)	Bulk density (kg/m^3)	Aeration porosity (%)	Sources
2500 - 3000[1]			Greacan et al. (1969); Sands et al. (1979); Campbell et al. (1988);
	1350-1600		Sands and Bowen (1978); Jones (1983)
		10 - 12 %[4]	Brady (1996); Grable (1971)

[1] mean value from several studies, other studies presented values as high as 5000 kPa

Restoring nutrient pools and soil nutrient cycles

Many roads and landings have low nutrient content, resulting from topsoil displacement that occurs during construction and leveling. Several rehabilitation techniques have the potential to restore nutrient pools on degraded sites, including topsoil replacement (Carr, 1987a), fertilization (Carr, 1987a), establishing N-fixing plants (Carr 1988; Power, 1994), and amending with nutrient-rich byproducts (McNab and Berry, 1985; Rose, 1994; Bauhus and Meiwes, 1994).

Nutrient removal through displacement of forest floors and topsoil affects numerous processes. Some of the changes are similar to those arising from site preparation, where survival and early growth of seedlings may depend as much on soil temperature and! moisture as on nutrient status. Munson et al. (1993) showed that the effects of vegetation control were greater than those of forest floor removal or fertilization on four-year height growth of eastern white pine and white spruce. Removal of forest floors from the sandy loam Podzolic soil resulted in a large loss of N, and reduced NO_3^- levels in surface mineral soil after four years, but microbial biomass C and N, foliar N levels, and tree growth were not significantly affected by removal of forest floors (Ohtonen et al. 1992). Also, as a result of vegetation control, foliar N levels increased, even though site N capital was depleted by 23 percent (577 kg / ha) compared to control plots.

Mycorrhizae are a major factor affecting nutrient uptake by forest trees (Read, 1991). Kranabetter et al. (1996) found that birch seedling survival and height growth after two growing seasons was similar for seedlings inoculated at time of planting with fresh soil from a nearby undisturbed area compared to seedlings inoculated with sterilized soil. Soil conditions remained poor on the rehabilitated site in the central interior two years after respreading a 30 cm layer of sidecast topsoil and subsoil onto an untreated roadbed. Mycorrhizal diversity of seedlings after two growing seasons was significantly greater for seedlings inoculated with fresh soil compared to those inoculated with sterilized soil, indicating that some restoration of biological function had occurred as a result of inoculation with fresh soil at the time of planting.

TECHNIQUES FOR RESTORING SOIL PRODUCTIVITY

Tillage

In forest soil rehabilitation, the primary goal of tillage is to alleviate compaction, reduce soil resistance to root penetration, and provide improved drainage and aeration for tree root growth. Secondary objectives may involve creation of a seedbed for cover crops or mixing and incorporation of organic amendments.

Our understanding of the effect of different tillage depths on forest productivity is derived largely from results in the United States (Andrus and Froehlich, 1983; McNabb and Hobbs, 1989), where soil and climatic conditions are different than those in many parts of BC. Soils derived from glacial materials in the interior often have effective rooting depths of only 30 cm because of naturally dense subsoils and low soil temperatures. Tillage of deeper soil layers, where rooting is restricted by low temperatures may be wasted.

Two broad strategies for tillage can be described. Extensive tillage refers to techniques that till the entire disturbed area to a specified depth. Various implements are used, often pulled by, or attached to, crawler tractors. Excavators with site preparation rakes and other attachments are also used to extensively till degraded forest soils. Spot, or partial, treatments till only a portion of the disturbed area. Equipment used for partial tillage includes excavators with various attachments including rakes and powered mixing heads, and other site preparation equipment such as disk trenchers or ploughs. A pilot rehabilitation project currently being carried out by Lignum Ltd. (Williams Lake) is evaluating some partial tillage techniques.

Winged subsoilers have two or three vertical shanks mounted on the back of a crawler tractor with a single wing or "shoe" attached to the bottom of each shank. As the implement is pulled through the soil at depth, the wings lift the soil, causing it to fracture. Research and development on winged subsoilers in the early 1980's resulted in a patented design for a self-drafting implement that is manufactured by Tilth Inc. of Monroe, Ore. This implement, which represents the most advanced subsoiler design currently available, can be direct-mounted to a crawler tractor, or mounted to a dolly that is pulled behind the crawler.

Winged subsoilers have proven to be more effective than other implements for tilling forest soils (Andrus and Froehlich, 1983). In a single pass operation, a winged subsoiler loosened 70 percent of the compacted volume of a clay loam soil, and 80-90 percent of a loam soil. The proportion of compacted soil loosened by rock rippers and brush blades was much lower (maximum 45 percent), and a disk harrow loosened only 20 percent of the compacted soil volume.

Despite the results of Andrus and Froehlich (1983), conventional rock rippers have been used to rehabilitate landings and skid roads in BC, and some of the results appear to be satisfactory, especially where soils have coarse texture with moderate gravel content and where several passes were made to ensure that the entire soil volume was loosened. The range of sites where rock rippers are suitable is not known, however, nor is the relative cost of using a rock ripper compared to other implements. In the southern interior, variations of a single ripper tooth and subsoilers have been mounted on an excavator and tested as tillage implements by Pope and Talbot (Nakusp) and Weyerhauser (Okanagan Falls).

Brush blades have been used in the past to rehabilitate forest soils in BC (Vyse and Mitchell, 1977), with similar results to those of Andrus and Froehlich (1983), indicating little effect below 12 cm depth. Brush blades are also expected to be slow. To avoid traveling over the tilled surface, the machine has to constantly reverse direction in order to till a small area between the front of the tracks and the blade.

