SOIL PRODUCTIVITY AND FOREST REGENERATION SUCCESS ON RECLAIMED OIL AND GAS SITES IN THE DAWSON CREEK FOREST DISTRICT

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ABSTRACT

We visited 27 reclaimed oil and gas well sites in northeast BC that were decompacted and planted with lodgepole pine between 1994 and 1999. The reclamation work was carried out as part of an effort to gain experience with reforestation as a potential strategy for improving abandoned oil and gas sites. Reclamation techniques included decompaction either with a winged subsoiler or a ripper, seeding a cover crop, fertilizing, and planting to lodgepole pine, which has previously been successful in reclamation of forestry disturbances. Of the 27 sites, three (11.1 percent) had been re-used by drilling rigs, and an additional site was re-used as a forest landing. We evaluated tree growth on 19 of the well sites, and collected detailed information on vegetation cover, ecological and soil conditions. Clay content for the sampled sites ranged from 0 to 40 percent and bulk density from 594 to 1803 kg/m^3. Soil chemical properties (C, N, available P, pH) were very similar to conditions found on nearby forest plantations and rehabilitated landings. Values of soil mechanical resistance in the rooting zone during July exceeded values that are expected to be growth-limiting on several plots, but values in June were below the threshold of 2500 kPa.

Approximately 50 percent of the plots had stocking levels above 600 stems per hectare. Subplots with subhydric, hygric and subhygric moisture regime appeared to have generally lower stocking levels than subplots with mesic and submesic moisture regime. Average stocking levels for well sites were lower than for rehabilitated forest landings and undisturbed plantations on similar sites in the BWBS, and the trees on the well sites were smaller than trees planted on landings that had similar site conditions. Field observations suggested that factors such as competition from seeded cover crops, moisture regime, selection of tree species, and well site construction / rehabilitation techniques affected seedling survival and growth on individual sites.

Where soil and site conditions are suitable, tree planting appears to be a useful technique that would enhance environmental values over the long term. To obtain the maximum benefit from reforestation efforts on well sites, a targeted approach is suggested, where efforts are directed at sites with the highest likelihood of success. This operational reforestation work has provided some key lessons that can be used to improve reforestation success on reclaimed oil and gas sites in the future.

INTRODUCTION

In northeastern BC, land disturbance caused by oil and gas exploration and development is substantial.

Although most of the area disturbed by oil and gas development originally supported productive forests, reclamation of such sites seldom involves reforestation as a primary goal. Establishing productive forests on such disturbed lands could improve sustainability of the local forest industry and enhance environmental values over the long term.

Reclamation of oil and gas sites is common practice in western Canada, and a large body of information is available on restoring site hydrology, soils, and vegetation to a productive state. Including reforestation as a goal in reclamation plans, however faces some challenges, such as:

- limited experience with reforestation as a reclamation objective,
- costs associated with restoring soil conditions and establishing seedlings,
- the long-term nature of forest establishment and growth, and
- the potential for re-use of the sites in future.

There is considerable evidence that reclamation and reforestation of disturbance caused by forestry development can be successful, and factors affecting successful rehabilitation of such disturbances have been described. If site characteristics on oil and gas sites were found to be similar to those on forestry sites, success could be expected for these sites as well.

This project evaluated the effectiveness of previous efforts to restore soil productivity on abandoned well sites in the Dawson Creek area of northeastern British Columbia. We used a retrospective approach where soil conditions, tree survival, and early growth were measured for sites that were operationally reclaimed and reforested between 1994 and 1999.

Our hypothesis was that tree growth and vegetation productivity will be higher where soil conditions for all factors are not growth-limiting for large parts of the growing season, compared to sites where one or more factors limit root growth for extended periods.

FIELD AND LABORATORY METHODS

We identified 29 reclaimed well sites that were planted with lodgepole pine between 1994 and 1999, and visited 27 of them. Three well sites had been re-used, 5 additional ones had no trees present (Figure 1), and one was not accessible by road, so these were discarded from detailed study. Eighteen of the remaining well sites were evaluated for tree growth and soil conditions. Fifteen of those sites were located in the BWBS biogeoclimatic zone (Figure 2).

