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An analysis of escaped fires from broadcast burning in the Prince George Forest Region of British Columbia

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Abstract

Prescribed fire is an important silvicultural tool. Several factors, including changes in silvicultural techniques, regulations regarding the use of prescribed fire, air quality concerns, and concerns over escaped fires have led to a declining use of prescribed fire for silvicultural purposes in British Columbia. Using records from 351 prescribed fires that escaped control measures in the Prince George Forest Region, we examined the feasibility of using "Control Rank" from Muraro's Prescribed Fire Predictor model as an indicator of the risk of fires escaping from broadcast burning, and estimated the costs of suppressing these fires. We also outline the benefits (including potential dangers) of prescribed burning, and provide recommendations on how to estimate the probability, or the risk, of a fire escaping from a prescribed burn. We found that 84.3% of the escaped fires occurred within control ranks 5 and 6, and control ranks 7 and 8. These control ranks also had the largest and most costly fires to suppress, in some cases running in the hundreds of thousands of dollars. Our results suggest that control rank is a useful indicator of risk. However, we recommend that better records of burning conditions of all prescribed burns be kept to allow for more complete analyses of risk in the future. To reduce the risk of fires escaping from prescribed burning, factors that should be carefully considered are also outlined in this paper.

KEYWORDS: *broadcast burns, escaped fires, Prince George Forest Region, Muraro's Prescribed Fire Predictor Model*

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Introduction

Prescribed burning has been defined as the knowledgeable application of fire to a specific land area to achieve predetermined forest management objectives (Merrill and Alexander 1987). The ecological and silvicultural benefits of prescribed burning in boreal and sub-boreal forests are well documented (Weber and Taylor 1992; Kranabetter and Macadam 1998; Man and Lieffers 1999; Densmore *et al*. 1999; Driscoll *et al*. 1999; Kranabetter and Yole 2000; Arocena and Opio 2003). When prescribed burning is carried out after logging, it usually involves an intentional burning of debris on a designated unit of land where the fuel has been piled (pile burning), windrowed (windrow burning), or spread freely over the entire area (broadcast burning). Although each of these methods reduces logging slash, pile and windrow burning does not necessarily benefit reforestation. When compared to broadcast burning, the concentration of logging slash in piles or windrows results in more severe local burning and increased fuel consumption (Arocena and Opio 2003).

Despite the benefits of broadcast burning, its use has declined in British Columbia for three main reasons.

1. Increased use of other techniques for reforestation (e.g., mounding, or disc trenching) and other forest management systems (e.g., management of riparian zones and wildlife tree patches), which restrict the applicability of prescribed burning. Some silvicultural systems, such as selection or shelterwood harvesting, are also not compatible with the application of prescribed burning (Weber and Taylor 1992).
2. Increased concern about air quality and related health issues in many areas of the province. As a result, smoke management is a critical factor that requires planning in burn operations, and this sometimes reduces the number of days when fire can be applied (Haeussler 1991; Weber and Taylor 1992).
3. Changes in public policy in the 1980s eliminated the forest industry's limited liability for prescribed fire (B.C. Ministry of Forests 1988). Therefore, the costs of suppressing escaped fires[1] and any resulting liability are borne entirely by the person (or company) that causes or lights the fire.

Indeed, the risk of escaped fires from broadcast burning and the loss of the limited liability legislation (B.C. Ministry of Forests 1988) may be the largest impediments to using prescribed burning as a silvicultural tool. Any expenditure or cost associated with prescribed burning is based on a fire manager's judgement of the risk of a fire escaping and the consequences of that escape. For example, in situations where the probability of an escape is high, auxiliary resources may be required to prepare a site for a safe burn. If a burn is postponed in anticipation of better weather or fuel moisture conditions, additional costs may be incurred. When a fire does escape the prescribed burn area, suppressing the fire can be extremely costly, and the escaped fire can also be destructive to the surrounding forest and other values.

When a fire does escape the prescribed burn area, suppressing the fire can be extremely costly, and the escaped fire can also be destructive to the surrounding forest and other values.

