Revegetation of Wellsites and Seismic Lines in the Boreal Forest

Arin MacFarlane
University of Alberta
Department of Biological Science
Honour's Thesis

April 17, 1999

Abstract

Rapid expansion of industrial development (petroleum, forestry and peat extraction) in northern Alberta has the potential to dramatically alter the composition and structure of the boreal forest. Non-forestry related developments (particularly seismic lines and wellsites) have largely been excluded from landscape level management, yet are ubiquitous across the boreal forest of Alberta. This study evaluates the rate of tree regeneration and direction of community succession on seismic lines and wellsites over three time periods. These features were sampled across a large area for landscape level applicability. Preliminary results show evidence of significantly smaller densities of regenerating trees on wellsites and seismic lines compared to natural regeneration after fire. As well, the tree diameter distribution remains similar in all age categories. This indicates that on seismic lines and wellsites, there is poor recruitment, growth and survival of trees. Tree densities on both seismic lines do not appear to change with time, rather site specific variables are more predictive. Tree growth on seismic lines is negatively correlated with disturbance and on wellsites is negatively correlated with high grass and herb cover in the understory. As with density, varying species compositions can be attributed to the conditions created by the initial disturbance and by the resultant environment. Further work is required to investigate causes for these trends in tree growth as well as the pattern in tree species composition over time. Regardless, these results have large economic and ecological implications.   Changes in age and growth characteristics of trees on these disturbances may result in cumulative long term losses of forested landbase which would limit timber supply for forestry companies. If wellsites and seismic lines are not returning to continuous forest they are contributing to the fragmentation of the boreal forest ecosystem. This has wide reaching implications for all species and for the integrity of the boreal forest as a whole.

Introduction

Increases in anthropogenic alterations to habitat and to the landscape are significant concerns in the boreal forest of northern Alberta. Few studies have dealt with the long term collective consequences of these disturbances. In addition to forestry, the oil and gas industry has placed a significant footprint on the boreal forest (Alberta Environmental Protection 1998). Cumulative effects could cause changes to the structure and species composition, the rate of ecological processes and the ecosystem's ability to respond to disturbances and other stresses (Kimmins 1991). However, stand replacing disturbances, predominately large fires, have occurred frequently in the boreal forest (Rowe and Scotter 1973). Evolution has favoured species adapted to boreal forest fire regimes. The processes of fire and subsequent succession sustain ecosystems over space and time, creating a range of natural variability responsible, in part, for regional biodiversity (Rowe and Scotter 1973).

In the age of ecosystem management these linear, randomly placed features are a significant divergence from the natural disturbance regime of the boreal forest (Passey and Wooley 1982). By modelling harvesting techniques on natural disturbances, forestry companies are attempting to mitigate potential negative effects of their resource extraction. These techniques are based on the assumption that boreal ecosystems are able to cope with man-made disturbances if they resemble those created naturally. Attempts to manage ecosystems to preserve biodiversity may be thwarted as a result of cumulative effects. Linear disturbances associated with seismic exploration and oil and gas development do not fall within the natural range of disturbances in the boreal ecosystem. In the case of seismic lines, little deviation from a straight line occurs except to bypass difficult obstacles such as lakes. Wellsite locations are chosen based on existing pipeline and road networks without consideration of landscape patterns (Passey and Wooley 1982). Unfortunately, few studies have examined the response of boreal plant communities to linear disturbances over long periods. Rather, emphasis has been placed on short-term revegetation. Is revegetation occurring along a similar successional path as in a burn or a forest gap, or are these areas being taken out of natural successional trajectories and left unforested?

If disturbed areas regenerate into forest cover over time, either naturally or by planting, the initial effect of industrial expansion would gradually decrease. Unfortunately, past reclamation techniques did not favour re-growth of merchantable trees. Wellsite reclamation standards prior to 1973 directed that disturbed sites be seeded with agronomic plant mixes. Natural re-colonisation of native shrubs and trees were restricted by seeded grass and legume species (Hermesh 1984; Hardy BBT Limited 1990; McCabe and Kennedy 1989). On seismic lines seeded plant species, as well as the change in microclimate, influence the composition of the regenerating plant communities (Revel *et al*.1984). Now, not only have guidelines changed, but also long term objectives have been established for the fate of the initial disturbance. The Alberta Environmental Protection Act (1993) states that reclaimed land should be returned to an equivalent land capability. After reclamation an ecosystem is not necessarily returned to its previous form, rather it is at a lower level of functioning, supporting various land uses similar to what existed prior to disturbance. Restoration is the process of restoring complete pre-disturbance conditions. Within new guidelines it is recognised that even though the goal of ecosystem restoration may progress substantially, the effects of the initial disturbance may not be completely erased (Gerling et al. 1996). As a result of these changes in guidelines, since 1997, seeding mixes are now composed of common boreal colonising species (Mahnic et al. 1993; Hardy BBT Limited 1989; Alberta Agriculture, Food and Rural Development 1998). Unfortunately, the costs of using native plants is high and the availability of these mixes is poor (Gerling 1999). Techniques in removing and replacing topsoil have also changed to facilitate revegetation. These improvements may effect revegetation rates on newly reclaimed sites. However, time lags are imposed before natural reforestation can begin.

Until a well is abandoned, reforestation will be prevented (Passey and Wooley 1983). As proper management, safety and reduced fire hazard at industrial facilities, pipelines are often left unforested after abandonment and the land area removed from the provincial 'productive forested landbase' (Alberta Environmental Protection 1998). Seismic lines, although not maintained, may be used for access to remote areas and subjected to further disturbances. Delayed reforestation will have negative impacts on future timber volumes, subjecting forestry companies to an increasing portion of unforested productive landbase. Increased industrial activity of oil and gas and forestry may have cumulative effects on the boreal ecosystem as well as on resource economics. Greater amounts of disturbed area may change the range of natural landscape variability by creating a younger and more fragmented forest. Consequences to the boreal forest may include an invasion of non-endemic plant species as well as losses of interior or old growth specialists (Gerling 1999; Catling, and Oldham 1997). Successful management of the boreal ecosystem must include consideration of the long-term revegetation dynamics of these linear disturbances.

Increasing fragmentation of ecosystems and the negative consequences of cumulative human induced changes to the environment have been demonstrated around the world. Northern Alberta already has nearly four million hectares of boreal forest altered by industrial activity (Alberta Environmental Protection 1998). These activities are expected to increase in the future. If the cumulative impacts of all resource development is not evaluated and incorporated into management practices, the ability to balance responsible resource extraction with ecological sustainability may be threatened. Determining the rate and direction of community development on these disturbed sites will help to understand the cumulative effects of present, past and future development. Once there is a better idea of the way the boreal landscape will evolve, steps can be taken to ensure that all demands on the forest are met without destroying the ecosystem and its resources.

Research Objectives:

1. Evaluate the rate of forest regeneration on seismic lines and abandoned wellsites.
2. Evaluate the successional stage of plant communities found on linear disturbances.

Study Area

The study area is within Alberta-Pacific's forest management area (FMA) in north eastern Alberta. This area falls within the mid boreal mixedwood ecoregion (Strong and Leggat 1992). In upland areas the dominant tree species is trembling aspen (*Populus tremuloides*) with balsam poplar (*P. balsalmifera*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*) occurring as secondary species

(Strong and Leggat 1992). The dominant soil types are Eutric Brunisols and Grey Luvisols on imperfectly to well drained sites. Lowland, poorly drained areas are dominated by black spruce (*Picea mariana*) stands. Soils in these stands are typically organic and peaty Gleysolic.

Selection of Study Sites

Evaluation of the rate of commercial tree species regeneration and community succession were examined with three components (Table 1). First, abandoned wellsites and seismic lines were sampled over three post-disturbance time classes; 0-10 years, 10-20 years and greater than 20 years. Second, wellsites and seismic lines that occurred within deciduous dominated (> 60% *Populus tremuloides*) and conifer dominated (> 60% Picea glauca) forests were sampled in each age category. These forest types were chosen because they exist on productive uplands and are of economic significance to the forest industry. Third, the difference in tree regeneration between edges and centres of seismic lines will be distinguished. Separating the edges from the centre has the potential to test the amount of ingress as well as highlight the effect of any additional disturbances.

The project goal was to replicate each component twenty times (Table 1). In total there was to be 120 wellsites sampled and 240 50m segments of individual seismic lines sampled; each wellsite and each 50m seismic line segment will be considered a replicate site. For landscape scale applicability the study sites were dispersed across the FMA.

Table 1. Replication of study variables.

Disturbance Type	**Forest Cover Type**	**Grouping of sample plots**	**Age Category**		
			Young	**Medium**	**Old**
Wellsites	Aspen		20	20	20
	Spruce		20	20	20
Seismic Lines	Aspen	Centre	20	20	20
		Edge	20	20	20
	Spruce	Centre	20	20	20
		Edge	20	20	20

Due to errors in information, some wellsites were not abandoned, seismic lines had been converted into roads or pipelines and some sites were inaccessible by ground. As a result the actual sample size is reduced from the original goal (Table 2). In the field season of 2000 more wellsites and seismic line, in particular the coniferous sites will be sampled in order to complete the required sample sizes.

Table 2. Total number of replicate sites at the end of the sampling period**.**

Disturbance Type	**Forest Cover Type**	**Age Categories**		
		< 10 Years	**10 – 20 Years**	**> 20 Years**
Wellsites	Deciduous	20	15	21
	Coniferous	8	8	10
Seismic Lines	Deciduous	42	19	37
	Coniferous	34	9	25

Selection Process

Selection of sites was done using Geographical Information Systems (GIS). This was possible as a large portion of the wellsites and seismic lines within Alberta-Pacific's FMA are in digital database format (ArcInfo software) and forest cover and land-use information contained within the Alberta Vegetation Inventory (AVI) database is also available digitally.

Alpac's FMA was stratified by density of wellsites and seismic lines in individual townships. Areas with densities of seismic lines greater than 100km per township were isolated for selection of study sites. Thirty townships for each disturbance type were selected. The top five were thrown out so as to avoid selection of the most disturbed townships. Combining the lists and subtracting these five, 51 townships were chosen to search for potential study sites.

Due to time constraints and potential delays in travel time to sites, only areas within 3 km of roads were examined.

Only wellsites that were no longer in use and therefore permitted to revegetate (labelled abandoned) were used. In total there are 13,502 abandoned wellsites in the digital database. In addition to location, the database included information on the date of the initial disturbance. Using these dates age groups of wells were sorted into young (<10 years), medium (10 to 20 years) and old (>20 years) age categories. It is important to note that the date of abandonment is unknown.

The seismic line database was not as easily organised. Presently there are 82,783km of seismic lines throughout the FMA, but there is neither information on time of disturbance nor information on whether the line is still in use. Therefore, the entire seismic line spatial database was used for all queries. Relative dating was done after a number of lines were selected.

The information on wellsites and seismic lines was overlaid onto Alberta Vegetation Inventory (AVI) forest cover information. In order to make the selection of research sites more efficient specific attributes of the AVI coverage were queried. First, the FMA was divided into productive and unproductive areas and only productive areas used. Re-disturbed areas were not sampled, therefore land burned by class E fires was removed from the productive landbase. Next, the AVI coverage was separated into different forest cover types. Stands were separated out by origin dates and overstory species composition. All forest stands older than 1950 that were deciduous dominated and coniferous dominated were selected. Each seismic line had to bisect the stand type for a minimum distance of 50m. A wellsite had to exist within the forest matrix of the desired stand type.

All sections of lines that met the above criteria were sent to an airphoto interpreter. The relative ages of the seismic lines were determined using airphotos over time.