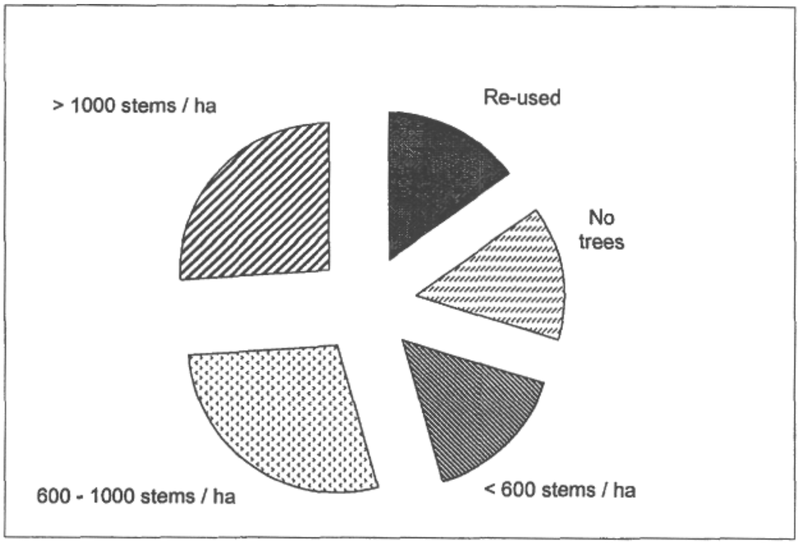

Figure 1. Status of reclaimed well sites when visited in 2001.

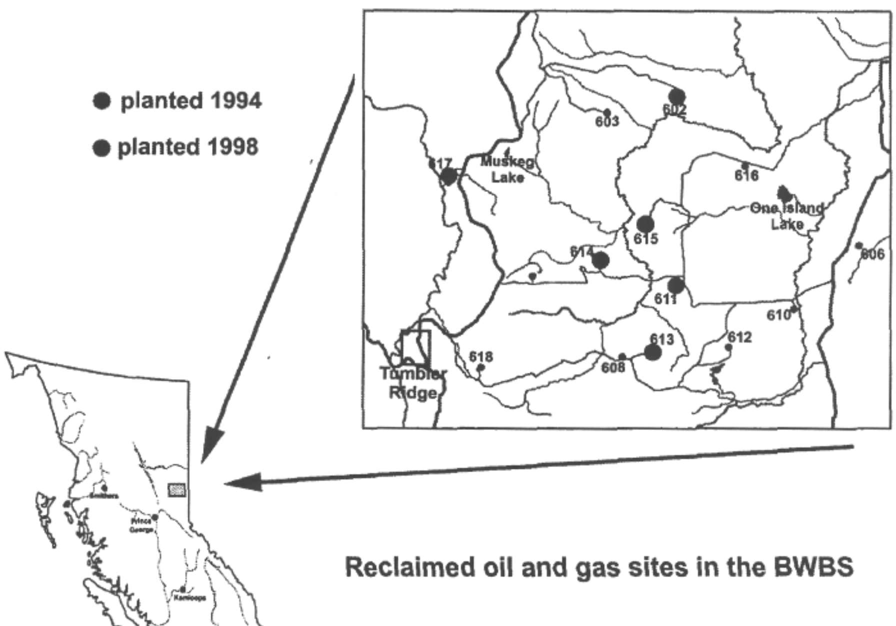

Figure 2. Map of the study area showing many of the wellsites in the BWBS biogeoclimatic zone.

For each sampled well site, GPS coordinates were obtained, a map was drawn (Figure 3), and five sample subplots were laid out in random locations. Circular, 0.005 ha subplots were established to evaluate stocking and growth of planted trees. At each subplot, we also collected detailed information on vegetation cover, ecological and soil conditions. Soil samples were collected from the surface (0-7 cm) layer using a 0.5 L core. Samples were dried, weighed and sieved to determine total and fine-fraction (< 2 mm) bulk density. Soil texture was determined using the hydrometer method. Samples of the fine fraction were sent to the BC Ministry of Forests analytical laboratory in Victoria for analysis of total C and N (dry combustion), pH (water), mineralizable N (anaerobic incubation), extractable P (Bray), and electrical conductivity (saturated paste).

A Rimik recording cone penetrometer was used to determine soil mechanical resistance at various times during the 2002 growing season, and soil water content at the time of penetrometer measurements were determined by removing a 2 cm core from the 0-20 cm layer and determining the water loss after drying at 105° C for 24 hours.

