Disturbance in Riparian Zones on Foothills and Mountain Landscapes of Alberta

Alberta Foothills Disturbance Ecology Research Series
Report No. 3

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Foothills Model Forest is one of eleven Model Forests that make up the Canadian Model Forest Network. As such, Foothills Model Forest is a non-profit organization representing a wide array of industrial, academic, government and non-government partners, and is located in Hinton, Alberta. The three principal partners representing the agencies with vested management authority for the lands that comprise the Foothills Model Forest, include Weldwood of Canada Ltd. (Hinton Division), Alberta Sustainable Resource Development and Jasper National Park. These lands encompass a combined area of more than 2.75 million hectares under active resource management.

The Canadian Forest Service of Natural Resources Canada is also a principal partner in each of the eleven Model Forest organizations and provides the primary funding and administrative support to Canada's Model Forest Program.

The Foothills Model Forest mission: We are a unique community of partners dedicated to providing practical solutions for stewardship and sustainability of our forest lands.

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EXECUTIVE SUMMARY

This third report in the FMF Natural Disturbance Program research series looks at fire patterns within riparian zones at four different scales using three different sets of data and methods. The report is essentially an integrated synthesis of all or parts of four separate research projects under the auspices of the FMF Natural Disturbance Program. Specifically, we looked at whether, or to what degree, burning patterns in riparian zones differ from that of the landscape as a whole. Other research has found evidence of differential fire behaviour in other ecological areas, and our summaries suggest that riparian areas are unique terrestrial habitat in terms of species composition, relative tree density, topographic position, and eco-site type.

We found that riparian zones positively influence the chances of survival from fire at very fine scales. Although there is no evidence of either the age-class distribution, or percentage of old forest of riparian zones differing from the rest of the landscape at very coarse scales, we did find evidence that small, partially burnt residual islands tend to form at or near riparian zones more often than expected. Such islands tend to survive the fires relatively intact, form at wide streams and on wetter sites, and chances are very high that the surviving trees will be white spruce. We also found evidence that fires tend to stop at riparian zones more than expected, and particularly so on large streams with steep slopes.

However, in all cases, the relationships are weak, and highly variable. All of our data demonstrates that fire burnt through the vast majority of the riparian zones we studied, and the majority of island remnants occur nowhere near riparian zones. Furthermore, the high variation in the results suggests that the most likely source of variation in fire behaviour is local fire weather. In other words, the chances of a given riparian zone surviving or coinciding with the edge of sequential fire events are extremely small on our study area.

We also found evidence to suggest that fire in riparian zones is at least partially responsible for the unique habitat characteristics of riparian zones. Field data demonstrated that some riparian zones experience steady ingrowth of tree species for many decades after a fire. Presumably fire “cleans” these sites when it burns through.

In summary, although we found considerable corroborating evidence to suggest that riparian zones burn somewhat differently than upland parts of the landscape, the fact that fire is an integral part of riparian ecosystems is inescapable. The removal or prevention of disturbances from these habitats would presumably have significant ecological consequences. On the other hand, the introduction of cultural disturbance techniques comes with many ecological pitfalls as well. The information in this report will hopefully help guide us through this dilemma by providing a foundation of understanding of the terrestrial side of fire in riparian areas.

INTRODUCTION AND REPORT OVERVIEW

This report is divided into several related parts.

Part 1 is a general overview of the FMF Natural Disturbance Program, and is common to all reports in this series.

Part 2 includes the introduction, analysis, and discussion of fire activity in riparian zones. It is the largest, most substantial section, and includes descriptions of the data, analyses and results at four scales: landscape, sub-landscape, event, and stand-level. Each section includes its own discussion, and builds on the knowledge gained from the preceding sections. The presentation follows logically from coarse to fine scales using research results from three individual FMF Natural Disturbance Program research projects.

Part 3 is a discussion that brings together the results and interpretations from the four research scales.

Part 4 relates the results to finding ways of managing riparian zones sustainably.

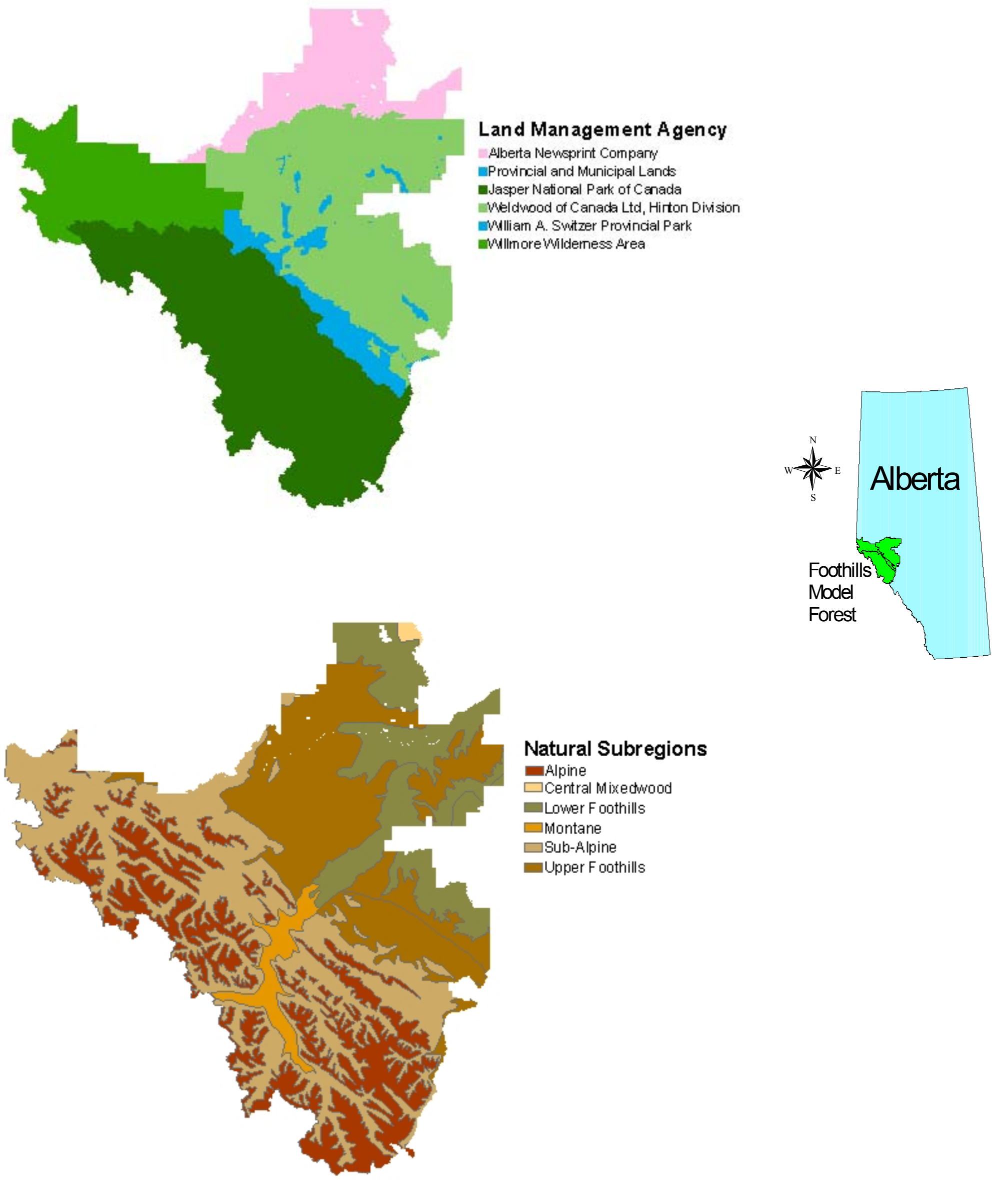
Part 5 draws several general conclusions.

Part 6 looks ahead at related future research opportunities.

Also note that there is a glossary at the end, which defines all of the technical terms used in this report.

Part 1: THE FMF NATURAL DISTURBANCE PROGRAM

In 1995, the Foothills Model Forest (FMF) in Hinton, Alberta initiated a research program to describe natural and cultural disturbance patterns across over 2.75 million hectares of foothills and mountain landscapes (Figures 1 and 2). The main purpose of the research is to provide FMF partners and co-operators with a complete picture of how natural and cultural disturbances have historically shaped these landscapes. Ultimately, each partner intends to use this information to help guide policy and management towards developing more ecologically sustainable land management practices.



Figures 1 and 2. Foothills Model Forest administrative areas and ecological zones.

The Foothills Model Forest natural disturbance program is a co-operative venture, led by a team of representatives from the Foothills Model Forest, Weldwood of Canada, Alberta Environmental Protection Land and Forest Service (LFS), Jasper National Park (JNP), and Alberta Newsprint Company (ANC). The comprehensive research program is partitioned into over 20 inter-related projects, each of which address a single disturbance question at a single scale. All projects are linked through a long-term research plan which includes details of the purpose and methods for each project and how they fit together to form a complete picture of natural disturbance patterns. It also defines ground-rules for conducting the research to maintain focus, assess progress, respond to new information, and effect the timely completion of the work. These self-imposed ground-rules are as follows:

1) The main assumption driving this research program is: ***In the absence of information on alternatives, using natural disturbance patterns to guide management is one of the best possible means of achieving ecological sustainability.*** Therefore, the main research focus is on patterns, and the disturbance processes responsible for those patterns. This is not to say that the ecological responses to those patterns are not important, but they are secondary issues/questions for which more basic knowledge and extensive research is required.

2) Since both natural and cultural disturbances affect pattern, the program implicitly considers all types of disturbances. The danger of the deliberate isolation and study of specific disturbance agents is the assumption of pre-conceived, and possibly incorrect, relationships between pattern and process.

3) The research is driven by operational needs and the results are designed to be readily interpreted. This means that the research must consider translations of results to management practices. This is being accomplished in two ways. First, direct linkages have been sought to monitoring programs through the description of pattern(s). Although the output of this research is non-species specific, it is highly quantitative, and it is possible in many cases to define “natural baselines”, making it well suited to monitoring. The second means of developing operational translations is through experimentation and demonstration. This allows for the evaluation of operational changes in terms of a) the success of creating the desired pattern(s), b) the biological responses of species and processes not part of the original research, c) practicality, and d) socio-economic impacts.

4) Finally, internalizing the research is to be avoided. High-quality research is conducted by professionals, openly peer-reviewed, presented at public meetings, conferences and tours, and published in FMF NDP Quicknotes, internal reports, news updates, posters, and refereed journals. A communications plan has been developed for the FMF Natural Disturbance Program to guide the dissemination and integration of the research.

SOME DEFINITIONS

The term "landscape" has many meanings at many different scales. As a research document, a "landscape" in this report refers to ***an ecosystem large enough to allow observation and understanding of the interaction of disturbance, geomorphology, and topography with the biota***. In other words, a large collection of forest stands, whose common link is their dynamic relationship to both disturbance and land features. In the foothills of Alberta, a landscape may be anywhere from 100,000 to 1,000,000 hectares. Like any ecological definition, this one is arguable, but it allows some convenient scale distinctions to be made:

1) **Regional**

Several landscapes spatially related and commonly influenced by regional climatic patterns. The FMF study area is a region, in which several large landscapes have been identified with unique topographic, biotic, and pattern (disturbance) features. Beyond a region is a biome.

2) **Landscape**

Ecosystems that share common disturbance and land associations, as well as the resulting arboreal (tree) relationships with disturbance and land features. The ecologically based natural subregions have proven useful in defining landscapes (which include the Lower Foothills, Upper Foothills, Subalpine East, Subalpine JNP, and the Montane – see Figure 2).

3) **Sub-landscape**

Sections of one or more landscapes that exhibit a combination of ecological, social, and economic characteristics. Sub-landscapes can be defined in different ways depending upon management needs. For example, in our research, sub-landscapes are arbitrarily chosen blocks within landscapes in which more detailed analysis will be completed at higher levels of resolution.

4) **Event / Meso**

Areas within or between landscapes that at some point in time are commonly affected by a single disturbance such as a forest fire. Events include one or more disturbance patches, and may cross landscape boundaries. They may also include both forested and non-forested patches.

The geographical terminology used in this document is as follows. The FMF consists of two major land areas divided by the foothills of the Rocky Mountains (see Figure 1). To the west of the foothills lies approximately 1.1 million hectares of Jasper National Park. To the east of the mountains is an area of approximately the same size, which covers the Weldwood Forest Management Agreement Area (FMA) but also includes William A. Switzer Provincial Park, the town site of Hinton, a large coal mine, and a strip of land under the management of Alberta Land and Forest Service. Outside the boundary of the FMF, but still in our study area is approximately 370,000 hectares representing the ANC FMA (Figure 1). The area to the west of the foothills is all JNP, and will be referred to as such. Since the area to the east of the mountains is a mixture of tenure, it will simply be referred to as the "Foothills East".

Although the Willmore Wilderness Area is a part of the Foothills Model Forest, it will not be discussed in this report as little data exists for this area.

Within Jasper National Park, three natural subregions exist: the Montane, Subalpine, and the Alpine. In the Foothills East there are also three main natural subregions: Lower Foothills, Upper Foothills, and Subalpine (Figure 2). To avoid confusing the two subalpine areas, they will be referred to as the "Subalpine JNP" and "Subalpine East".

THE DISTURBANCE RESEARCH REPORT SERIES

This research report is the third in a series that will be published by the Foothills Model Forest on natural disturbance dynamics on foothills and mountain landscapes in Alberta.

For more information on the FMF Natural Disturbance Program, or the Foothills Model Forest, please contact the Foothills Model Forest in Hinton, Alberta at (780) 865-8330, or visit our website at: http://www.fmf.ab.ca. Copies of reports and Quicknotes are available on the website in Adobe Reader® format.

Reports available in the research series:

Andison, D.W. 1999. Assessing forest age data in foothills and mountain landscapes in Alberta. Alberta Foothills Disturbance Ecology Research Series, Report No. 1, December, 1999. Foothills Model Forest, Hinton, Alberta.

Andison, D.W. 2000. Landscape-level fire activity on foothills and mountain landscapes in Alberta. Alberta Foothills Disturbance Ecology Research Series, Report No. 2, July, 2000. Foothills Model Forest, Hinton, Alberta.

Part 2: FIRE ACTIVITY IN RIPARIAN ZONES

BACKGROUND

The study of natural disturbance patterns and processes is a complex subject area. Not only does the research require considering a wide variety of time and space scales, but the understanding gained through study inevitably leads to a variety of other ecological, social, and economic issues that are intimately related. Perhaps the best demonstration of this inherent complexity is the role of natural disturbances in riparian zones.

