

Patch and Event Sizes on Foothills and Mountain Landscapes of Alberta

Alberta Foothills Disturbance Ecology Research Series
Report No. 4

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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 partnership dedicated to providing practical solutions for stewardship and sustainability on Alberta forestlands. What we learn will be:

- reflected in on-the-ground practice throughout Alberta and elsewhere in Canada, where applicable
- incorporated in forest and environmental policy and changes;
- widely disseminated to and understood by a broad spectrum of society.

This will be the result of a solid, credible, recognized program of science, technology, demonstration and outreach.

ACKNOWLEDGEMENTS

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The Foothills Model Forest (FMF) Natural Disturbance Program was the vision of two individuals; Hugh Lougheed from Weldwood of Canada Ltd., and Dan Farr, then with the Foothills Model Forest. Since then, the unflagging support of the FMF Natural Disturbance activity team is reflected in the thoroughness of the research, and quality of the data. I would like to thank Dan, Hugh, Gord Stenhouse (then with Weldwood), George Mercer, Al Westhaver and Dave Smith from Jasper National Park, Don Harrison and Herman Stegehuis from Alberta Sustainable Resource Development, Greg Branton from Alberta Newsprint Company, and Rick Blackwood, Mark Storie and Don Podlubny from the Foothills Model Forest for their perpetual faith and support. Also, many thanks to the FMF Board of Directors, and in particular Bob Udell, for their unrelenting belief in the Natural Disturbance Program.

The FMF Natural Disturbance Program was fortunate to inherit some exceptional raw age data thanks mostly to the vision and efforts of Jack Wright, formerly of Weldwood of Canada Ltd, and Gerald Tande, who did his graduate work in Jasper National Park. These data were complimented by the meticulous work of MP Rogeau who coordinated all of our outstanding stand-origin sampling and mapping. Kim MacLean was instrumental in putting together the island remnants database and some preliminary analysis. The massive GIS manipulations and conversions originally fell mostly on the capable shoulders of Carol Doering of The Forestry Corp for the Foothills East, and Helen Purves at Jasper National Park. More recently Christian Weik of the FMF has been instrumental in providing any and all forms of GIS support to our research program in general, and these projects in particular.

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EXECUTIVE SUMMARY

This fourth report in the FMF Natural Disturbance Program research series looks at size patterns over time and space for a) disturbance patches and events, c) old forest patches, and d) non-operating patches. The report represents an integrated synthesis of parts of two separate research projects under the auspices of the FMF Natural Disturbance Program. While the data, assumptions and analysis used in this study were fairly complex and specific, there are several general conclusions that emerged that are relevant to planning and monitoring.

First, we learned that the Alberta natural subregions provide a reasonable, ecologically-relevant basis for differentiating landscapes according to disturbance regimes and their impacts in Alberta. Disturbance, old forest, and non-operating patch size patterns are unique to natural subregions, and consistent with what we know about the natural and cultural disturbance history, and the ecology, topography, and climate of these landscapes. The effects of cultural activities on disturbance, old forest, and non-operating patch sizes are also landscape specific.

We also found that disturbance events are composed of one or more disturbance patches. So-called “natural pattern emulation” management systems should be differentiating between these entities at a minimum since their size distributions are distinct.

The size distribution of disturbance patches was fairly typical of fire-dominated landscapes. A small number of disturbance patches larger than 2,000, and in some cases over 10,000 hectares, historically dominated all five landscapes. The considerable influence of these large events on modern-day disturbance patch size distributions suggests that natural disturbances such as fire still play an important role on landscapes today. However, cultural disturbance activities in the foothills since 1950 have shifted this pattern considerably, and created a prevalence of disturbance patches between 10-40 hectares – regardless of harvesting history. This suggests that all forms of cultural disturbance create a single patch-size footprint.

In fact, a wide range of “cultural” disturbance activities are noted on the Model Forest landscapes. The biological impacts of short-term cultural disturbances such as harvesting are likely fundamentally different than that of medium to long-term cultural disturbance activities such as residential and recreational development, road building, and mining. It would be advisable to differentiate between them for planning and monitoring purposes.

We also learned that most of the old forest on a given landscape exists as large “patches” that a succession of fires has left behind. However, the vast majority of old forest exists as small residual “islands” that are spatially isolated by a single disturbance event. Cultural activities over the last 50 years have affected both types of old forest by fragmenting old forest patches, and not allowing for island old forest. Harvesting is the cultural activity having the greatest impact on patch size changes of older forest, but other non-targeted cultural activities are influencing older forest patch sizes to a high degree as well.

Mitigation efforts can allow for higher levels of old forest islands, but old forest patch fragmentation is going to be a landscape attribute for several decades to come due to the fragmentation of most merchantable areas of the working forest.

Non-forested patch sizes in the foothills are declining in such a way that suggests that non-selective cultural activities (such as road or seismic line building, mining, oil and well site installation or rural development) are completely eliminating very small patches, and fragmenting larger ones. The biggest threat to non-operating areas in the study area is the loss of entire patches to industrial and commercial (non-targeted) development.

Finally, disturbance activities of any kind have been severely curtailed in Jasper National Park over the last several decades. This means the total area of old forest has increased, which in turn means the opportunity for larger contiguous pieces of old forest increases. This has obvious consequences for natural disturbance risk, as well as habitat type shifts.

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 patch size patterns and dynamics. It is the largest, most substantial section, and includes descriptions of the results.

Part 3 is a discussion of patch size dynamics as they relate to each landscape.

Part 4 summarizes general conclusions and,

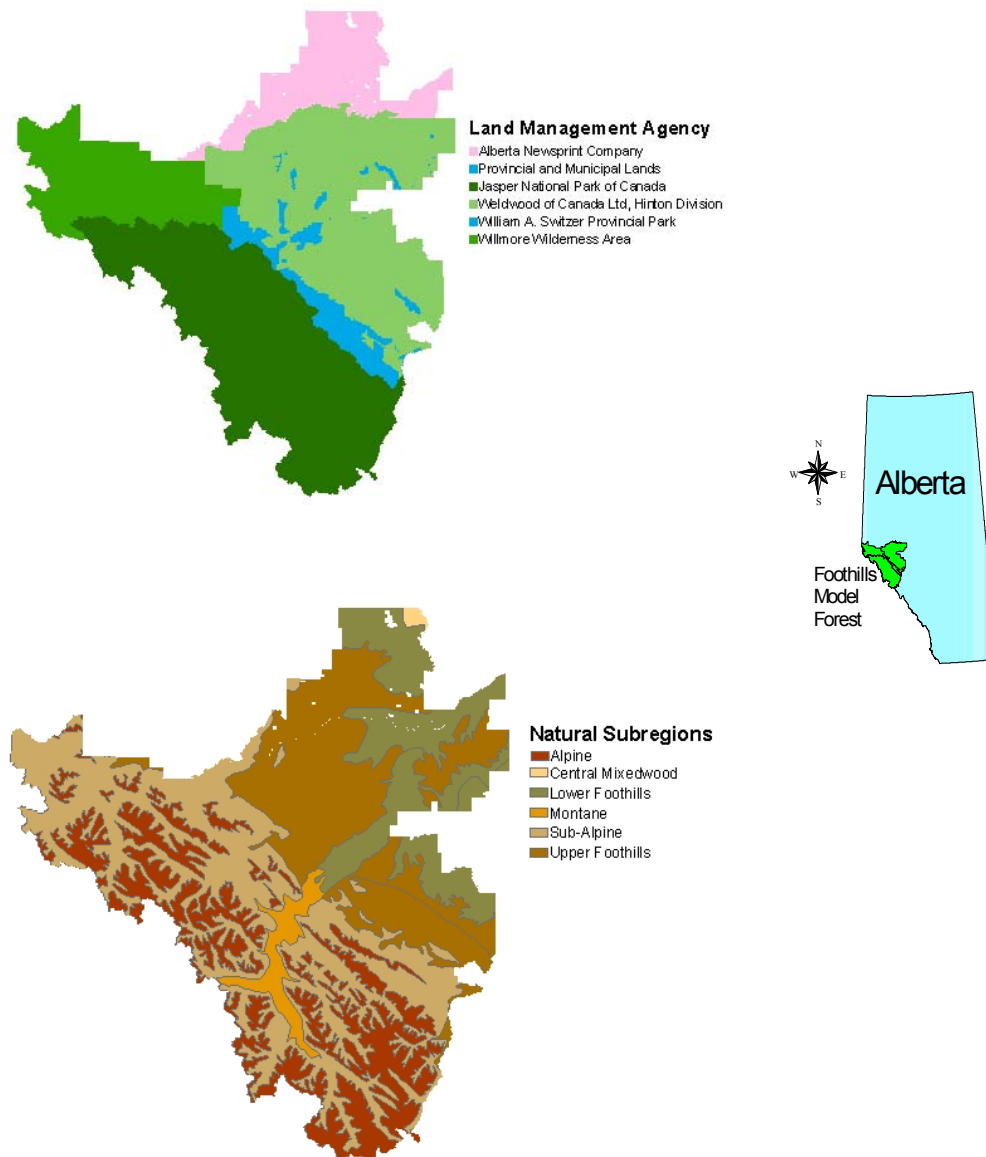
Part 5 provides interpretive tables.

Appendix A and B include the methods used to derive the patch and event size estimates used in Part 2, and to develop the tables in Part. 5

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 fourth 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.

Andison, D.W., and K. McCleary 2002. Disturbance in riparian zones in foothills and mountain landscapes of Alberta. Alberta Foothills Disturbance Ecology Research Series, Report No. 3, February, 2002. Foothills Model Forest, Hinton, Alberta.

Part 2: PATCH AND EVENT SIZES

BACKGROUND

The most apparent attribute of a forest landscape is its mosaic. From high in the air, forest landscapes are a collection of many different patch types. These patches are defined by age, tree species, density, and height, as well as non-vegetative features such as lakes, bogs, and meadows.

Some patch types are more enduring than others. For instance, most naturally occurring non-forested patches today were probably present in the same form 2-300 years ago. Forested patches tend to be more dynamic over time. Although tree species commonly found in foothills and mountain landscapes tend to have site preferences, the size, structure and composition of a given stand in any given year can vary considerably over several decades. This variation is largely due to an active and multi-dimensional disturbance regime, which includes fire, floods, wind-throw and insect and disease outbreaks. For example, the average time to burn an area equivalent to the size of the landscape (or the “fire cycle”) is between 61 and more than 180 years in various parts of the study area (Andison 1999).

The nature and size of forested patches is understandably of great interest and value to those interested in developing natural range of variation (NRV) emulation strategies under the auspices of ecosystem management. By understanding the dynamics of forest patches across a landscape over time, it is possible to capture and compare one of the most basic natural landscape attributes. Furthermore, it is possible to make a direct comparison between patches created by natural processes, and those created by cultural activity.