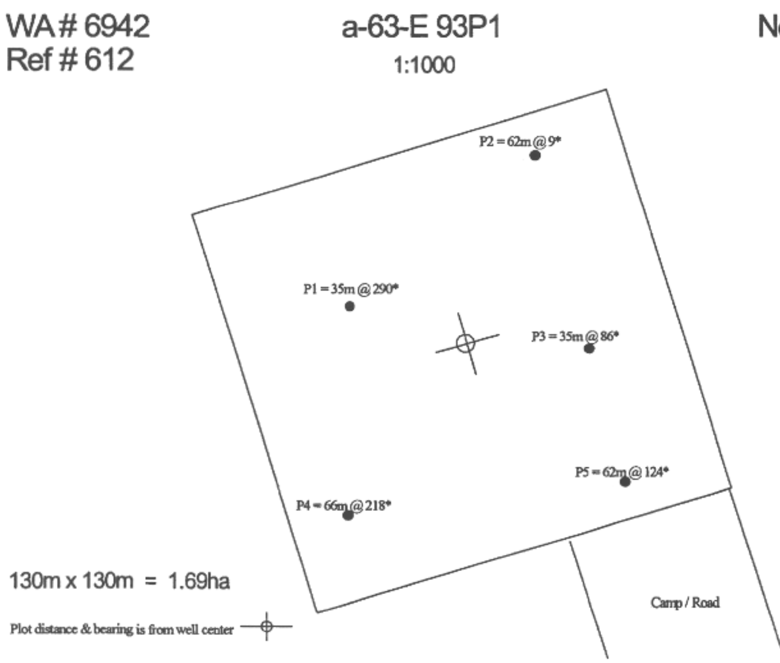

Figure 3. Example of subplot establishment map for reclaimed and planted well site. (Original map is at 1:1000, but this image has been reduced).

RESULTS

Soil Physical Conditions

None of the reclaimed sites had any forest floor development, and only minor amounts of coarse woody debris were encountered during sampling.

The most common soil texture was loam (Figure 4). Clay content for the sampled sites ranged from 0 to 40 percent, and bulk density from 594 to 1803 kg/m^3 (Figure 5). For the rehabilitated well sites, there was an apparent trend towards increasing bulk density with increasing clay content, which is in contrast to the usual relationship for undisturbed soils. The trend may reflect ineffective decompaction of the clay soils during rehabilitation work, or other factors.

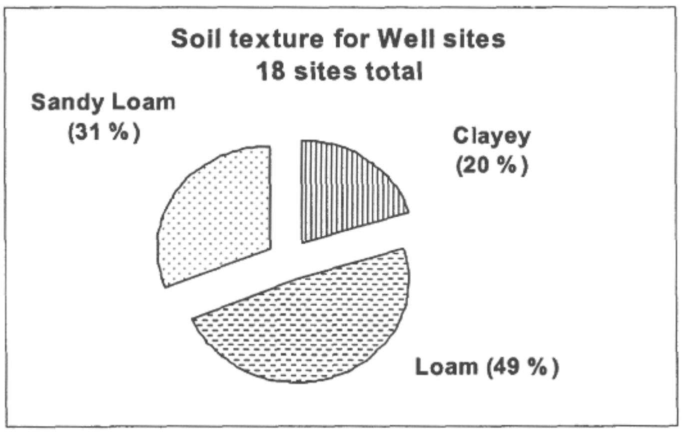

Figure 4. Soil texture of the study sites. Clayey textures include sandy clay loam, clay loam, and silty clay loam.

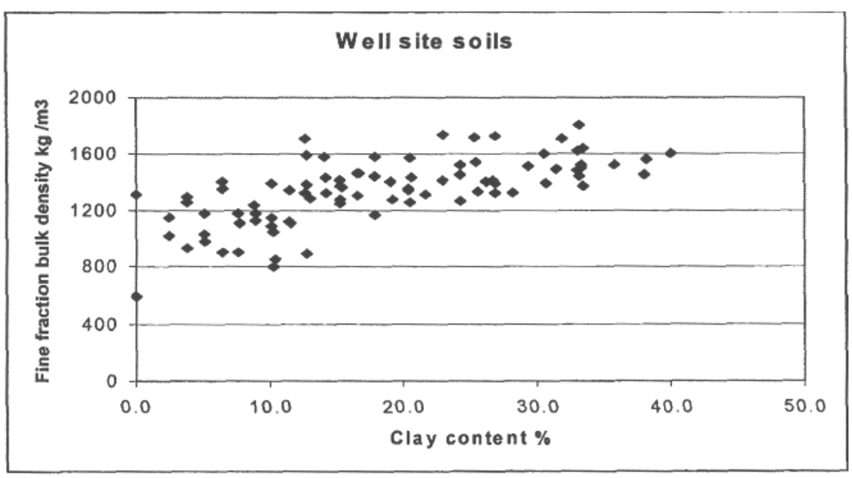

Figure 5. Clay content and bulk density of rehabilitated well site soils.

Proctor compaction values were obtained for an undisturbed and a reclaimed soil from the Noel-Ministik Creek area in the Dawson Creek Forest District. Maximum (Proctor) bulk density for a medium-textured soil with less than 20 percent clay and 1.0 % carbon content was near 1850 kg / m^3, while the plantation soil (1.7 % carbon) had a maximum bulk density near 1605 kg / m^3. Some research on agricultural sites has shown that plant growth was affected when bulk density of a field soil was higher than 80-85 percent of the Proctor compaction value. Based on these assumptions, values above 1573 kg / m^3 for the soils with low organic matter content and less than 20 % clay would suggest degraded soil physical conditions that may affect tree growth. For soils with higher organic matter content, values near 1284 kg / m^3 may be in the range where growth limitation would be expected. Many of the soils that we evaluated on the well sites appear to have lower bulk density than such values (Figure 6).