The selected sites were made in ArcView coverages and subsequently printed onto maps and taken out into the field. As mentioned, some sites were eliminated upon inspection as we did not sample any re-disturbed seismic or well nor non-abandoned wells. For example, wellsites and seismic lines that were within cutblocks or within fires were not sampled.

Sampling Methods

Seismic Line Sampling Method

Regenerating trees and shrubs were sampled on seismic lines using 3 parallel belt transects, subdivided into 1.5m x 3.5m plots (Figure 1). Each seismic line had 10 sample plots in total; 13% of the area sampled.

The centre point of the width of seismic line was the centre of the first transect. The other two transects were spaced equal distances from the centre point and the seismic line edges. The 1.5m x 3.5m plots were spread over the 50m distance, length parallel to the line. Each was centred on the transect line and spaced a minimum of one plot length from successive plots to prevent overlapping samples (Figure 1).

(NOTE: diagrams not to scale)

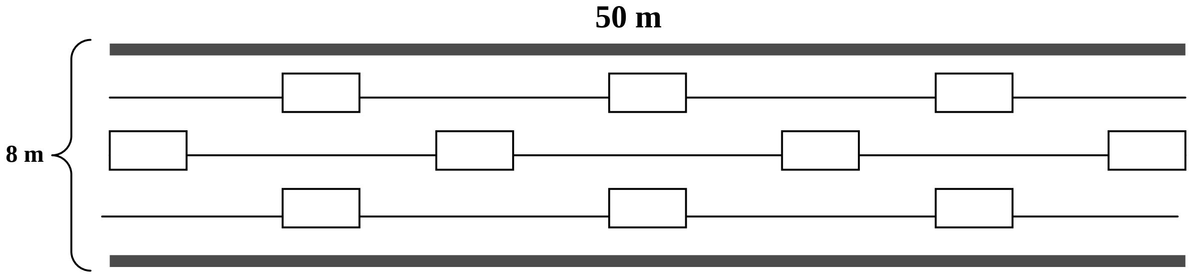

Figure 1. Diagram of subdivided belt transects on a seismic line.

In each plot species and height class of each tree and tall (> 1m) shrub was recorded. The height classes for trees and shrubs were 1 (0.01-0.5 m), 2 (0.6-1.3 m), 3 (1.4-3 m), 4 (3-5 m) and 5 (>5 m). Trees that were over 1.4m tall (≥ class 3) had the diameter at breast height (dbh, 1.3m) measured.

Wellsite Sampling Method

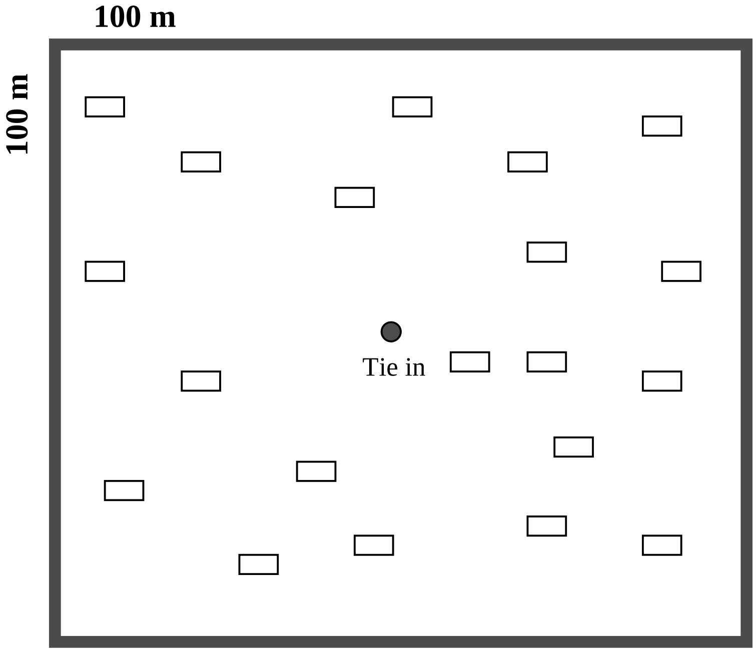

Figure 2. Diagram of random plot placement on a wellsite.

Wellsites will be sampled with multiple 1.5m x 3.5m plots (Figure 2). Each wellsite, approximately 1 ha in size, will have 20 plots; approximately 1% of the area sampled. Plots will be randomly placed with a minimum distance apart of one plot length.

As in the seismic line plots, species and height class (same as seismic lines) of each tree and tall (> 1m) shrub were recorded. Trees over 1.4m tall (≥ class 3) had the dbh measured.

Measurement of Disturbance

As an evaluation of recent and previous disturbances a percent of mineral soil was recorded for each plot at each site. The percent cover classes will follow the Braun-Blanquet cover scales (Kent and Coker 1992) (Table 4).

Any recent disturbances, such as ATV trails, were evaluated in each plot at each site (seismic and wellsite). The type of disturbance was recorded as a comment as well a relative measure of the magnitude of the disturbance (Table 3).

Table 3. Disturbance scale categories**.**

Disturbance Scale	
Low (1)	Short-term damage to vegetation. None to small amounts of mineral soil exposed due to disturbance. Indication of infrequent occurrence.
Medium (2)	Moderate damage to vegetation. Exposed mineral soil due to disturbance. Has the potential to revegetate within season.
High (3)	Long-term damage to vegetation. Large amounts of area with exposed mineral soil. Indication of frequent re-disturbance.

Understory Vegetation Sampling

Due to time constraints, understory was sampled half way through the field season, throughout July and August. This resulted in a small number of replicate sites. While sampling within this narrow time frame, understory species categories were used to give generalised information on successional trajectories. These categories included all plant species less than 0.5m tall: shrubs, dwarf shrubs, forbs, grasses, mosses, fungi and lichens.

Understory plants were sampled with a 0.5m x 0.5m plot nested within a tree plot. There was one nested understory plot per tree plot. Altogether, ten 0.5m x 0.5m plots on a seismic line and twenty plots on a wellsite.

Each category of plant in the plot was visually classified into percent cover classes. Percent cover of downed wood and bare soil was also visually categorised. The classes will follow the Braun-Blanquet cover scales (Kent and Coker 1992) (Table 4).

Table 4. Braun-Blanquet cover scales.

Value	
+	Less than 1% cover
1	1-5% cover
2	6-25% cover
3	26-50% cover
4	51-75% cover
5	76-100% cover

Results

Problems with Statistical Analyses

Originally, the methods were set up to collect data that could be used in a nested ANOVA design (plots within sites). Density, diameter at breast height and tree height on seismic lines and wellsites would be compared to forests originating from fire. The variables would be the three different year categories and the two forest cover types. The data on natural revegetation was to come from Alberta Research Council's Fire Harvest and Residual Project (1997). In this study they sampled a chronosequence of tree, shrub and understory revegetation data; 2 years, 14 years and 28 years post-fire. Unfortunately, at this point, I have been unable to obtain the entire database and only have reported figures to use for comparison.

No parametric tests were used as the data on tree density did not conform to a normal distribution (each year category Kolmogrov-Smirnov $p < 0.001$). The distributions of the site and plot tree densities were highly skewed to the right due to a large number of zeros. Log transformation did not produce a normal curve. Attempts were then made to test the data using a general linear model using a negative binomial or Poisson distribution (Wilson et al. 1996). This attempt failed mostly due to my inability to manipulate the software (SYSTAT) into performing this operation.

Long term goals for analysis include examining patterns of species abundance and richness at different levels – tree, shrub and understory – using the year category and disturbance variables. For this conical correspondence analysis is best suited (Kent and Coker 1992).

For use in models it will also be important to quantify any changes of tree densities, heights and diameter over time. This analysis is made difficult by large amounts of site specific variation (see Figures 15 and 16). Any statistical model that is fitted to the data has to overcome the problem for potentially greater site to site variation than year to year variation.

Due to these problems, tree density data has not been analysed with rigorous statistical methods. Therefore, the results presented below are qualitative. The problems with analysis have shown a much more complex picture of the regeneration of these features that will take much more time to tease apart.

Problems with the Data

For conifer sites there are two outstanding problems. First, there are much smaller sample sizes in comparison to deciduous sites. Second, the category 'conifer' could have included white spruce, jack pine, balsam fir or black spruce (on upland sites) as the dominate conifer. This results in very drastic site to site variation becoming incorporated into the study database.

Figure 3 is an example the range of data found. Out of the 22 coniferous seismic lines, greater than 20 years old, only 3 sites contained balsam fir and jack pine trees. Yet the abundance of these species would be high enough to misrepresent their importance in relation to other species. In addition, their proportion of total species may be inconsistent with their abundance across the landscape.

The deciduous sites are generally not as variable. There are higher numbers of deciduous wellsites and seismic lines sampled. The site conditions are somewhat more continuous as either aspen or balsam poplar dominates the overstory of the surrounding forest. Therefore, I will focus the remainder of this report on the revegetation of deciduous seismic lines and wellsites over time.

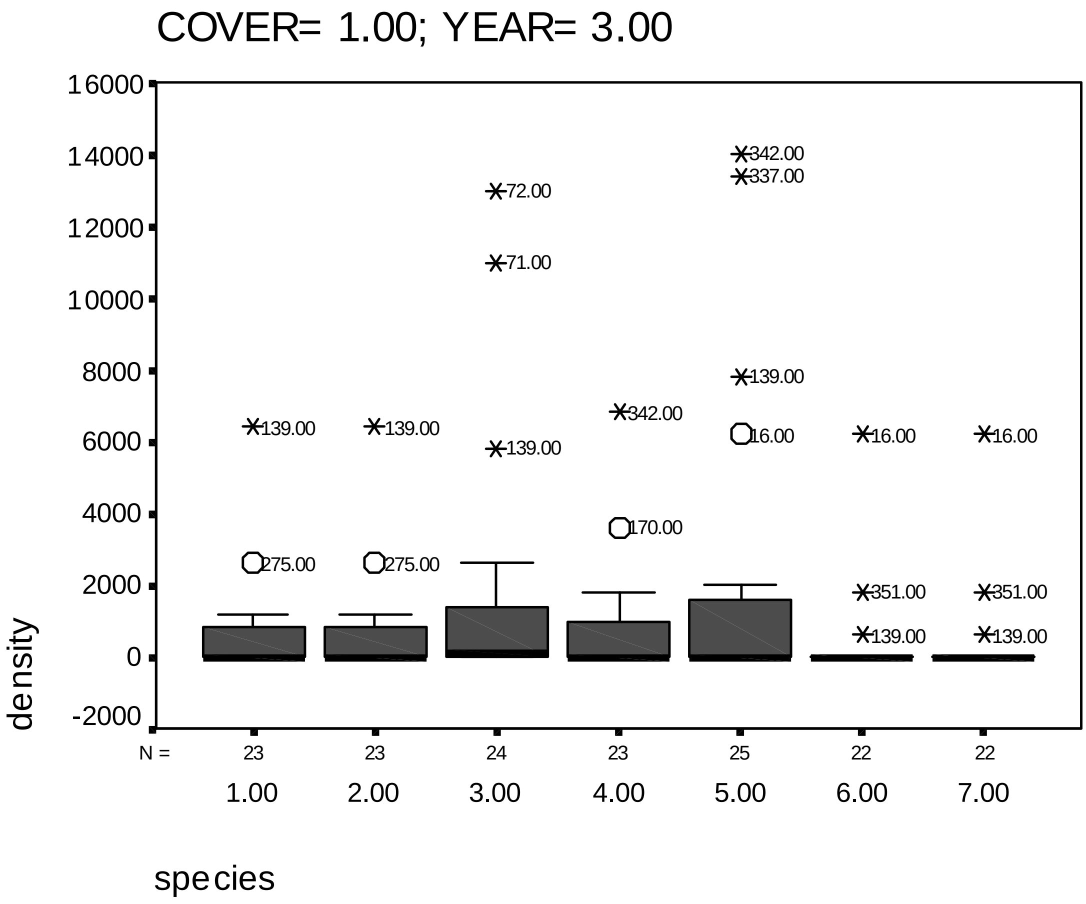

Figure 3. Boxplot of individual tree species densities occurring on the greater than 20 year old coniferous seismic lines. Each box displays the median, interquartile range and maximum and minimum trees per hectare (the whiskers). This figure also shows any extreme values or outliers from the rest of the data. These outliers have been labelled by site number. The x-axis categories are the tree species sampled: 1) aspen 2) balsam poplar 3) white spruce 4) black spruce 5) paper birch 6) balsam fir 7) jack pine. The number above the category denotes the sample size.