Riparian “corridors” have always received special attention in forest planning and management exercises. Current forest management guidelines in Alberta mandate the maintenance of riparian buffer strips in forest management agreement areas (FMAs) (Alberta Environmental Protection 1994). The width of buffer strips varies from 60m for large permanent streams to 30m for small permanent streams, to zero for intermittent streams.

The main reason for mandating riparian zone buffer strips is protection. Recognizing that riparian zones are the link between the terrestrial and the aquatic components of a landscape ecosystem, they are assumed to be not only unique habitat, but also particularly sensitive to disturbance. For instance, it has been demonstrated in other ecological regions that the frequency and intensity of wildfire events is lower in riparian zones (Suffling et al. 1982, Swanson et al 1988, Timoney and Robinson 1996, Timoney and Peterson 1996) or that the presence of riparian zones influences fire behaviour (Everett et al. 2000, K. Lertzman[1], Pers. Comm.). Consistent with the theory of natural disturbance emulation strategies, this justifies special management consideration under these circumstances. However, given the fact that we know very little about the interaction between natural disturbances and riparian zones in the Alberta Foothills and Mountain Regions, we should be wary of borrowing knowledge or assumptions from other areas. Towards that, this research attempts to understand and describe the relationship between riparian zones and forest fires in this part of Alberta.

What is a Riparian Zone?

A “riparian zone” in this report simply refers to the terrestrial area adjacent to any body of water such as creeks, rivers, streams or lakes (Voller 1998). More specific definitions refer to the “area of influence” of riparian ecosystems (BC Ministry of Forests 1994) and variously use high-water marks, soils, topography, or vegetation. However, for practical purposes this is a misleading level of precision given the ability of current inventories to identify such attributes. At the risk of oversimplifying the issue, we will use distance from water in this report as the only measure of “riparian zones”. At least it is universal, and can be applied easily within and beyond the boundaries of the study area.

Riparian zones are usually considered to be unique habitat in large part because of the presence of water. However, it is worth considering whether, or in what way, riparian zones represent unique terrestrial habitat. We used 50m pixel data from across the FMF (from the FMF Natural Disturbance Meso-Scale study) to summarize the frequency distributions of soil moisture, topographic position, and dominant vegetation for each natural subregion overall, and then for those “riparian” pixels that have creeks passing through them. (See Table 5 for an overview of these data).

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The results indicate that not only are the riparian pixels unique terrestrial habitat, but that the definition changes for each natural subregion. For example, soil moisture is significantly higher in riparian zones in all landscapes for which soil data is available (soil data was only available from eco-site layers for the Weldwood FMA). As Table 1 demonstrates, the percentage of riparian zones that have moisture regimes (MR) of between 3-5 is 20-28% less than the landscape average. On the other hand, the percentage of riparian zones that have wet soils (MR = 7-9) is 14-25% more than the landscape average. Large differences in soil moisture are evident for all three natural subregions, but are somewhat more pronounced in the Subalpine landscape, and slightly less obvious in the Lower Foothills landscape (Table 1).

Table 1. Soil Moisture Regime of Riparian Zones Relative to the Entire Landscape.

Natural subregion	Area	Average Soil Moisture (MR)	
		Dry (3-5)	Wet (7-9)
Subalpine	Landscape	69	14
	Riparian Zone	41	39
Upper Foothills	Landscape	63	14
	Riparian Zone	36	31
Lower Foothills	Landscape	55	25
	Riparian Zone	35	39

The topographic position of riparian zones also differed from the overall landscape averages. Applying a neighbourhood algorithm on the elevation model for four natural subregions, each pixel was classified into one of 14 unique positions topographically. These were summarized into six classes for simplicity. Unlike soil moisture, the unique nature of riparian habitat varied widely by landscape (*i.e.*, natural subregion). The only characteristic common to all natural subregions was the much higher prevalence of riparian zones in toe-slopes and valleys. Otherwise, the tendencies varied. In both the Montane and Subalpine landscapes, riparian zones tended to occur more often on flat areas, and were less prevalent on slopes of all kinds relative to the entire landscape (Table 2). In contrast, riparian zones in the Upper Foothills landscape were represented well by the landscape averages (aside from the higher proportion in toe-slopes and valleys). In the Lower Foothills, riparian zones were actually *less* likely on flat sites (Table 2).

Table 2. Topographic Position of Riparian Zones Relative to the Entire Landscape.

Natural subregion	Area	Percent of Area by Topographic Position					
		Flat	Toe, Valley	Ridge	Gentle Slope	Steep Slope	Locally Complex
Montane	Landscape	31	5	3	23	11	18
	Riparian Zone	39	14	1	12	4	20
Subalpine	Landscape	6	6	5	12	17	36
	Riparian Zone	12	18	2	5	5	41
Upper Foothills	Landscape	33	4	2	8	4	42
	Riparian Zone	30	9	2	7	4	42
Lower Foothills	Landscape	49	4	2	0	0	43
	Riparian Zone	41	11	2	0	0	44

The dominant tree specie differences between riparian zones and the overall landscape are also natural subregion specific. In the Montane area, the biggest difference in riparian zones is the higher percentages of Douglas -fir, and lower amounts of pine compared to the landscape averages (Table 3). In Subalpine areas, riparian zone vegetation is fairly similar to that of the surrounding landscape, except for the higher occurrence of riparian zones in non-forested areas. Non-forested areas are also much more frequent in riparian zones in the Upper Foothills landscapes, while pine-dominated stands are less frequent. Finally, riparian zones in the Lower Foothills area are over-represented in both non-forested and White spruce dominated stands, and under-represented in both pine and aspen-dominated stands (Table 3). The dominance of white spruce in the Lower Foothills is particularly interesting, considering that our 1950 map does not account for the large white spruce that were logged in riparian zones in the early part of the century for railway ties. Under more "natural" conditions, we might expect white spruce to be even more dominant in riparian zones in this area.

Table 3. Dominant Tree Species of Riparian Zones Relative to the Entire Landscape.

Natural subregion	Area	Percent Forest by Dominant Tree Species					
		Non-Forested	Pine	White Spruce	Black Spruce	Poplar	Douglas -fir
Montane	Landscape	14	46	20	-	-	19
	Riparian Zone	16	35	23	-	-	26
Subalpine	Landscape	24	34	39	2	-	-
	Riparian Zone	31	28	41	1	-	-
Upper Foothills	Landscape	14	57	9	13	3	-
	Riparian Zone	23	49	11	12	2	-
Lower Foothills	Landscape	7	34	13	23	22	-
	Riparian Zone	18	24	21	27	9	-

This summary of riparian zones follows logically. For example, we would be very surprised if riparian soils were not wetter on average than other parts of the landscape. Similarly, since water flows over the path of least resistance, valley bottoms and (flat) floodplains will logically have more riparian zones. Together, this means that the species composition will favour those adapted to wetter soils and/or flood plains, as well as non-forested wetlands and un-treed bogs. Not surprisingly (although not shown here) riparian sites, according to the Ecological Land Classification (Beckingham *et al*. 1996), tend to be richer and wetter (*i.e*., less Labrador tea and rye rice sites, and more horsetail, bog and fen site types).

In summary, we may conclude that riparian zones are unique terrestrial habitat. This is a significant conclusion because, until now, any special management consideration specified for riparian zones was largely due to the presence of the water therein. We now see that there are other reasons for considering riparian zones as special places, and perhaps warranting special management. However, despite our desire for sustainable ecosystems, we know very little of the appropriate degree or nature of the management activities necessary to maintain the terrestrial component of riparian zones. Again, riparian management decisions have been largely dictated by the perceived needs of the aquatic systems. Therefore, there is a need to better understand the processes and patterns within the terrestrial part of riparian zones in order to manage them more sustainably.

NATURAL DISTURBANCE IN RIPARIAN ZONES

Riparian zones represent a unique challenge to the natural pattern model of forest management. On one hand, our current reluctance to harvest in riparian zones in foothills and boreal forests is well founded. Harvesting and skidding trees in and across creeks and rivers create mechanical disturbances such as rutting, compaction, and erosion that have no natural equivalent. Even the most severe fire will not alter the physical properties of either the soil or streambeds. Furthermore, the removal of biomass (dead or alive) from riparian zones represents another significant departure from the so-called "natural" model of managing forests.

Yet riparian zones are clearly disturbed naturally on some level historically, and this research aside, there is widespread understanding that wildfires burn through riparian zones in northern forests on a regular basis. What we hope to gain from this research are more specific insights into exactly to what degree, how, where, and why, riparian zones are influenced by natural disturbances.

The riparian disturbance question can be posed at several different scales. In this report we draw on data, methods, and analysis from three different projects within the FMF Natural Disturbance Research Program (the Meso-Scale Patterns and Processes study, the Patterns of Island Remnants Study, and Riparian Disturbance Dynamics) (Andison 2001). Using these results, we have created a comprehensive understanding of how, where, and why fire moves through riparian zones. In other words, we want to know if fire is any more or less severe, frequent, or predictable in its behaviour in riparian zones, relative to the upland portion of the landscape.

Landscape Scale Analysis

At the very coarsest scales, the behaviour of fire over very large areas and many decades can be observed. Although technically a snapshot (in time), each landscape today represents patterns of burning tendencies of a large number of fires over many years and across a wide range of weather, fuel, and topography conditions. We can use this knowledge to ask and answer general-level questions about burning preferences. For instance, if fire *in general* does not burn as frequently in riparian zones (over decades), we should see this reflected in differences in the forest age structure of riparian forests relative to the entire landscape.

Hypothesis: Fire burns less often in riparian zones compared to the rest of the landscape.

Methods

Six areas of the foothills east, and one large area of Jasper National Park were chosen as sub-landscape sample areas on which to conduct more detailed intermediate-scale spatial analysis. Inventory, stand origin age (See Andison 1999), topography, ecosite, soils, and provincial stream course data layers were clipped from ARCINFO files for each area, gridded at a resolution of 50m or ¼ hectare, converted to comma-delimited ASCII files and merged into a single file for each sub-landscape. These data are part of the Meso-Scale Patterns and Processes study from the FMF Natural Disturbance Program.

To address this question, all seven files were merged and analysed as a single area, totalling over 800,000 hectares. This was possible because spatial relationships are irrelevant in this case. The age-class distribution was then calculated for the entire landscape, and then for the class of pixels associated with the presence of streams. From the age-class distributions, both average age, and the percent forest that originated prior to 1850 were estimated. The calculations represented two different ways of considering the influence of riparian zones on landscape fire behaviour. If riparian zones were less likely to burn, as hypothesized, then the average age of riparian zones and the percentage of forest originating prior to 1850 would both be higher. The calculations were summarized for each natural subregion and by stream order. Note that these estimates were made for the 1950 landscape using the stand origin age data with no harvesting (see Andison 1999 for details).

Results

The average age results are inconsistent. Of the four natural subregions, the average ages of riparian zone forests overall were actually *less* than the respective landscapes in three of them, and only 2 years higher in the Subalpine. Even the average age of forests associated with higher stream orders (*i.e.*, generally larger streams, designated here by stream orders 4 through 7 in Table 4) were less than the surrounding landscape in two of the natural subregions, and dramatically so for the Subalpine (Table 4). The only increase in average age of more than two years occurred in the Lower Subalpine forests of higher order streams (70 years vs. 74 years).

Table 4. Average Age and Percentage of Old Forest of Riparian Forests, by Stream Order.

Natural subregion	Area	Average Age			% Forest <1850		
		Overall	Riparian by Stream Order		Overall	Riparian by Stream Order	
			All	4-7		All	4-7
Lower Foothills	177,839	70	66	74	24	16	27
Upper Foothills	413,148	76	75	77	21	24	26
Montane	72,439	82	81	76	30	28	23
Subalpine	221,773	107	109	95	40	43	39

The percentage of older forest in riparian zones is only marginally more informative. For the Lower Foothills, the percentage of old forest in riparian zones is actually 8% lower than the amount of old forest in the Lower Foothills overall, although higher order streams have much higher amounts of old forest. The percent of old forest in riparian forests of the Montane is also less overall compared to the overall landscape, and declines even further with increasing stream order (Table 4). For the Upper Foothills riparian zones, a slight increase in the proportion of old riparian forest is seen overall (21% versus 24%), and the amount of old forest associated with stream order 4 and higher increases to 26%. In the Subalpine, the amount of old forest in riparian zones increases overall from 40% to 43%, but then declines to 39% for higher order streams.

Discussion

The influence of riparian zones on overall fire behaviour at landscape scales is unconvincing. There is no evidence of a clear and consistent relationship between the age of forests and riparian zones – even when differentiated by stream order. Both tests reveal that fire most likely burns as often through all types of riparian zones as it does through the rest of the landscape, in at least three out of the four landscape types. The 5% increase in the amount of older forest in the Upper Foothills for forests associated with higher order streams is not enough on its own to suggest that there is a relationship. In any case, there is no compelling reason at this point to believe that higher stream orders for the Upper Foothills are unique. In other words, why did this relationship not show up for lower stream orders, or higher stream orders in other natural subregions?

It is more constructive to consider the high levels of variability in these results, suggesting that fire behaviour at this scale simply does not respond to the presence or absence of riparian zones. Although not shown, a breakdown of old forest by individual stream order shows even more dramatic variation in all natural subregions, and none demonstrate a consistent relationship between stream order and forest age.

Actually, the most interesting result overall is the 8% decline of old forest in the riparian zones of the Lower Foothills. This may in part be due to historical tie-cutting activities early in the century, which focused specifically on riparian zones in the Lower Foothills.

It is important to keep in mind that we are not asking *if* average ages or the percent of old forest is significantly different as one would with a statistical test. Our "sample" in this case is about 50% of the "population", totalling over 800,000 hectares, so there is little doubt that the actual numbers differ. With such a large sample, we can move directly to asking why there might be differences. A consistent relationship between riparian zones and forest age would suggest (but not prove) that riparian zones survive fire more often than other parts of the landscape. In this case, the fact that the results are inconsistent (*i.e.*, some being older, others younger) strongly suggests that the primary reason for the observed differences in age is probably not the presence or absence of the riparian zones.

Having said that, there are still many good questions left to ask. For instance, there is no reason why there may be more specific burning tendencies, or behaviour of a different sort, which a simple age comparison may not pick up. All we have determined so far is that we cannot use the presence or absence of a riparian zone alone to stratify the landscape into disturbance types based target age-class distributions.

Sub-Landscape Scale Analysis

An alternative pattern of burning over large areas may have more to do with the formation of edges, rather than avoidance and outright survival from fire. In other words, as fires move through a landscape, they may tend to form edges at riparian zones. Such a pattern would not necessarily show up as an age differential between riparian forest and upland forest from our landscape scale analysis.