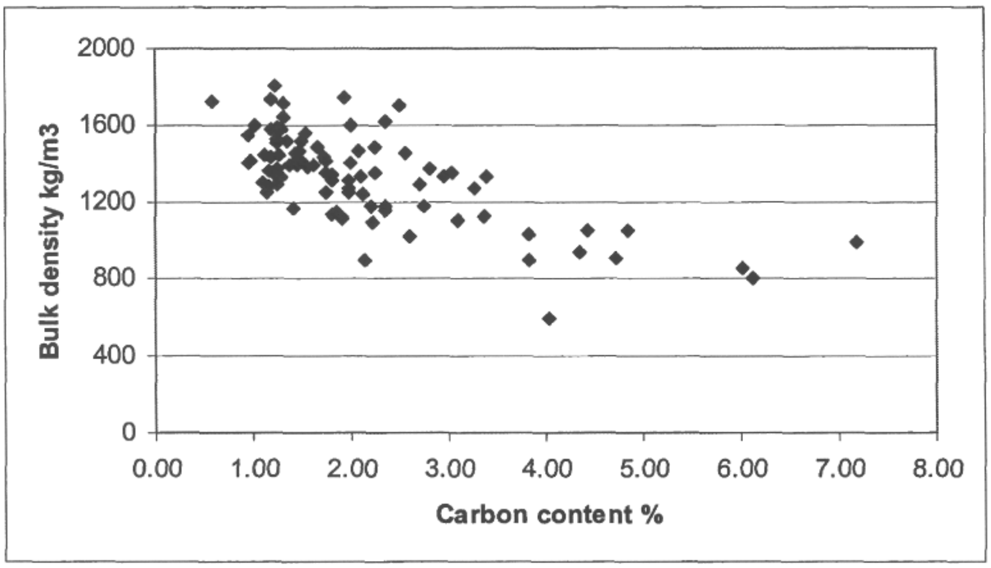

Figure 6.

Carbon content and bulk density of rehabilitated well site soils.

Soil Chemical Conditions

In comparison to nearby forest plantations and rehabilitated forest landings, chemical characteristics of the soils on reclaimed well sites were similar (Table 1). Electrical conductivity was below the range where plant productivity is expected to suffer from osmotic stress.

Table 1. Chemical properties of wellsite soils in comparison to forest landings and plantations on mesic sites in the BWBS biogeoclimatic zone.

	%C	%N	Mineral N ppm	Avail P ppm	pH/H2O	dS/m
Well sites	1.9(0.3)	0.11(0.01)	20.2(4.1)	16.2 (10.8)	6.4 (0.5)	0.2(0.1)
Landings	1.7 (0.3)	0.11(0.01)	18.9(4.1)	8.9 (3.0)	5.8 (0.5)	
Plantations	2.0 (0.6)	0.12(0.02)	23.2 (6.0)	18.4(10.5)	5.1 (0.4)	

Soil Mechanical Resistance

Soil mechanical resistance in the rooting zone appeared to be higher for most well sites in July compared to June (Figure 7a,b), which coincided with lower July water content (data not shown). Mechanical resistance values were below the expected growth-limiting threshold of 2500k Pa for all sites in early June, but trees growing on several sites may have experienced soils that were too strong to allow root growth during July.