This section is divided into three sub-sections, representing the three main types of patches about which disturbance history research can inform us: A) disturbance patches and events, B) old patches, and C) “non-operating” patches, which includes all land not capable of producing merchantable timber. In each of these sections, this report explores and compares landscape patch dynamics over space and through time using a variety of data sources. Note that the main body of the report includes very little information on methods, data, assumptions, tests, or models. Those are provided in Appendices A and B.

Section A: DISTURBANCE PATCHES AND EVENTS

The distribution of natural disturbance sizes is the most apparent natural pattern for fire-dominated landscapes, and potentially the simplest to measure and compare. This section will compare and contrast the sizes and numbers of both disturbance patches and fire events from “natural” landscapes between the five main natural subregions in the study area. It is important to keep in mind that the natural landscapes I refer to here are based on a 1961 stand origin map, plus intensive mapping and tree aging to “fill in” areas of development such as the Hinton town site, mines, and a small number of fires and areas harvested during the 1950’s. Thus, the 1950 data in fact represents an estimate of the “natural” landscape as of 1950. (see Andison 1999 for details). Where possible, I will compare these figures to those of a culturally-altered landscape from 1995.

Historical Disturbance Patch Sizes

Historical (or “natural”) disturbance patch sizes were estimated using 1) historical fire occurrence data for six million hectares of the Alberta foothills, 2) the youngest patch data from the stand origin map for the Weldwood FMA and Jasper Park, and 3) highly detailed disturbance patch data from 25 historical fires from the foothills area. Please see Appendix A for details on how the final estimates of disturbance patch sizes were made.

Overall, the data reveal disturbance patch size distributions very typical of fire-dominated landscapes. In all five natural subregions, while most of the patches are quite small, the majority of the disturbed area is accounted for by a small number of very large patches. For example, on average, disturbance patches over 2,000 hectares account for 0.6% of the disturbance patches (Figure 3) but 43% of the disturbed area (Figure 4).

On the other hand, the high level of precision of the estimates is new information. In other similar studies of patch and fire sizes, the smallest patch size-class is <40 hectares, and in rare cases <10 hectares. The multiple datasets developed at the FMF allowed this size-class to be refined to a much higher level of resolution (see Appendix A). As it turns out, this added precision is highly relevant. While almost 85% of all disturbance patches are less than 40 hectares in size, the vast majority of those are less than two hectares. In fact, in all but one landscape, disturbance patches less than two hectares account for more than half of all disturbance patches (Figure 3). In contrast, disturbance patches 10-39 hectares only represent an average of 7.7% of all disturbance patches.

Figure 3. Estimated Disturbance Patch Size Distribution by Numbers in 1950

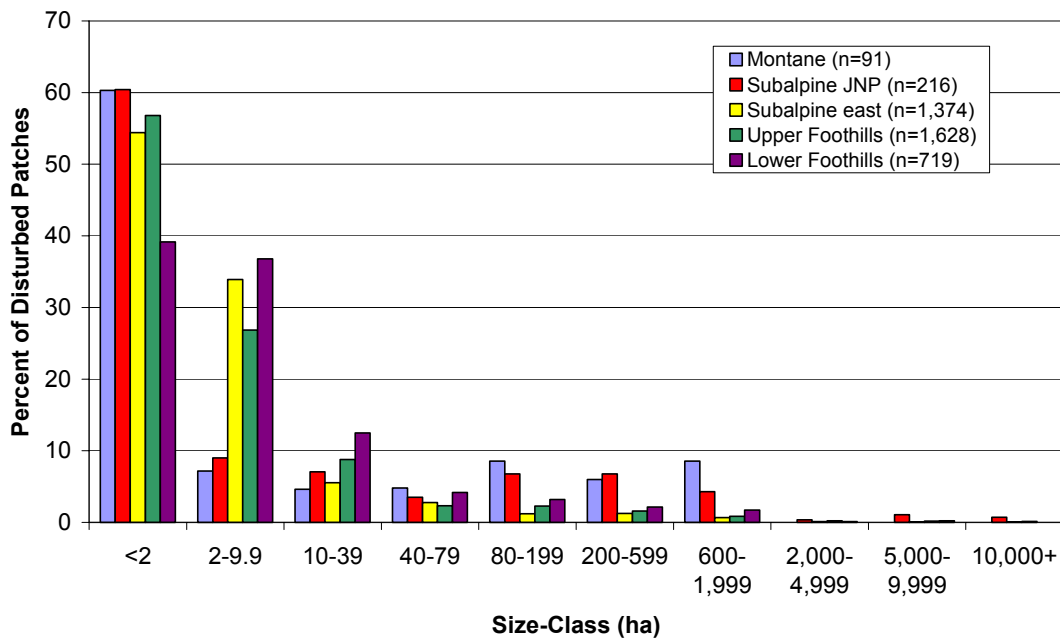
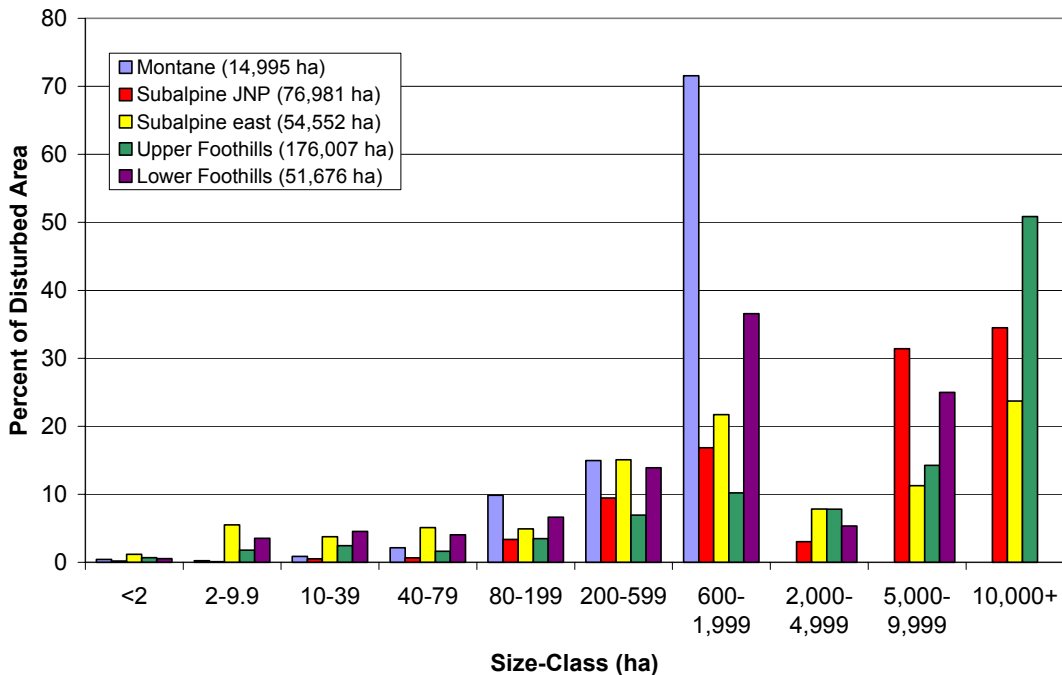


Figure 4. Estimated Disturbance Patch Size Distribution by Area in 1950



The data suggest that there are significant differences in disturbance patch sizes between landscapes. The largest disturbance patches occur in the Upper Foothills landscape, where more than half of the disturbed area is in patches greater than 10,000 hectares (Figure 4). Both Subalpine landscapes are also dominated by very large disturbance patches (69% and 43% of the disturbed area in patches over 5,000 ha for Subalpine JNP and Subalpine East respectively). However, the proportion of patches greater than 5,000 ha in the Subalpine JNP is 0.7%, compared to 0.1% for the Upper Foothills and Subalpine East. This means that in the Subalpine JNP, a relatively high number of patches represent a significant area in large patches. For the other two landscapes, a very small number of patches represent a significant area in large patches. The Upper Foothills and Subalpine East both have disturbance patches much larger than 10,000 hectares. In fact, the Upper Foothills has one over 50,000 hectares in size. The largest disturbance patch in the Subalpine JNP landscape is far smaller.

In contrast, both the Lower Foothills and Montane landscapes are dominated by smaller disturbance patches. The large area in disturbance patches between 600-2,000 hectares in the Montane landscape is particularly notable (Figure 3). Seventy-one percent of the disturbed area of the Montane is in patches between 600 and 2,000 ha – far more than any other landscape (Figure 4).

Historical Disturbance (Event) Sizes

Sizes of historical disturbance events were estimated using the same datasets as outlined above for historical patch sizes (see Appendix A for details).

As one might expect, the patterns of disturbance event sizes and numbers are similar to the numbers and sizes of individual patches. As with the disturbance patch data, most disturbances are very small, but most of the disturbed area is accounted for by very large disturbances (i.e., fires). However, a far greater

proportion of disturbance events are large relative to individual disturbance patches. For example, on average, 6.5% of all disturbance events are greater than 2,000 hectares (Figure 5) and they account for over 67% of the area disturbed (Figure 6). Recall from the previous section that individual disturbance patches greater than 2,000 hectares account for an average of less than 1% of all disturbed patches and only 43% by area. Similarly, disturbance events less than two hectares in size account for about 39% of all events, but disturbance patches less than two hectares account for over 54% of all disturbed patches (Figures 5 and 6).