Hypothesis: Fires tend to form edges at or near riparian zones more often than expected.

If riparian zones affect coarse-scale fire behaviour, we would expect to find that over large areas, fire edges occur more often at, or close to, riparian zones. This is not to say that all parts of every fire are more likely to stop at a riparian zone, but rather that all things being equal, there may be circumstances where the side or flank of a fire may stop moving because of topography, soil and fuel moisture, or fuel-type changes associated with a riparian zone. If this is true, then we should see a higher than expected level of forest fire edges associated with riparian zones.

Methods

The data for these tests also come from the Meso-Scale Patterns and Processes study in our research program. Recall that these data are 50m pixel data overlays of major vegetation types, soils, ecological land classification, slope, aspect, elevation, and creek layer. The size of the sample areas ranges from 280,954 ha in Jasper Park, to 83,760 ha in the foothills east (see Table 5). The resolution of these data is adequate for identifying both fire "edges" and riparian zones.

To test for the occurrence of riparian edges using these data, we start by calculating the total number of disturbance edges in each of seven sub-landscapes.

Since we have a stand origin map to work with for the foothills east (Andison 1999), any change in polygon age is (or was at some time) the edge of a fire. The total number of disturbance edges in an area from many different fires over the past 100 years or more can thus be counted. An "edge" in this case is identified by comparing the ages of neighbouring forested pixels (*i.e.*, forest to non-forest edges do not count in this case). The origin, size, or shape of each fire is not important for this calculation, only the existence of a historical fire edge.

To find the coincidence of creeks and fire edges, creek pixels were isolated and the total number of forest edges counted relative to the total number of forest to forest edges. This was expressed as a percentage (column 4 in Table 5). So in Table 5, the first row of data in column 4 means "2.4% of the pixel edges tested in the riparian zones of East 1 were fire edges".

The observed edge count was compared to two different baselines for this test. First, the total proportion of fire edges was calculated for the entire sub-landscape in question. This is the "Area Average" column in Table 5. Using the same example, the area average for East 1 was 2.4%. Since the area average was exactly the same as the riparian average for East 1, it was not difficult to conclude that fire edges in this case were no more or less likely to form in riparian zones. However, if we move to the "All" areas results from East 3, the area average was 4.0, and the riparian average was 4.8. Does this mean that riparian zones in this case were in fact more likely to be associated with fire edges? The usual way of testing this question statistically is to use something like an "Electivity Index" which calculates an expected value based on the baseline. However, such a test assumes that both values in question exhibited spatial independence, which in this case was not a valid assumption. Both riparian zones and fire edges were highly spatially correlated, which can bias the test in unknown ways.

Table 5. Percentage of Sub-landscape Pixel Edges that are Fire Edges on the FMF.

Sub-Landscape	Natural Subregion	Percentage of Pixel Edges that are Fire Edges				
		Area Average	All Stream Orders		Stream Orders 4-7	
			Riparian	Offset Ave (Std Dev)	Riparian	Offset Ave (Std.Dev)
East 1 (144,148 ha)	All	2.4	2.4	2.2 (1.6 - 2.7)	3.5	1.9 (0 – 4.0)
	Subalpine	2.7	2.6	2.6 (2.0 – 3.4)	3.6	2.2 (0 – 6.4)
	Upper Foothills	1.9	2.0	1.7 (0.8 – 2.7)	3.5	1.8 (0 – 3.9)
East 2 (83,760 ha)	All	2.4	2.6	2.1 (1.6 – 2.6)	2.8	2.6 (1.1 – 4.0)
	Subalpine	3.3	**3.5**	1.5 (0 – 3.4)	**3.8**	1.4 (0 – 3.6)
	Upper Foothills	2.1	2.0	2.4 (1.7 – 3.0)	2.4	2.9 (1.1 – 4.8)
East 3 (177,305 ha)	All	4.0	**4.8**	4.0 (3.7 – 4.3)	n/a	n/a
	Lower Foothills	3.7	4.5	4.1 (3.4 – 4.9)	n/a	n/a
	Upper Foothills	4.5	**5.2**	3.8 (2.9 – 4.8)	4.6	3.9 (3.0 – 4.7)
East 4 (93,934 ha)	All	3.2	3.2	3.0 (2.6 – 3.4)	2.6	2.9 (1.5 – 4.3)
	Lower Foothills	3.2	3.2	3.4 (2.8 – 3.9)	2.7	3.0 (1.4 – 4.6)
	Upper Foothills	3.1	3.3	2.6 (1.9 – 3.3)	2.3	2.3 (0 – 5.2)
East 5 (94,752 ha)	All (Upper)	2.8	**3.2**	2.7 (2.2 – 3.1)	3.6	2.9 (1.8 – 3.8)
East 6 (131,202 ha)	All (Upper)	2.9	3.0	2.8 (2.5 – 3.1)	2.8	2.8 (1.7 – 4.0)
Jasper (280,954 ha)	All	2.9	3.0	2.9 (2.6 – 3.3)	3.5	3.0 (2.1 – 3.8)
	Montane	4.0	**4.3**	3.0 (2.0 – 4.1)	3.7	3.1 (2.0 – 4.3)
	Lower Subalpine	2.4	2.6	2.8 (2.3 – 3.3)	3.2	2.4 (1.4 – 3.5)
	Upper Subalpine	1.7	**1.0**	2.9 (1.8 – 4.1)	n/a	n/a

Another way of considering the question is whether the spatial configuration of the riparian zones is affecting the outcome of the edge test. The statistical problem is that riparian zones are spatially correlated to other riparian zones (and not randomly scattered across the landscape). We can address this issue by testing the coincidence of fire edges with different spatial arrangements of the riparian zones. In this case a sample of alternative (random) riparian patterns was created by applying offsets of 2,000m on the riparian data in the E-W direction. In other words, we are taking the same riparian zones from each sub-landscape, and dropping them down in different places on top of the relevant creek layer to obtain a number of other creek-fire boundary possibilities. The test then is whether or not the actual overlay of the two is significantly different than the average of the sample of artificially generated offset overlays.

Several combinations of factors were tested. The tests were done for each of the seven areas as a whole, and then by natural subregion. The calculations were made using all streams, and then isolating only the larger streams (orders four and higher). Those tests that involved less than 250 edges were arbitrarily removed from the summary due to sample size. In all, 33 different riparian combinations were tested against the two baselines.

Results

The results were variable, but weakly support the idea of the coincidence of fire edges with riparian zones. Six of the 33 edge tests completed show that riparian edge proportions were significantly different than the results from the offset data (dark blue bolded results in Table 5). Even if one were to argue that the sample size in this case is so large (over 800,000 hectares) that statistics are irrelevant, a simple count of those observed riparian percentages that were higher than the offset averages, versus those that were lower, yielded much the same result. Twenty-three of the 33 edge tests completed showed the proportion of fire edges in riparian zones was higher than the corresponding offset run averages (in blue), compared to only seven lower than the offset averages (in yellow). The area average numbers showed a similar pattern by comparison.

Edge locations in sub-landscapes East 1, 2, 3, and 5 are more influenced by riparian zones than either East 4, 6 or the park. One could argue that in these latter three areas, riparian zone influence on edge formation is relatively neutral. In all but a few cases (such as the Montane area of the park) the observed edge percentages are very close to those expected by either the area averages or the offset runs (Table 5).

Natural subregion distinction did nothing to improve the predictive ability of the results. For instance, the Subalpine area of area East 1 shows no difference between riparian (2.6%) and either the offset average (2.6%) or the area average (2.7%). On the other hand, the Subalpine area of East 2 (3.5) is significantly higher than the offset average (1.5%), although not all that different than the area average (3.3%). In contrast, the two Subalpine areas of JNP are *lower* than expected, compared to both the offset or area averages. The Upper and Lower Foothills show similar inconsistent results (Table 5).

Nor are higher stream orders consistently associated with fire edges overall. For example, in East 1, the higher stream orders were all positively associated with higher fire edge coincidence, but in East 4, higher stream orders are actually less likely to be associated with fire edges (Table 5).

Certainly, one could argue that the results are sensitive to the sub-landscape areas, but there is nothing obviously unique about these areas, and in any case they are not a significant distance from each other. The increasing trend of a negative association between fire edges and riparian zones in JNP in the Subalpine areas suggests that perhaps topographic complexity is a factor. However, if this is the case, we would expect to see the same negative pattern in the other Subalpine areas in the foothills east – which we do not.

Discussion

Overall, there is weak, but consistent evidence to suggest that fire edges tend to form at riparian areas more often than the expected (relative to the landscape average). However, the issue is not resolved, and many questions remain unanswered. This was a coarse, first approximation test of general-level landscape fire behaviour. There are many other biotic and abiotic factors that may interact with the presence of a riparian zone that may create a higher than expected occurrence of fire edges. Some of these will be investigated further in this report.

It is also possible that the response of fire to riparian zones is at a scale too fine for this particular analysis. We can now move on to those finer scale questions.

Event-scale Analysis

Another possible way that riparian zones may influence fire behaviour is by affecting within-fire severity. A considerable amount of material survives most fires in the boreal forest, and it is possible to test for a relationship between the surviving vegetation and the presence of riparian zones. More specifically, it is possible to test for any spatial relationships between unburnt island remnants, and riparian zones. Such patterns would not necessarily show up in the coarse-scale age analysis presented earlier. Several different tests were possible, but they all fall under one general question.

Hypothesis: Unburnt residual / remnant material leftover within a fire is more often than expected associated with riparian zones.

Methods

The data for this test originated from the FMF Island Remnants study, described in more detail in MacLean et al. (1998). From 1997 to 1999, forest fires that burnt between 1950 and 1970 across the Alberta Front Range were selected and interpreted using aerial photographs. Using both Alberta's forest fire inventory (Delisle and Hall 1987) and the Lands and Forest Service historical maps as the baselines, we selected fires for sampling based on the following criteria:

1) Post-fire photography at no less than 1:20,000 available within five year after the fire (all but three were within two years)
2) Pre-fire photography at no less than 1:20,000 available within five years prior to the fire.
3) No overlap with other fires.
4) Within any part of the Lower Foothills, Upper Foothills, or Subalpine natural subregions of Alberta.

Historical photos were obtained for the twenty-five fires that met these criteria, and fire and island remnant boundaries for each were interpreted and digitised using five classes of mortality, from 0-100%. Other spatial data such as slope, aspect, elevation, and the presence of water features were obtained for each fire location. For 14 of the fires, aerial photos taken immediately prior to each fire were used to interpret the pre-burn vegetation cover, and of these 12 had creeks crossing through them. Finally, historical data on fire suppression and fire weather were also complied for each fire.

The island remnant data is being used for several different research projects under the auspices of the FMF Natural Disturbance Program. In this case, we used ARCVIEW to buffer all creeks within each of the twelve eligible fires with creek data. Buffer widths of 25m, 50, 100m, and 200m were used to create new digital layers. Each buffer layer was then overlain on the island remnant data layer and an area summary completed. The results were considered from a variety of perspectives.

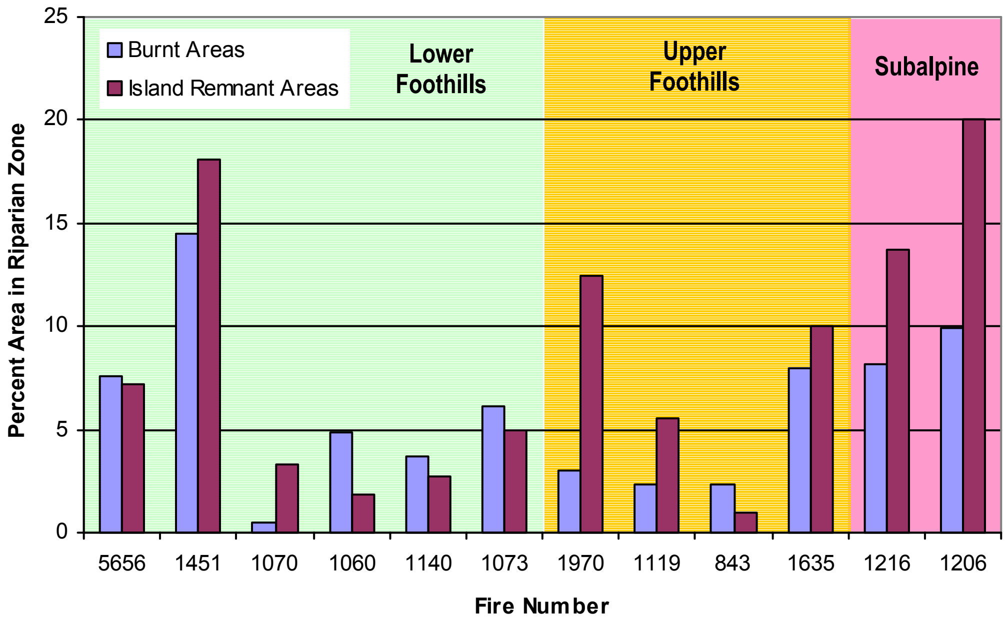
Results

Question 1. What proportion of island remnants exist in riparian zones relative to that in the burnt areas of fires?

This was tested by direct comparison of area proportions in Figure 3. So in fire number 1970, 3% of the total area burnt occurred in riparian zones, and 12.4% of the total area in island remnants occurred in riparian zones (Figure 3). We would expect that these percentages are roughly the same if island remnant formation is not associated with riparian zones. In fact, of the 12 sample fires, the proportion of island remnant area in riparian zones was higher than the proportion of burnt area in riparian zones in only seven (Figure 3). However, of the other five fires, the difference between the riparian proportions was less than 1.5% in four of them (fires 843, 5656, 1140, and 1073). Furthermore, the larger differences seemed to occur within fires with greater areas in island remnants. Over the 12 fires, the average percentage of island remnant area in riparian zones was about 8.4%, compared to 5.9% for burnt areas. The difference was not significant statistically (using a t-test), but the relationship is worth exploring further.

Although our sample size is very low, it is interesting to consider the results by natural subregion. In Figure 3, the first six fires (shaded green background) are from the Lower Foothills landscape. Although there is considerable variability, the average percentage of island remnant area in riparian zones for these six fires is almost exactly the same as the proportion of burnt area in riparian zones (6.4% versus 6.2% respectively). Furthermore the Lower Foothills accounts for four of the five fires in which riparian impacts on island formation are negative (fires 5656, 1060, 1140, and 1073). In the Upper Foothills landscape (shaded orange background in Figure 3), the percent of island remnant area in riparian zones is 7.3%, compared to 3.9% for the burnt portion of the fires. Finally, in the two Subalpine fires, the percent island remnant area in riparian zones is almost 17%, compared to only 9% for burnt areas. Keep in mind that there is no statistical significance to the differences observed here because of the high variability and low sample size.