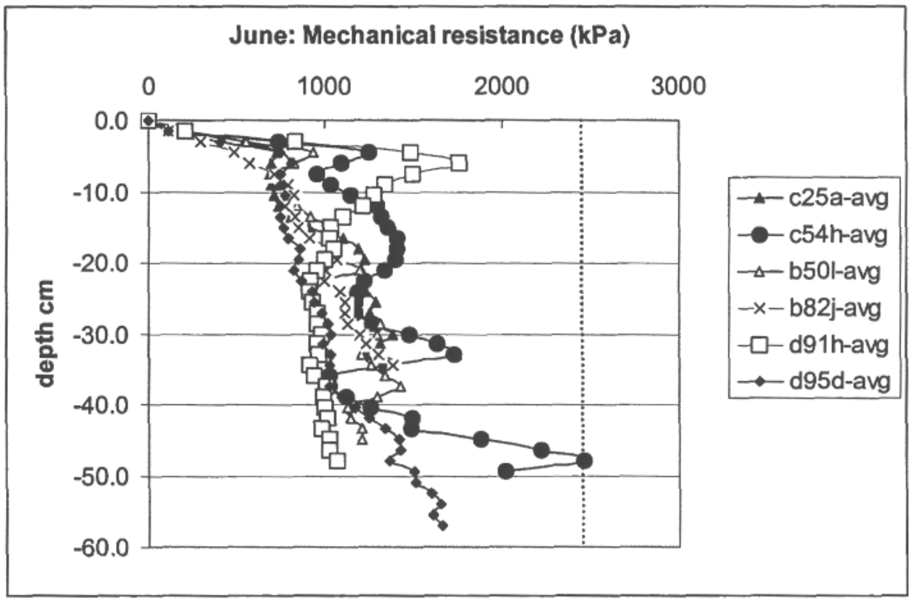

Figure 7a.

Soil mechanical resistance in June. The dashed line at 2500 kPa illustrates the value where root growth limiting conditions are expected. Statistical analysis has yet to be performed on these data, but the trend indicates that average values for all six wellsites were below growth-limiting thresholds through most of the soil profile.

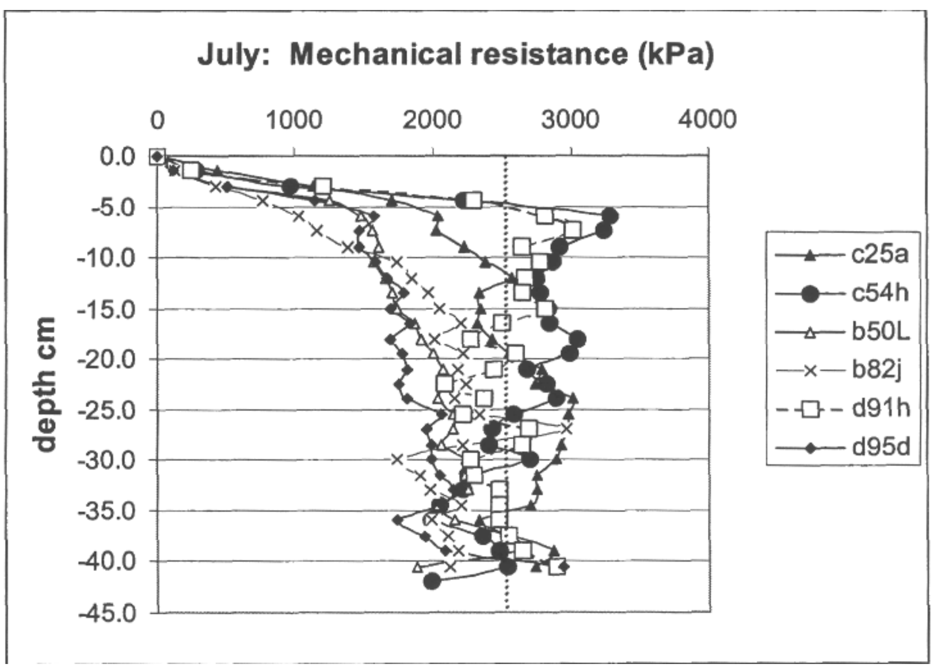

Figure 7b.

Soil mechanical resistance in July. The dashed line at 2500 kPa illustrates the value where root growth limiting conditions are expected. Statistical analysis has yet to be performed on these data but the trend suggests that three of the six wellsites had average values that exceeded the growth-limiting thresholds in the upper part of the soil profile.

Stocking and Tree Growth

Stocking levels were often below 600 stems per hectare (Figure 8). Subplots with subhydric, hygric and subhygric moisture regime had lower stocking levels than subplots with mesic and submesic moisture regime. Lower stocking levels and reduced establishment success has also been observed on rehabilitated forest landings with wet site conditions. Establishment success for lodgepole pine on well sites appeared to be below that for rehabilitated forest landings in the same area (Figure 9), which were measured as part of a companion project.

Two well sites that had no trees present in 2002 were stocked in 1999 during a preliminary site visit carried out by field personnel from the Dawson Creek Forest District, indicating that seedling mortality can occur for several years following planting. During our site visits in the summer of 2001, we observed several examples of severe seedling damage caused by winter dessication.

Growth rates for trees planted on the reclaimed well sites appeared to be lower than for rehabilitated landings (Figure 10).