Figure 5. Estimated Disturbance Event Size Distribution by Numbers in 1950

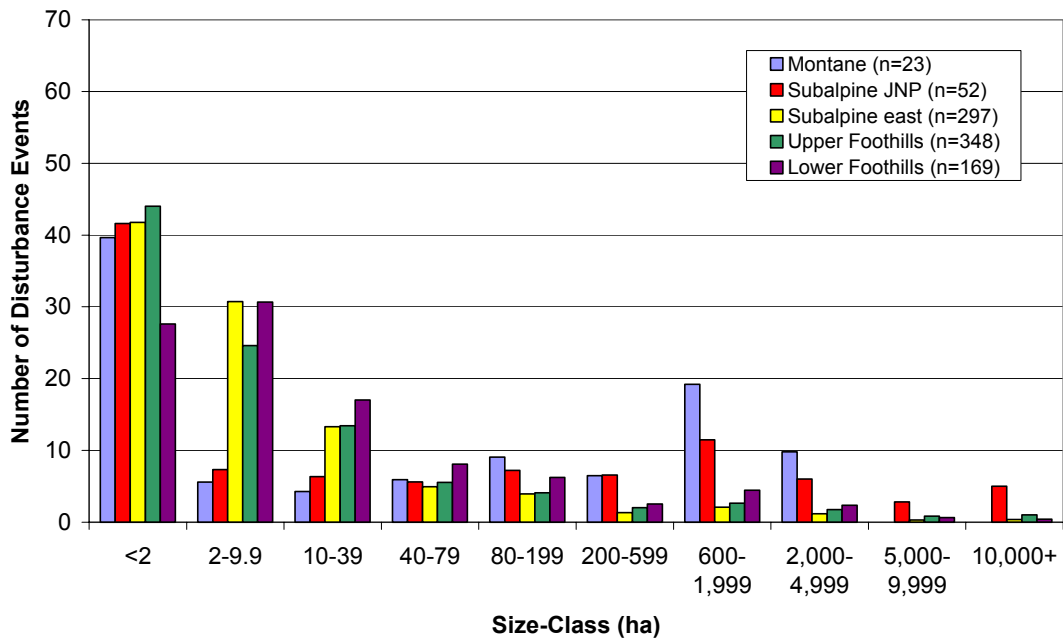
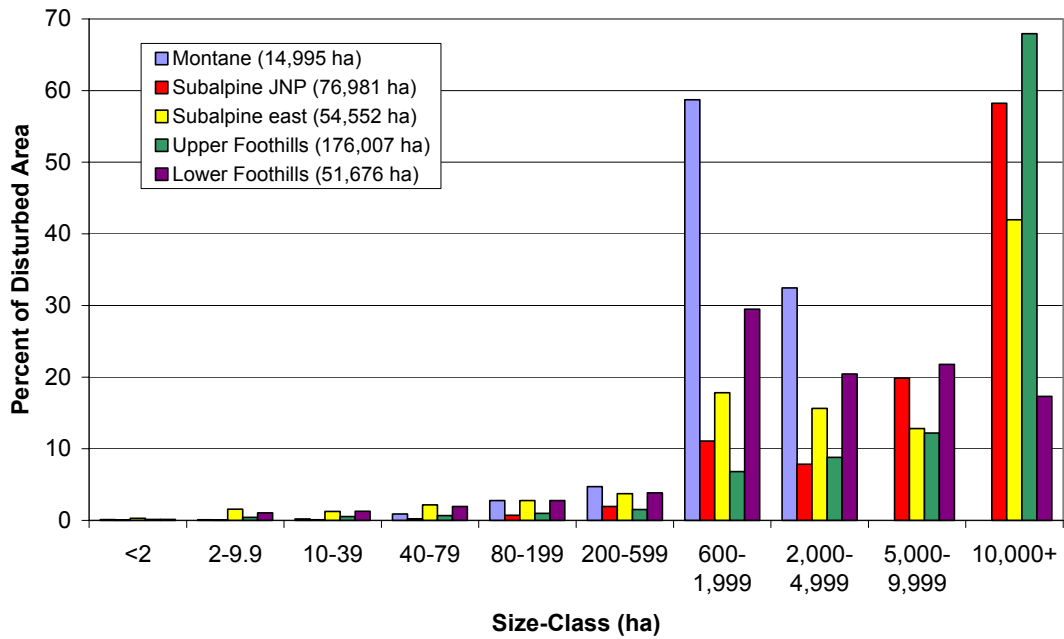
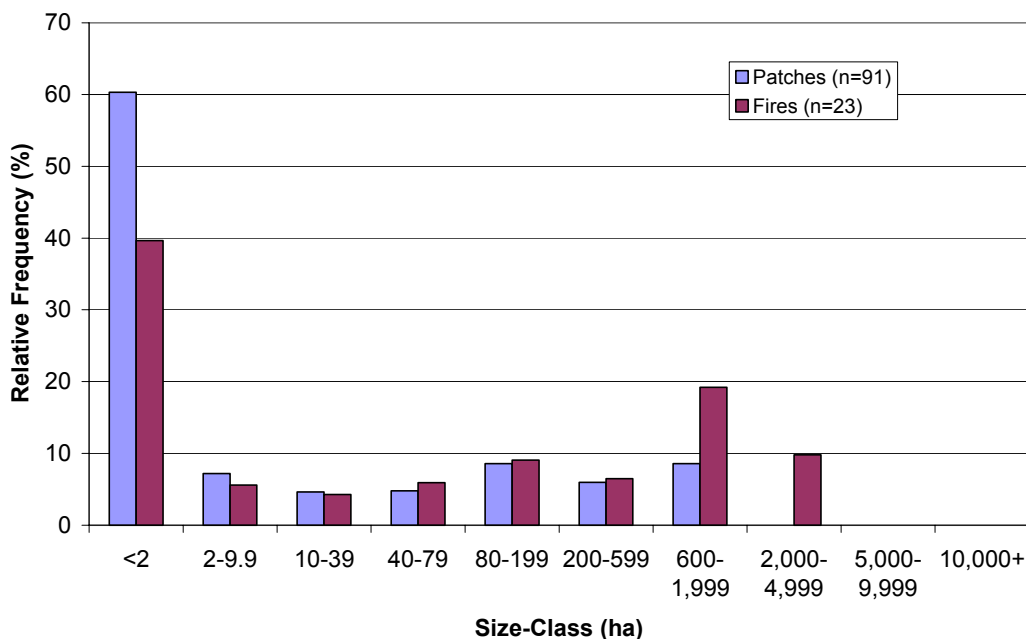


Figure 6. Estimated Disturbance Event Size Distribution by Area in 1950



An example of a direct comparison between disturbance patches and disturbance events for the Montane is shown in Figure 7. In this case, the percentage of disturbance patches less than two hectares is 20% higher than the percentage of disturbance events of the same size. Similarly, the percentage of disturbance patches larger than 600 hectares is about 9%, while the percentage of disturbance events greater than 600 hectares is almost 30%. Also note that although no individual disturbance patches are larger than 2,000 hectares, disturbance events larger than 2,000 hectares account for 10% of the area disturbed (Figure 7).

Figure 7. Comparison of the Number of Disturbance Patches With the Number of Fires in the Montane



These patch-event size differences reflect the manner in which disturbance patches cluster spatially to form disturbance events. More specifically, they reflect the manner in which fires burn across landscapes. The fact that there are proportionally more large events than there are large disturbance patches follows logically from the fact that events are comprised of patches, and one would be surprised if this were not the case. The fact that the ratio of small to large disturbance patches is higher than the ratio of small to large events means that events include a higher proportion of smaller patches. For example, I estimated that the Montane landscape has 70 disturbance patches less than two hectares in size, but only 10 of those are individual fires. The other 60 small disturbance patches are part of larger disturbance events.

Individual landscapes show disturbance event size patterns similar to those of disturbance patches. Over 2/3 of the disturbed area in the Upper Foothills landscape is associated with disturbance events larger than 10,000 hectares. The Subalpine JNP landscape has the next highest proportion of disturbances over 10,000 ha (58%), followed by Subalpine East (42%) and the Lower Foothills (17%). Individual disturbance events larger than 5,000 ha were not found in the Montane landscape (Figure 6).

It is interesting to note that the proportion of very small disturbance events is quite high in the Upper Foothills and Subalpine East landscapes. Events less than 40 hectares account for 86% and 82% of all disturbances in the Subalpine East and Upper Foothills Landscapes respectively – more than in any of the other landscapes. Yet, these are also the two landscapes with the largest disturbance events. This suggests that fires in these two landscapes have difficulty growing to any substantial size, but once beyond a certain threshold, chances are good they will be very large. In contrast, the Montane landscape only has 49% of all disturbances less than 40 hectares. The lack of large disturbances in the Montane suggests that once fires start in the Montane, their chances of growing beyond several hectares are much better, but they are unlikely to become very large.

In summary, although small fires are far more common, the large disturbance events are responsible for the vast majority of the area disturbed. While this was true for all five landscapes in our study, each landscape displays a unique historical disturbance patch and event size distribution. I also determined that the majority of small and very small disturbance patches are part of larger disturbance events, and only a small number of them are actually individual disturbances. The event-patch relationship will be explored in greater detail in the next FMF Natural Disturbance Program Report in this series.

Contemporary Disturbance Patch Sizes

With an estimate of historical disturbance patch and event sizes, it is now possible to evaluate more recent disturbance patterns. Over the last 50 years, we have been imposing a fundamentally different disturbance regime on foothills landscapes. Fires have been suppressed, and cultural disturbance activities include harvesting, road-building, well-site and mine development, clearing for agriculture and grazing, and residential and recreational development. The impact of this regime shift should be evident in the disturbance patch size distributions.

For such a comparison to be meaningful, I used the raw disturbance patch size data from the stand origin data. None of the “corrections” discussed in Appendix A were applied to these data. This is because I was unable to apply the same corrections to the raw disturbance patch data from the 1995 landscape snapshots I used for the comparison. Accordingly, these are technically comparisons of “young forest patches”, as opposed to “disturbance patches” (although I will continue to use the same terminology within the text as above to avoid confusion). In any case, the specifics are less important than the trends. The point of the exercise is to compare natural disturbance patch size trends to contemporary disturbance patch size trends.

The shift from large disturbance patches to small ones is dramatic in each of the three Foothills East landscapes (Figures 8-10). Disturbed patches less than 40 hectares in size in 1995 account for an average of 35% of disturbed area; compared to just over 2% in 1950 (Figures 8-10). For context, that 35% represents about 88% of the number of disturbance patches. In fact, of the over 17,000 disturbance patches in the 1995 dataset, only 192 are larger than 80 hectares, and 34 larger than 200 hectares.