Figure 3. Percent of Burnt Areas and Island Remnant Areas in Riparian Zones



Question 2. Are there other biotic or abiotic attributes of fires that affect the tendency of riparian zones to burn?

To test this, we included fire size, percent of non-forested area, number of fire polygons, the average number of hectares burnt per day (as a rough surrogate for fire intensity), and the proportion of the gross fire area in riparian zones (using the 25m buffer width) as independent variables in regressions. Other fire data such as season of burn were not universally available.

As expected, by far the most important variable determining the proportion of riparian zones left in island remnants was the total percent of the fire in riparian zones to begin with. Also significant was the percent of the fires in non-forested land. None of the other variables tested proved to be useful in predicting the amount of island area in riparian zones. However, these two variables accounted for almost 80% of the variation. The best fit equation using linear regression was:

% islands in riparian zones = 5.81 + 1.035(% of fire in 25m riparian buffer) – 0.29(% non forested)

R-squared of 0.79, SE of 3.24, and N=12 (see figure 4).

In other words, the proportion of island remnant area that exists in riparian zones is positively correlated to the total amount of riparian area, and negatively correlated to the proportion of non-forested land in the fire. Both are logical relationships. Clearly, the greater the percentage of land in riparian zones, the greater the chances of island remnants falling into them. Similarly, in areas with high percentages of non-forested areas, there is substantially less opportunity for forested riparian zones (recall from above that riparian zones are strongly and positively associated with non-forested areas), and therefore we would expect a smaller proportion of island remnant areas to exist in riparian zones.

Figure 4. Relationship Between Non-Forested Areas, Island Remnant Areas, and the Percent of Island Remnant Area in Riparian Zones

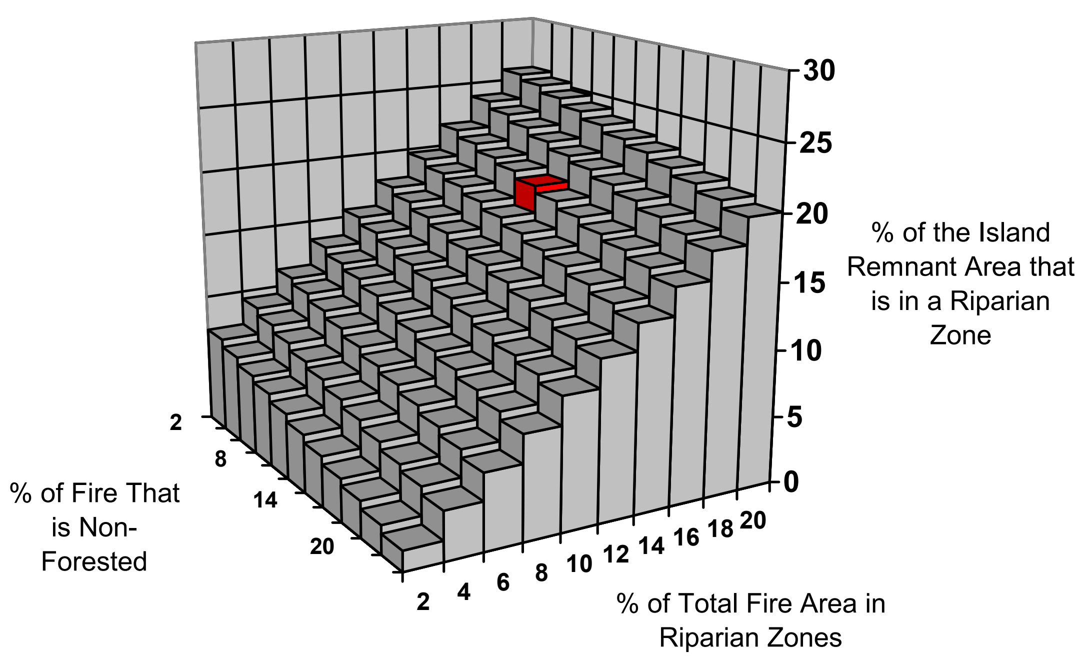
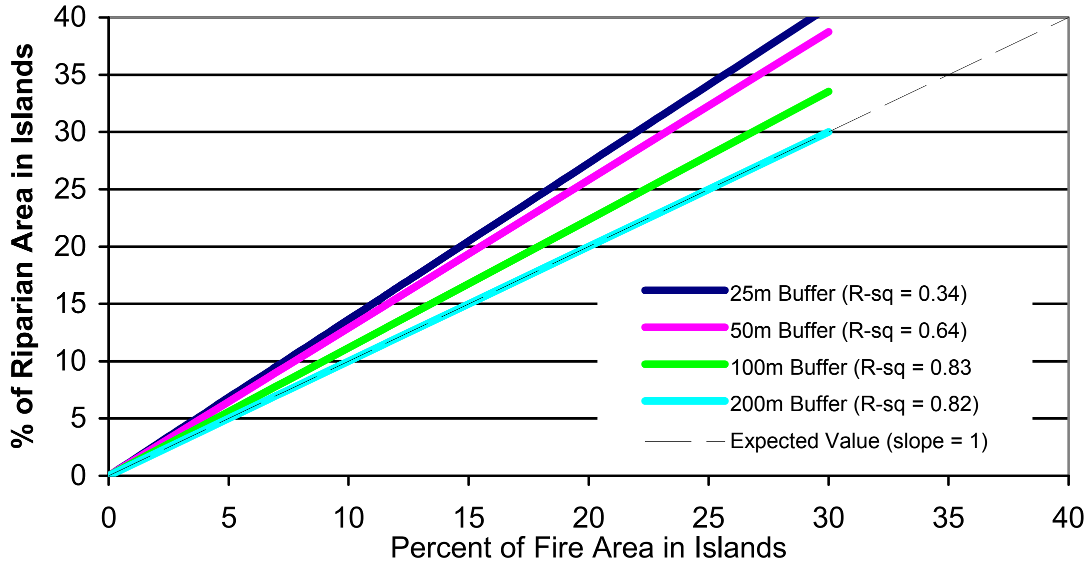


Figure 4 expresses this relationship visually. The way to read Figure 4 is as follows. Let us say there is a 1,000 hectare fire (gross area), of which 100 hectares (or 10%) is non-forested, and a 25m buffer on all creeks accounts for 160 hectares (or 16%). The model would predict 5.81 + 1.035 x 16(riparian area) – 0.29 x 10 (non-forested) = 19.5% (highlighted in red in Figure 4). So if that fire has 50 ha in island remnants, we predict that 50 x 19.5% = 9 ¾ ha of that island area would be in a riparian zones.

Question 3. What effect does buffer width have on the relationship between island remnants and riparian zones?
Until now, we have been using a 25m buffer for defining a riparian zone. The tests above were repeated using buffers of 50m, 100m, and 200m, but this time comparing the percent area in island remnants of the entire fire to that of just the riparian zones (which is just an alternative way of posing the question). For comparative simplicity, linear regression equations were fit using the percent of fire in island remnants as the only independent variable, and also forcing the relationship through the origin. In this case, we "expect" a 1:1 relationship, or a slope of 1. In other words, if a given fire has 10% of the area in island remnants, we *expect* 10% of the riparian areas to have islands as well. By using linear equations forced through the origin, we can compare the slopes of the different lines (Figure 5).

Figure 5. Comparison of the Percent of Riparian Area in Islands Using Different Buffer Widths

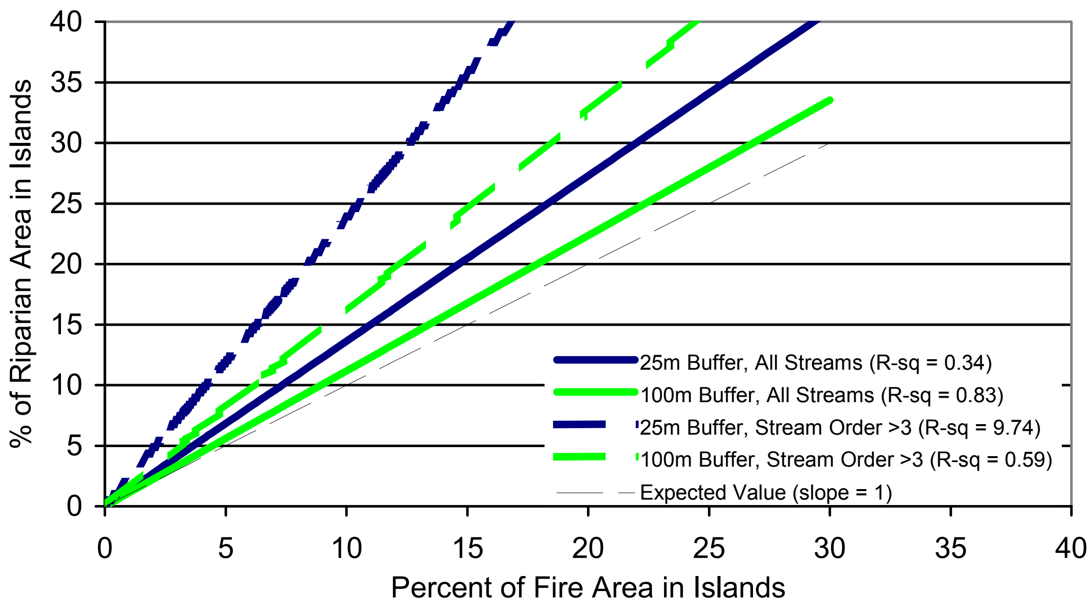


The slope of the line for the 25m buffer is about 1.4, meaning that if a fire had 10% of it's area in islands remnants, we predict (poorly in this case) that about 14% of all riparian zones (defined by a 25m buffer) would have island remnants. However, the point is that the riparian zone effect is clearly a local one. The slopes of the lines decrease as the size of the riparian buffer increases until at 200m it is virtually identical to the expected value of 1.0 (Figure 5). This suggests that the relationship between riparian zones and island remnants is strongest immediately adjacent to creeks.

Question 4. Does the relationship between riparian zones and island remnants change with stream order?

We repeated the test used for question 3 for different stream orders. The results suggest that there is a stronger tendency of islands to form in riparian zones of higher order streams. For instance, the slope of the line describing the relationship with 25m buffers increases from 1.4 to 2.4 when the test is limited to stream orders greater than 3. A similar increase is seen in the impact on the 100m buffer (Figure 6). In other words, not only are island areas more likely to occur close to streams, but also near higher order streams.

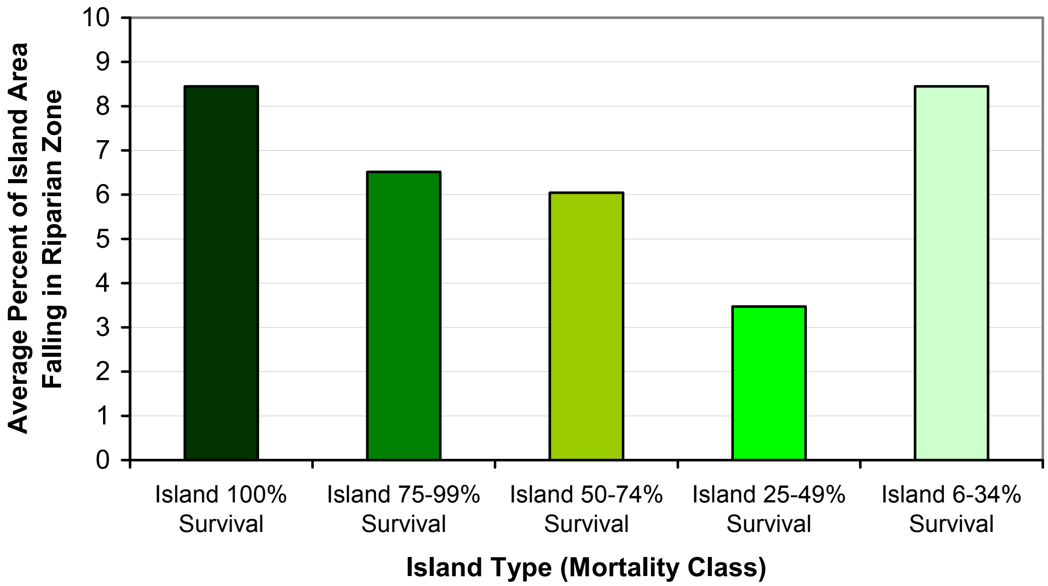
Figure 6. Influence of Stream Order on Percent of Riparian Area in Islands



Question 5. Do relative island mortality levels change within riparian zones?

The last thing we were able to test using the island remnants data was whether or not island type was related to the tendency of islands to form in riparian zones. We had five classes of islands in our dataset based on five levels of mortality; 100%, 75-99%, 50-74%, 25-49%, and 6-24% survival. The same data used in Figure 3 was averaged for all 12 fires (using 25m buffers), and broken down into survival classes and presented in Figure 7. Thus, for the area in islands in the 100% survival class (darkest green bar), on average, 8.4% of their total area in a fire was in riparian zones (Figure 7). Similarly, for island area in the 75-99% survival class, 6.5% of that area was in riparian zones (on average).

Figure 7. Average Relative Percent of Island Remnant Area Falling into Riparian Zones, by Island Type



The summary suggests that islands with higher levels of survival are more likely to occur in riparian zones. The proportion of island types occurring in riparian zones steadily declines from 8.4% for intact islands (100% survival), to 3.5% for heavily burnt islands (25-49%). The single exception to this trend is the area in the lowest survival class of islands (6-34%). However, this may be misleading since 1) this class of island is the most rare, accounting for less than 4% of the total area in island remnants, and 2) the high average is largely due to a single observation (*i.e.*, one fire).

Discussion

The island remnant data has provided the most detailed information yet on to what degree, and in what way fire patterns differ in riparian zones. We found some evidence to suggest that:

1) Island remnants occur in riparian zones in higher proportions than expected.
2) This tendency decreases as the width of the riparian zones increases.
3) As the amount of riparian area in a fire increases, the proportion of island remnant area in riparian zones increases.
4) As the amount of non-forested area within a fire increases, the proportion of island remnant area in riparian zones decreases.
5) Riparian zones of higher order streams are more likely to have islands than those of lower order streams.
6) The proportion of high-survival islands in riparian zones is higher than the proportion of low-survival islands (relative to the whole fire).