Tree Densities

Averaging all species of trees, on all sites, there does not seem to be differences in tree densities on wellsites between years (Figure 4). However, there seems to be higher densities on seismic lines in the 10 to 20 year category. When comparing these average tree densities to those recorded in the Fire Harvest and Residual Study the actual tree regeneration is put into perspective (Figure 5).

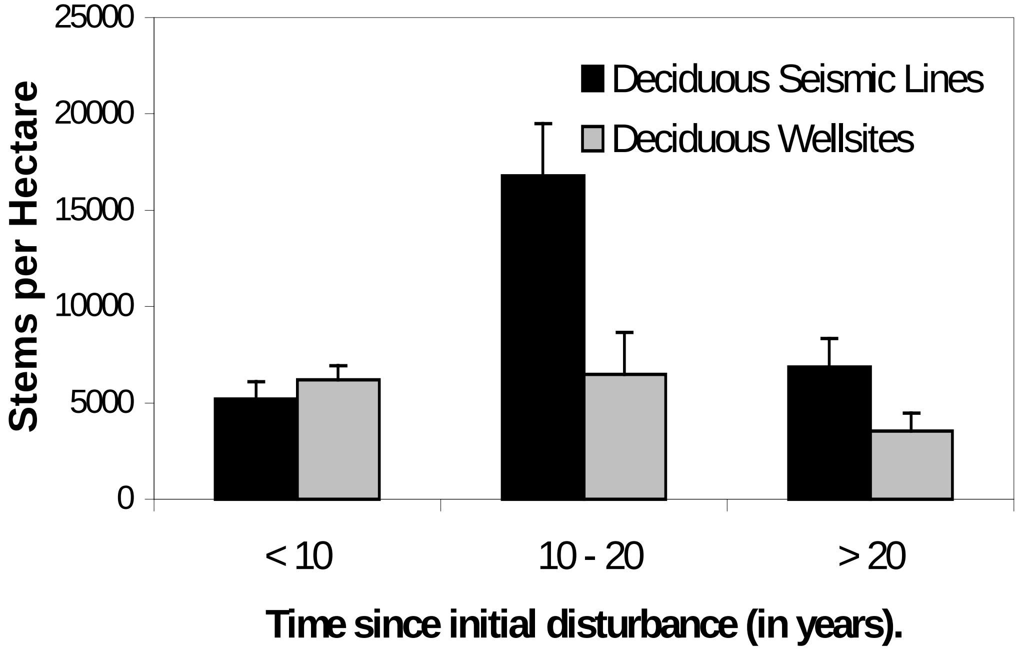

Figure 4. Average number of stems per hectare for trees on deciduous and coniferous seismic lines and wellsites in each year category.

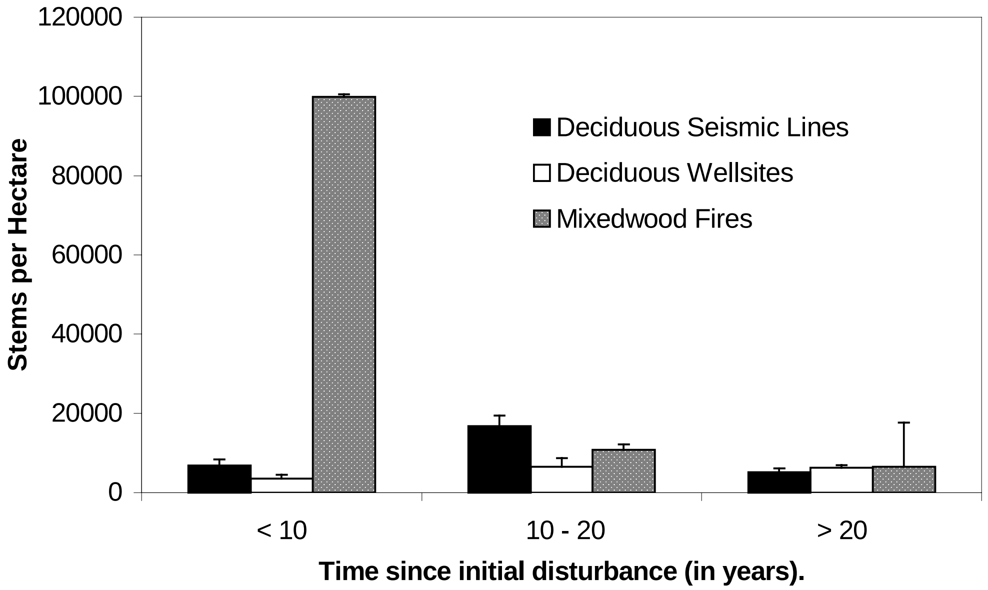

Figure 5. Average number of stems per hectare for trees on deciduous and coniferous seismic lines and wellsites, including average number of trees on mixedwood wildfire stands. Wildfire stands are aged 2, 14 and 28 years post-fire.

Although not tested with statistical methods, there is evidence that initially (within the first age class) there are significantly lower tree densities on seismic lines and wellsites than within wildfire stands. This is not the case with the later age categories. Here the evidence points to similar tree densities between wildfire stands, seismic lines and wellsites.

Tree Diameters

In comparison to figures 4 and 5, it is possible to see that once trees shorter than 1.4m are removed from the calculation of density, the actual mean densities on wellsites and seismic lines are less than the fire stands for all age categories (Figures 6, 7, and 8).

Examination of the diameter distributions seismic lines and wellsites in comparison to fire stands show that disturbances older than 20 years had fewer large diameter trees (Figures 6c, 7c and 8c). The 28 year old fire stands have a diameter distribution that follows a bell-shaped pattern. Conversely, there are no trees in the larger diameter classes in neither the greater than 20-year-old wellsites, nor the greater than the 20-year-old seismic lines. This may be an indication that the trees on wellsites and seismic lines are younger. This cannot be confirmed, as age of trees was not measured directly.

The diameter distribution of trees on seismic lines and wellsites in the 10 – 20 year age categories are similar to those in the 14 year old fire stands (Figures 6b, 7b, and 8b). Trees on the less than 10 year old wellsites and seismic lines had trees in a wider distribution of diameters than the 2 year old wildfire stands (Figures 6a, 7a and 8a). This may be due to sampling error in which trees on the edges of seismic lines or wellsites, that were not part of the regenerating cohort, were counted.

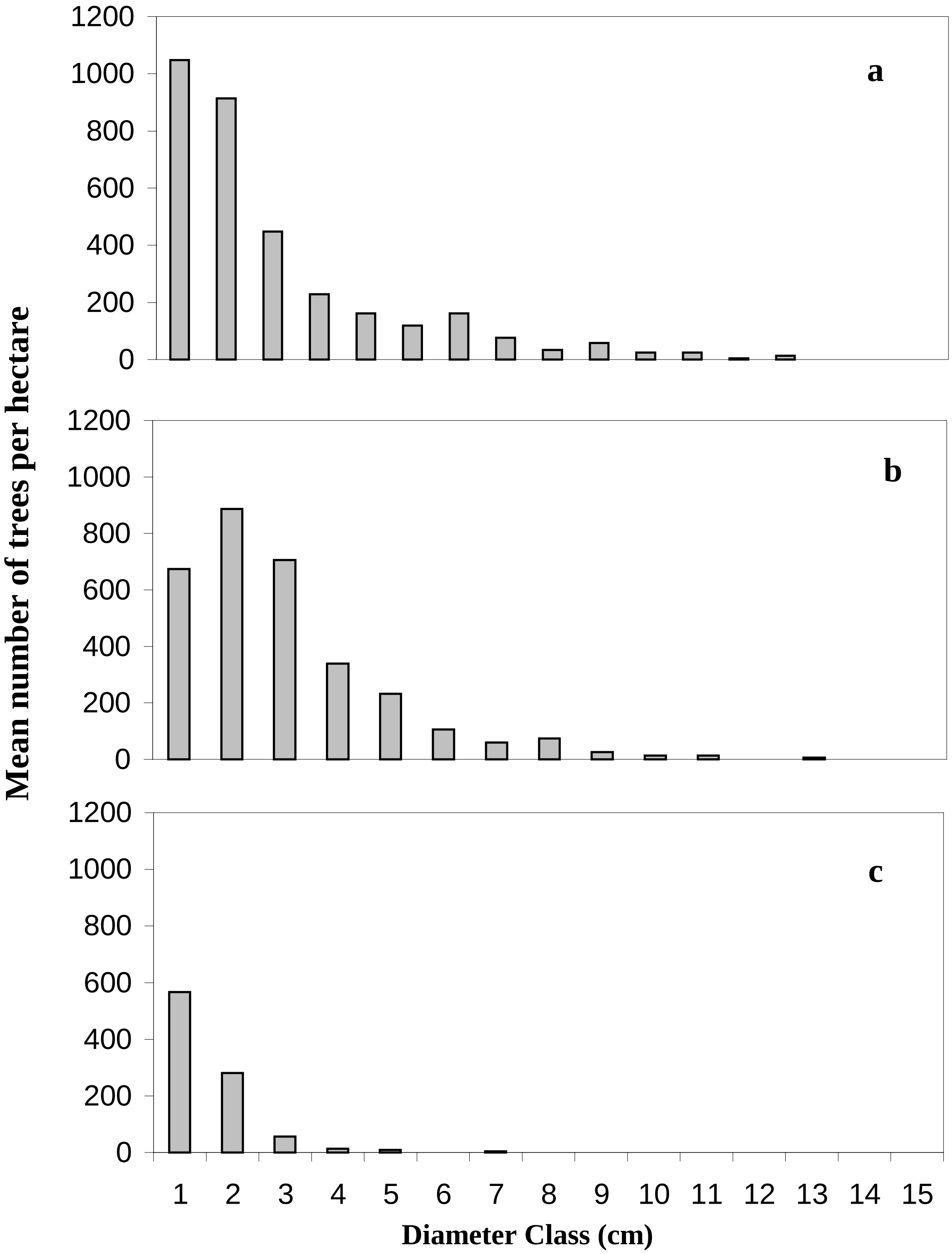

Figure 6. Mean number of trees per hectare within diameter classes in a) less than 10 years b) between 10 and 20 years and c) greater than 20 years after initial disturbance on deciduous **wellsites**. Only trees with heights greater than 1.4m had diameter at breast height measured.