Figure 8. Upper Foothills Young Forest Patch Size Distribution by Area

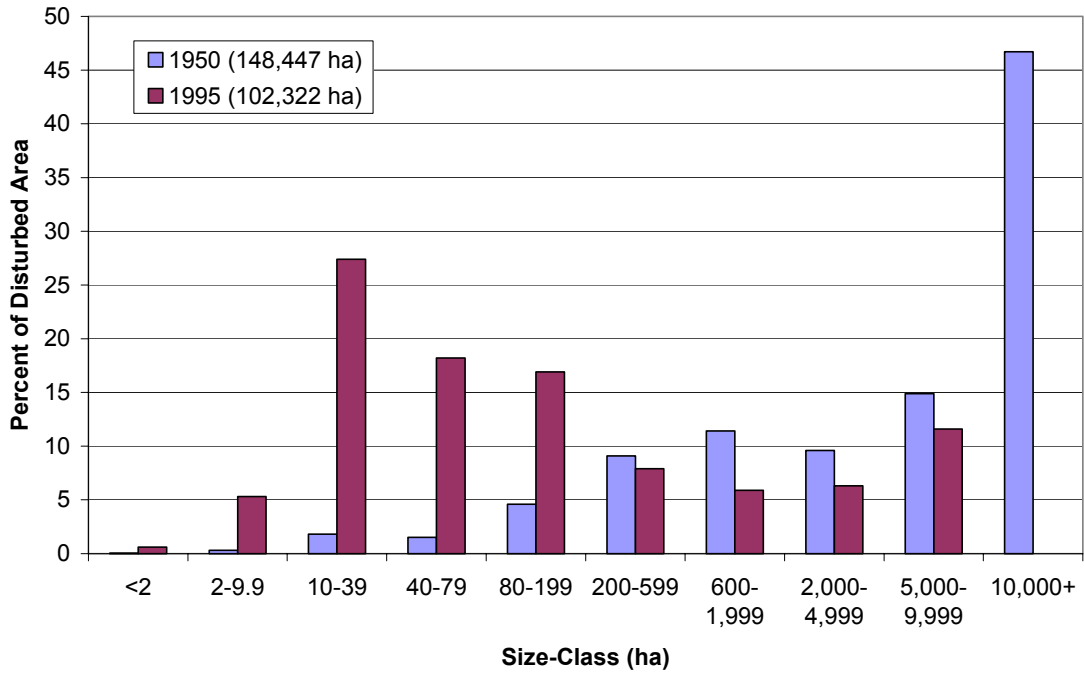


Figure 9. Lower Foothills Young Forest Patch Size Distribution by Area

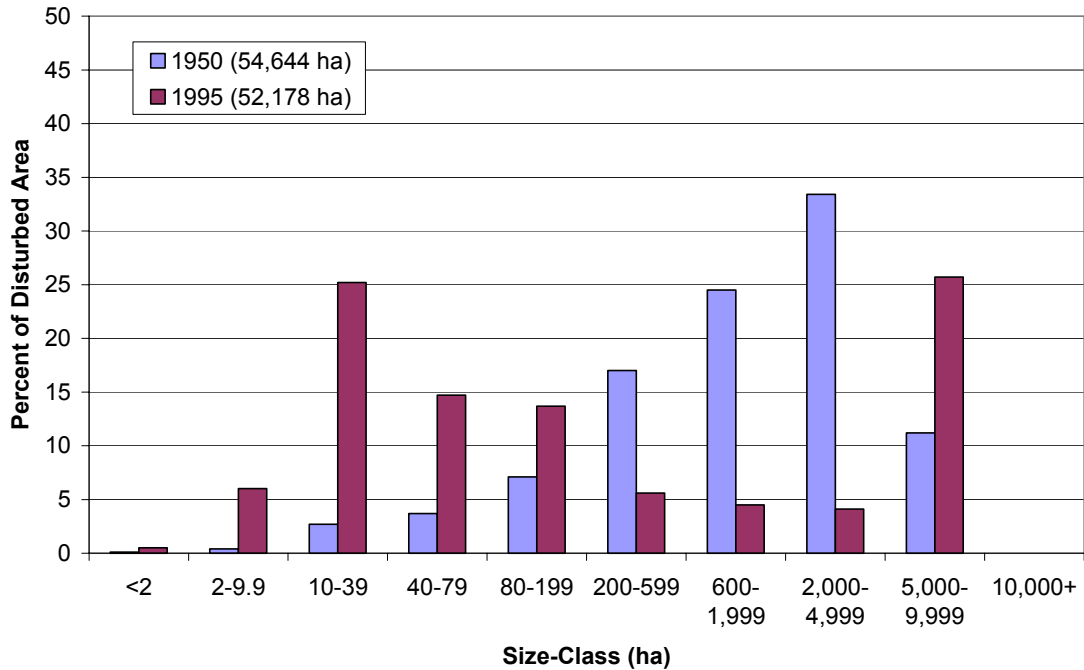
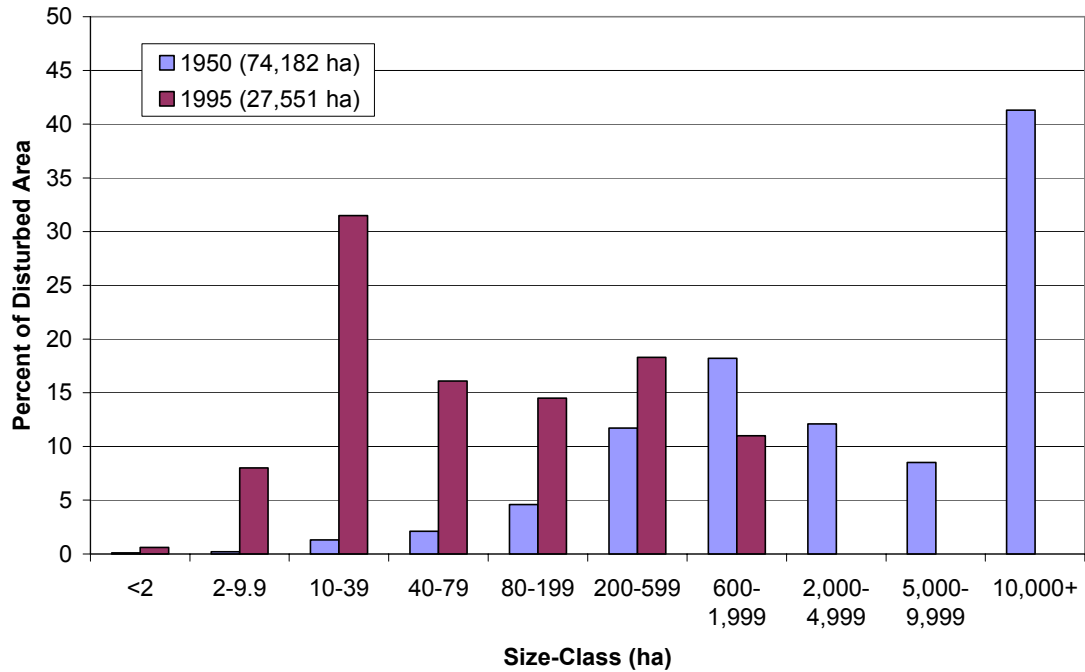
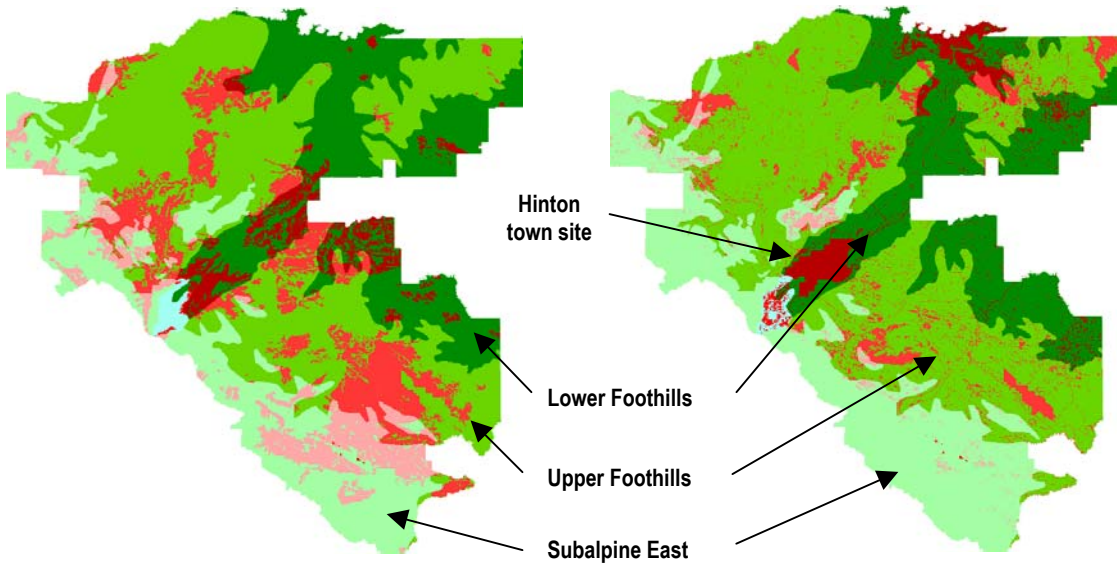


Figure 10. Subalpine East Young Forest Patch Size Distribution by Area



Although the 1995 data include all forms of disturbance (natural and cultural), the shift in disturbance patch sizes identified here is due mainly to the impact of cultural disturbance activities, which tend to be small and ubiquitous. For example, the spike of area in the 10-40 ha patch size is consistent across all landscapes, and represents the range of harvest block sizes sanctioned over the last several decades in this part of Alberta. This effect can be seen clearly in Figure 11. Even at a minimum resolution of 4 hectares, the number and distribution of small cultural disturbances is dramatic.

Figure 11. Recent Disturbance Patches (in red) on Foothills East Landscapes in 1950 (left) and 1995 (right).



Note that not all disturbance patch size distributions shifted similarly. The Subalpine East represents the most dramatic shift, showing no disturbance patches over 2,000 hectares in 1995, compared to having over 60% by area in patches over 2,000 hectares in 1950 (Figure 10). The Upper Foothills landscape from 1995 has significantly less area in large disturbance patches than in 1950, but does have a very small number of large patches (Figure 8). A similar trend is noted in the Lower Foothills landscape (Figure 9).

The explanation in both cases is a combination of the presence of a small number of large natural disturbances and a few large cultural disturbances. For example, both landscapes have experienced fairly large fires since 1950 – most notably the Gregg River fire depicted by the “C”-shaped disturbance south of the Hinton town site, and a large fire on the northern edge of the Lower Foothills landscape (Figure 11). Similarly, the Hinton town site can be seen in the western-most end of the Lower Foothills landscape, and a large mine can be seen in the southern end of the Upper Foothills in the 1995 snapshot.

These results not only demonstrate the long-term impact of imposing “unnatural” disturbance regimes on forested landscapes, but also the significant impact that a small number of large disturbance patches can have. The imposition of an artificially small range of disturbance sizes is quite clear in these data, but in the case of the Upper Foothills and Lower Foothills landscape, this impact is mitigated by the presence of only three or four large fires.

However, it would be misleading to include the impact of large cultural disturbances such as the Hinton area in that statement. For that matter, it is misleading to consider a single category of “disturbance” for comparative purposes. Road building, residential and recreational development, mine and well sites, and many other land clearing activities tend to be longer-term, and such land is not necessarily returned to trees or even vegetation within several years or decades. While such activities are technically disturbances, they cannot be equated ecologically with disturbance activities such as harvesting where trees are usually growing within a few years of the event. This is why I included the Hinton town site in the 1995 estimates –

while the town has been there much longer, it represents a “cumulative” disturbance impact on the Lower Foothills landscape. In fact, in the 1995 landscape snapshot of the Lower Foothills, harvesting accounts for only ¼ of all disturbance activity, and less than half of the cultural disturbance activity. In contrast, most of the cultural disturbance activity in both the Upper Foothills and Subalpine East landscapes is harvesting, although there are still substantial areas influenced by other cultural disturbance in both areas. The distinction between short-term and long-term cultural disturbances is of great importance, and will be explored in future FMF Natural Disturbance Program research projects.

It is interesting to note that despite these differences in the source or type of the cultural disturbance, the effect is the same in terms of the distribution of disturbance sizes. This suggests that openings of less than 80 hectares, and in particular 10-40 hectares, are common to many types of cultural disturbance activities, and not necessarily an indicator of harvesting activity.

Section B: OLD FOREST PATCHES

Old forest has both ecologic and social value, regardless of whether the forest system in question is boreal, mountain, or coastal. Although previous work has evaluated the natural range of variation in the total amount of old forest (see report #2 in this series), it is essential to consider how old forest is arranged in space.