Having said that, it is important to talk about degree. All six points listed above are either well supported weak relationships, or they are only weakly supported by the data. In most cases, there is no statistical significance because of the weakness of the trends, the high amount of external variability, and/or the low sample size. It would therefore be misleading to conclude from the event scale analysis that island remnant fire patterns are remarkably different in riparian zones relative to the rest of the landscape. More accurately, there are certain pattern relationships that are more probable than others, but the probabilities are *in most cases* only slightly higher than expected elsewhere on the landscape.

However, even this analysis may have missed some site-specific details that may be important for generating unique fire behaviour in riparian zones. Therefore, the last part of this study focuses on stand-scale questions of fire patterns.

Stand-scale Analysis

At the stand scale, there may be site details that are only obvious from ground observation that are relevant to the behaviour of fire in riparian zones. Field-based data are also valuable for corroboration of previous findings that were based on un-verified remotely sensed digital data. In this case, our interest was in determining any unique characteristics of vegetation patterns in riparian zones relative to the upland part of the landscape. There are again several questions that we can ask, but they all fall generally under a single hypothesis.

Hypothesis: Fine-scale fire patterns within riparian zones are unique, and related to site-specific attributes.

Methods

From a digital stream inventory, we used aerial photos, inventory maps, and stream order classifications to stratify all riparian zones into eligible sampling areas on the Weldwood FMA. Eligible areas had to be accessible, forested, and not influenced by cultural management activities. Within the eligible areas, we then randomly selected 56 locations on creeks or streams. Candidate transects were marked on copies of the photos, and located in the field.

We ran 2 meter wide transects perpendicular to the stream at each of the 56 points. Transect length varied according to the width of the riparian area but included at least 100m of upland forest on each side of the riparian zone in 53 transects, and at least 50m of upland for the other three transects. We collected species and diameter at breast height (dbh) data for each tree that we counted along the transect. Slope, aspect, and ecological site classification data were also collected. Increment cores were taken for at least 10 trees in each upland portion of the transect and at least 5 trees in the riparian area. Cores were taken as close to the base of the tree as possible to get accurate age information. Increment cores were air dried and glued to wooden mounts after vertically aligning the xylem tracheids. They were then cut at right angles to the tracheids using an exacto knife and rubbed with white chalk to help differentiate ring boundaries. Disks were sanded then polished with progressively finer sandpaper. After preparation, rings were visually counted using a binocular microscope. An estimate of number of years necessary to grow to coring height (about 20 cm in most cases) was not added to the number of rings on the core or cookie, since we were interested in the relative age differences between trees, not the exact ages of each tree.

Results

Question 1. Is the structure and composition of riparian areas different from upland areas?

It is not difficult to imagine that one might think that the disturbance history of riparian zones might differ from that of the rest of the landscape. In many cases, riparian zones simply *look* different. To better define these differences, we used ANOVA to compare species composition (relative density/ha), tree dbh and tree density between riparian and upland areas.

In terms of tree species composition, aspen was significantly more common in upland areas in both the Upper and Lower Foothills (Figures 8 and 9). Lodgepole Pine was more prevalent in upland areas in the Upper Foothills compared to riparian areas (Figure 8). Both of these results agreed with the findings in Table 3 on species composition differences using landscape (inventory) data. However, recall that the landscape analysis predicted much higher levels of White spruce in the Lower Foothills area (Table 3), which our field data was unable to confirm.

Structurally, we found fewer small trees in riparian zones relative to upland forest (Figure 10). Specifically, upland areas had more trees less than 30 cm dbh relative to riparian zones. Both live and dead tree density was also higher in upland areas compared to riparian areas. Figure 11 shows mean tree density in riparian areas (3,375 trees/hectare) was lower than density of trees in upland areas (5,827 trees/hectare).

Figure 8. Relative Density of Tree Species in Riparian and Upland Areas in the Upper Foothills Natural Subregion.

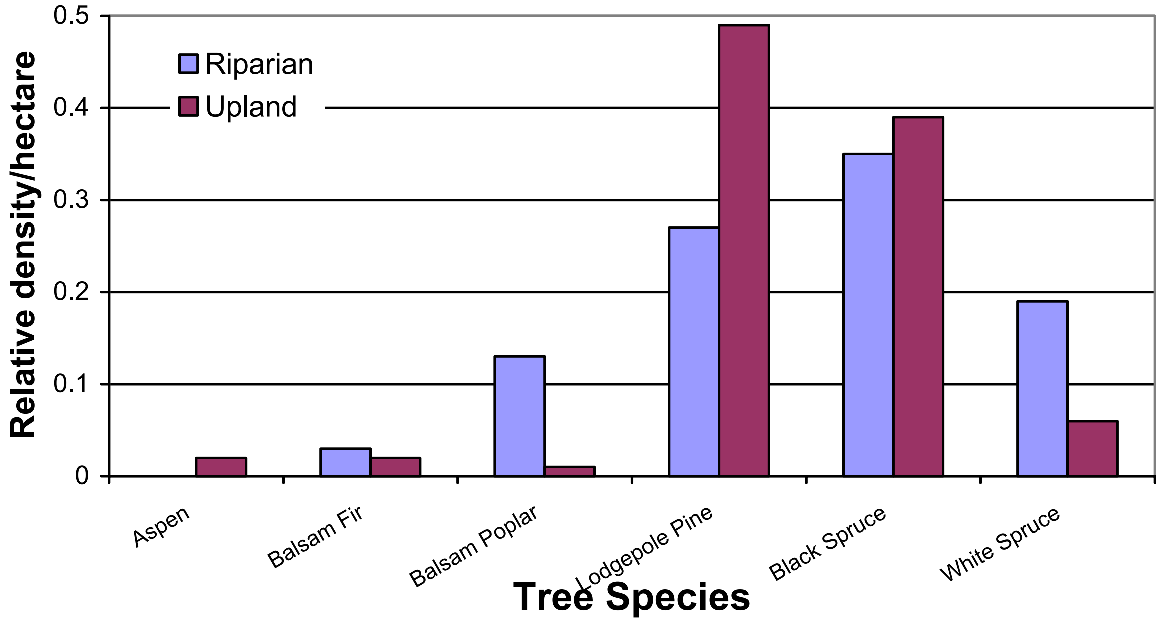


Figure 9. Relative Density of Tree Species in Riparian and Upland Areas in the Lower Foothills Natural Subregion.

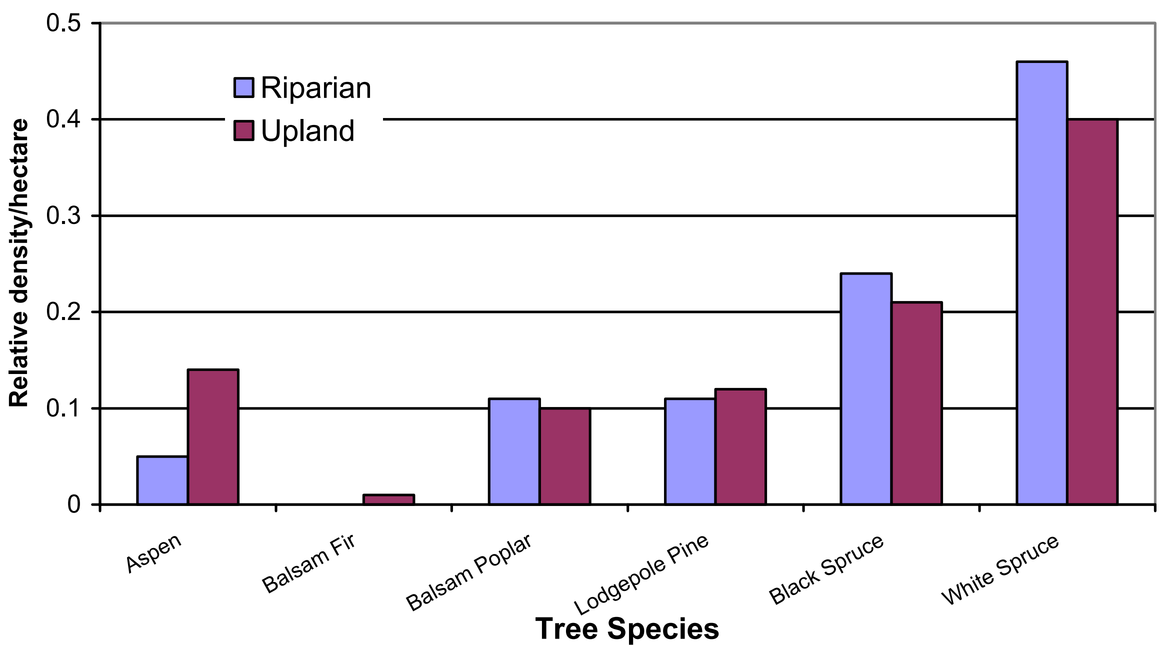


Figure 10. Density of Live Trees by Diameter Class per Hectare.

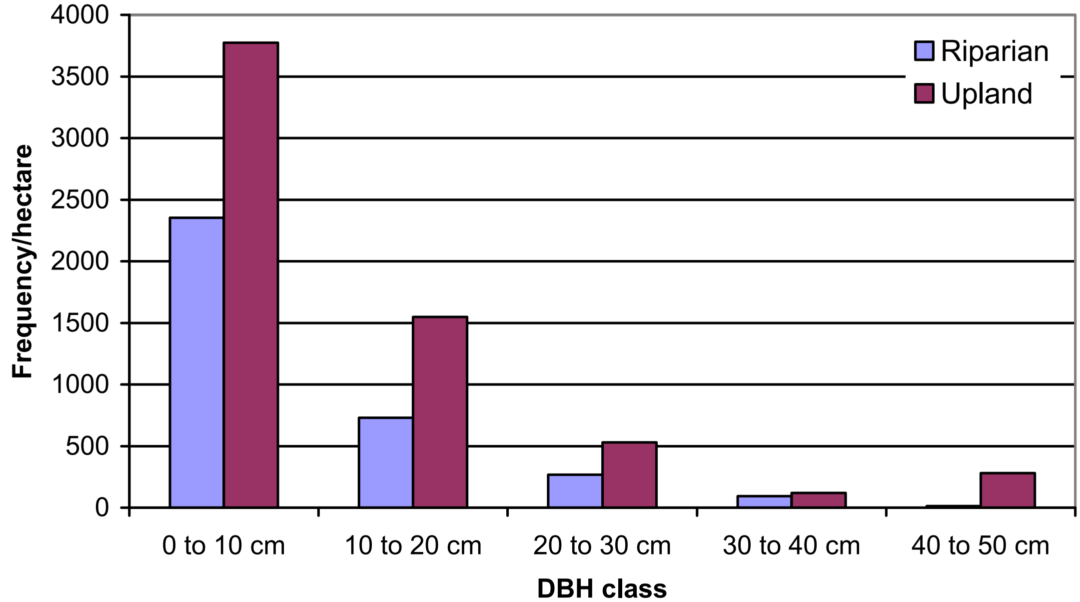
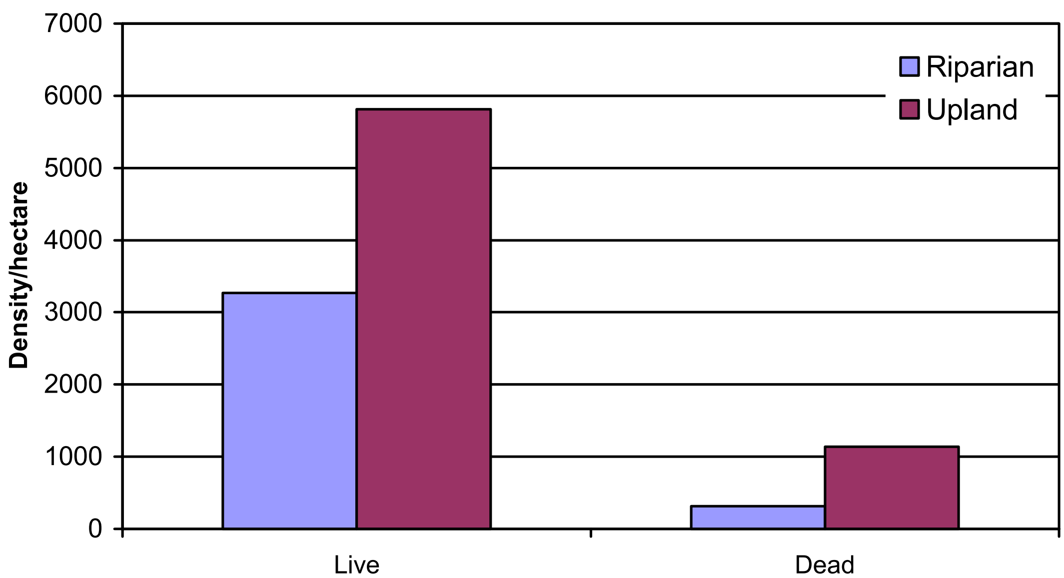


Figure 11. Density of Live and Dead Trees in the Riparian and Upland For all Transects.

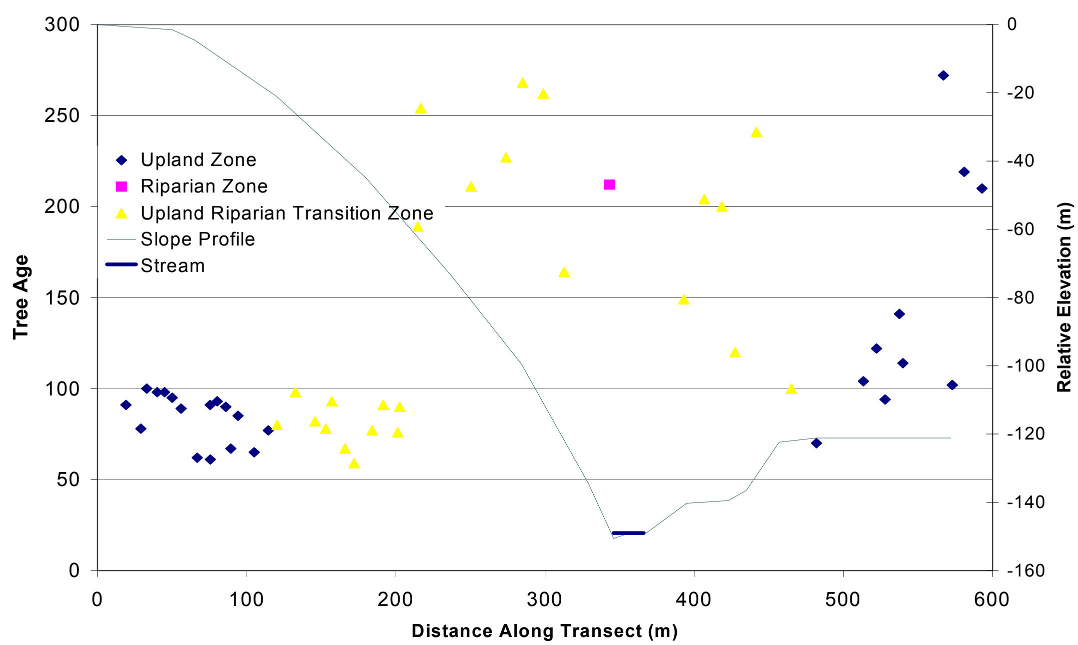


The stand level summaries of the differences between the composition of riparian zones and upland areas are in general agreement with our landscape level summaries. Pine and aspen are less likely to be present in riparian zones, although we did not find a dramatic increase in White spruce. We also found that tree density is lower in riparian zones, and there are fewer smaller stems. Based on this knowledge, it is not difficult to see how these differences might be interpreted to be due to differences in disturbance type, frequency, or severity.