We investigated the history of the use of prescribed fire for silvicultural purposes in the Prince George Forest Region. We found that no complete historical record exists of the number of broadcast burns within the region. This is explained by the large number of companies and personnel involved in prescribed burning, and the changes to legal requirements for permits to burn or report prescribed burns (S. Harvey, Senior Protection Officer, Prince George Fire Centre, B.C. Ministry of Forests, pers. comm., 2002). However, according to the Ministry of Forests' fire records, 351 wildfires resulted from silvicultural burns from 1970 to 1997.

The largest escaped fire from a silvicultural burn occurred in 1970 in the Fort St. John Forest District. This fire consumed 3216 ha of surrounding mature and immature forests. In 1986, a 597-ha fire in Fort St. James Forest District cost $995 000 to suppress. Between 1990 and 1997, the largest escaped fire covered 356 ha in the Prince George Forest District. This fire occurred in 1990 and cost over $61 500 to suppress.

The application of fire to a landscape is not only a science, but also an art (Murphy 1990). In deciding whether or not to conduct a prescribed burn on a

[1] In this paper, we define an "escaped fire" as a fire that spreads beyond the authorized area for burning as described in Section 88 of the B.C. Ministry of Forests Policy Manual (B.C. Ministry of Forests 1997).

landscape, a fire manager must answer several questions, such as:

1. What is the probability of a fire escaping to unintended locations?
2. What would be the cost of suppressing the escaped fire?
3. What are the potential consequences (social, economic, legal, and political) of the escaped fire?
4. Are there other site treatment options (mechanical, chemical, and biological site preparation) that are better suited for a particular cutblock than prescribed burning?

In this paper, we focus on providing answers to questions 1 and 2. Other studies (e.g., Trowbridge *et al.* 1989; Pearse 1990; Feller 1996; Stock *et al.* 1996; Densmore *et al.* 1999) have already addressed, directly or indirectly, questions 3 and 4.

Muraro's Prescribed Fire Predictor

Muraro (1975) developed the Prescribed Fire Predictor (PFP) as a planning tool for broadcast burning in British Columbia. The PFP relates four fire behaviour characteristics (ease of ignition, rate of spread, difficulty of control, and fire impact on logging slash) to the fire environment variables (weather, fuels, and topography). These relationships are included in two sets of tables presented in a slide-rule format. The tables on Side I constitute the Daily Prescribed Fire Predictor, which is used as a real-time predictor of relative ease or difficulty and impact of a burn on a specific day. The tables on Side II constitute the Prescribed Fire Planner, which allows the fire manager to determine burning conditions required to meet specific objectives, and to develop prescriptions.

For a fire manager, the risk of a fire escaping from a prescribed burn is one of the most important concerns. Thus, in this paper we have chosen to examine the "Control Rank" of the PFP as an indicator of risk. The control rank is a numerical method of assessing the degree of difficulty in handling a broadcast burn after it is ignited. Control rank is derived from measures of the Duff Moisture Code (DMC), the Drought Code (DC), and the slope of the area (Muraro 1975; Alexander and Pearce 1993). Duff moisture code is based on daily rainfall, temperature, and humidity; drought code is based on daily rainfall, noon temperature, and month (Turner and Lawson 1978).

Muraro (1975) grouped eight control ranks into four categories and these are classified as follows.