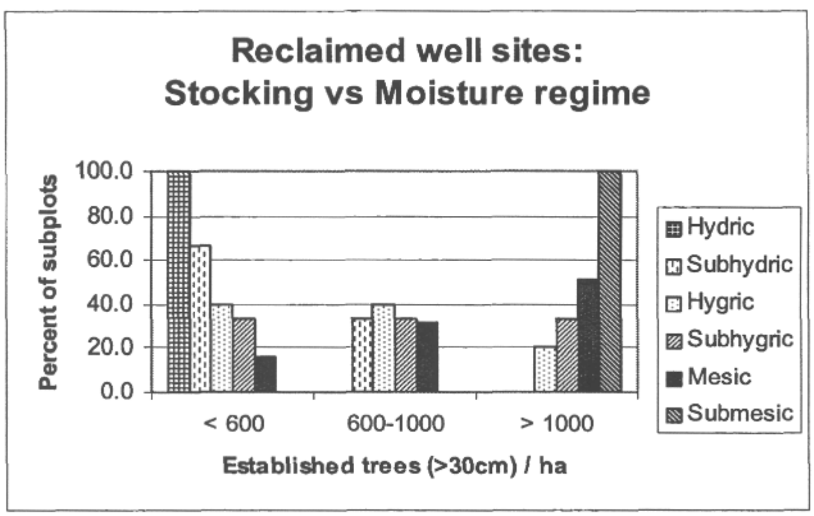

Figure 8. Stocking levels for well sites by moisture regime. Based on evaluation of stocking levels and ecological conditions on 90 subplots.

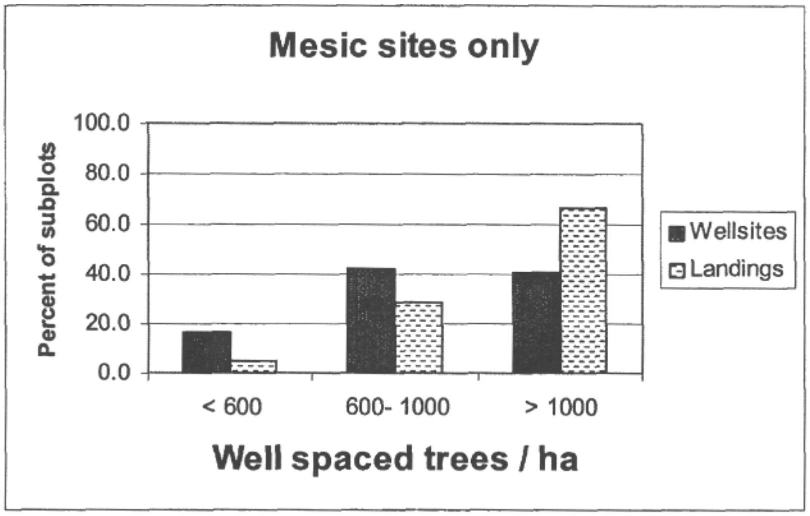

Figure 9. Stocking levels for well sites on mesic **sites, in comparison to stocking levels on rehabilitated and planted forest landings..**

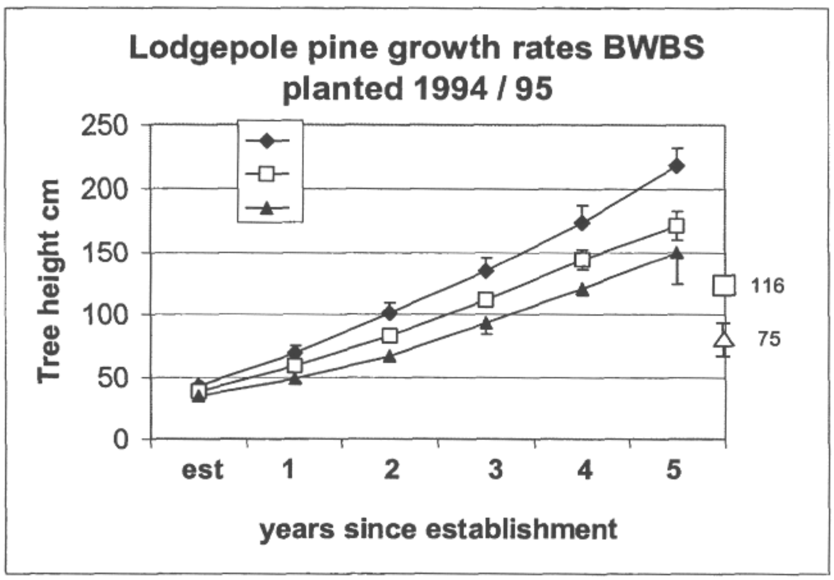

Figure 10. Tree growth rates for well sites planted in 1994 (triangles), compared to rehabilitated landings planted in 1995 (squares), and plantations (diamonds). Error bars represent 95 % confidence interval of the mean. Values for the line plots were derived from trees that had attained the age indicated, and are considered representative of the potential growth rates for trees once they become established. The isolated symbols on the graph margin indicate the average attained height for all established **trees on well site and landing subplots during 2002, and provide a better representation of what the sites were supporting at the time of measurement.**