As with report #2 (Andison 2000a), “old” will be defined here only by stand age, and thus does not necessarily correspond to one of the many interpretations of “old growth”. Furthermore, my interest here is restricted to the patch sizes of the oldest forest on a given landscape, which is ultimately a manifestation of the disturbance regime over many decades. Thus “old” is represented in this analysis simply by the oldest 15% of the landscape (the range is 14-18% - see Appendix B for details). The imposition of a percentage rule allows the results of this report to be universally applicable. The alternative would be to use a rigid age limit such as those used in report #2 for seral-stage ranges (Andison 2000a). However, we already know from report #2 that the absolute amount of the old seral-stage varies dramatically over time on a given landscape, making comparisons impossible. For example, it is unlikely that the “old” patch size distribution of a landscape with 3% old forest will look anything like the old patch size distribution of a landscape with 30% old forest. The landscape with 3% old forest will have experienced far more disturbance activity and spatial deterioration than the landscape with 30% old forest, and thus relatively fewer large contiguous patches of old forest will have survived intact. The results presented here are applicable to the oldest 15% of any forest, on any foothills landscape, regardless of the total amount of old forest.

Furthermore, I made no assumptions about the form or function of old patches. These results include both “patches” of old forest as well as “island remnants” that are old forest. See Appendix B for a more detailed explanation.

Historical Old Forest Patch Sizes

As expected, there are far more small old patches relative to small disturbance patches. On average, the percent of old forest area in patches less than 40 hectares is 12% (Figure 12), compared to about 5% for disturbance patches less than 40 hectares. However, this 12% represents about 97% of the total number of old forest patches (Figure 13). Even more dramatic is that 4.4% of the old forest area is in patches less than two hectares (Figure 12), which represents about 88% of all old forest patches by density (Figure 13). However, most of the area of old forest is still in patches over 600 hectares (Figure 12). There are even rare instances of old forest patches in excess of 5,000 hectares. Of over 23,000 old forest patches on all five landscapes, only 22 were larger than 2,000 hectares.

Figure 12. Old Forest Patch-Size Distribution by Area

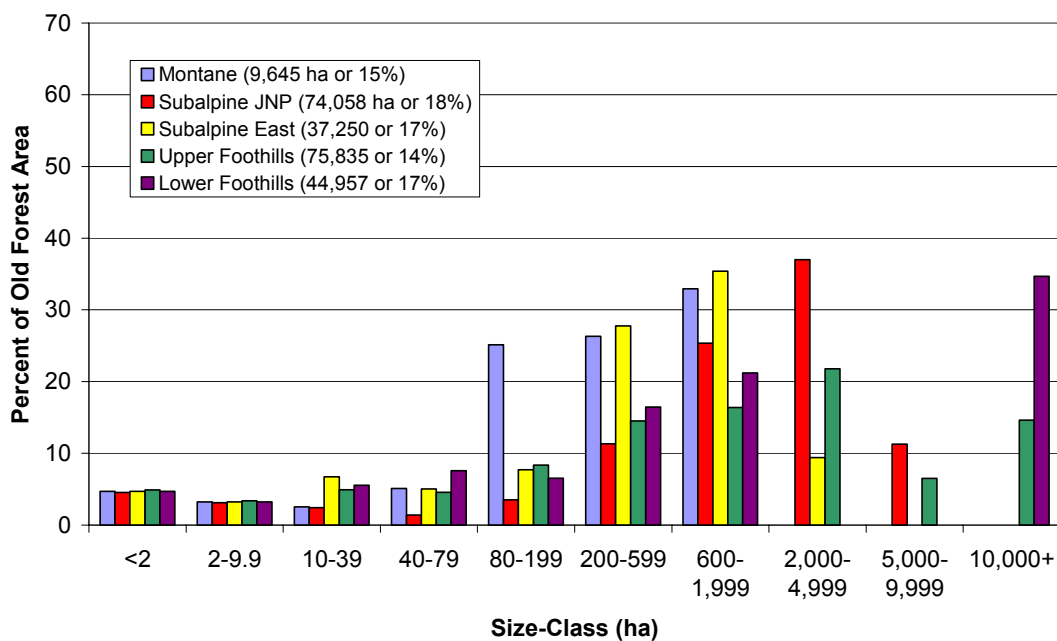
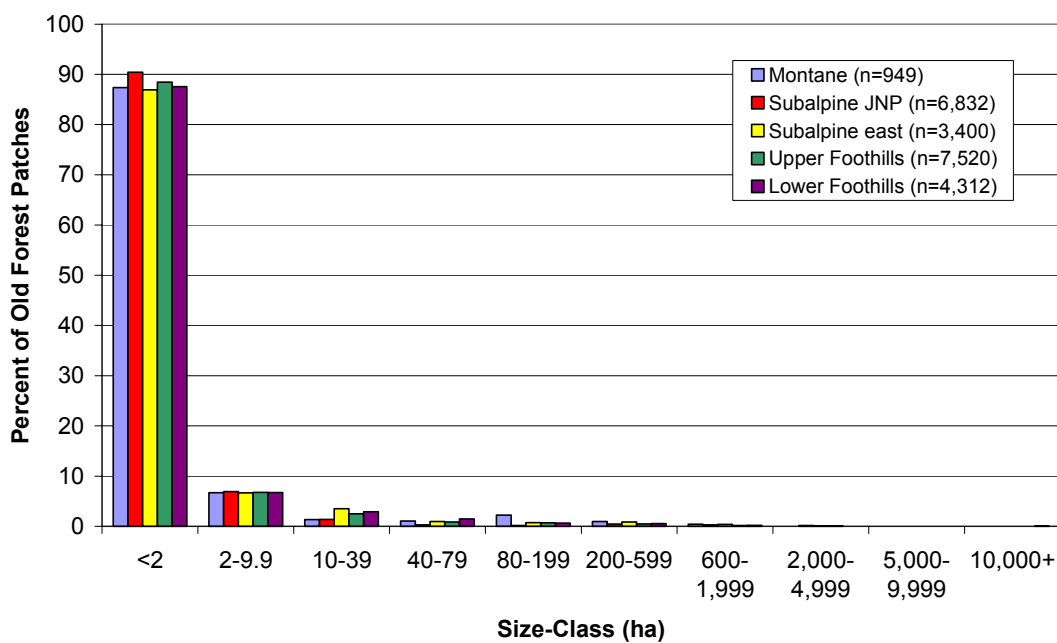


Figure 13. Old Forest Patch-Size Distribution by Numbers



Although not shown here, I estimated that about 90% of the old forest patches smaller than 10 hectares are residual islands left within fires. Thus the majority of old forest patches in total are island remnants. However, most of the area of old forest is of non-island origin, and in much larger patches. This dichotomy raises important questions about the function(s) of old forest patches, and underscores the importance of maintaining the full range of old forest patch sizes across large areas. For example, is allowing for the existence of the very largest old forest patches sufficient? By not including island remnants in our definition of old forest, are we potentially ignoring many other ecological benefits such as “life-boating” for non-motile species and providing local seed sources?

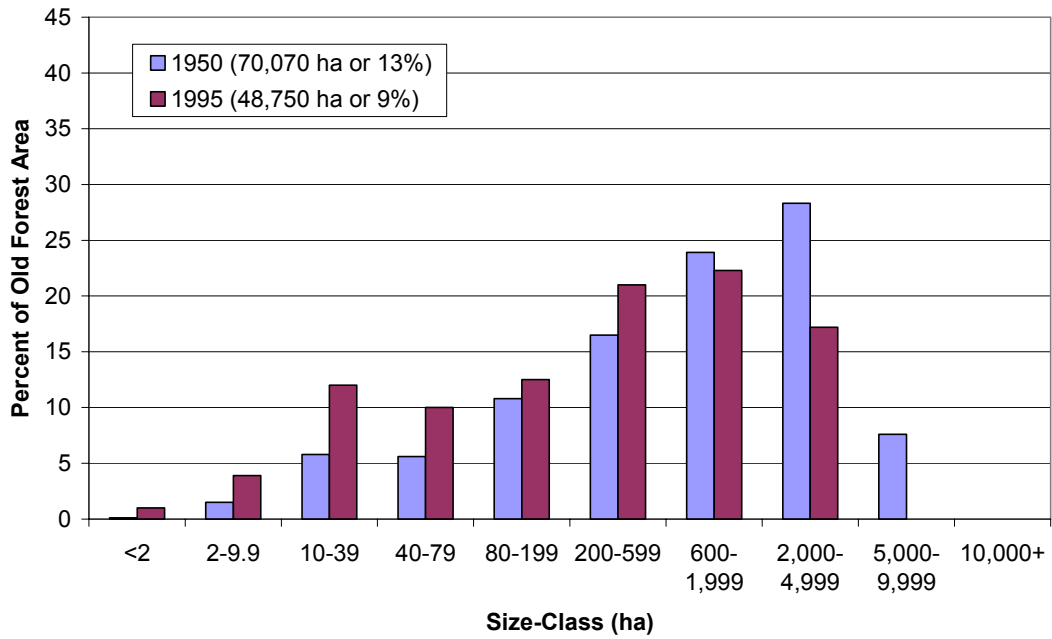
Contemporary Old Forest Patch Sizes

As with the disturbance patch data, it is possible to compare the patch size distribution of old forest today with that from a “natural” pattern in 1950. Similar to the disturbance patch size data, I used the uncorrected and unpooled (across landscapes) data to allow direct comparison of data collected in identical ways. The contemporary patch size distributions of old forest were not calculated for the two mountain (i.e., Jasper) landscapes. A detailed explanation of the reasons for this is given in Part 3 of this report under the heading “Jasper National Park – A Special Case”.

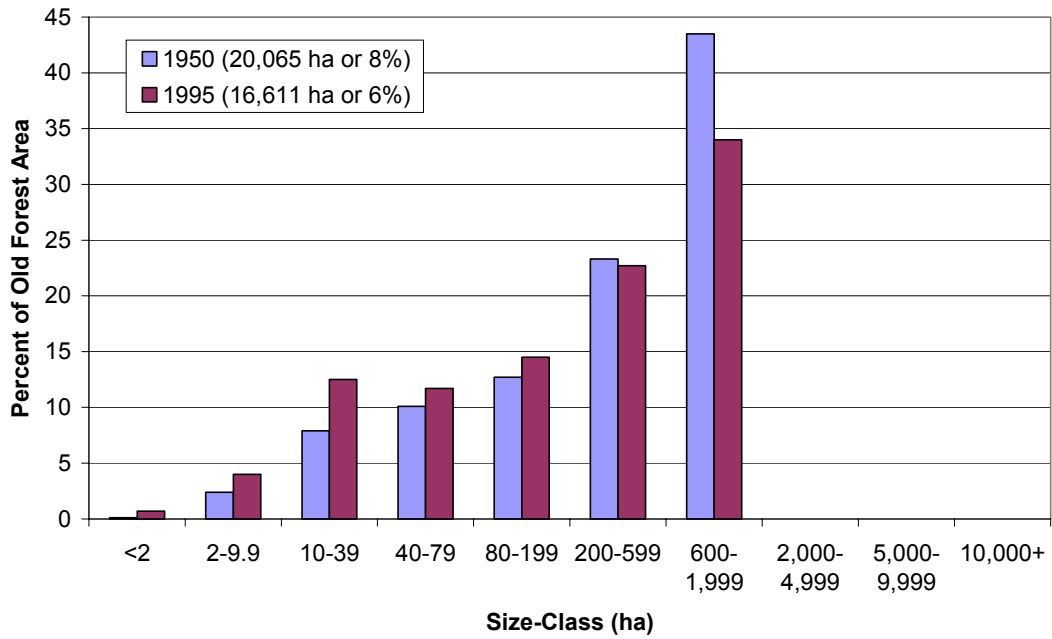
In all three Foothills East landscapes, the size-class of old forest patches has shifted downwards over 45 years of development (Figures 14-16). In each case, the size of the largest patch has been compromised considerably. For example, the largest old forest patch in the Upper Foothills landscape in 1950 was 5,301 ha, and in 1995 the largest old patch was just 2,384 ha. The percent of area in patches over 2,000 hectares has declined from 15% in 1950 to 6% in 1995 overall (Figures 14-16). The area in old forest patches in every size-class smaller than 600 hectares has increased on average since 1950. The increase is spread fairly evenly across all size-classes, but is most prominent in the <2 ha size class, where the area jumped from 0.2% to 0.7% - which corresponds to an increase from 29% to 48% of all old forest patches.