Question 2. Do fires tend to stop at creek boundaries, and if so, why?
This is a more complex question than we asked at the sub-landscape scale above. Using field data this time, we used the two-sample Kolmorgorov-Smirnov goodness of fit test to determine whether the tree age distribution of the upland and riparian areas are similar on each transect. The main disadvantage of this test is that it gives exact results only if the underlying distributions are continuous and the sample sizes are large. Our data are discrete, although in most cases our sample sizes generally appear to be adequate. In most cases, the test confirms what was obvious from the raw data. For example, in Figure 12, a fire approximately 100 years ago clearly stopped near the Cardinal River within a stand that at the time would have been approximately 170 years of age.

Our tests confirmed that fires stopped in the riparian area in 11 of 56, or on 20% of the transects we sampled. Unfortunately, we had no means of comparing this to an “expected value”, since the only other data we had on fire edges was at a much coarser scale. Thus, we cannot say whether or not 20% was more or less than we would have expected under neutral (no effect of riparian zones on fire boundaries) conditions, but we suspected it was higher based on our sub-landscape edge analysis results. However, the details of which fires did stop at the riparian zone is worth exploring further.

Figure 12. Example of a Fire-Stopping Event Conciding with a Creek



Based on the results from this analysis, we isolated the 11 transects where differences in age distributions between one of the upland sites and the other upland site and the riparian site was noted. We then tested the following biotic and abiotic variables for their relationship with the 11 transects: stream order, tree species composition, tree density, riparian area width, slope of transect and the riparian-upland transition zone, soil moisture, landform, and the Rosgen stream classification (Rosgen 1996). Spearman's rank correlation coefficient (SPSS 1999), Goodman and Kruskal tau (SPSS 1999), Fisher's exact test (MathSoft 1999) and ANOVA (SPSS 1999) were used to determine if there was a relationship between the fire behaviour class of a transect (*i.e.*, either the fire did or did not burn through the riparian zone) and the biotic and abiotic variables. Spearman's rank correlation coefficient provided a nonparametric measure of correlation between two ordinal variables. Goodman and Kruskal tau was used for nominal variables. Fisher's exact test is a test for independence between row and column variables in a contingency table. This test performs best when the number of counts is less than 200; in cases where the number of counts is greater than 200, the chi square test is preferable.

Of the variables tested, only a few showed any significant relationship to a fire-stopping event. Streams where fire did not cross the creek tended to have steeper slopes (>20%) in the riparian-upland transition area, and be of higher order (4 to 7). The transect shown in Figure 12 is an excellent example of both; the fire stopped while moving downhill towards a fairly large river (the Cardinal). Fires also tended to burn through sites on floodplain or fluvial origin slopes.

No relationships were found between a fire-stopping event, and tree species, tree density, riparian area width, moisture regime, or the slope of the transect, and no relationship was noted with the Rosgen stream classification. Figures 13 and 14 show the relative density/hectare of tree species in riparian and upland areas in the Lower and Upper Foothills natural subregions for sites where fires crossed the riparian area and sites where fire stopped at the riparian area. Although it appears that there is a difference in the relative density of some species (Balsam Poplar and White spruce for example), the variance in relative density between the fire behaviour classes was too high for the differences to be statistically significant.

Question 3. Do fires behave differently in riparian zones?

The next question we explored was whether or not fire severity changes through riparian zones, resulted in a higher than expected number of "veteran trees", which survived the last fire. This question logically follows from our discovery that riparian zones were generally wetter sites than the rest of the landscape. Wet sites meant changing fuel moisture conditions, and thus potentially different fire behaviour.

To test for veterans, we applied the same two-sample Kolmorgorov-Smirnov goodness of fit test on the age-class distributions of the riparian zones versus the upland zones, as described in Question 2 above. Recall that this test compared the age-class distributions of the upland areas with those of the riparian zones. This means that it identified not the presence of veterans, but rather a significantly higher proportion of veterans relative to the upland areas.

Figure 13. Relative Tree Density for Sites Where Fire Crossed and Did Not Cross the Riparian Areas in the Lower Foothills Natural Subregion

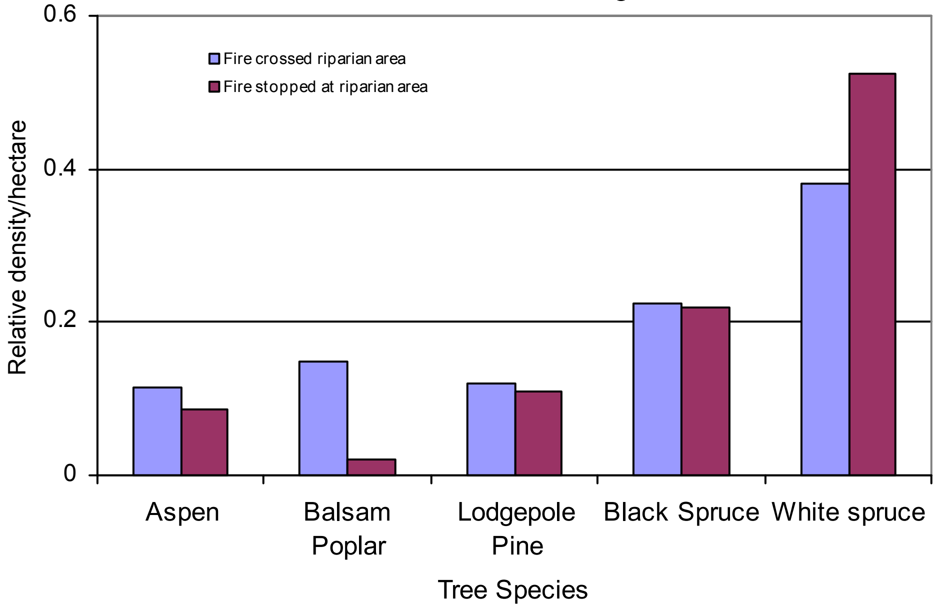
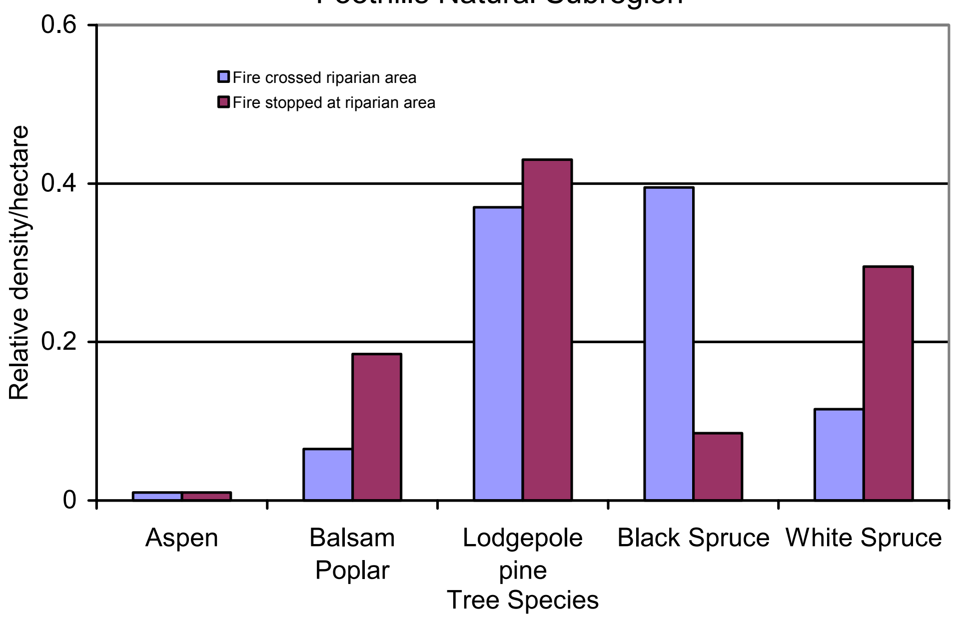


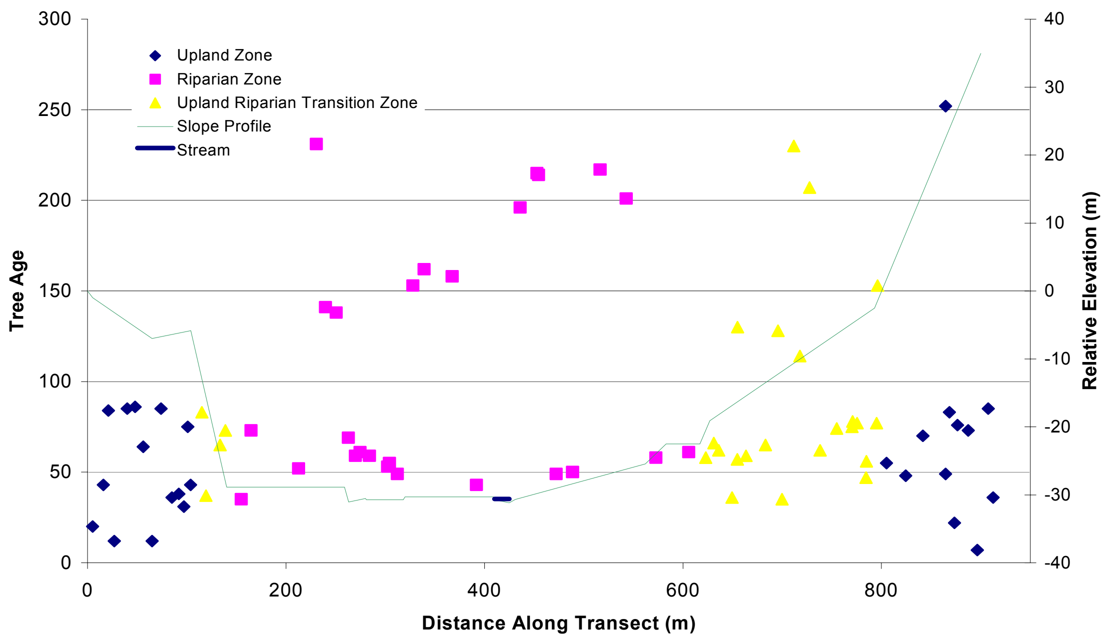
Figure 14. Relative Tree Density for Sites Where Fire Crossed and Did Not Cross Riparian Areas in the Upper Foothills Natural Subregion



The K-S tests revealed evidence of higher than expected densities of veteran trees in riparian areas in eight of the 56 (15%) of transects we sampled. Figure 14 is an example of one of those eight transects, where a fire approximately 80 years ago burnt through a riparian zone (*i.e.*, the fire did not stop), but left a large number of veterans that, at the time, were up to 150 years old.

This result *is* significant, because, unlike the fire-stopping events discussed above, we can reasonably conclude that the "expected value" of this test outcome is close to zero. In other words, if we ran 56 similar transects through the forest randomly, we would expect the number of significantly different age-class distributions of the middle third of each transect, compared to the other parts of the transect, to be close to zero. The fact that 15% of transects had more veterans than expected in riparian zones translates directly to an estimate of 15% of the riparian zones on the landscape having more veterans than expected.

Figure 15. Example of Significant Veterans

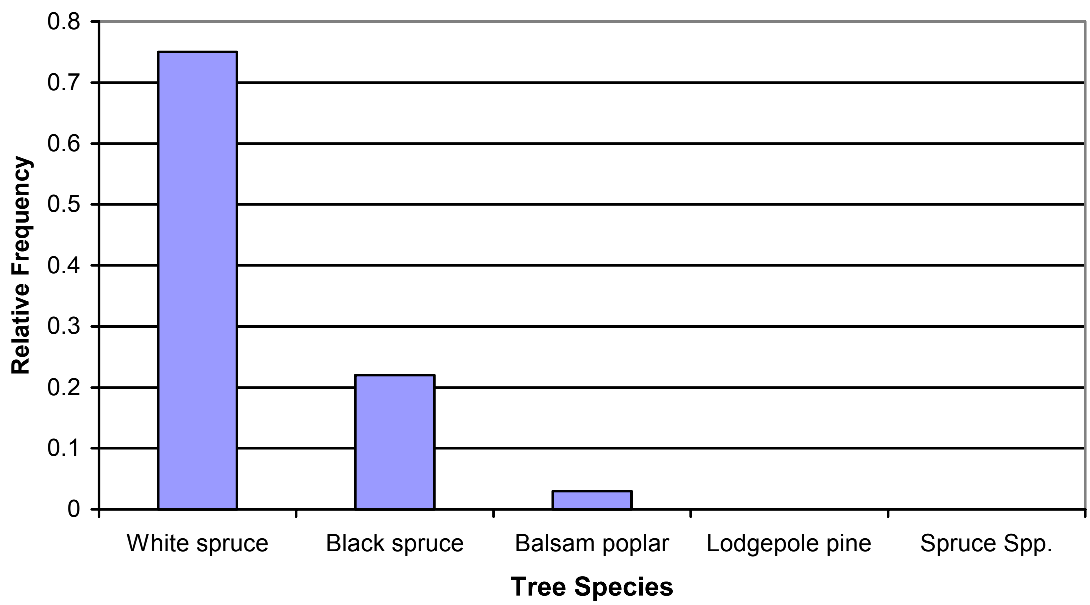


We then performed the same comparison tests as noted above (*i.e.*, Spearman Rank, Fisher's exact tests, Goodman and Kruskal tau, and ANOVA) to determine if there were any biotic or abiotic characteristics associated with higher than expected density of veterans. What we found was that riparian areas with veterans tended to be wider than riparian areas without veterans (199 m vs 74 m on average) and tended to be associated with higher-order streams (similar to our previous findings with the island remnant data) (Table 6). For example, the riparian zone in Figure 15 was over 400m wide along a major (stream order 5) river. We also found that sites with veterans in the riparian area tended to be dominated by the J ecosite, which was the wettest site found on the study area other than fens and bogs.