- **1 or 2: Extremely easy or very easy** – Normal precautions will suffice. Spread in exposed flashy fuels will be similar to that in the dominant fuel type in the area. Under semi-open or closed canopies, low vigour fronts develop slowly; spread is slow and persistence is low. Mop-up will be easy. Only unusual circumstances should cause problems at these control ranks. In spring, depressed moisture will increase the probability of crown fires (i.e., fires ascending into the crowns of trees and [or] spreading from crown to crown).
- **3 or 4: Easy to moderately easy** – Only exposed or semi-exposed fuels will present control problems. Spread may be similar to that in the dominant fuel type in the area. Spread under closed canopies will be slow. Fronts of moderate intensity may develop under stands; torching (i.e., a single tree or very small clump of trees that is firing or flaring up) may occur, but crown fires are unlikely. Fire persistence and mop-up effort will be moderate. Conscientious attention to ignition, with adequate mop-up and surveillance, will avoid most problems. Poor ignition with adequate spread when DC exceeds 300 can present problems.
- **5 or 6: Moderately difficult to difficult** – Most fuel types will present some control problems. Exposed and semi-exposed fuels can present serious problems depending on spread. Duff moisture codes over 50 indicate the potential for crown fires. Drought codes over 300 indicate persistent, deep burning and difficult mop-up of fuels. The potential for extensive loss is present and complete mop-up will be necessary. Burning should only be done with spread ranks (i.e., numerical ratings of fire spread, from extremely slow [rating of 1] to extremely fast [rating of 8]) of 4 or greater to ensure a complete burn. Only areas that favour burning and easy control should be attempted. Burning costs will range from normal to above normal if caution is exercised.
- **7 or 8: Very difficult or extremely difficult** – All fuel types will present control problems. Surface fronts develop rapidly under all stands and torching is probable when DMC exceeds 25. Crown fires are likely on steep slopes or with moderate winds. Fire persistence will be extreme, requiring intensive efforts to extinguish. Removal of all organic materials is probable, even if spread is not rapid. Extreme vigilance, with more than normal control resources, will be required. Mop-up should be immediate and complex. Only areas with ideal layout and the least risk of escape should be attempted. Burning costs will be greater than normal (Muraro 1975).

Objectives

To gain a better understanding of why fires escaped containment, we conducted a complete analysis of the history of silvicultural escaped fires in the Prince George Forest Region. The objectives of our study were:

- To determine whether or not control rank is a good indicator of the risk associated with a fire escaping from a broadcast burn
- To determine suppression costs of these escaped fires
- To outline the benefits (including potential dangers) of prescribed burning
- To provide recommendations on how to estimate the probability (assess indicators) or the risk of a fire escaping from a prescribed burn

Study Design

Data

To evaluate the PFP's control rank concept, we used 1970–1997 data[2] on escaped fires from prescribed burning operations in the Prince George Forest Region. Although data on escaped prescribed fires is available from the 1950s, some of the earlier data on burning conditions were incomplete. We chose to start the analysis with 1970 data because the Canadian Forest Fire Weather Index (FWI) System and the regular recording of weather and fuel moisture numerical data were introduced in this year. The FWI System is currently used to determine fire danger classes for different regions in Canada, which helps in the assessment of forest use restrictions and preparedness levels. At the time this study was conducted (i.e., 1999–2000), no data after 1997 were available. Furthermore, complete data on the number of ignitions conducted in the Region from 1970 to 1997 were not available.

Analysis

The data set consisted of records on 355 escaped prescribed fires. Four fires were removed from the data set: three re-lights (i.e., fires that did not escape the designated area and thus, zero growth was recorded), and one fire with insufficient information. The remaining 351 escaped fires were placed into four control rank groups according to their respective duff moisture codes and drought codes using the tables of Muraro's (1975) Prescribed Fire Predictor (Alexander and Pearce 1993). The percentage of fires in each control rank group was then compared to the total number of escaped prescribed fires.

The data for each of the four control rank groups were visually inspected. Clearly, the data distributions were highly skewed because of the presence of extreme values (outliers). Sample means can give a distorted measure of the centre of distributions with outliers (i.e., because its value is pulled toward the extreme observations); however, sample medians are resistant to the influence of outliers, or are not affected by them (Kitchens 1998). Thus, for each control rank we determined the median escaped prescribed fire size. The lognormal distribution was fitted to each of the four groups of control ranks, and to all of the four groups combined. The lognormal probability density function is given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \frac{e^{-\left(\frac{(\ln x-\mu)^2}{2\sigma^2}\right)}}{x} \quad 0 \leq x < \infty; -\infty < \mu < \infty; \sigma > 0, \quad [1]$$

where x is any particular value of random variable X; μ is the mean (for the reasons given above, we used the median rather than the mean); σ is the standard deviation (or the square root of the variance); and σ^2 is the variance. The parameters (μ and σ) were estimated using the PROC RELIABILITY procedure (SAS 2000), and the goodness of fit was assessed graphically by constructing quantile plots of observed data against theoretical quantiles from lognormal distribution. After the parameters of a lognormal distribution were estimated, the fitted distribution was used to calculate a number of quantities, including the median size (e^{μ}) of a future escaped fire, and the probability that a fire exceeds a particular size, x, which is given by:

$$P(X > x) = \int_{x}^{\infty} f(x)dx, \quad [2]$$

where P is the probability, and X is the lognormal random variable (SAS 2000).