The differences in the shifts of old forest patch sizes between landscapes are minimal. While the Lower Foothills experienced the greatest decline in the largest patch of old forest (from 12,135 ha to 1,375 ha), most of that is now in several patches 600-2,000 hectares in size. Of the three landscapes, the Subalpine East showed the least loss of very large old patches, and the smallest increase in small old forest patches (Figure 16).

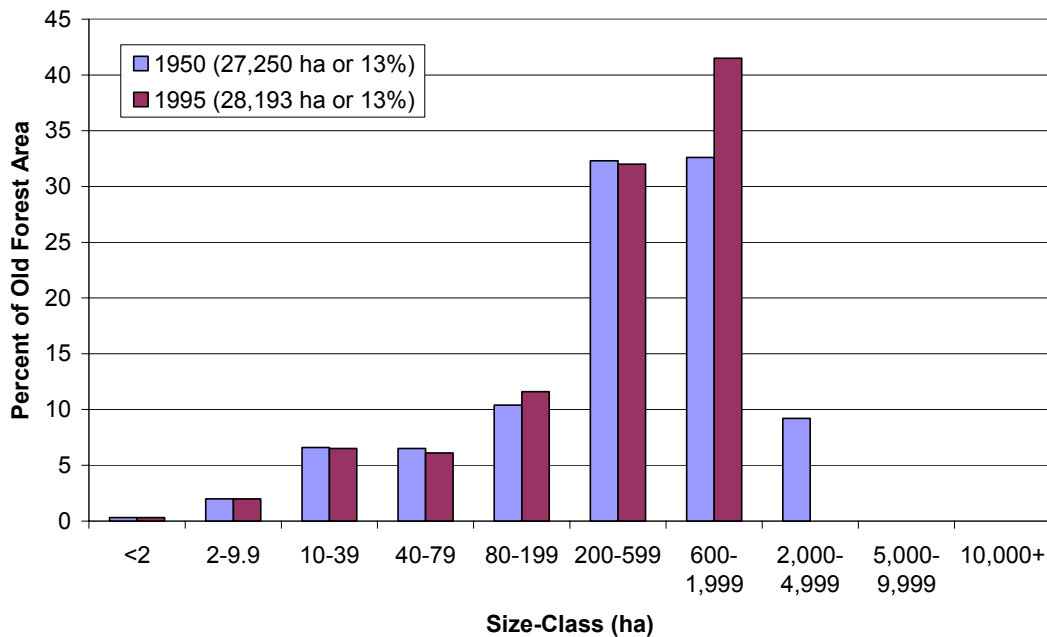
**Figure 14. Upper Foothills Old Forest Patch Sizes in 1950 and 1995
(Uncorrected and Unpooled)**



**Figure 15. Lower Foothills Old Forest Patch Sizes in 1950 and 1995
(Uncorrected and Unpooled)**



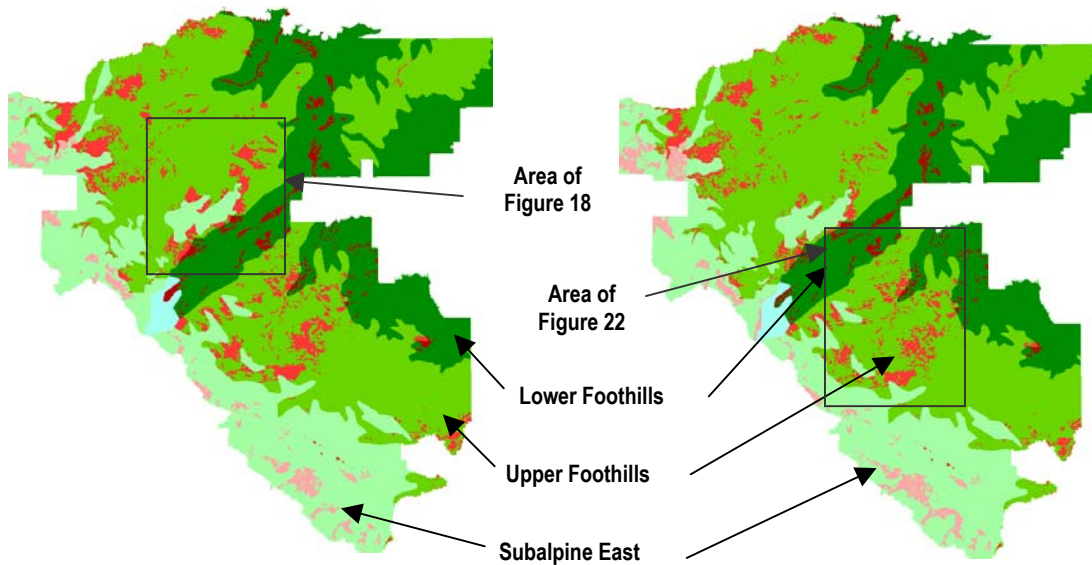
**Figure 16. Subapline East Old Forest Patch Sizes in 1950 and 1995
(Uncorrected and Unpooled)**



The changes in old forest patch size noted in these data between natural and contemporary landscapes suggest that patches are being broken up into smaller pieces or “fragmented”. This process can be seen clearly in Figure 17. Cultural activities such as harvesting concentrate on mature and old forest areas. The size requirements of such activities mean that breaking-up large contiguous areas of older forest into many smaller ones is inevitable. However, the consistent decline in the patch size of old forest patches across all three natural subregions suggests that harvesting is not the only, nor necessarily always the dominant, cultural activity affecting old forest patterns. Harvesting in the study area has focused primarily in the Upper Foothills landscape and is not nearly as dominant in the Lower Foothills landscape. Yet the old forest patch size distribution of the Lower Foothills landscape has been altered over the last several decades in a pattern similar to that of the Upper Foothills. Other cultural activities must be contributing here to the shift in old forest patch sizes.

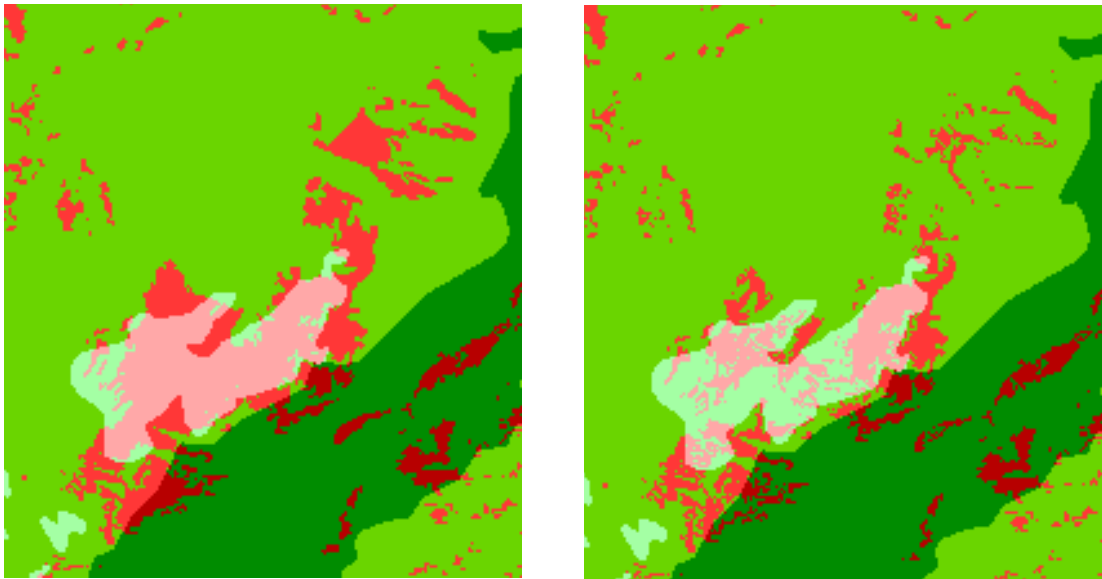
The more surprising result is that the degree of fragmentation of the oldest portion of the forest is not as high as one might expect. At first glance, the two images 45 years apart in Figure 17 look much the same. There are two reasons for this. First, the images represent over a million hectares and openings less than 20 hectares in size are not easily identified. Second, harvesting is having a significant impact in younger merchantable forest areas.

Figure 17. Oldest Forest Patches (in red) on Foothills East Landscapes in 1950 (left) and 1995 (right).



To illustrate both the resolution and the age-limit issues, Figure 18 magnifies an area of about 150,000 ha of the Foothills East showing all forest established (by fire) prior to 1810 in red. Two things are immediately evident from the images. First, it is much easier to see on a smaller area how single large patches of older forest are fragmented into many smaller ones – thus the term “fragmentation”. Second, an expanded definition of “older” reveals a more dramatic level of fragmentation. Recall that for the analysis in Figures 14-16, and the images in Figure 17, the age limits for older forest varied by natural subregion between 1810 and 1760. In figure 18, “older” is defined by a constant 1810 across all landscapes, and now includes the entire island of Subalpine East forest north of Hinton. The expanded definition allows us to see the high degree of fragmentation in this locale. We would expect that if the definition were expanded to include forest from 1850 and older (which is still merchantable), even greater levels of fragmentation would be evident.

Figure 18. Forests Originating Prior to 1810 (in red) From 1950 (left) and 1995 (right) on a Magnified Area from Figure 17.



The pattern differences demonstrated by the age-limit change of “old” between Figures 17 and 18 can be interpreted in two ways. On one hand, the very oldest forest patches in the Foothills East landscapes are not as fragmented as one might have predicted. Contiguous old forest patches over 1,000 hectares still exist on all landscapes. This is surprising given that these landscapes have experienced perhaps more historical cultural activity than any other forest area of equivalent size in Alberta. On the other hand, most of the merchantable forest is similarly fragmented. In other words, the oldest 30-40% of the Foothills East is no less fragmented than the oldest 15%. Since this forest has no chance of becoming any less fragmented as it ages, we already know that over at least the next 20-30 years, old forest on Foothills East landscapes will remain moderately fragmented regardless of how, or to what degree, we manage it.