Table 6. Summary of Transects With Veteran Trees in the Riparian Area.

Transect Number	Stream ID	Dominant Riparian Ecosite	Riparian Area Width (m)	Strahler Stream Order	Leading Species in Riparian Area
6	Little Berland River	J	477	5	Lodgepole Pine
11	Embarras River	J	43	5	White spruce
14	McLeod River	E	148	6	White spruce
20	Antler Creek	J	28	1	Black spruce
25	Erith River	F	59	3	Black spruce
36	Tributary to Wildhay River	J	74	1	Black spruce
46	Sundance Creek	I	305	3	Black spruce
54	Athabasca River	J	460	6	White spruce

Figure 16. Relative Frequency of Veteran Tree Species.



The dominant tree species in the J ecosite in the Lower Foothills is Black spruce with smaller amounts of white spruce often present. J ecosites in the Upper Foothills are dominated by white spruce with smaller amounts of lodgepole pine, black spruce, subalpine fir and balsam poplar present on many sites. It is thus not surprising that white spruce is the most common veteran tree species (75%), followed by black spruce (22%) and balsam poplar (3%) (Figure 15).

Question 5. Are there any other notable relationships between riparian zones and fire?
During our comparison of transect age-class distributions, we noted that 11 of the 56 sites (or 20% of our samples) had higher than expected levels of younger trees in riparian zones. For example, Figure 17 is the transect age profile of a tributary to Beaver Creek showing a fire that burnt cleanly through a riparian zone, with no veterans. However, since the fire, ingress into the riparian zones has been steady and considerable. Sites with ingress tended to be small streams with steep slopes in the upland-riparian transition zone. Sixty-four percent of transects showing evidence of ingress were on first order streams and 88% of ingress transects had slopes of over 20% (Table 7).

Similar to veterans, white spruce was the most common ingress species (Figure 16), but just barely. Only 34% of ingress trees were white spruce, compared to 75% white spruce as veterans. Black spruce, balsam poplar and lodgepole pine accounted for about another 20% each as ingress species. Aspen, balsam fir and larch trees were not represented among ingress trees.

Figure 17. Example of Ingress

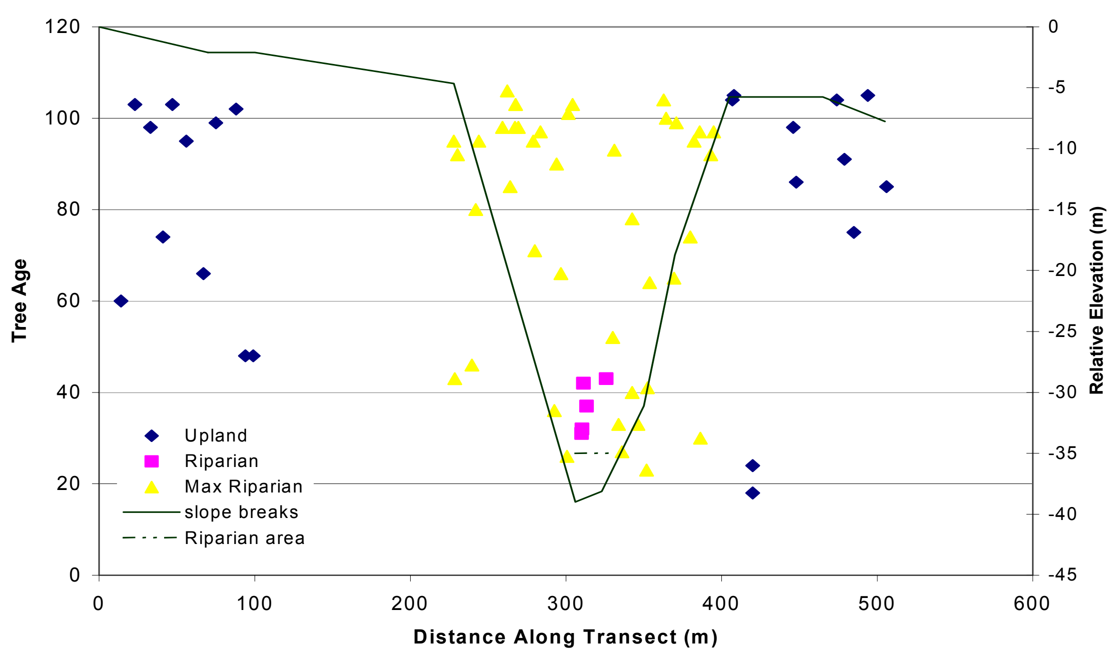
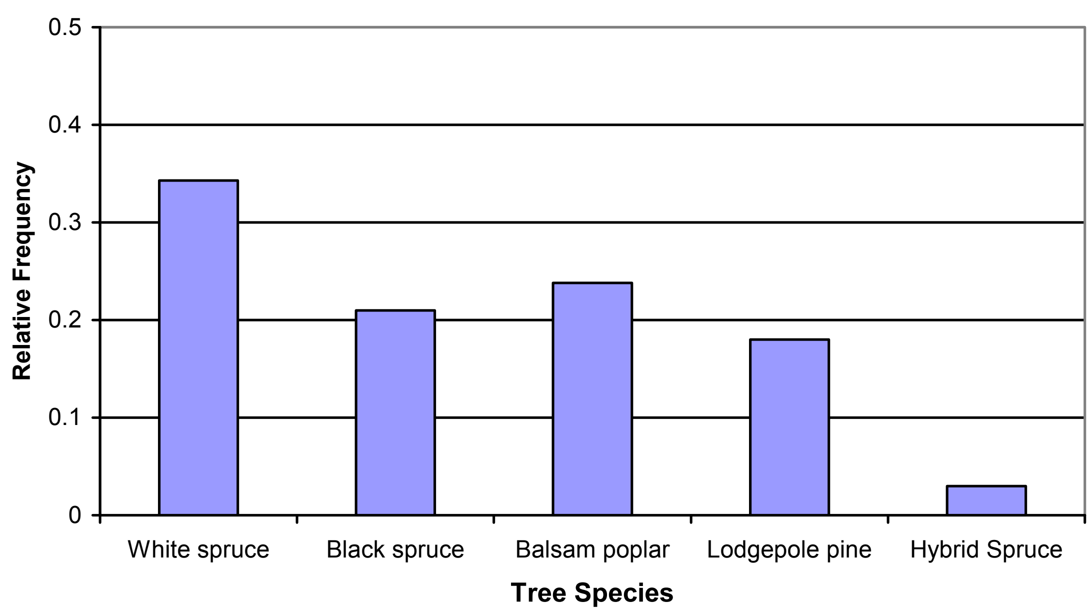


Table 7. Summary of Transects With Significant Ingress in the Riparian Area.

Transect Number	Stream ID	Riparian Area Width (m)	Strahler Stream Order	Leading Species in Riparian Area
3	Tributary of Beaver Creek	22	1	Black spruce
5	Tributary of Cabin Creek	68	3	Spruce
7	Tributary of Doctor Creek	20	3	Lodgepole pine
19	Tributary to Gregg River	53	1	Black spruce
31	Tributary of Lovett River	47	1	Black spruce
40	Wildhay River (Transect 40)	229	7	White spruce
42	Tributary of Wildhay River	27	1	Balsam poplar
43	Moberly Creek	264	5	Balsam poplar
44	Tributary of Moberly Creek	27	1	Lodgepole pine/Balsam poplar
50	Tributary of Little Sundance Creek	57	1	White spruce
52	Wildhay River (Transect 52)	165	1	Balsam poplar

Figure 18. Relative Frequency Ingress Tree Species.



Discussion

It is reassuring to find that the species shifts noted in our landscape-level analysis are similar to those found in our field data. Our field data shows that riparian zones tend to have less pine and less aspen than their upland counterparts. Furthermore, we found both live and dead tree densities are lower, and in particular the density of small trees (less than 30cm in diameter) is much lower in riparian zones. This further supports the notion that riparian zones are unique terrestrial habitat. The fact that we did not find significantly higher amounts of White spruce in the Lower Foothills (as the coarse-scale analysis did) may reflect the difficulties of stand photo interpretation in mixedwoods.

The fine-scale interaction of fire and riparian zones seems to be multi-faceted, and issue-specific.

Whether or not a fire crosses a riparian area seems to be associated with site topography and the width of the stream. Keep in mind that this analysis did not test whether or not fire tends to stop at creeks or rivers (which is covered more appropriately in the sub-landscape section of this report), but rather, for those fires that did stop, are there variables that may help us predict when or where. In this case, we found that fires tend to stop at riparian zones on sites with slopes greater than 20% in the upland-riparian transition zone, and/or wide rivers. Having said that, in most cases we are not able to attribute fire behaviour to the presence of either the stream or topography. On one site, the fire stopped at the creek, although the creek is only 9 meters wide and the topography is relatively flat. Furthermore, we found no relationship between fire behaviour in the riparian zone and tree species, tree density, soil moisture or site type, or even the Rosgen stream classification. In other words, fire behaviour in riparian zones is probably largely driven by fire weather conditions.

It is particularly surprising that there is no relationship to tree species. Although Bessie and Johnson (1995) suggest that fire behaviour should not vary strongly with species composition, Cumming (2000) demonstrates quite convincingly that forest composition influences fire behaviour at both the regional and local scales and that this influence persists even under extreme weather conditions associated with large fires. This remains an important question, and could perhaps be addressed with a larger sample of transects dominated by deciduous species (only eight of our transects were dominated by deciduous species in the riparian zone).

We also found evidence that about 15% of our riparian zones have higher than expected levels of surviving veterans. We can only surmise that this finding is due to a combination of changes in site conditions, and tree species composition and tree density. Recall that riparian zones are wetter, have a lower density of trees overall, lower density of small trees (as ladder fuel), and lower proportions of pine. Presumably, these factors combine to create higher fuel moisture and less continuous fuel both vertically and horizontally. This deduction is supported by our analysis of variables related to the presence of veterans, which suggests that veterans tend to occur on wetter sites, in wider riparian zones or higher-order streams. Recall that our island remnant results also demonstrated a positive relationship between higher-order streams and riparian island remnants.

Finally, we were surprised to find a third category of age-class differences in our field data. The presence of higher than expected levels of ingress was found on 20% of the transects, and those with ingress tended to be small stream orders and steep riparian-upland transition zone slopes. Although unexpected, this finding was significant because it suggests that fire is a mechanism by which riparian zones are "cleaned" of understory trees. It was not difficult to imagine a fire burning through every 100 years or so (which is close to the average for the foothills landscapes – See Andison 2000), killing all of the smallest trees and leaving only larger ones as veterans. Yet we have already noted that natural levels of tree densities were lower in riparian zones relative to upland forests. In other words, disturbance in riparian zones may be maintaining a part of the unique habitat characteristic of riparian zones.

Part 3: PUTTING IT ALL TOGETHER

We were fortunate to be able to consider the interaction between riparian zones and forest fire activity on such a wide range of scales. Two distinct pattern possibilities have emerged; changing burning conditions through riparian zones, resulting in different survival rates, and localized fire-stopping events.

The test results of changing burning conditions through riparian zones were mixed. At the very coarsest scale, we could find no significant relationship between fire and the survival of trees (from fire) in or near riparian zones. There was no indication that either overall age-class distributions or the percent of older forest in riparian zones were any different than those of the rest of the landscape. We did find evidence of appreciably less old forest in riparian zones of the Lower Foothills area, which we hypothesize may be indicative of historical "tie-cutting" in that area.

On the other hand, we did find evidence that very small patches associated with riparian zones were likely older than the rest of the landscape. The island remnants analysis suggested that unburnt island remnant patches tended to form at riparian zones in greater proportions than expected (relative to the rest of the landscape). The landscape analysis understandably did not pick up this relationship because the scale of that data was too coarse. The data we used for the island remnant analysis was interpreted using photos taken within two years after each fire, and designed specifically to identify islands of various types at high levels of resolution. This distinction between fine and coarse-scale influence of riparian zones on fire behaviour was consistent with our buffer width analysis in the island remnants study, which suggested that the relationship between the two diminished markedly as the width of the buffer zone increased, and was essentially non-existent at 200m.

Our conclusion that island remnants tend to form in riparian zones is supported by the field transect data. Recall that 15% of our transects have veterans in higher than expected proportions compared to the rest of the landscape. The connection between the two is logical; where we now have veterans many decades after the last fire, there were once island remnants. We just studied them at opposite ends of their life span. However, one important difference is that our field study only found those islands that have *survived* the last 100 years. So either all riparian islands survive for extended periods, or the original proportion of islands (*i.e.*, veterans) in riparian zones is even higher than 15%. Our island remnant data does not suggest a significantly larger proportion of islands in riparian zones, so this would seem to suggest that riparian islands might in fact be long-lived. Furthermore, we have found a lower proportion of dead trees in riparian zones, suggesting that survival of stems – and by extension perhaps island veterans – is higher. On the other hand, we found that riparian islands tend to be of the high-survival type, so these islands could still experience limited mortality and be recognized as an "island" 100 years later. In any case, this is a question worthy of further study.

The field data also provides valuable detail on where island remnants are even more likely to form; namely at wide streams and rivers, on wetter sites, and at streams of higher-order (*i.e.*, larger). We also know that White spruce is heavily favoured as a veteran tree species in riparian island remnants.

Although these results are purely descriptive (*i.e.*, cannot be verified statistically with a sample size of 12), there is also evidence that fires in more topographically complex areas, such as the Subalpine and parts of the Upper Foothills, may be more likely to form islands in riparian zones than simpler landscapes such as the Lower Foothills. Considering the high proportion of steep, complex, and toe slopes in Subalpine landscapes relative to the other areas in this study (Table 2), the suggestion is logical. Certainly, the idea that fire becomes increasingly responsive to topography in more complex landscapes is not a new one.

With respect to fires "stopping" at riparian zones, we did find a weak, but fairly consistent relationship between the coincidence of creeks and rivers, and the edges of fires in the sub-landscape study. So we have evidence of fire-stopping events at or near creeks in higher frequencies than expected relative to the rest of the landscape. This finding is important for disturbance design (*i.e.*, defining disturbance boundaries), but also dovetails well with our field study. Recall that we could not state whether or not the 20% of the transects we found in which fires stopped is significantly different than expected. However, the sub-landscape analysis suggests that this number is in fact slightly higher than expected. The field data also adds some significant detail to the edge-forming discussion by suggesting that the most probable conditions for fires forming edges at riparian zones are at wider streams, and on steeper slopes.