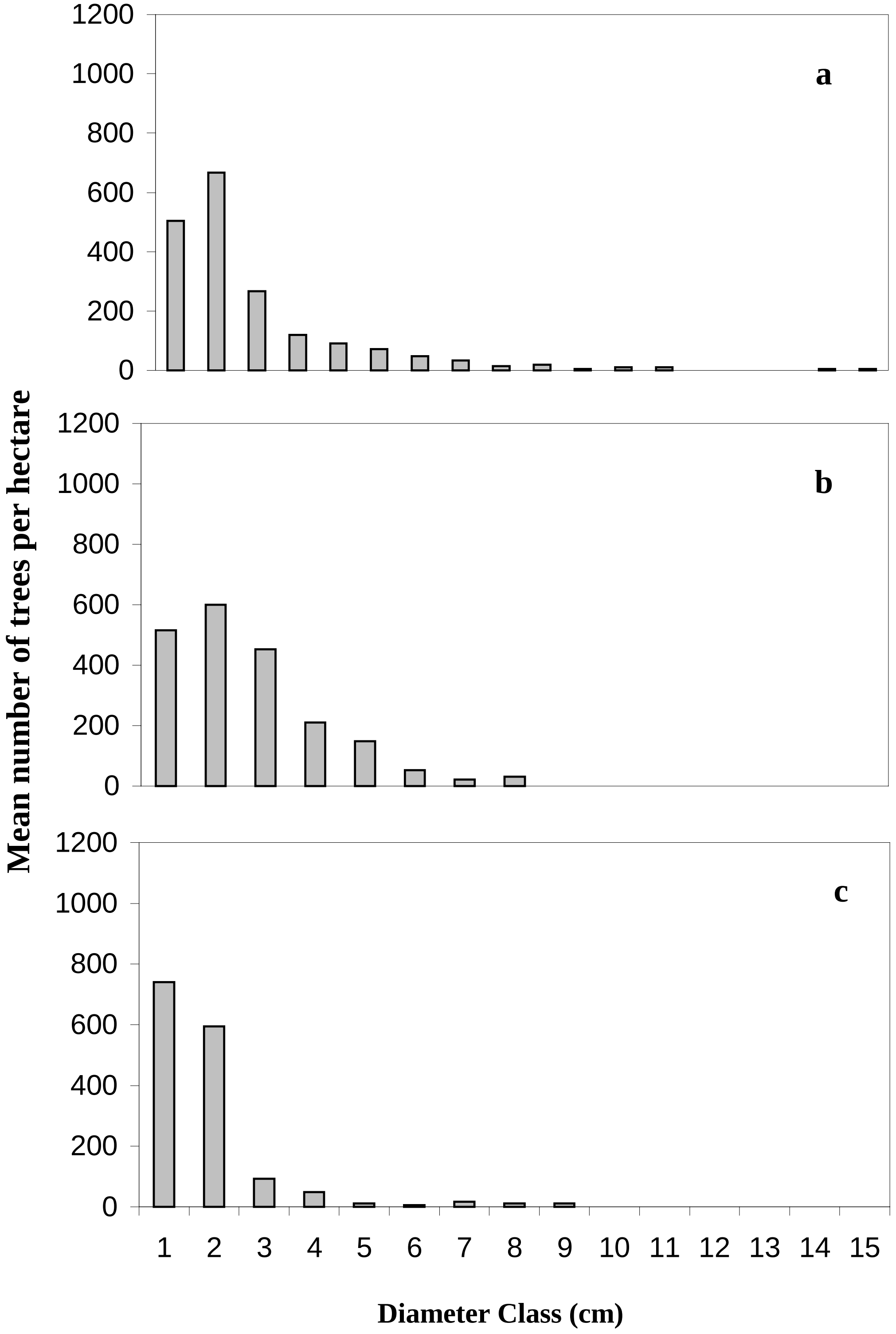

Figure 7. Mean number of trees per hectare within diameter classes in a) less than 10 years b) between 10 and 20 years and c) greater than 20 years after initial disturbance on deciduous **seismic lines**. Only trees with heights greater than 1.4m had diameter at breast height measured.

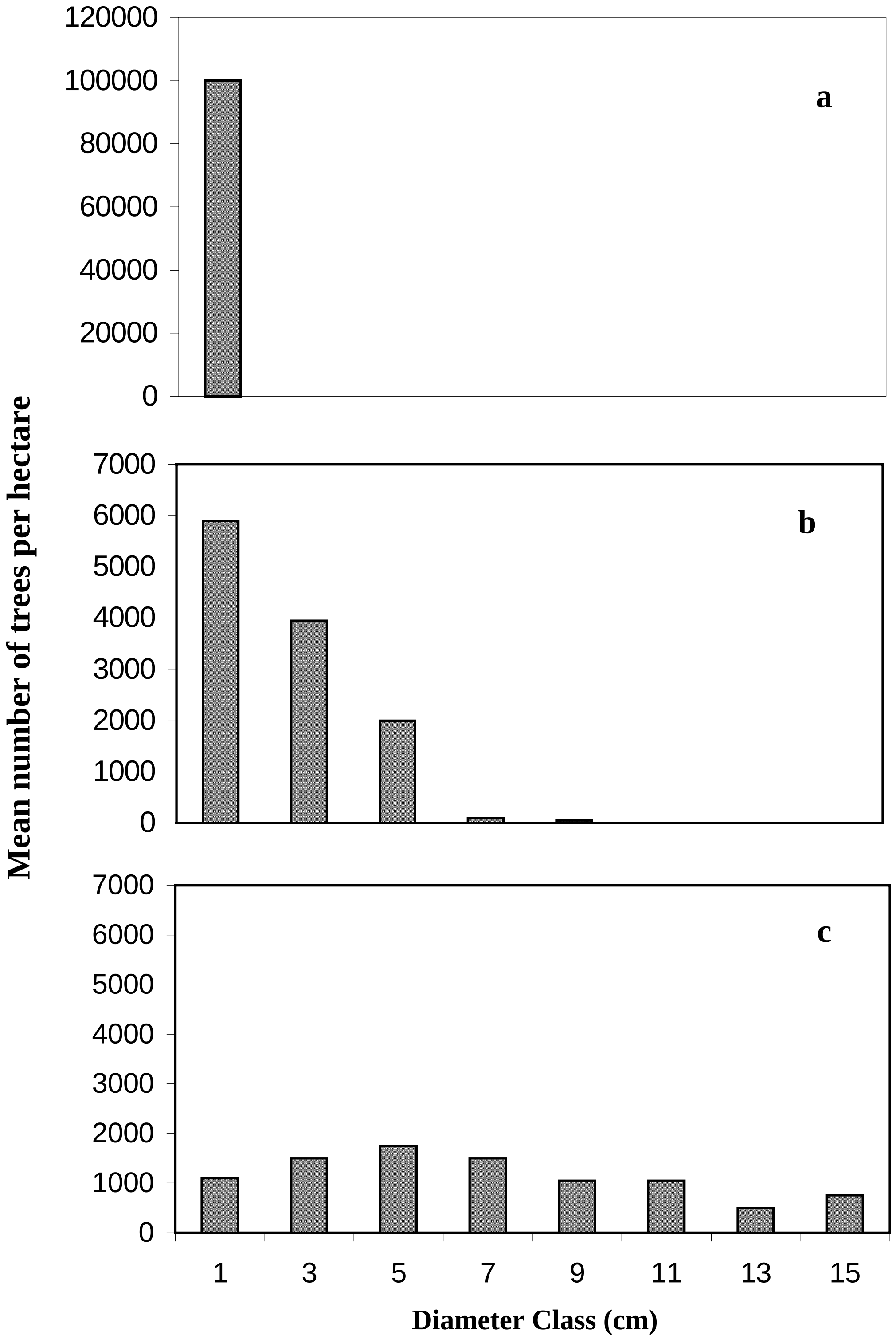

Figure 8. Mean number of trees per hectare within diameter classes in a) 2 b) 14, and c) 28 years post fire. Trees in the 14 and 28 year old stands only trees with heights greater than 1.4m, had DBH measured. In the two year old stands, there was no height restriction and all trees were measured at the highest point on the stem.

Wellsites and seismic lines are anthropogenic disturbances, and therefore it is appropriate to compare their revegetation to other anthropogenic disturbances. There has been considerable research done on predicting regeneration after logging, and we can assume that they have some reasonable standards in place that would ensure a regenerating cutblock is on a natural, or at very least a sustainable, trajectory.

The Alberta Forest Regeneration Survey Standards outline a plot by plot method for calculating the acceptable tree density (stocking) of a cutblock. A deciduous plot is considered adequately stocked if it has at least 3 acceptable, established deciduous seedlings. The definition for an acceptable deciduous seedling are: a) aspen, poplar or birch seedlings of minimum 1.5m (class 3), b) white spruce, black spruce and balsam fir seedlings of minimum 40cm (class 1), c) jack pine saplings of minimum 75cm (class2). A cutblock will be considered to be adequately revegetating if 80% of the plots on a site are stocked.

When applied to deciduous seismic lines and wellsites (Table 5) very few seismic lines and no wellsites meet these standards.

Table 5. Percentage of seismic lines and wellsites considered stocked using Alberta Forest Regeneration Survey Standards.

	< 10 Years	**10 to 20 Years**	**> 20 Years**	**All Sites**
Seismic Lines	5.4 %	21.1 %	11.9 %	11.2 %
Wellsites	0.0 %	0.0 %	0.0 %	0.0 %

Tree Species Composition

It is difficult to break down the complete database into species and find a pattern in species regeneration due to variation in site conditions. Sorting out the appropriate methods to understand this site to site species variation will require much more time and resources.

In general, on the deciduous seismic lines, aspen and poplar have generally high densities as compared to the other species (Figure 9a). Their numbers seem to be increasing through time. Birch seems to peak in abundance in the 10 – 20 year old category. After 20 years, it has the highest densities next to aspen and poplar.