Welch's approximate t-test (Sokal and Rohlf 1995) was used to determine whether significant ($P < 0.05$) differences in the parameters (including their standard errors) existed between control rank groups. Since no significant ($P > 0.05$) differences existed between the control rank groups for either of the parameters, the data were pooled to obtain an overall estimate of the parameters. These parameter estimates and their standard errors are listed in Table 1. Other statistical tests, such as the Bonferroni correction for multiple comparisons (Zolman 1993) and Duncan's multiple range test (Zolman 1993), produced similar, but not better results than Welch's t-test.

[2] This data was collected by B.C. Ministry of Forests fire management field staff.

TABLE 1. Parameter estimates from the fitted lognormal distributions of escaped prescribed fire sizes (1970–1997) in the Prince George Forest Region (n = 351)

Control rank	Parameter[a]	Estimate	Standard error	Asymptotic normal 95% confidence limits Lower	Upper
7 and 8	μ	2.4182	0.1464	2.1313	2.7050
7 and 8	σ	1.9340	0.1054	1.7380	2.1520
5and 6	μ	2.3369	1.1615	2.0203	2.6536
5and 6	σ	1.7764	0.1150	1.5647	2.0167
3 and 4	μ	1.5880	0.3175	0.9658	2.2102
3 and 4	σ	2.2313	0.2386	1.8094	2.7515
1 and 2	μ	2.0647	1.0974	–0.0861	4.2155
1 and 2	σ	2.4538	0.7760	1.3203	4.5605
All	μ	2.2691	0.1042	2.0649	2.4733
All	σ	1.9493	0.0752	1.8074	2.1024

[a] The Location parameter is the mean (μ) and the Scale parameter is the square root of the variance (σ). These parameter estimates are in log-space, rather than the original scale of measurement (i.e., mean (μ) and variance (σ^2) parameters that are used in equation 1).

We were unable to determine whether the risk varied with intended prescribed burn size and the same burning conditions because data were not available on the planned size of each prescribed fire and the size of the resulting escape minus the area of the intended fire.

The cost of escaped prescribed fires, based on the median escaped fire size in each control rank group, was calculated and then adjusted for inflation, with 1992 as the official base period, using the Consumer Price Index values for British Columbia (Statistics Canada 2003). We used median escaped prescribed fire size as a surrogate for both escaped prescribed fire size and difficulty of control because it was not possible to conduct a two-way analysis to determine whether suppression costs of escaped prescribed fires varied with control rank, as well as escaped prescribed fire size. A two-way analysis generally requires an examination of how two or more independent variables affect one dependent variable (Rawlings 1988; Sokal and Rohlf 1995). In our study, we had only one independent variable (i.e., the control rank), and two dependent variables (i.e., fire size and cost).

Results

Classification of the Characteristics of Escaped Prescribed Fires by Control Rank

Escaped Prescribed Fire Size and Control Rank

Summary statistics are given for escaped prescribed burns in Table 2. The number of escaped fires varied with control ranks. The lowest number (1%) of escaped prescribed fires was observed in control ranks 1 and 2. However, the median fire size in control ranks 1 and 2 was 2.89 ha higher than that of control ranks 3

TABLE 2. Summary statistics for escaped prescribed burns (1970–1997) by control rank in the Prince George Forest Region (n = 351)

Control rank	No. fires	% total fires	Median fire size (ha)
1 and 2	5	1	7.88
3 and 4	50	14	4.89
5 and 6	121	35	10.34
7 and 8	175	50	11.20

and 4. The greatest number (50%) of escaped prescribed fires occurred in control ranks 7 and 8, with the median fire size slightly higher (0.86 ha) than that of control ranks 5 and 6. Based on the 351 escaped prescribed fires, about 84.3% of these fires occurred within control ranks 5 and 6, and control ranks 7 and 8. Only 15.7% of all escaped fires occurred within control ranks 1 and 2, and control ranks 3 and 4.