Section C: NON-OPERATING PATCHES

The previous section introduced the idea that forest harvesting is not always the only, or necessarily the dominant, cultural disturbance activity on foothills landscapes. This section explores that hypothesis further by tracking any changes to patch sizes for areas of the landscape where harvesting activities do not, and are not likely to take place.

In this report I adopted the term “non-operating” to refer to areas where harvesting operations do not occur, but the definition is identical to that of “non-productive forest land” from the Alberta government as it refers to any land not capable of producing merchantable timber, or “land not capable of meeting the specific productive and potentially productive growth time lines.” (from <http://www3.gov.ab.ca/srd/forests/fmd/timber/Glossary.html>). Thus, the term includes all naturally non-forested areas such as bogs, muskegs, brush land, grassland areas, open meadows, and rock outcrops, as well as naturally-occurring low volume stands. I preferred the use of the term non-operating here instead of non-productive since it is more precise - many areas that are not harvested (such as bogs or muskegs) have very high levels of biological productivity.

For the analysis, I compared the uncorrected and unpooled data from the stand origin map from the 1950 and 1995 snapshots for the three eastern landscapes. No corrections or small-patch estimates were made for non-operating areas. As with the disturbance patches and old forest patches, it is the comparative analysis that is most informative, as opposed to the absolute size distribution of non-operating areas.

Overall, there is only a slight downward shift in the size of non-operating patches between 1950 and 1995, and it is relatively well distributed across most of the larger size classes (Figures 19-21). The area in non-operating patches less than 200 hectares rose from an average of 42% in 1950 to just 45% in 1995 (Figures 19-21). However, over the same period, the net area of non-operating land declined by 7,350 ha (or about 6.4%) and the total number of non-operating patches declined by 18% from 1,806 to 1,473. Furthermore, the vast majority of that loss was smaller patches. Of the 333 non-operating patches lost over the 45 years between snapshots, 216 were less than two hectares in size. This effect can be seen in the magnified area of a particularly heavily impacted area of the Foothills East shown in Figure 22 (refer to Figure 17 for the location of this magnified area).

Thus, the impact of non-targeted cultural activities on non-operating land may not always be reflected in patch size comparisons alone, but also the net area in non-operating patches. The obvious question this raises is the nature of the “loss” of non-operating land. Whether or not this conversion is permanent, semi-permanent, or temporary is unknown, but one can surmise that the cultural activities involved (such as road building, gravel pits, mine and well site development) are likely more permanent in nature than harvesting operations. The temporal consequences of cultural disturbance on non-operating land are an excellent question worthy of more detailed study.

Figure 19. Upper Foothills Non-Operating Patch Size Areas

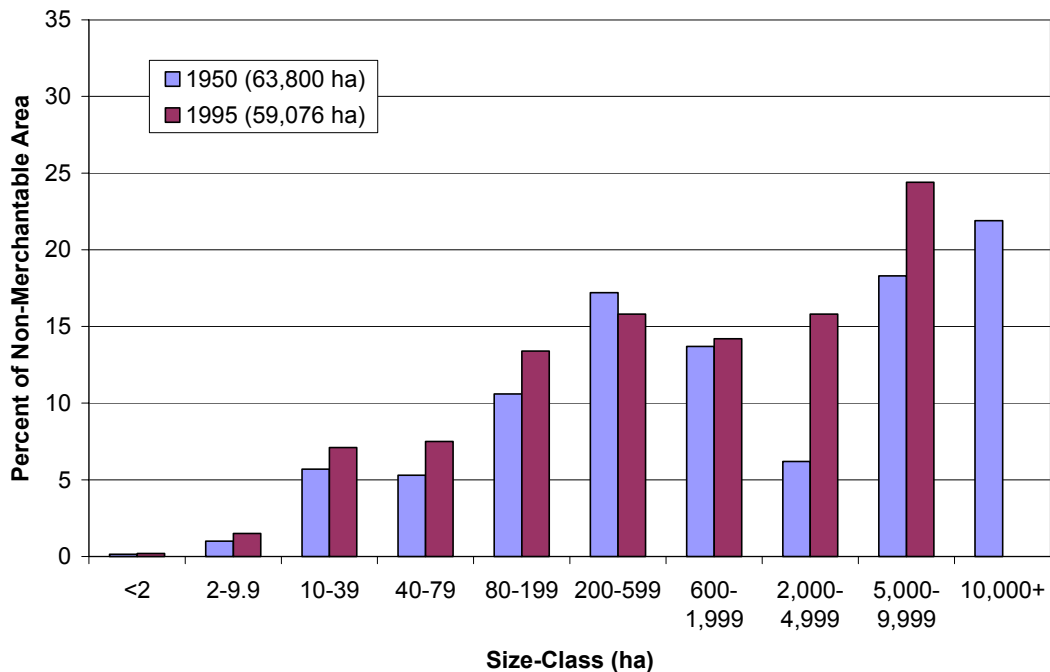


Figure 20. Lower Foothills Non-Operating Patch Size Areas

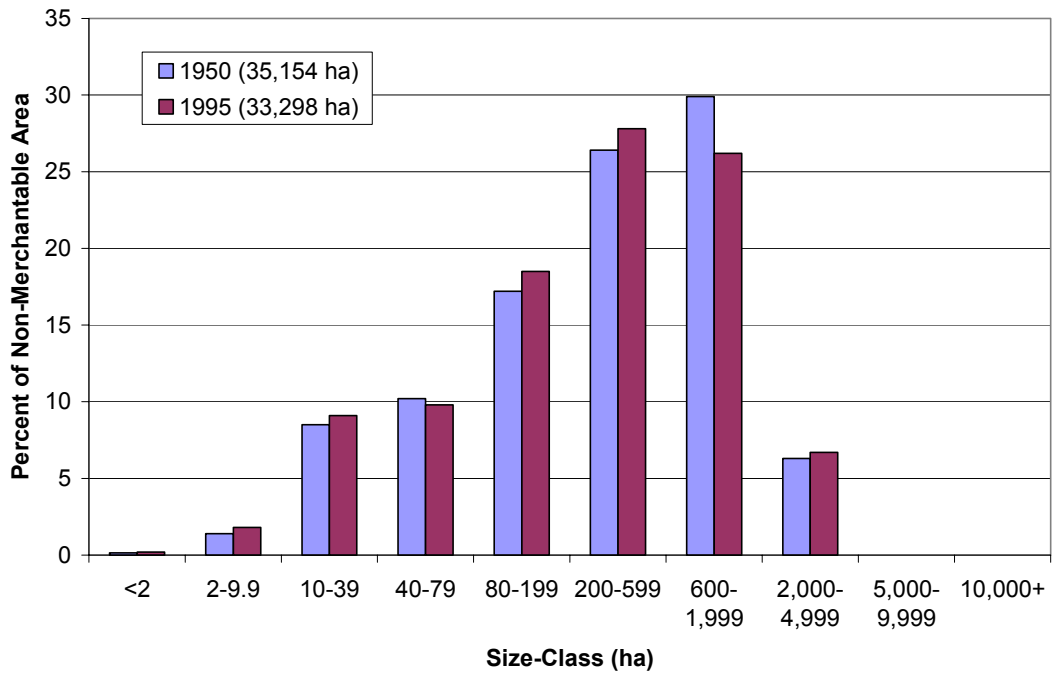


Figure 21. Subalpine East Non-Operating Patch Size Areas

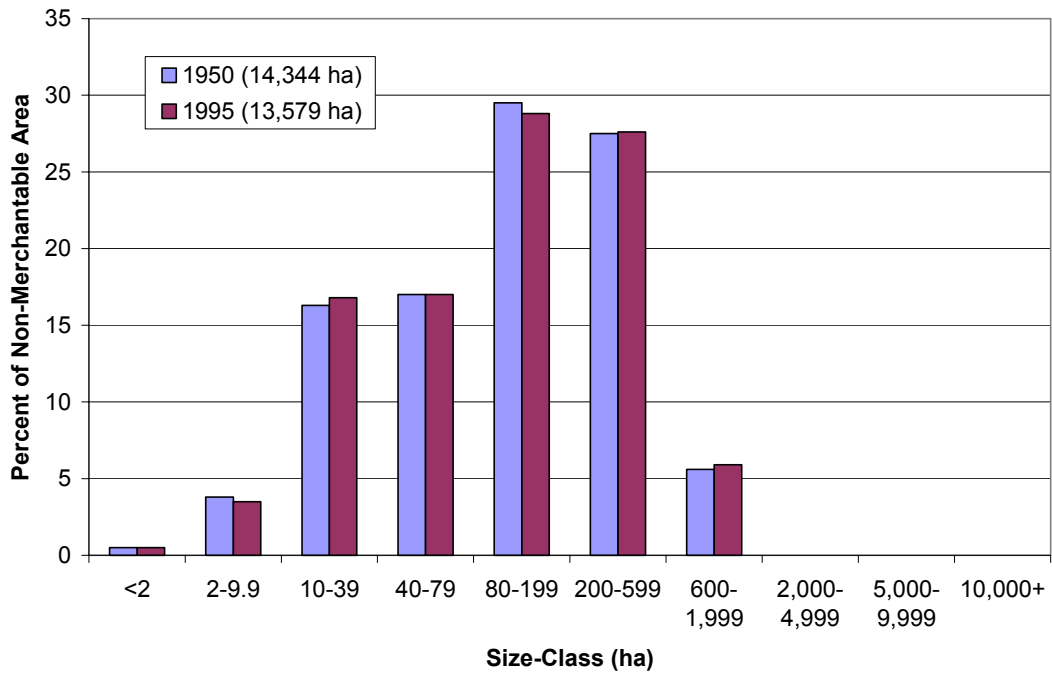
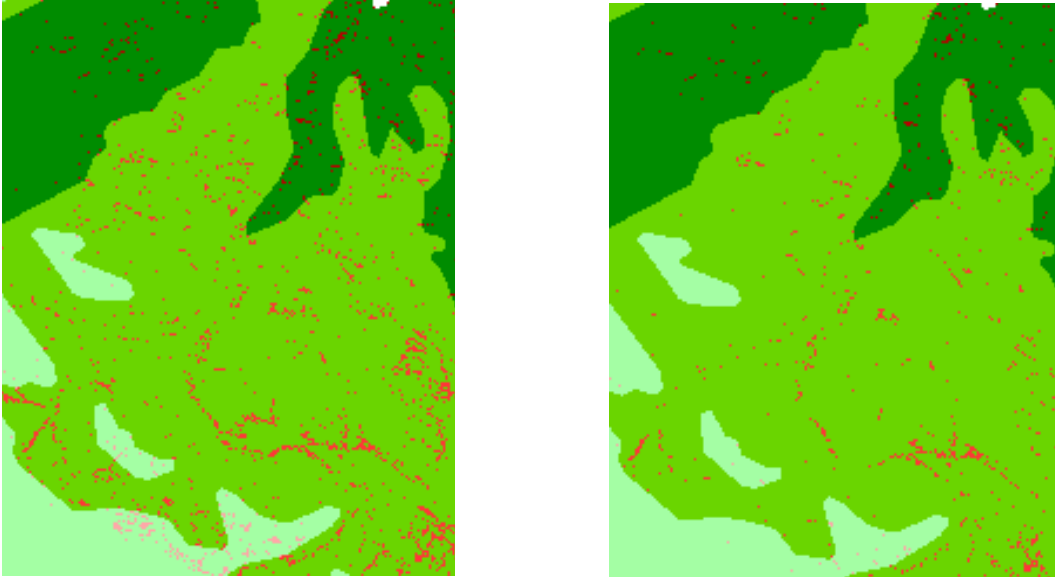


Figure 22. Non-Operating Areas (in red) From 1950 (left) and 1995 (right) on a Magnified Area of Figure 17.