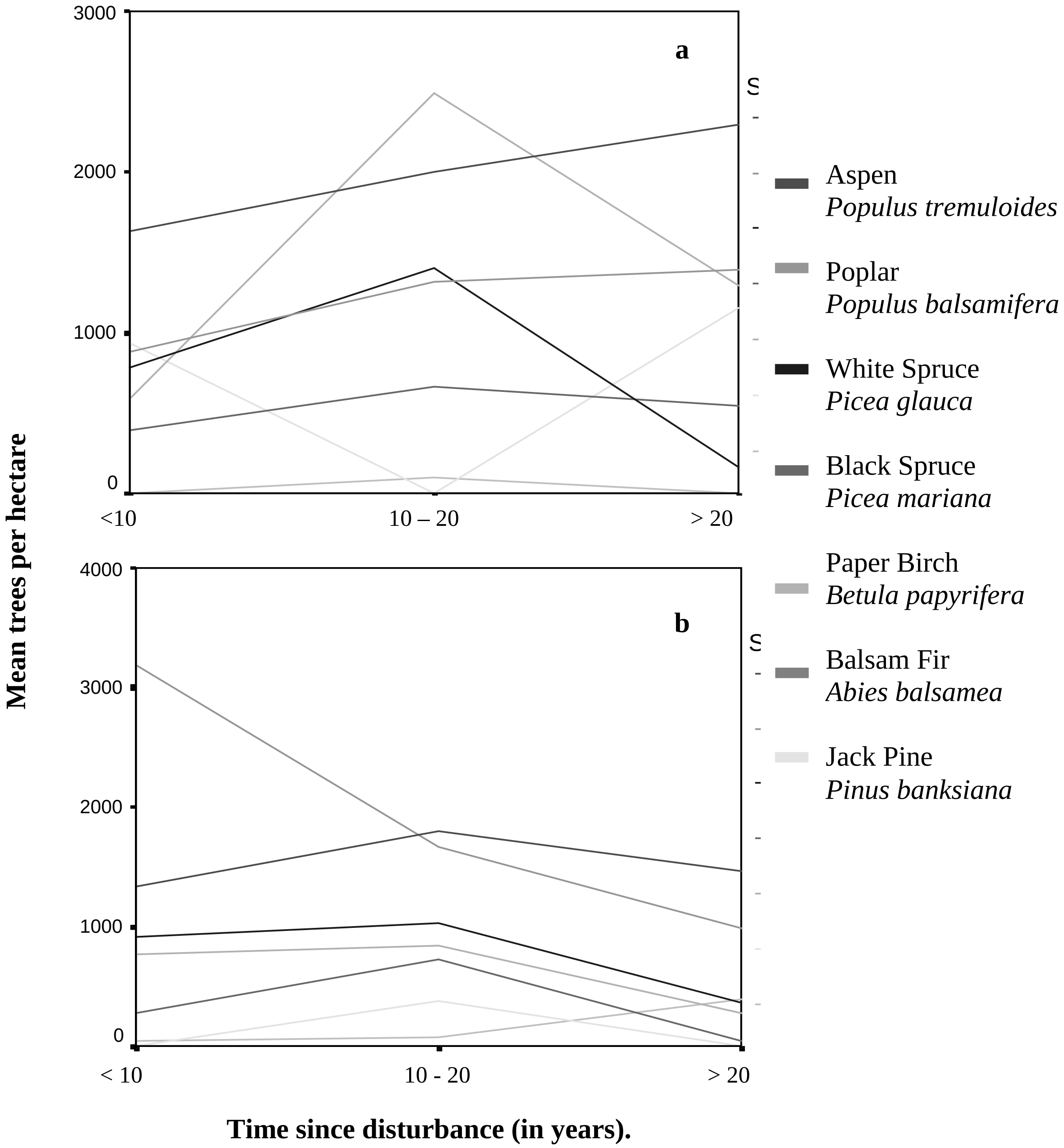

Figure 9. Average densities of tree species on deciduous a) seismic lines and b) wellsites over the three time periods.

Coniferous trees on seismic lines are less abundant than the deciduous trees. White spruce had higher densities than black spruce but they seem to follow the same trend. They increase in number from the less than 10 years to the 10-20 years category then decline at ages greater than 20 years. Balsam fir is in low abundance consistently throughout the age categories.

On the deciduous wellsites (Figure 9b) aspen and poplar again have consistently higher densities than the rest of the species. This was unlike seismic lines where paper birch and white spruce had a peak of density, higher than aspen or balsam, in the 10 – 20 year category. On wellsites the aspen and poplar follow dissimilar patterns. Aspen is initially at lower abundance than balsam poplar but increases by the second year category. After this initial high density, balsam poplar shows a steep decrease in density over time. White spruce, black spruce and paper birch all seem to show a slight increase form the less than 10 years to the 10-20 years category, then a decrease in abundance greater than 20 years after initial disturbance. Balsam fir increases, at low densities, over the three time periods and ends at the same density as white spruce.

Tree Species Diversity

The diversity of trees for each site was calculated using the Shannon-Wiener Diversity Index. The goal was to test the species composition changes between years using a statistical analysis. Again, the distributions were not normal (Shapiro-Wilk $P>0.05$) so a non-parametric ANOVA was used. At no time does the diversity on seismic lines does not change (Figure 10) (Kruskal-Wallis $x^2=.49$ df=2 p=.780). However, wellsites significantly increased in tree diversity over time (Kruskal-Wallis $x^2= 11.7$ df=2 p=0.003). Tukey-style post-hoc tests found that there was no significant increase between the less than 10 and 10-20 years since disturbance categories, but that there was a significant increase of tree diversity in the greater than 20 years category (See Appendix A).

Shrub Species Diversity

Shrub diversity was calculated for each site in each age class. The distribution was not normal (Shapiro-Wilk $p>0.05$). Similar to tree species diversity, shrub diversity on seismic lines remained constant over time (Figure 11) (Kruskal-Wallis x^2=1.33 df=2 p=0.512). However, shrub diversity on wellsites significantly decreased over each of the three time periods (Kruskal-Wallis x^2= 13.6 df=2 p=0.001; Appendix A). This is contrary to tree diversity on wellsites (Figure 12). The less than 10 years since disturbance sites and greater than 20 years after disturbance sites have the greatest differences in species diversity.

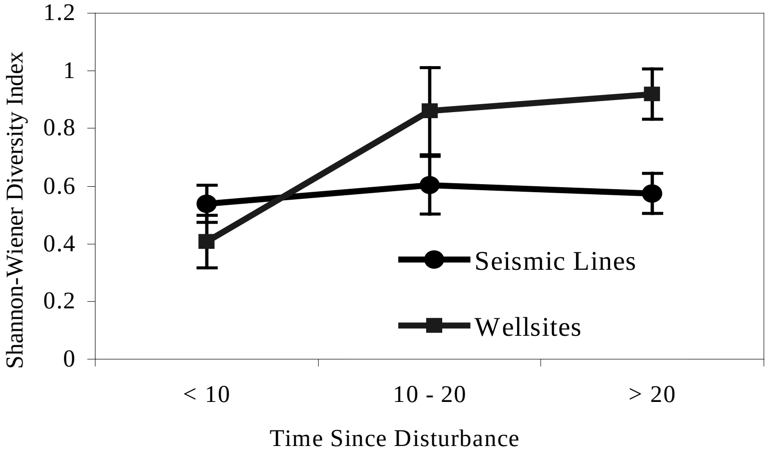

Figure 10. Mean value and standard error of the Shannon-Wiener diversity index for tree species on deciduous seismic lines and wellsites over time.

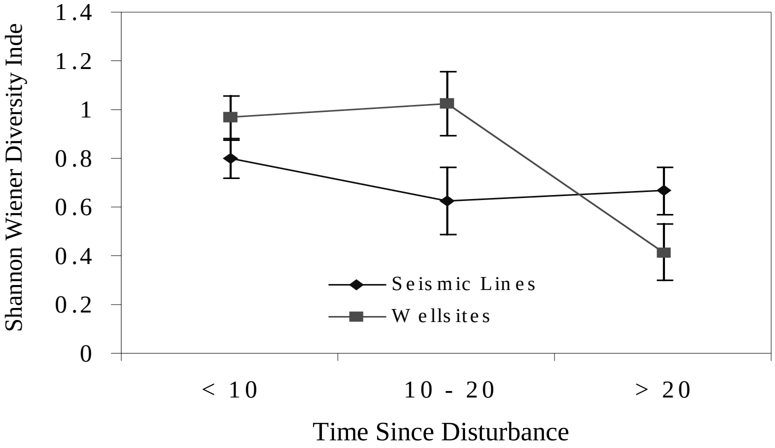

Figure 11. Mean value and standard error of the Shannon-Wiener diversity index calculated on shrub species on deciduous seismic lines and wellsites over time.

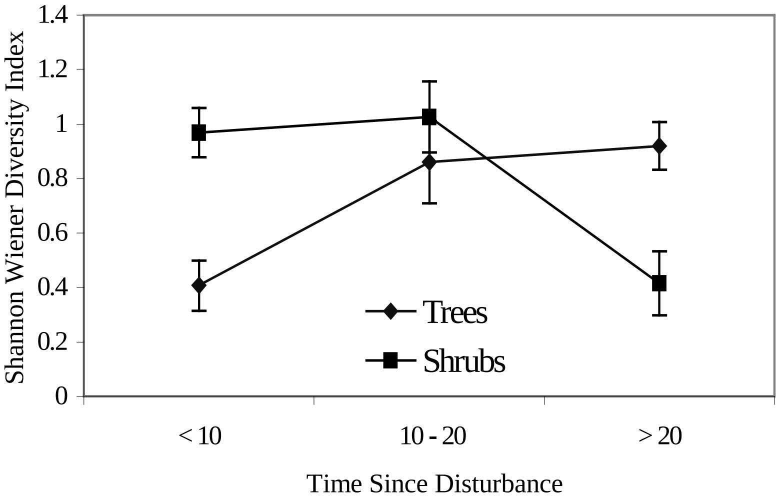

Figure 12. Relationship of tree and shrub diversity on deciduous wellsites over the three time periods. Diversity was calculated using the Shannon-Wiener Diversity Index for each time since disturbance category.

Shrub Densities

The densities of shrubs decreased over time on wellsites (Figure 13). Seismic line densities seem to slightly decrease or remain constant. These are density trends are similar to those of shrub diversity.

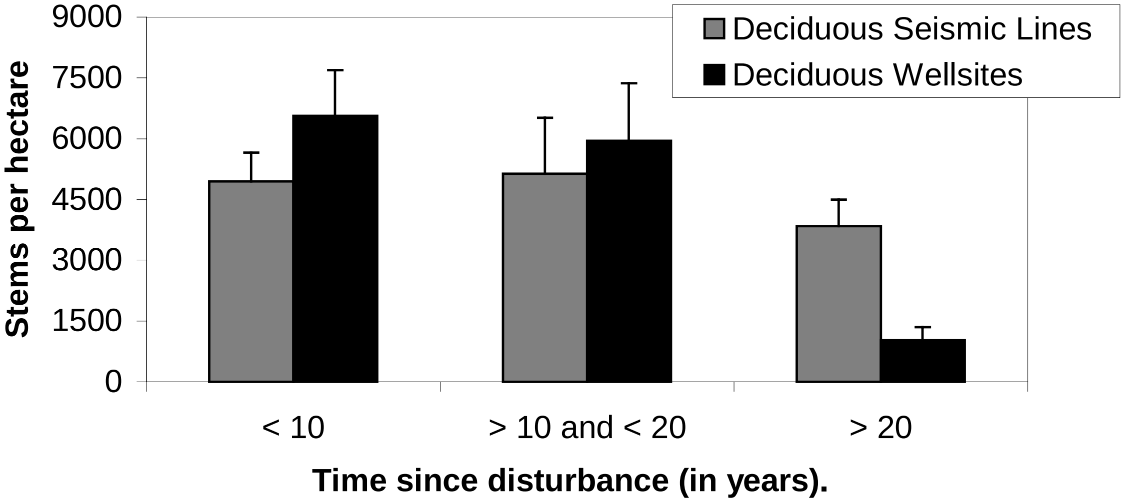

Figure 13. Average number of shrub stems per hectare on deciduous seismic lines and wellsites in each age category. Shrub stems are defined as the point of germination for individual plant. Shrubs with multiple stems coming from one point of germination were counted as a single plant, clonal shrubs with multiple plants in a dense formation were counted as individual stems.

Re-disturbance

The importance of quantifying re-disturbed is apparent, yet our methods have proven to be somewhat inadequate at dealing with this issue. Within the database we have a relative measure of disturbance in each plot and an estimate of percent bare soil exposed. Field workers were instructed to comment on the cause of the disturbance but this was subjective and was not consistently carried out. Therefore, disturbance type and severity are unknowns along with time of re-disturbance. Past disturbances may not be obvious to a field person and may have been missed, or may not have been noticeable.

Of the reported types of disturbances, the most common on seismic lines were animal trails and quad trails (Table 6). With the exception of the instances of a bulldozer damage, which was low, each disturbance type occurred in very similar proportions. On wellsites, each of the disturbance classes occurs on a third of the total sites. Quad disturbance and slash are slightly lower in proportion than the other three.

Table 6. Proportion of total seismic lines or wellsites experiencing each disturbance type. Each site may experience more than one type of disturbance as different plots may capture different occurrences. Also, a site may not have any plots with disturbances recorded. Severity of disturbance is not considered in proportions.