The variability in the range of escaped prescribed fire size is evident in Table 3. In control ranks 1 and 2, the escaped fires varied from 0 to 499.9 ha in size. In control ranks 3 and 4, 36% of the fires were between 1 and 9.9 ha in size, and four fires were greater than 100 ha. In control ranks 5 and 6, approximately 50% of escaped fires were between 1 and 9.9 ha. In control ranks 7 and 8, approximately 41% the escaped fires were between 10 and 99.9 ha in size, and 40% of the escaped fires were between 1 and 9.9 ha.

Based on the lognormal distribution function, the median size of a future escaped prescribed fire is expected to be 9.67 ha. Thus, in the absence of other information, we would expect that the next escaped prescribed fire would be almost 10 ha in size before being extinguished. In a similar vein, we can calculate the probability (using equation 2) of an escaped prescribed fire exceeding a particular size. As an example, the probability of an escaped prescribed fire exceeding 100 ha would be 0.115, and the probability of an escaped prescribed fire exceeding 10 ha would be 0.507.

Suppression Costs of Escaped Prescribed Fires

The cost of suppressing escaped prescribed fires during the study period (1990–1997) was approximately $1154/ha. Using this as a baseline, we estimated the costs of suppressing a median escaped prescribed fire in each of the control rank categories:

- Control ranks 1 and 2 (median size of 7.88 ha): $9093
- Control ranks 3 and 4 (median size of 4.89 ha): $5643
- Control ranks 5 and 6 (median size of 10.34 ha): $11 932
- Control ranks 7 and 8 (median size of 11.20ha): $12 925

Discussion

We determined that the median escaped prescribed fire size for control ranks 1 and 2 is larger than the median fire size for control ranks 3 and 4 (Table 2). However, only five escaped fires were classified within control ranks 1 and 2; therefore, this median may not be a precise reflection of its true median size per control rank distribution. The greatest number of ignitions (and the fewest number of escaped fires) may also have occurred at control ranks 1 and 2, but this is impossible to substantiate without data on the numbers of ignitions per control rank. The distribution of escaped prescribed fire sizes within the control ranks shows an increase in fire size and frequency as the control rank increases (Table 2). The largest number of fires (50%), the largest median fire (11.20 ha), and the largest fires occurred in control ranks 7 and 8. Thirty-five percent of all escaped prescribed fires occurred within control ranks 5 and 6, with a median fire size of 10.34 ha (Table 2).

The data used in our calculations were collected from several sources within the B.C. Ministry of Forests. We assumed this data was accurate, although the data collection techniques of different individuals may vary. Some of the earlier weather data (1970–1975) included weather readings from nearby towers and towns, and its

TABLE 3. The variability in the range of escaped prescribed fire size (1970–1997) by control rank in the Prince George Forest Region (n = 351)

	No. fires by size range (ha)						
Control rank	**0.0–0.9**	**1.0–9.9**	**10–99.9**	**100–499.9**	**500–1000**	**> 1000**	**Total**
1 and 2	1	2	1	1			5
3 and 4	12	18	16	4			50
5 and 6	6	60	38	13	3	1	121
7 and 8	12	70	71	18	1	3	175

accuracy may be doubtful. Nonetheless, from 1976 to 1997, most of the weather data were collected from on-site weather stations (S. Harvey, Senior Protection Officer, Prince George Fire Centre, B.C. Ministry of Forests, pers. comm., 2001).

Another problem we encountered in this study was that the documentation for prescribed fires covered only the conditions on their specific ignition day. Changing weather conditions and the effect on fire growth over time was not considered. To incorporate changing weather conditions into the analysis, an individual case study would be required for each fire, which would present some very complex issues. For this study, we therefore assumed that most weather conditions remained consistent throughout the duration of the prescribed fires.