Factors Affecting Seedling Establishment and Growth

We evaluated a number of factors that may have affected survival and early growth of planted trees, including clay content, bulk density, depth of loose soil, and grass cover. Many of the relationships we

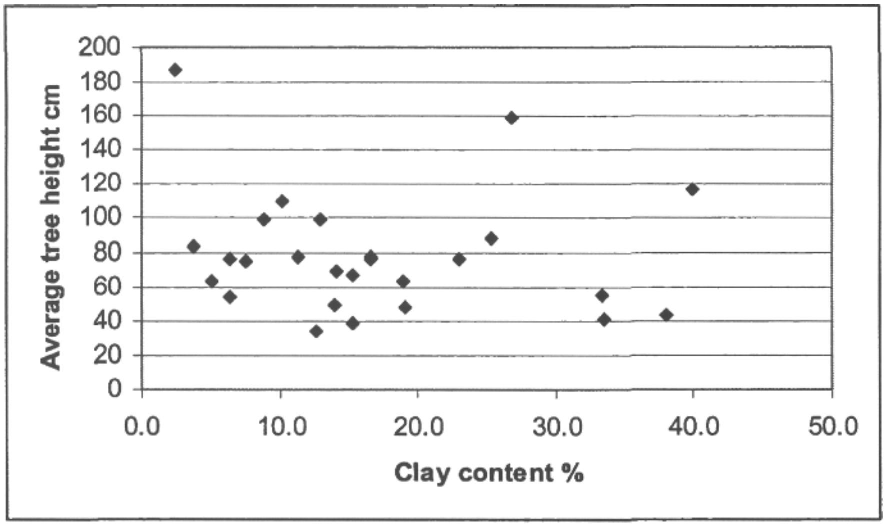

Figure 11. Tree heights compared to clay content for sites planted in 1995.

Seeding and fertilization treatments carried out during the reclamation work contributed to vigorous growth of grass and legume cover crops on some sites. We observed a weak trend towards reduced tree performance on sites with extensive competition (Figure 12).

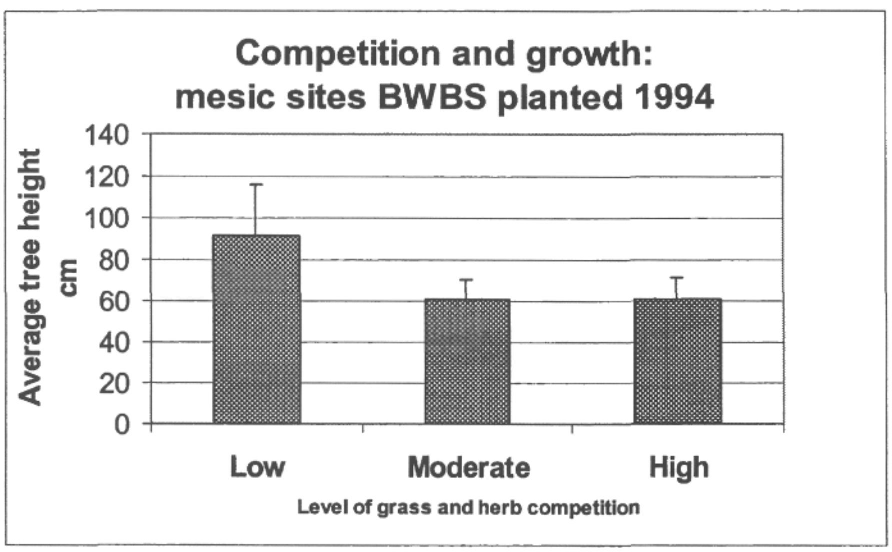

Figure 12.

Average tree heights for subplots with low, moderate and high levels of vegetation competition. Competition level was assessed on each subplot by evaluating percent cover of grasses and herbaceous species, density of sod cover, and other characteristics of the vegetation. Error bars represent the 95 percent confidence interval of the mean.

DISCUSSION

Retrospective studies, which look at existing examples of rehabilitation, can deliver results more quickly than experimental approaches that require the installation of treatment areas. However, the conclusions that can be drawn are sometimes limited because retrospective studies often lack detailed information on initial conditions for the sites, and it can be difficult to locate reliable control plots. Results from this research project, when considered in view of results from similar projects, provide useful information to improve attempts to reclaim and reforest disturbed oil and gas sites.