Disturbance Type	Seismic Lines	Wellsites
Animal Trail	.44	.36
Quad trail or tire marks	.38	.32
Slash	.28	.32
Bladed or a road	.13	.36
Downed Trees	.32	.36
Total Sites	(98)	(56)

The relative severity of the disturbance can be calculated by averaging the disturbance values (1-3) over all plots. The resultant value will be an index of each site's disturbance level. This index includes all types of disturbances recorded. When graphed with the density of trees on each seismic line there seems to be a trend for sites with high numbers of trees to have lower average disturbances (Figure 14). Wellsites showed no such trend.

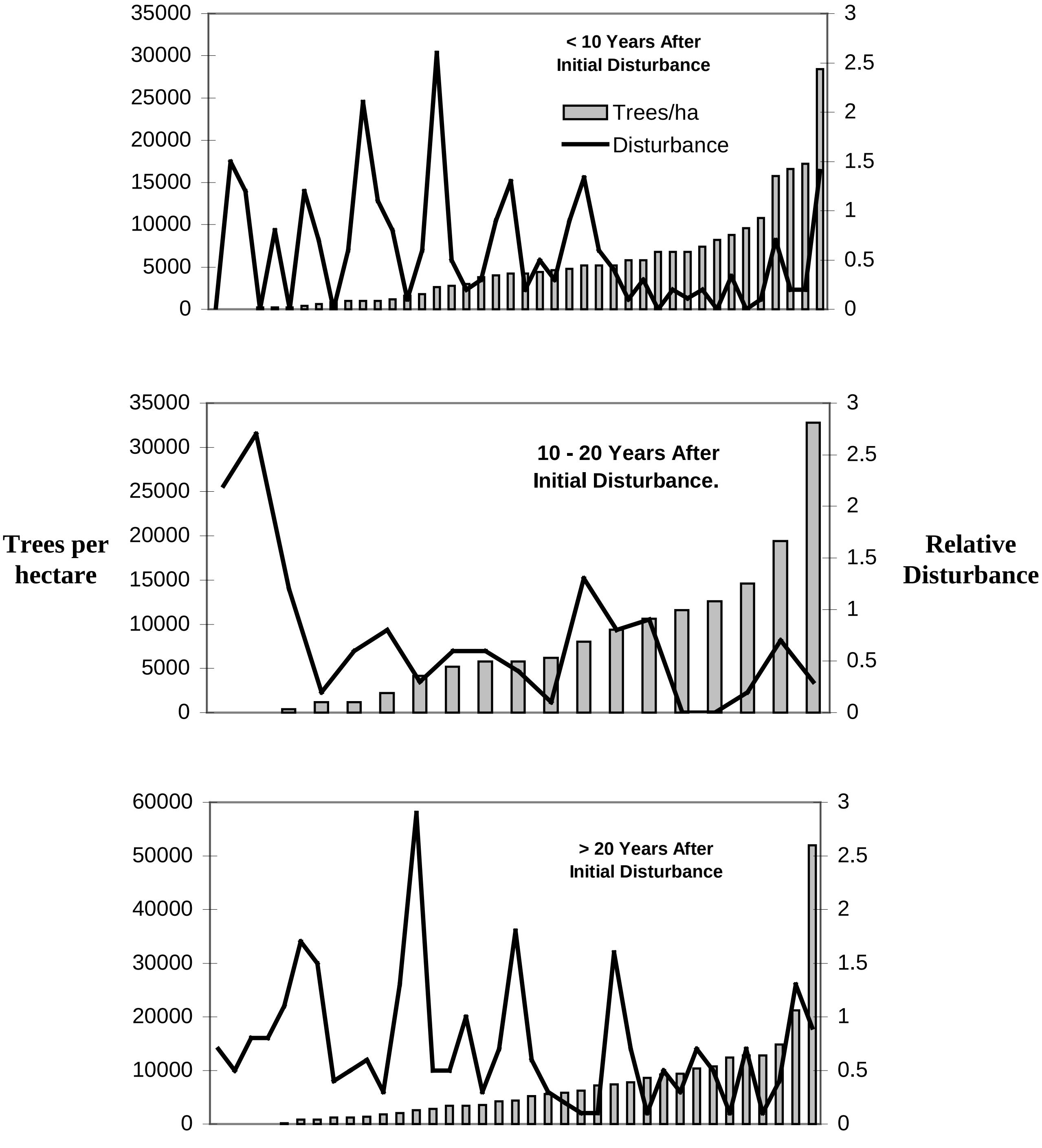

Figure 14. Distribution of seismic line tree densities with corresponding average disturbance for each site. Density was calculated using all species and sizes of trees. Average disturbance was calculated by averaging all relative disturbance measures recorded for each plot within each site.

Site to Site Variation in Density

As mentioned, large site to site variation is a concern when doing statistics. Predictive ability decreases when the site to site variation is greater than the variation from year to year (Crites 1997). From the distribution of site densities (Figures 15 and 16) it is obvious that this is the case.

The range of site conditions may effect both density and diversity calculations. Therefore, examining this variability may enable us to understand the trends in revegetation or simply narrow down the questions we need to ask from the data.

If you apply a standard of tree density above which sites would be considered stocked and below which sites would be inadequately revegetating one can distinguish between a “good” versus a “bad” site. This line is placed at 7000 trees per hectare based on a forestry rule of thumb for cutblock regeneration (Gitte Grover pers. comm.). It differs from the above calculation of a stocking standard in that it can be applied to an entire site rather than on a plot by plot basis. Again, very few sites meet or exceed this standard. In fact, the majority of seismic lines and wellsites have tree regeneration below 7000 trees per hectare; 68% and 66% respectively. “Good” sites are the goal for seismic line and wellsite revegetation so we should take note on the different conditions between these and the poorly regenerating sites.

On seismic lines the evidence points to differences in disturbance severity index (Figure 14) and categories influencing regeneration (Table 7). Sites that have high regeneration have higher levels of slash or fallen logs as well as lower levels of ATV or bulldozer disturbance than sites with lower tree densities.

Table 7. Proportion of all seismic lines with tree densities above or below 7000 trees per hectare, having either downed wood or vehicle disturbance.

	Slash or Fallen Trees	ATV or bulldozer
< 7000 trees/ha (67 sites)	.37	.54
7000 trees/ha (31 sites)	.55	.35

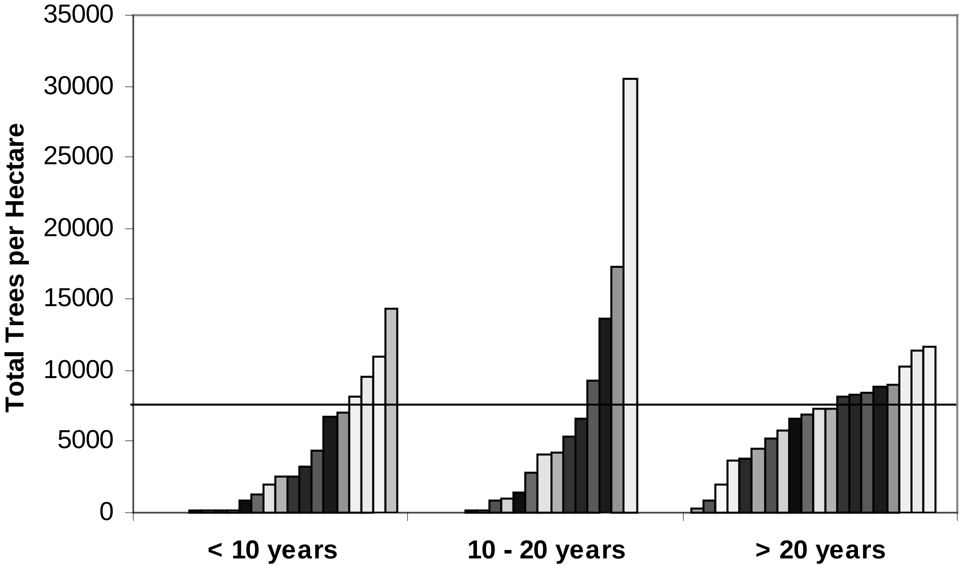

Figure 15. Total number of trees per hectare on each deciduous **wellsite** within each age class. All species and heights of trees were included in the total. The line represents a forestry standard for an adequately stocked site (7000 trees/ha)

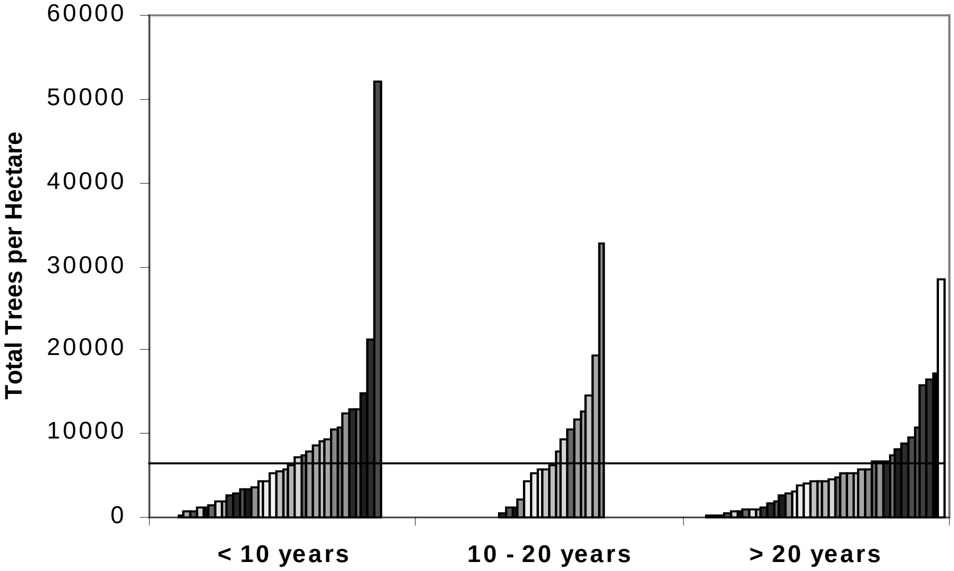

Figure 16. Total number of trees per hectare on each deciduous **seismic line** within each age class. All species and heights of trees were included in the total. The line represents a forestry standard for an adequately stocked site (7000 trees/ha).

Wellsites seem to be influenced by other site-specific factors, in particular high understory herbaceous cover (Figure 17). From these two charts it seems that grass cover and herb cover negatively influence tree growth. Those sites with densities above 7000 trees per hectare generally have the lowest grass and herb cover. As would be expected, when there is lower grass cover there is also more exposed soil but these high density sites also seem to have larger amounts of slash.

There are a few exceptional sites (12 and 13). These sites seem to have high grass/herb cover yet have high densities of trees. At this point there does not seem to be a ready explanation. There is no pattern of understory cover, or tree density, changes over time (Figure 18) enforcing the evidence that tree regeneration is related to site specific variables.