Fire managers require tools that assist in decisions about whether to set a fire and when to set a fire. Thus, input factors such as fuel, topography, weather, and other aspects of burn conditions are required to estimate the probability or risk of a fire escaping from a prescribed burn. However, other factors may also contribute to risk. For example, the experience, training, and confidence level of a fire manager, or the lack of a timely prescription window, may contribute to higher levels of risk taking.

Recommendations

The intent of our study was to outline the importance of prescribed burning and the potential dangers of escaped fires from prescribed burns. We also wished to stimulate research on estimates of probability (indicators) or the risk of fires escaping from a cutblock deemed suitable for burning. A complete record of the number ignitions that were conducted annually, fully documenting the reasons for prescribed fire escapes when they occurred, would have been beneficial to our research.

Muraro's PFP control rank concept, although valid, valuable, and based on significant operational knowledge, was developed in 1975. However, we believe that if a better tool were developed, the analysis of the risk of fires escaping from prescribed burning could be improved. Such a tool would build on Muraro's control rank concept by integrating other factors, such as fine fuel moisture, the cutblock's position on a slope, and the shape of the cutblock, with the intensity classes in slash fuel types outlined in the "Field Guide to the Canadian Forest Fire Behaviour Prediction (FBP) System" (Taylor *et al*. 1996). These factors all influence fire behaviour characteristics (Muraro 1975). Thus, within the expectancy of the control for a particular microclimate, the likelihood of escaped fires could be dramatically reduced. Nevertheless, it is impossible, regardless of how many precautions are taken, to eliminate the risk of fires escaping from prescribed burning.

Regardless of how many precautions are taken, it is impossible to eliminate the risk of fires escaping from prescribed burning.

Conclusions

Despite the present issues and controversies surrounding the use of prescribed fire for silvicultural purposes in British Columbia, when applied under the right conditions, fire is an important tool for manipulating the growth of vegetation on logged areas (Haeussler 1991). Fire is an important ecological process within boreal and sub-boreal ecosystems. It produces immediate benefits for site preparation, such as the increase of temperature, nutrients, pH levels, and available nitrogen in the short term. However, the probability of an escaped fire must be carefully considered when executing a broadcast burn. For instance, the costs of suppressing escaped fires may exceed any reasonable expenditure estimated for a site that requires mechanical, chemical, or physical alteration (this requires a cost-benefit analysis of prescribed fire versus other site preparation methods or treatments, a task that was not part of our study). Other factors, such as smoke management and public concern, must also be addressed in the decision to conduct a broadcast burn.

Based on our study of 351 escaped prescribed fires (1970–1997) in the Prince George Forest Region, 84.3% of these fires occurred within control ranks 5 and 6, and control ranks 7 and 8. These control ranks also had the largest and most costly fires to suppress. Only 15.7% of all escaped fires occurred within control ranks 1 and 2, and control ranks 3 and 4. However, we did not (and could not) consider the number actual ignitions because most successful ignitions were not recorded nor were burning permits issued for all prescribed fires. Nevertheless, control rank is obviously a useful indicator of risk.

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References

Alexander, M.E. and H.G. Pearce. 1993. Tables of Muraro's prescribed fire predictor. Forest Technology Division, New Zealand Forest Research Institute, Rotorua, N.Z.

Arocena, J.M. and C. Opio. 2003. Prescribed fire-induced changes in properties of sub-boreal forest soils. Geoderma 113:1–16.

B.C. Ministry of Forests. 1988. Protection manual. Volume 1: Organization and fire management, Section 4.6–Prescribed burn escape liability, authority: Policy Manual III-PRO-013. B.C. Ministry of Forests, Victoria, B.C.

________. 1997. B.C. Ministry of Forests Policy Manual. Volume 1: Resource management, Chapter 9: Fire and aviation management, Policy 9.5–Prescribed fire. URL: *www.for.gov.bc.ca/tasb/manuals/policy/resmngmt/rm9-5.htm*

Densmore, R.V., G.P. Juday, and J.C. Zasada. 1999. Regeneration alternatives for upland white spruce after burning and logging in interior Alaska. Canadian Journal of Forest Research 29:413–423.