Extensive tillage can also be carried out with an excavator, and, although the costs per hectare tilled are higher than those for winged subsoilers (Lawrie et al. 1986), the versatility of excavators provide justification for their use in many situations. These machines are capable of thoroughly loosening soil to any reasonable depth. Excavators are also able to restore site drainage, replace topsoil, move debris, incorporate amendments, and break up large clods in order to prepare a seedbed.

Treatments that create individual planting spots have potential advantages over extensive tillage methods, including lower energy costs, and they may allow for the use of machines (e.g. excavators) that are expensive when applied to entire areas. Spot treatments also have the potential to influence surface relief, creating mounds or trenches, which may be advantageous for seedling establishment on sites where excess moisture, low temperatures, or drought adversely affect seedling performance, or where protection of existing trees is desired. A variety of site preparation machinery is available in BC that could be used to prepare spots, mounds, trenches, or furrows and address a wide range of growth-limiting conditions.

The potential advantages described above for spot treatments can only be realized if long-term productivity of the entire site is restored. Because spot treatments do not till the entire degraded soil volume, roots will eventually encounter soil that has not been treated. This would reduce overall site productivity unless (1) tree roots were able to penetrate and proliferate through the untreated soil when they encountered it, or (2) above-ground site productivity was not affected by the inability of roots to exploit the untreated soil.

Topsoil replacement

In rehabilitation work, topsoil is the upper layer of the soil where most of the roots are located, with or without the forest floor. Replacing topsoil is an effective technique for restoring productivity (e.g. Halvorson et al. 1986; Heilman, 1990). Compared to subsoil materials, topsoils usually have better physical properties (Potter et al., 1988; Sharma and Carter, 1994). While many of these benefits are related to the presence of soil organic matter, soil texture also plays a role in topsoils derived from medium- and fine-textured parent materials. In many parts of BC, soil development has resulted in natural topsoils that contain less clay than subsurface layers, and thus have inherently more stable macropores than their associated clay-rich subsoils.

Nutrient pools and cycling are also enhanced by the presence of topsoil on rehabilitated sites. For coal spoils in Washington, nutrient content of replaced topsoils was more than twice as high as for subsoils, although the levels in topsoil were still below those in undisturbed forests (Heilman, 1990). Foliar nutrient levels in Douglas-fir reflected the soil N levels, and 6 to 12 year old Douglas-fir growing in reclaimed soils with topsoil had similar site index to plantations on undisturbed soil. Topsoil also acts as a seedbank, which can be an important resource for revegetation with native species (Young, 1990).

Although the advantages of replacing topsoil are well documented, planning is required to do the job efficiently. Topsoil conservation, stockpiling and replacement add significantly to the costs of access construction and rehabilitation. Locating the most convenient place to stockpile topsoil during construction, so that costly repiling is avoided, requires foresight and experience on the part of the construction crew.

Reforestation and revegetation

The goal of establishing trees on rehabilitated soils is the same as that for general silvicultural planting on undisturbed sites, namely to achieve high survival rates *and* rapid early growth. Early successional species such as Douglas-fir on the coast and lodgepole pine in the interior have been favored for rehabilitation. In the future, other species may prove equally successful on suitable sites. Recently on the coast, in addition to red alder, plots have been established to evaluate the performance of Western red cedar, Western hemlock, Amabalis fir and yellow cedar (Hickling et al. 1996). In the interior, white birch, white spruce, and western larch have also been established on rehabilitated sites.

Despite the possibilities, there has been limited experience with the use of different stock types on rehabilitated forest soils in BC. A wide range of stock types and cultural techniques are available in a modern nursery and our understanding of the effect of various greenhouse practices on field performance of planted stock is improving. In addition, the awareness that mycorrhizae and other biological partners play an important role in water and nutrient uptake has led to the development of various biological inoculants that have potential to improve the performance of planted seedlings.

Techniques for controlling erosion by establishing grasses and legumes were the subject of several research projects in the early 1980's. Results been have presented in several reports (Carr, 1980, 1985; Homoky, 1984, 1987). Some revegetation issues remain unresolved, however, and others have been raised more recently, including (1) the ecological benefits and hazards associated with establishing grasses and legumes on rehabilitated forest soils, (2) the potential for improving soil structure through biological tillage, and (3) the potential for enhancing site nutrient pools through biological nitrogen fixation.

A native shrub program was initiated in 1980 and more than 40 native BC tree and shrub species were propagated. A propagation manual was written, and field trials were established between 1981 and 1984 (Marchant and Sherlock, 1984; Homoky, 1984; 1987; Carr, 1985).

Native woody species are useful in rehabilitation because they provide deep rooting, and long-term erosion control, although it takes longer for the surface cover to develop than with grasses and legumes. On sites where immediate erosion control is not a major concern, however, they provide a means for re-establishing ecosystem characteristics similar to those of undisturbed areas.

The potential benefits of nitrogen-fixing species for restoring nutrients on rehabilitated sites has been known for some time. For interior sites, use of legumes has been investigated in the Prince Rupert Forest Region on rehabilitated landings (Marsland, 1994), on blade scarified areas (Coates et al. 1993), and on cutovers subject to various forms of site preparation (Trowbridge and Holl, 1989). Results of this work have shown good success for establishing a variety of legumes, including birdsfoot trefoil on landings, and alsike clover on blade scarified areas.

CONCLUSION

For successful soil rehabilitation, keep in mind the following points:

1. *Develop clear goals,*
2. *Drainage and erosion control is the first step*
3. *Match tillage and revegetation techniques to the limiting conditions on the site*
4. *Keep records of the treatments and the results.*

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