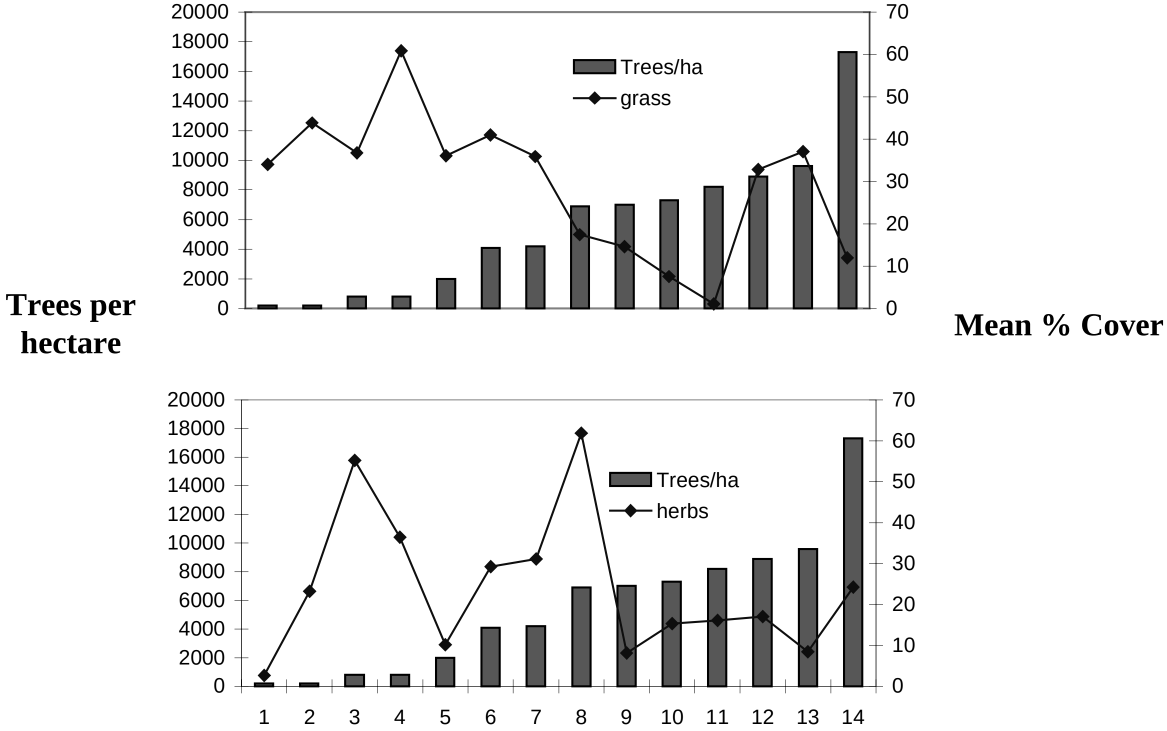

Figure 17. Distribution of wellsite tree densities with mean grass and mean herb % cover for each site. Density was calculated using all species and sizes of trees. Mean percent cover was calculated by averaging the median value of each cover class for each plot within each site. The x-axis denotes the site number.

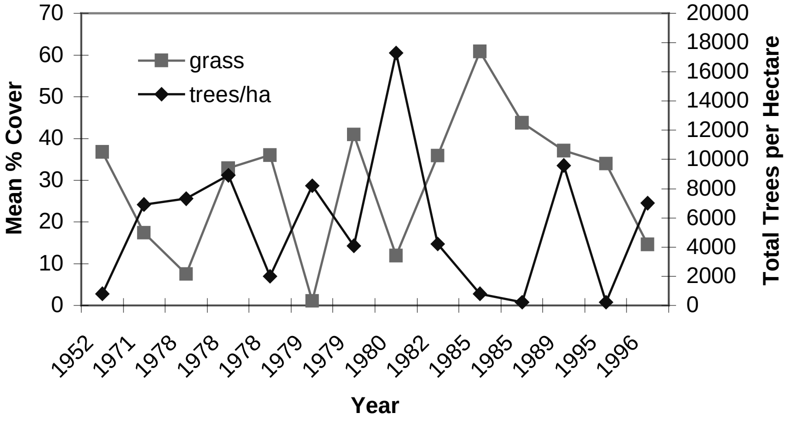

Figure 18. Change in wellsite tree density and understory grass cover over time.

Discussion

The large differences in tree densities on wellsites and seismic lines compared to fires provide evidence that the rate of revegetation of these features is much slower than natural. The trees that are growing are of smaller diameters and could be younger than expected based on the time passed since initial disturbance.

Fire causes death of overstory trees, blackens the soil and allows light to warm it. These factors cause prolific suckering of aspen and balsam poplar trees (Horton and Hopkins 1965). Apical dominance is removed, suckering is stimulated and competition is prevented allowing the suckers to grow vigorously. A wellsite disturbance partially resembles these characteristics. The canopy trees are removed, releasing apical dominance, the soil is exposed and allowed to warm and competition is removed mechanically. Large numbers of regenerating aspen and balsam poplar trees would be expected. Average densities and diameter distributions on wellsites do not support this rationale. Wellsites do not have abundant of suckering initially, and as there was no apparent difference in tree density over time. There seems to be no period that wellsite recruitment equals that after fire nor, at any time, do they approach the standards set for regenerating cutblocks. Based on this evidence and the size of the trees over each time period, recruitment is extremely slow, growth is slow and mortality may be high.

Severe fires may cause root damage or deeper suckering and have a negative influence on suckering (Horton and Hopkins 1965). There will be reduced numbers and poor sucker growth. This more likely the case with wellsites. Each site has its topsoil and overburden removed. This removes the existing roots from the sites, thereby preventing suckering at the time of the drilling. When the overburden and topsoil are replaced the roots ability to sucker may be lost. This would be especially true of wellsites that were in production for a long period of time. Therefore, regeneration by suckering would begin at the periphery of the wellsite and work its way to the centre. In cases where there is repeated burning, comparable to repeated clearing of a wellsite, a 94% reduction in expected aspen suckering occurs (Perala 1974).

The results presented indicate that where grass has been seeded for erosion control it will outcompete tree and shrub seedlings. This factor in conjunction with vegetation control during the life of well, may prevent vigorous revegetation of wellsites by deciduous trees and severely restrict conifer seedling establishment (Gerling et al. 1996; McCabe and Kennedy 1989). According to reclamation guidelines the practice of seeding was to be replaced by native species revegetation. Yet, through personal observation it seems that many of the sites less than 10 years post-disturbance have been seeded with sod-forming grass species.

The clonal nature of many shrub species enhances their ability to colonise wellsites and seismic lines after initial disturbance (De Grosbois et al. 1991). In general wellsite shrub densities were low. Also, both density and species diversity declined over time. Competition between shrubs and trees on wellsites seem to influence the species composition on these disturbances. This could be compared to the findings of Timoney et al. (1997) on succession of the Peace River floodplains. They found a negative correlation of tall shrubs to total trees, indicating a successional trajectory of willow-alder communities into forest communities.

A seismic line can be compared to a smaller fire. In this situation, a fire would cause the death of relatively few trees, the soil would be slightly warmed and suckering would be stimulated. In small fires, if the remaining overstory is dense enough to substantially impede light, the suckers will not exhibit good health and survival (Peterson and Peterson 1992). Light is not critical for initial sucker growth but is required for good survival and production. Light at half the intensity of full sunlight is enough to reduce the sucker production to less than 10% of that at full light (Peterson and Peterson 1992).

On seismic lines these low light conditions prevent growth of high densities of aspen and balsam poplar, but are favourable to shade tolerant species such as white spruce (Bella 1986). Paper birch, according to our findings, also thrives on the conditions provided by a seismic line. These species may be responding to the conditions on seismic lines as they might to a forest gap. In the study of gaps in the boreal forest of Quebec, Kneeshaw and Bergeron (1998) found that birch and spruce were important secondary gap colonisers in mixed and conifer dominated forests.

White and black spruce may also have benefited from the original clearing of the line. These species seed well on exposed mineral soil and seismic cutting often produces large areas of scarified ground. They also do very well on large downed trees. Increased amounts of decaying wood either from initial clearing or from fallen trees could provide a good medium for a conifer seedling to establish.

Revel et al. (1984) found that even though conditions supported conifer establishment the overall survival and growth was poor in comparison to clearcut areas. Growth of trees were inhibited, in part, by ATV traffic (Revel et al. 1984). Disturbance of the soil surface from off-road vehicles results in loss of surface organic horizons, soil compaction and reduced infiltration rate (Peterson, Kabzems, and Peterson 1989). Direct damage to shallow aspen and balsam poplar roots result in decay and dieback of stems, as well as winter drying of bark (Zalasky 1970; Mackintosh 1979). Grazing, browsing and trampling of regenerating trees also causes mortality (Smith et al. 1972).

Much more work needs to be put into understanding the plant community successional trajectories on seismic lines. Competition among understory species may also prevent establishment and growth of trees (Revel et al. 1984). For now, the evidence suggests that these linear disturbances are revegetating at neither a natural nor a predictable rate.

Much of the reforestation delay of seismic lines and wellsites can be attributed to site to site differences in clearing the techniques and the resulting conditions. For seismic lines this includes the depth of the initial blade and the severity and frequency of re-disturbance. For wellsites, the time between when a wellsite was first drilled and when it was finally abandoned may be important in determining the extent to which reforestation was prevented. The sequence of these disturbances could not only affect the rate of tree regeneration (by direct mortality) but could change the community structure in the long term.

Rights-of-ways subjected to different mechanical and chemical treatments produced different, but predictable, plant communities (Bramble et al. 1991). If different disturbances are considered similar to these treatments then it is conceivable that they may be altering plant communities independent of the amount of time sites have to reforest. Therefore, once we understand the consequences that a specific disturbance or combinations of disturbances have on the community succession, we might be able to predict human induced changes. In the case of wellsites, disturbance does not appear to be a factor influencing the plant community structure. In this case, the "treatment" would be the invasion sequence of different species. Site conditions could favour certain species, possibly graminoids, which are able to influence community development long after their initial introduction (Robinson and Dickerson 1987).

To understand these variables on seismic lines will require much more of an-depth site by site examination of small-scale variables, such as soil. It could also involve a manipulative study in which the factors influencing revegetation were directly isolated. Quantification of the actual numbers of ATVs using a seismic line in a season would be a start. In addition, to obtain a direct measure the growth of vegetation without any disturbance exclosures could be positioned along random lines. But again, time is a trickster and unless a long-term study was in place to measure the community succession from day one, one could never be sure of starting conditions or the frequency of re-disturbance. Examining seismic lines that have been burned can be used to evaluate any inherent properties of a line that prevent it from regenerating. This has the advantage over a long term exclosure as the results would be immediate, but at the same time results would still be plagued with doubts about the disturbance history of the line.

Wellsite reclamation and restoration is an active area of research. Unfortunately, most of the research has been concentrated on the prairie region (i.e. Soulodre et al. 1999). However, their methods would be easy to duplicate on the scale this study is interested in. A comparison of different treatments could be pulled from our existing database; sites seeded with agronomic mixes (old sites), seeded with native species (sites in the last 5 years) and sites naturally regenerating (unknown, may have to create our own). These could be used to verify if grass is indeed the cause of the delay of tree regeneration.

Quantifying the rate of revegetation of wellsites and seismic lines seems far more complicated than originally imagined. The primary goal to simply evaluate the rate of merchantable trees remains valid as it provides key information on long term trends and allows for managers to take action while establishing long-term research projects. However, it now seems appropriate to attempt to describe the factors leading to preferred densities of trees. In forestry terms this would be the stocking standard of 7000 trees per hectares, in ecological terms this means continuous forest. Understanding the successional trajectories will enable us to not only make predictions about the future boreal forest but may also help to reform the management of these features.

Implications

This study has evaluated regeneration of trees species and found that densities are less than would expected after a fire or after logging. This trend seems to persist over each time period. The loss of tree growth on seismic lines and wellsites has economic and ecological consequences.

Perala (1974) suggests that stands aged 2 years should have a minimum density of 10, 000 aspen stems per hectare to become economically viable in the future. According to the results of this study, neither the regeneration on wellsites nor seismic lines could be expected to meet economic standards. Existing guidelines state that on small disturbances, such as wellsites and pipelines, trees are only planted if the age of surrounding stand is less than 20 years older than the newly replanted area. If the difference in age is greater than this, the area cannot be harvested in the future as a unit (Gerling et al.).