Our broad conclusions regarding factors affecting survival and growth, including the effect of site moisture regime on seedling establishment and growth appear to be in agreement with results from other studies. The more detailed evaluations of soil conditions such as bulk density, clay content, etc., along with the ecological descriptions of vegetation cover, appear at this time to have limited predictive ability, and may be most useful for identifying groups of sites with similar conditions. The high levels of site to site variability and the numerous interacting factors affecting tree growth are the likely cause of poor predictive ability from such measurements. These evaluations have been particularly useful, however for illustrating that many of the important features of the reclaimed wellsites, including texture, bulk density, and nutrient levels, are not substantially different from rehabilitated forest landings in the area, where reforestation success was better.

The Practicality of Replanting Well Sites

Concern has been expressed over the likelihood that reclaimed sites would be re-used, thereby wasting the effort and expense of rehabilitation. Approximately 15 percent of sites that were rehabilitated had been reused within 8 years. In reclamation work involving soil decompaction, fertilization, grass seeding, and tree planting operations, the cost associated with tree planting ranges from approximately 35 - 50 percent of the total cost for reclamation, or $1500 - $2000 per hectare. Our results suggest that these efforts will often be rewarded with successful forest establishment. Success could likely be further improved through improved revegetation prescriptions that consider appropriate tree species and the interaction of cover crops and trees. Rehabilitation achievements can also likely be improved through topsoil conservation and re-use particulary on sites of high value. Compared to simpler revegetation strategies like grass seeding, the additional expense of planting trees is substantial, and won't be justified for all sites, particularly where the potential for re-use is high. However, where soil and site conditions are suitable, and where future needs of the site can be predicted with some reliability, tree planting appears to be a useful technique that would enhance environmental values over the long term.

Factors Contributing to the Success of Reforestation Efforts

Physical site factors

Our results indicate that the best chance for successful reforestation with lodgepole pine occurs on mesic and submesic sites. Well site construction and reclamation techniques can have a large influence on the moisture regime experienced by planted trees. Incorporating drainage into reclaimed areas is necessary to ensure restoration of site hydrology as it affects erosion potential and water movement, and should also be considered from the perspective of providing a suitable site for trees, if reforestation is a reclamation goal.

Although our results were inconclusive regarding the influence of clay content on reforestation success, a large body of information gathered throughout BC indicates that coarse textured soils can be returned to productivity with simple techniques like decompaction and tree planting, whereas finer textured soils are more difficult to restore. Soil bulk density was not well correlated with tree growth, suggesting that either values were below growth-limiting thresholds, or other factors were obscuring any trend. We intend to further evaluate bulk density as a factor affecting growth by comparing values to the maximum (Proctor) compaction values for individual sites.

Values for mechanical soil resistance were below growth-limiting thresholds in the early part of the growing season, but appeared to exceed such thresholds in July on several sites.

The soil chemical properties on the well sites we studied were similar to those for undisturbed forest soils in the area, and no indication of salinity problems were encountered.

Vegetation

A key aspect of successful reforestation is matching the tree species to the site conditions. We observed some sites where pine was not the most suitable choice for reforestation, as the sites were too wet. We also observed situations where competition from seeded cover crops appeared to be causing distress to planted trees, either through competition for water and nutrients in the soil, or by overtopping and vegetation press causing physical damage to the seedlings. On sites where the erosion potential is high, seeding with cover crops is essential to prevent erosion. On other sites where erosion potential is limited, and where other attributes of cover crops (e.g. building soil organic matter; providing shade) are not required, a revegetation strategy based simply on planted trees and the ingress of native species may be more successful.

CONCLUSION AND MANAGEMENT IMPLICATIONS

Our results suggest that the initial reforestation efforts on the well sites were moderately successful. Many of the reforested well sites appear to have the potential to develop into forest ecosystems.

Growth rates of lodgepole pine were lower than for rehabilitated forest landings in the area, even though soil conditions were not substantially different. This suggests that the success of reforestation efforts could likely be improved by adopting an ecological approach to planning reforestation efforts on well sites. Such an approach, which is typically followed for forest site rehabilitation, would involve collecting information on soil and site conditions prior to reclamation, and using the information to identify appropriate site preparation techniques, species selection, and other aspects of the reforestation work that are expected to contribute to success.

To obtain the maximum benefit from reforestation efforts on well sites, a targeted approach is suggested, where the efforts are directed at sites with the highest likelihood of success. Drawing from the results of this study, and related on work on soil rehabilitation in forestry, success appears more likely when the following conditions are present:

- mesic or drier moisture regime, which allows drainage of excess water so plant roots have access to a well aerated environment,
- coarse textured soil which allows for effective decompaction and soil drainage,
- gentle terrain requiring limited use of imported fill or cut / fill construction,
- replacing organic-rich surface layers which contribute to water holding capacity and nutrient supply,
- limited erosion potential so grass seeding would not be essential.

ACKNOWLEDGEMENTS

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