Driscoll, K.G., J.M. Arocena, and H.B. Massicotte. 1999. Post-fire nitrogen contents and vegetation composition in sub-boreal forests of British Columbia's central interior. Forest Ecology and Management 121:225–236.

Feller, M.C. 1996. Use of prescribed fire for vegetation management. *In* Integrated forest vegetation management: options and applications. P.G. Comeau, G.J. Harper, M.E. Blanche, J.O. Boateng, and L.A. Gilkeson (editors). Canadian Forest Service and B.C. Ministry of Forests, Victoria, B.C. FRDA Report No. 251. pp. 17–34.

Haeussler, S. 1991. Prescribed fire for forest vegetation management. Canadian Forest Service and B.C. Ministry of Forests, Victoria, B.C. FRDA Memo No. 198.

Kitchens, L.J. 1998. Exploring statistics: a modern introduction to data analysis and inference. 2nd edition. Brooks/Cole Publishing Company, Pacific Grove, Calif.

Kranabetter, J.M. and A.M. Macadam. 1998. Ten-year results from operational broadcast burning trials in northwestern British Columbia. B.C. Ministry of Forests, Victoria, B.C. Research Report No. 15.

Kranabetter, J.M. and D. Yole. 2000. Alternatives to broadcast burning in the northern interior of British Columbia: short-term tree results. The Forestry Chronicle 76(2):349–353.

Man, R. and V.J. Lieffers. 1999. Effects of shelterwood and site preparation on microclimate and establishment of white spruce seedlings in a boreal mixedwood forest. The Forestry Chronicle 75(5): 837–844.

Merrill, D.F. and M.E. Alexander. 1987. Glossary of forest management terms. National Research Council, Ottawa, Ont.

Muraro, S.J. 1975. Prescribed fire predictor. Environment Canada, Canadian Forest Service, Victoria, B.C.

Murphy, P.J. 1990. The art and science of fire management. *In* The art and science of fire management. Proceedings of the First Interior West Fire Council Meeting and Workshop. M.E. Alexander and G.F. Bisgrove (editors). Canadian Forest Service, Edmonton, Alta. Inf. Rep. NOR-X-309. pp. 21–27.

Pearse, P. 1990. Introduction to forest economics. UBC Press, Vancouver, B.C.

Rawlings, J.O. 1988. Applied regression analysis. Wadsworth and Brooks, Pacific Grove, Calif.

SAS. 2000. SAS for Windows, SAS Institute Inc., Cary, N.C.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. 3rd edition. W.H. Freeman and Company, New York, N.Y.

Statistics Canada. 2003. Consumer price index, 2001 basket content, annual (index, 1992 = 100), British Columbia. URL: *www.statcan.ca/start.html*

Stock M., J. Williams, and D.A. Cleaves. 1996. Estimating the risk of escape of prescribed fires: an expert system approach. AI Applications 10(2): 63–73.

Taylor, S.W., R.G. Pike, and M.E. Alexander. 1996. Field guide to the Canadian forest fire behaviour prediction system. Canadian Forest Service and B.C. Ministry of Forests, Victoria, B.C. FRDA Handbook No. 012.

Turner, J.A. and B.D. Lawson. 1978. Weather in the Canadian Forest Fire Danger Rating System: a user guide to national standards and practices. Environment Canada, Canadian Forest Service, Victoria, B.C. BC-X-177.

Trowbridge, R., S. Schmidt, and L. Bedford. 1989. Slashburning severity guidelines for the moist cold sub-boreal spruce subzone (SBSmc) in the Prince Rupert Forest Region. B.C. Ministry of Forests, Victoria, B.C. Insert for Land Management Handbook No. 10.

Weber, M.G. and S.W. Taylor. 1992. The use of prescribed fire in the management of Canada's forested lands. The Forestry Chronicle 68(3):324–334.

Zolman, J.F. 1993. Biostatistics: experimental design and statistical inference. Oxford University Press, New York, N.Y.