This indicates that the importance of the overall revegetation of these features is unrealised. The amount of area that seismic lines occupy across Al-Pac’s FMA at this moment is equal to sixty years of logging (Jack O’Neill pers. comm.). Currently there are 62,915 ha of seismic lines and 23,144 ha of wellsites. Across the boreal forest there are 3,673,648 ha of seismic lines and 88,588 ha of wellsites (Alberta Environmental Protection 1998). A decrease in the number of trees growing back over this large area puts the fibre supply at risk. Forestry companies will be faced with a decrease in timber supply and associated reductions in annual allowable cut. Oil and gas exploration and extraction activities are expected to increase in the future, therefore the problem will only increase.

The extent of these disturbances and the evidence for non-natural revegetation rates causes concern regarding the integrity of boreal forest ecosystem. Seismic lines and wellsites contribute to overall habitat fragmentation of the forest. The consequences to biodiversity could include a loss of large, wide ranging animals, loss of area sensitive or interior species, loss of genetic integrity from within species or populations, and increases in abundance of habitat generalists characteristic of disturbed areas. The resulting forest would lose much of its unique and distinguishing characteristics.

If the causes for the reduction tree densities and sizes can be determined then specific solutions can be applied to prevent long term alterations to the functioning of the boreal forest. If the trend is not explainable by re-disturbance or specific reclamation practices, for example, then limits to amounts of new exploration or extraction must be considered. Forestry, oil and gas and the public will have to work together to establish guidelines that are in the best interest of the forest rather than in the best interest of economics.

Acknowledgements

I would first like to thank Shawn Wasel and Alberta-Pacific Forest Industries Inc. for initiating and supporting this project. I am also grateful to Susan Crites, Brad Stelfox and Terry Osko for extensive direction and help in designing this study. Jack O’Neill gave phenomenal GIS assistance, compiling the information that enabled me to age the wellsites and seismic lines as well as producing the maps to find them. I also thank Stephanie Kurulok, Josh Nichol, Roanna Koroluk, Erin Berry, Tony Gaboury, Dorothy Kelker, Morgan Ward and Josh Stobie for their hard work in collecting and entering the data.

Appendix A

Table A1. Wellsite **tree** diversity post-hoc tests after a significant non-parametric ANOVA using a test similar to the Tukey test.

Year Category	**N**	**Mean Rank**
< 10	20	34.83
10 – 20	15	33.43
> 20	21	18.95

Comparison	**Difference Between Ranks**	**SE**	**q**	**qcritical**	**Signifcance**
1 vs 2	1.4	3.5	0.4	2.394	p>0.05
1 vs 3	15.88	3.742	4.242	2.394	p< 0.001
2 vs 3	14.48	3.561	4.065	2.394	p< 0.001

Table A2. Wellsite **shrub** diversity post-hoc tests after a significant non-parametric ANOVA using a test similar to the Tukey test.

Year Category	**N**	**Mean Rank**
< 10	20	33.17
10 – 20	15	36.57
> 20	21	18.29

Comparison	**Difference Between Ranks**	**SE**	**q**	**qcritical**	**Signifcance**
1 vs 2	18.28	3.5	5.223	2.394	p< 0.001
1 vs 3	36.57	3.742	9.771	2.394	p< 0.001
2 vs 3	18.29	3.561	5.135	2.394	p< 0.001

Table A3. Wellsite **shrub** density post-hoc tests after a significant non-parametric ANOVA using a test similar to the Tukey test.

Year Category	**N**	**Mean Rank**
< 10	20	38.2
10 – 20	15	35.33
> 20	21	14.38

Comparison	**Difference Between Ranks**	**SE**	**q**	**qcritical**	**Signifcance**
1 vs 2	20.95	3.5	5.986	2.394	p< 0.001
1 vs 3	35.33	3.7427	9.440	2.394	p< 0.001
2 vs 3	14.38	3.561	4.037	2.394	p< 0.001

Literature Cited

Alberta Agriculture, Food and Rural Development. 1998. Draft Native Plant Revegetation Guidelines for Alberta. Government of Alberta.

Alberta Environmental Protection. 1998. The Boreal Forest Natural Region of Alberta. Natural Resources Service, Recreation and Protection Areas Division, Natural Heritage Planning and Evaluation. Edmonton AB.

Alberta Environmental Protection and Enhancement Act. 1993. Conservation and Reclamation Regulation, Section 1(i).

Anonymous. 1991. Forest management in Alberta. Report of the Expert Review Panel. Department of Energy, Forestry, Lands and Wildlife. Edmonton, Alberta.

Alberta Research Council. 1997. Fire and harvest residual project: A comparison of wildfire and timber harvest residuals on the soils, forest structure, and biodiversity in aspen/mixedwood communities in Alberta. Progress Report. Alberta Research Council, Vegreville AB.

Beckingham, J.D. and J.H. Archibald. 1996. Field guide to ecosites of northern Alberta. Canadian Forest Service Northwest Region Northern Forestry Centre, UBC Press, Vancouver, BC.

Bella, I.E. 1986. Tree growth response along seismic liens in Alberta. The Forestry Chronicle, February:29-34.

Bramble, W.C., W.R. Byrnes, R.J. Hutnik and S.A. Liscinsky. 1991. Prediction of cover type on rights-of-way after maintenance treatments. Journal of Arboriculture 17:38-43.

Catling, P.M. and M.J. Oldham. 1997. The recent spread of autumn-olive (*Elangus umbellata)* into south Ontario and its current status. Canadian Field Naturalist 111:376-380.

Crites, S. 1997. Changes in composition, density, and diameter of regenerating trees and snags in post-fire and post-harvest stands. In: Fire and harvest residual project: A comparison of wildfire and timber harvest residuals on the soils, forest structure, and biodiversity in aspen/mixedwood communities in Alberta. Progress Report. Alberta Research Council, Vegreville AB.

De Grosbois, T., G.P. Kershaw, and J.R. Eyton. 1991. The regrowth production and allocation of *Salix arbusculoides* in three growing seasons following right-of-way clearing. Canadian Journal of Forest Research. 21:1171-1179.

Gerling, H.S., M.G. Willoughby, A. Schoepf, K.E. Tannas and C.A. Tannas. 1996. A

Guide to Using Native Plants on Disturbed Lands. Alberta Agriculture, Food and Rural Development and Alberta Environmental Protection. ISBN 0-7732-6125-7. 247 pp.

Gerling, H.S. 1999. Alberta's draft native plant guidelines. Presented at the 24th annual meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon Saskatchewan.

Hardy BBT Limited. 1990. Natural plant invasion into reclaimed oil sands mine sites. Alberta Land Conservation and Reclamation Council Report No. RRTAC 90-3.

Hardy BBT Limited 1989. Manual of plant species suitability for reclamation in Alberta - 2nd Edition. Alberta Land Conservation and Reclamation Council Report no. RRTAC 89-4. 436 pp.

Hermesh, R. 1984. Revegetation of the Alaska highway gas pipeline prebuild. Techman Engineers Ltd. for Canadian Land Reclamation Association.

Horton, K.W. and G.J. Hopkins. 1965. Influence of fire on aspen suckering. Canada Department of Forestry, Forest Research Branch, Ottawa, Ontario. Publication 1095.

Johnson, E.A. 1992. Fire and vegetation dynamics – Studies from the North American Boreal Forest. Cambridge Studies in Ecology. Cambridge University Press. Cambridge, UK.

Kent, M. and P. Coker. 1992. Vegetation description and analysis: a practical approach. CRC Press, Boca Raton, FL.

Kimmins, J.P. 1997. Forest Ecology: A Foundation for Sustainable Management 2nd edition. Prentice Hall, Toronto, ON.

Kneeshaw, D.D. and Y. Bergeron. Canopy gap characteristics and tree replacement in the southeastern boreal forest. Ecology 79:783-794.

Mackintosh, E.E. 1979. Impact of recreation on vegetation and soils in Rushing River Provincial Park, Ontario. Environment Canada, Canadian Forest Service, Great Lakes Forest Research Centre, Sault Ste Marie, Ontario. Information Report 0-X-290.

McCabe, D.C. and A.J. Kennedy. 1989. An evaluation of non-seeding reclamation techniques on a an oil sands pipeline right-of-way. *In* Powter, C.B. (compiler). Alberta Conservation and Reclamation Conference 1988. Proceedings of a Symposium sponsored by the Alberta Chapters of the Canadian Land Reclamation Association and the Soil and Water Conservation Society.

Mahnic, R.J., L.J. Knapik, T.R. Bossenberrry and G.C. Mott. 1993. Proceedings of the Alberta Wellsite Reclamation Criteria Workshop. Alberta Conservation and Reclamation Council Report No. RRTAC 93-10. ISBN 0-7732-6044-7.

Passey, G.H. and D.R. Wooley. 1982. Environmental planning for rights-of-way in a rapidly developing multiple resource setting in Alberta Deep Basin. Canadian Land Reclamation Association Report ISSN–0705–5927.

Perala, D.A. 1974. Repeated prescribed burning in aspen. USDA Forest Service, North Central For Exp. Stn. St Paul, Minnesota. Research Note NC-171.

Peterson, E.B., R.D. Kabzems and N.M. Peterson. 1989. Hardwood management problems in northeastern British Columbia: An information review. B.C. Ministry o of Forestry, Victoria B.C., Canada, B.C. Forest Resource Development Agreement. FRDA Report no. 66.

Peterson, E.B. and N.M. Peterson. 1992. Ecology, management and use of aspen and balsam poplar in the prairie province, Canada. Forestry Canada, Nortwest Region, Northern Forestry Centre, Edmonton, Alberta. Special Report 1.

Revel, R.D., T.D. Dougherty, and D.J. Downing. 1984. Forest Growth and Revegetation Along Seismic Lines. University of Calgary Press, Calgary AB.

Robertson, J.V. and J.E. Dickerson, Jr. 1987. Does invasion sequence affect community structure? Ecology 68: 587-595.

Rowe, J.S. and G.W. Scotter. 1973. Fire in the boreal forest. Quaternary Research 3:444-464.

Smith, A.D., P.A. Lucas, C.O. Baker and G.W. Scotter. 1972. The effects of deer and domestic livestock on aspen regeneration in Utah. Utah Division of Wildlife Resources, Logan. Publication No. 72-1.

Soulodre, E.M., A. Naeth and A.M. Hammermeister. 1999. Native prairie revegetation on wellsites in southeastern Alberta. In A.M. Hammermeister (compiler) *Perspectives in Land Reclamation and Restoration.* 24th annual meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon, Saskatchewan. 175 pp. ISSN 0705-5927.

Stelfox, J.B. (editor) 1995. Relationships between stand age, stand structure, and biodiversity in aspen mixedwood forests in Alberta. Jointly published by Alberta Environmental Centre (AECV95-R1), Vegreville, AB, and Canadian Forest Service (Project No. 0001A), Edmonton, AB.

Strong, W.L. and K.R. Leggat. 1992. Ecoregions of Alberta. Alberta Forestry, Lands and Wildlife. Edmonton, AB.

Timoney, K.P., G. Peterson, R. Wein. 1997. Vegetation development of boreal riparian plant communities after flooding, fire and logging, Peace River, Canada. Forest Ecology and Management. 93: 101-120.

Wilson, K., B.T. Grenfell and D.J. Shaw. Analysis of aggregated parasite distributions: a comparison of methods. Functional Ecology 10: 592-601.

Zalasky, H. 1970. Disease problems of poplar in the western interior of Canada. Canadian Forest Service, Department of Fisheries and Forestry, Forest Research Laboratory, Edmonton, Alberta. Information Report A-X-39.