It is worth noting that our Meso-Scale Patterns and Processes study within the FMF Natural Disturbance Program will also address the relationship between fire edges and riparian zones in combination with other biotic and abiotic factors (such as topographic complexity). However, that particular study goes far beyond riparian zone analysis alone, and we have decided to report those results in a separate report.

In summary, there is ample evidence to suggest that fire behaves at least marginally differently within riparian zone habitats compared to the rest of the landscape. However, the results also suggest that predicting where or when a particular fire might stop, or leave an island within a riparian zone is not likely to be successful. Most riparian zones burn as often, and as severely as their upland counterparts, and local fire weather conditions are in all likelihood the main variable determining their fate. In other words, disturbance by fire is a common, and therefore presumably important process for all riparian zones in the study area.

Part 4: WHAT DOES IT ALL MEAN?

Despite the tentative nature of many of the results, there are several recurring themes. Keep in mind that these conclusions relate only to the forest ecosystems in the foothills of Alberta. Whether or not, or to what degree any or all of these statements apply beyond this region is unknown.

First, clearly riparian zones are unique terrestrial habitat in and of themselves. In other words, aside from the aquatic component of riparian ecosystems, riparian zones are deserving of some degree of special consideration. Add to that the fact that they serve as the interface between the terrestrial and aquatic systems, and riparian zones become even more crucial. In other landscapes, riparian areas provide a disproportionately high amount of wildlife habitat for the area they occupy on the landscape. In the southern United States, 82% of all species of birds breeding annually in northern Colorado occur in riparian vegetation and 51% of all species in southwestern states are completely dependent upon this vegetation type (Knopf et al 1988). The high value of riparian areas in providing habitats to other vertebrates has been documented by other authors (Brode and Bury 1984, Cross 1985, Bury 1988). Although the degree may differ, we have no evidence so far to suggest that riparian zones are any less important in the Foothills of Alberta.

Second, the overlapping nature of the various research studies and various scales presented in this report represent the difference between poorly supported results, and finding weak relationships. There are no doubt many useful relationships reported in this document concerning suggestions of how best to manage riparian zones at various scales, and most of those relationships can be traced back to the unique characteristics of riparian zones. However, we can say with a fair degree of confidence that the nature of the relationship between fire and riparian zones is largely controlled by random variation (*i.e.*, probably local fire weather). If or where fire either stops at or before a riparian zone, or leaves islands (or veterans) can only be weakly predicted by biotic and abiotic features of a site or of the greater landscape.

Third, and following logically from the previous conclusion, disturbance by fire is, and always has been, an integral part of riparian zones. Although there are some weak tendencies towards fire stopping or leaving veterans, there is no evidence that riparian zones on these landscapes act as fire refugia or "safe sites". In other words, if a riparian site did manage to survive (in whole or part) one fire, chances are that it will not survive the next one. Similarly, there is little chance that a particular riparian zone will coincide with more than one fire edge over several hundreds of years.

This brings us to our fourth and last conclusion; that disturbance by fire in riparian zones is actually a necessary element or process. This study noted higher than expected levels of continual regeneration, or ingress, in riparian zones. It is not difficult to conclude that fire is responsible for controlling ingress, and thus maintaining part of the unique nature of riparian habitat. Similarly, others have noted the role that fire plays in maintaining important processes within riparian zones. On the terrestrial side, trees and coarse woody debris provide habitat for other plant species, vertebrate, invertebrate and decomposer bacteria and fungi and play a crucial role in energy flow and nutrient cycling (Harmon et al. 1986). In the aquatic environment, fires contribute to water chemistry and fluvial processes and supply woody debris to facilitate sediment storage, dissipate streamflow energy and affect channel morphology by creating channel complexity (Grizzel and Wolff 1998). In the end, any "special management consideration" for riparian zones should include maintaining the natural disturbance regime.

Part 5: EMULATING NATURAL DISTURBANCES IN RIPARIAN ZONES: THE DILEMMA

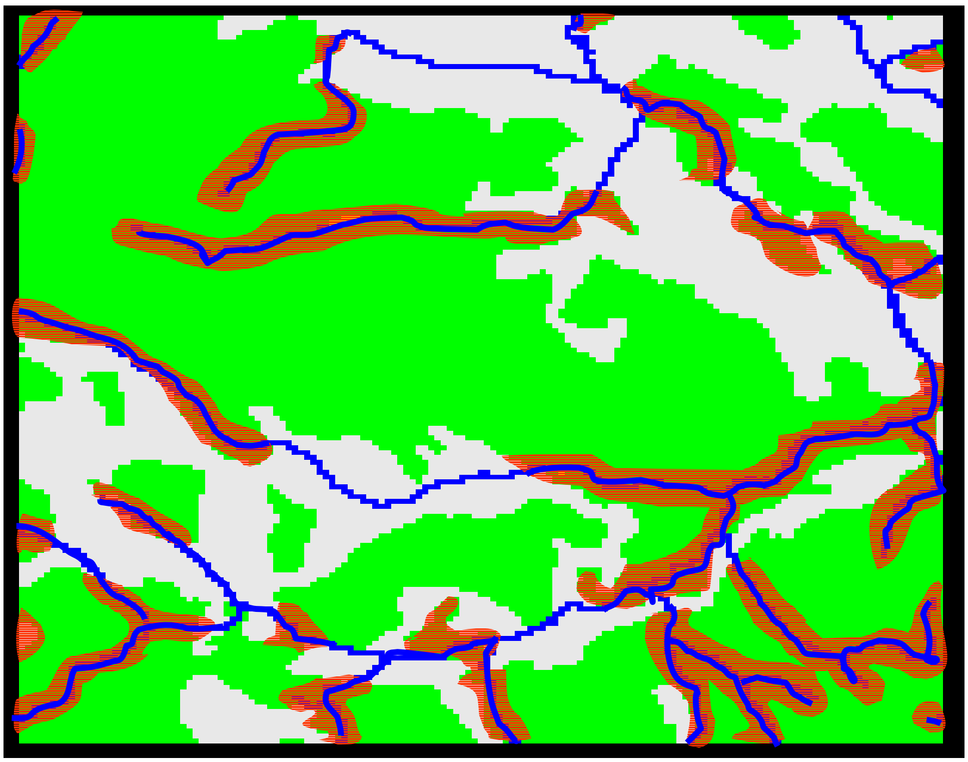
There are no easy answers when it comes to the decision of how to manage riparian zones. In fact, the management of riparian zones may be the most challenging issue of the day.

On one hand, the universal protection of riparian zones from disturbance (through the use of buffer zones and fire protection) will inevitably lead to changes in the short and long-term structure, composition, and dynamics of both the terrestrial and aquatic systems therein. For example, a landscape simulation exercise on the Weldwood FMA demonstrated that applying the current stream buffer rules to the landbase would inevitably lead to entirely "unnatural" (*i.e.*, beyond the natural range of variation) levels of old White spruce-dominated forest (Weldwood of Canada Ltd. 2000). In other words, because the White spruce-dominated forests tend to be in riparian zones, and they are all protected from disturbance, the percentage of old White spruce-dominated stands keeps increasing.

The universal protection of riparian zones raises several concerns. First, the proportion of *young* riparian forest declines. Presumably young riparian forest is no less important as habitat than old riparian forest. Second, the amount of old riparian forest continues to rise. It is not difficult to imagine that such areas may create - quite literally - lightning rods for natural disturbance risk (through either fire, insects or disease). Third, protecting riparian zones may inadvertently focus old growth efforts to these areas. For example, the overall targets for old growth in the BC Biodiversity Guidelines (BC MoF and MoE 1995) can be met simply by maintaining all creeks permanently in buffers (Andison and Marshall 1998), which means there is no obligation to maintain *any* upland old growth habitat. Fourth, the ecological functions that fire provides to both the terrestrial and aquatic systems previously outlined will not be maintained. Ingress will not be controlled, coarse-woody debris will not be sustained, and habitat opportunities will not be created (as they were historically). Finally, by restricting our disturbance activities to only the upland portion of the landscape, we may severely limit our opportunities to otherwise emulate more "natural" disturbance patterns. For example, Figure 18 represents a 5,600 ha operating area in the Upper Foothills of the Weldwood FMA. With standard riparian buffers (shaded areas) it is not difficult to imagine that opportunities for creating larger disturbance events become much more limited. In fact, it is possible that on more complex landscapes, the net effect of stream buffers results in fragmentation.

On the other hand, some harvesting activities in riparian zones have already proven to be detrimental to soil and water quality, as well as aquatic habitat. This results mainly from the use of mechanical machinery within riparian zones, potentially creating soil compaction, rutting, and erosion, but is also caused by the removal of biomass. As we understand it, trees form important structural features with many ecological functions in both terrestrial and aquatic systems. Removal of this material (or removal of recruitment trees) would likely destabilize the channel and increase sediment export from the system (Grizzel and Wolff 1998), as well as diminish the terrestrial habitat opportunities.

Figure 18. Example of an Operating Area with Universal Stream Buffer Restrictions.



It is not the purpose of this report to pose solutions to this dilemma, but rather to help define the bounds of it. Specifically, considering the number of independent variables tested against fire patterns in riparian zones, and the luxury of having several large, high quality datasets, the *lack* of relationships identified – including the Rosgen stream classification system – is telling. This is perhaps the most important finding of all, and can be viewed as either a problem or an opportunity. In any case, this research focuses only on the terrestrial side of the equation, and if nothing else, it is now clear that defining rules based on the needs of only one part of the ecological system is inadequate. This research will hopefully contribute to the solution of the riparian dilemma by providing a common foundation of understanding of the interaction of the terrestrial component of riparian zones and natural disturbance.

Part 6: LOOKING AHEAD

As with all good research, we have answered some questions, and created a few new ones. In most cases, ongoing research at the FMF Natural Disturbance Program is dealing with these questions in one form or another.

The relationship between riparian zones and non-forested areas could be explored in much greater detail. The fact that the two are so highly correlated with each other suggests that spatial analysis beyond the use of simple buffers is required. Edge-forming analysis involving riparian-related non-forested areas would also be worthwhile. Our Meso-Scale Patterns and Processes study is addressing both of these questions. Given that the influence of riparian zones on fire behaviour seems to be localized in nature, it would be interesting to test the interaction of the presence of riparian zones with other biotic and abiotic factors, such as slope, slope position, soil moisture, stand age, stand type, and so on. The potential relationship between topographic complexity (i.e., Subalpine landscapes) and the tendency of riparian areas to form islands is particularly attractive. Our Meso-Scale Patterns and Processes study is addressing this question specifically.

Both the field transect and the island remnants datasets could be expanded to improve our sample size and the strength of our and fine-scale tests results.

We found evidence to suggest that island remnants have survived for well over 100 years in riparian zones. This raises several important questions, including the relative level of “survivability” of other types of island remnants, and more generally the dynamics of different types of island remnants over time. Our natural disturbance research will be studying island remnants in much greater detail using the data discussed in this report, but we have no plans to deal with island dynamics over time thus far.

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GLOSSARY OF TERMS

The following is a list of technical terms used in this document that are either uncommonly technical, or are used ambiguously. We define them here only for clarity.

Biodiversity - a qualitative feature of natural systems describing the numbers and types of different biological elements at different scales. Not the same thing as diversity.

Burn faction – a relative measure of flammability, or probability of burning for different parts of a forest landscape. Normally expressed as the average percentage burnt, per type, per year.

Crown fire - fire actively or passively reaches into the crowns of trees. Crown fires are virtually always associated with surface fires, but mortality can vary widely.

Cultural disturbance – Disturbances from anthropogenic sources only. (*e.g.*, harvesting, prescribed burning, road building).

Disturbance - any abrupt event that results in the destruction or damage of any part of the biota. Disturbances can occur at any scale.

Disturbance frequency - the probability that a specific area is disturbed in a given time period. Reciprocal of return interval.

Disturbance rate - the percentage of area affected by disturbance over a given period. In this case, the period was 20 years. Sometimes the reciprocal of fire cycle when expressed on an annual basis.

Disturbance regime - types, frequencies, periodicity, severity, and sizes of disturbances.

Diversity - the number (and sometimes the relative amounts) of different types of elements. Diversity is *one* element of biodiversity.

Ecological rotation – The number of years that forest stand-types generally survive intact before being disturbed from natural sources, or otherwise change form or function.

Fire behaviour - how, how fast, where, and what an individual fire burns. Contrast with Landscape fire behaviour below.

Fire cycle - the average number of years required to burn an area equivalent in size to the study area / landscape.

Fire intensity - the actual temperature at which a fire burns - as opposed to fire severity.

Fire refugia - a fine-scale area which has survived one or more fire events, and therefore tends to be older than surrounding areas of forest.

Fire return interval - the average return time of fire at a specific location. North-facing slopes may have longer fire return intervals than south-facing slopes.

Fire severity - the amount of damage or mortality caused by a fire. Not necessarily related to fire intensity.

Island remnant – A patch or clump of trees that survived the last stand-replacing disturbance event in whole or part.

Landscape - a mosaic of stands large enough to have identifiable large-scale (fire) behaviour emerge. The natural subregions are referred to as landscapes in this document.

Landscape fire behaviour - how, how often, where, and what fires burn – on average - over decades or centuries.

Meso-scale - the scale of an individual fire. Between stand and landscape scales.

Natural disturbance – Disturbances that originate from natural, non-anthropogenic sources. In this report, "natural" is usually used together with "historical" to describe disturbance processes, this allows for the inclusion of unknown levels of historical aboriginal activity.

Natural range of variability / variation – (NRV) Structural, compositional, and functional variation of an ecological system, at any spatial or temporal scale, predominantly (but not wholly) caused by natural disturbance regimes.

Non-forested - anything other than merchantable forest, including water, meadow, brush, rock outcrop, swamp, and under-stocked forest.

Patch - a contiguous area of the same type (defined by age, composition, structure, or other feature). Patches are not necessarily fires, since fires skip and overlap each other.

Pattern - any behaviour (spatial or temporal) that is not random.

Riparian zone – terrestrial area immediately adjacent to water bodies, creeks, rivers, or streams.

Seral-stage – Stand development categories that relate to structure and composition, but are often simply associated with broad age-classes. In this report we use four seral-stages; Young, Pole, Mature, and Old.

Surface fire - fires that burn along the ground, only occasionally "torching" individual trees. Tree crowns are usually unaffected.

Stand-origin map – map showing the year of the origin of the stand, or the date of the last stand-replacing disturbance event. Also often referred to as a time-since-fire map.

Veteran – An individual tree that survived the last disturbance event.