The patch size shifts of non-operating areas reveal some major differences between landscapes. In fact, the only significant change in non-operating patch sizes occur in the Upper Foothills landscape. Here, non-operating patches less than 200 ha in size accounted for 23% of the non-operating area in 1950, and 30% in 1995 (Figure 19). Similarly, very large non-operating patches (over 5,000 hectares) in the Upper Foothills declined from 40% by area in 1950 to 24% by area in 1995 (Figure 19). In contrast, the Lower Foothills and Subalpine East landscapes showed only a slight downward shift in non-operating patch sizes between 1950 and 1995. For example, the area in non-operating patches less than 10 hectares in the Lower Foothills changed from 10% in 1950 to 11% in 1995 (Figure 20), and in the Subalpine East the difference was only 0.2% for the same comparison (Figure 21). Nor do the proportions of very large non-operating patches change in either case. In fact, the proportion the very largest non-operating patches actually increased in both cases between 1950 and 1995, but only because the gross area of non-operating areas decreased.

The total area in non-operating land in all three landscapes declined, but was slightly higher in the Upper Foothills (7.5% loss for the Upper Foothills, compared to about 5% loss for both the Lower Foothills and Subalpine East). So the Lower Foothills and Subalpine East are still losing small non-operating patches entirely, and the fact that the size distributions are similar to those from 1950 suggests that the remaining patches are beginning to be fragmented.

In summary, the non-operating areas of the Upper Foothills have been most affected by cultural activity, although the impacts of cultural disturbance (through loss of area and numbers of patches) are evident in the all three landscapes.

Part 3: WHAT DOES IT MEAN

Rather, the question at this point might be ‘does it mean anything?’ The worst case-scenario in any natural disturbance study is that the patterns identified may be nothing more than artefacts of data, assumptions, or small sample sizes. Even the use of natural subregions as landscape boundaries is little more than a working hypothesis at this point (that patch size distributions differ significantly from one natural subregion to another). Appendix A and B describe how I dealt with some of the more significant assumptions of data. Beyond that, we already know quite a bit about the topography, ecology, and natural and cultural disturbance history of these landscapes. Thus, while it is not possible to verify all of the numbers estimated in this report, it is possible to critically validate the findings here based on logic and prior knowledge, and ask: are the relative patch and fire size relationships revealed here consistent with what we already know about these landscapes? This question will be considered for each of the five landscapes in turn.

Upper Foothills

The Upper Foothills is heavily pine-dominated and gently rolling; with about 11% non-forested land (Andison 2000a). Thus, there are neither fuel nor topographic barriers to fires becoming very large if fire weather conditions are amenable. We also know that the historical lightning activity on this landscape is relatively high, meaning there is no shortage of natural ignition opportunities. Furthermore, “natural” average fire cycles are between 80-90 years, which is moderate for this region. Given these factors, one would expect to see a large number of small fires, and a small number of very large fires, which occur when exceptional burning conditions occur. Recall that this is precisely the pattern of disturbance patch and event sizes observed in this study.

We also know that the Upper Foothills landscape has been the most affected by harvesting activity. Thus, it is no surprise that the disturbance size comparisons in this study showed a significant change between disturbance patch sizes between the 1950 and 1995 landscapes. However, the disturbance patch size distributions from 1995 in the Upper Foothills landscape also include the impact of two large fires, and at least one large mine. If these three events had not occurred, the disturbance patch size contrast between 1950 and 1995 would have been considerably greater.

It was somewhat surprising to see the (negative) shift in the non-operating patch size distribution for the Upper Foothills landscape and the large decrease in non-operating land area. Since harvesting does not affect non-operating areas, this suggests that the Upper Foothills experiences a high level of non-harvesting cultural activity relative to other landscapes. These other cultural activities are by definition land-type neutral, and include road building, seismic line construction, surface mining, installation of well sites, and clearing for residential, recreational, or farming development. Given the high levels of access, high levels of recreational use, and wide range of other cultural, economic, and ecological values in the Upper Foothills, this is a reasonable assertion, but the degree to which other cultural activities are having an impact in the Upper Foothills landscape is still surprising.

Further to this observation, one could argue that the frequency distribution of disturbance patches in the Upper Foothills from 1995 is misleading. Despite the fact that I included all types of disturbances in the calculations, we know that they do not have equivalent biological impacts. While the recovery time¹ from fire and harvesting are relatively short, mines, roads, and towns have longer-term impacts. They are technically not disturbances in the same way that a forest fire is, since they rarely go through predictable stages of vegetation development immediately following the disturbance event. One could even argue that longer-

¹ By “recovery time”, I refer here to the time required to produce vegetation consistent with the stand initiation stage of development, which includes tree seedlings, shrubs, grasses, and herbs.

term disturbance events are for all intents and purposes temporary or permanent deletions from the productive land base, as well as dramatic long-term modifications to habitat types. The distinction between short and long-term disturbances was not explored in great detail in this study, but it is an issue worthy of more study and discussion.

Perhaps the most unexpected pattern of the Upper Foothills patch size analysis was with the oldest forest. Given the high levels of harvesting and other cultural activities in the Upper Foothills landscape, one would expect that the level of fragmentation of oldest forest patches would be very high relative to other landscapes. In fact, the shift in old forest patch sizes estimated from this study over the last half century was no more significant than that noted in either the Lower Foothills or Subalpine East landscapes. We know that one reason for this is that harvesting did not necessarily focus on the very oldest forest in this landscape. So, despite very high levels of cultural disturbance activity, the oldest forest of the Upper Foothills is only moderately fragmented. Unfortunately, that activity has affected all merchantable forest, and the oldest forest in the Upper Foothills landscape will be at least moderately fragmented for many decades to come.

Lower Foothills

The Lower Foothills landscape has gently rolling topography, and the species composition is a mix of hardwood-dominated, softwood-dominated, and mixedwood stands. Although historical lightning activity on this landscape is higher than in any other landscape in this study, the chances of any given ignition, under even extreme fire weather conditions, producing a very large fire in mixedwood or hardwood forest types is far less than in softwood-dominated landscapes such as the Upper Foothills. Even when fires ignite in softwood-dominated stands of the Lower Foothills, the matrix of the landscape is such that at some point they will encounter (less flammable) hardwood. Thus, the large number of intermediate-sized fires in the Lower Foothills suggested by this study is not unexpected.

The recent disturbance patch size distribution in the Lower Foothills is very similar to that of the Upper Foothills – a large proportion of the disturbed area is in small patches, but still a moderate amount of land exists in large patches. The similarity was unexpected considering the fact that far less harvesting has occurred in the Lower Foothills. Certainly the single large fire and the development in and around the Hinton town site explain the large disturbance patches. However, the total area in small disturbances over the last several decades in the Lower Foothills is surprising. Of the area recently disturbed, 60%, or about 31,300 hectares, is in patches less than 200 hectares. Considering that very little of this area represents harvesting, we can assume that this represents the impacts of other forms of cultural development. We know that the Lower Foothills is the most accessible and most developed natural subregion of the three eastern landscapes, and the patterns noted here likely reflect everything from urban sprawl, to major highway corridors, to recreation area development. This suggests that there is a single common cultural patch-size footprint on foothills landscapes, regardless of the cause. Combined with the different biological recovery times associated with different cultural activities, this begs many questions about desired future landscape conditions, and strategies for achieving them.

Knowing that the Lower Foothills is heavily affected by non-harvesting cultural activities, one would expect that the impact on non-operating areas to be the highest of all landscapes (since they are generally not land-type specific). However, the data in this study does not support this hypothesis. Although the total area in non-operating land dropped 5% from 35,154 ha in 1950 to 33,298 ha in 1995, it is still less than the decline in the area of non-operating land for the Upper Foothills. Furthermore, the patch size shift of non-operating areas of the Lower Foothills was only very small. Recall that the Upper Foothills non-operating patch-size distribution shifted noticeably. One possible explanation for this difference may be that cultural

development in the Upper Foothills was more industrial in nature, while development in the Lower Foothills was more residential and recreational. Industrial development, such as mining and road building, is typically less concerned about site conditions, whereas most residential and recreational developments concentrate on the best upland sites.

One way of testing this theory is to look at the old forest patch size shifts over the last half century. If we know that harvesting has not been prevalent on this landscape, but suspect that non-harvesting cultural activity is selecting for the best sites, we should see at least a moderate level of old forest patch size fragmentation from those activities (since a “good” site is not necessarily associated with old forest). In fact, this is what I found, with a moderate loss of area in old forest patches above 200 hectares (from Figure 15). However, this is hardly proof of the theory, and the nature of cultural development patterns on the Lower Foothills remains a valid question for future study.

Overall, the contrast between the development histories and patch size responses in the Lower Foothills and Upper Foothills demonstrates well the uniqueness of each landscape both biologically and culturally. It also demonstrates the dangers of extrapolating knowledge, management strategies, or monitoring protocols from one to the other.

Subalpine East

The Subalpine East landscape is arguably the most topographically complex of the five landscapes, but is heavily conifer-dominated, and has very few non-forested areas (Andison 2000a). It also has very long fire cycles (well over 100 years), likely in part because of the very short growing and fire seasons and low levels of lightning activity (Andison 2000a). Thus, although the Subalpine East has highly continuous, relatively flammable fuel that is capable of carrying very large fires under extreme fire weather conditions, we expect that in most cases the complex topography is a limiting factor for fire growth in these forests. Given these conditions, one would expect the Subalpine East to have many small fires and a very small number of very large fires – which is exactly what the data from this study suggests.

The disturbance size comparison between 1950 and 1995 for the Subalpine East showed the most dramatic shift away from “natural” sizes, which is surprising considering that it is the landscape least affected by cultural disturbance activities. However, there were at least three relevant mitigating factors involved. First, the Subalpine East has had very little natural disturbance over the last 50 years. Recall that the Upper Foothills and Lower Foothills experienced large forest fires. No such fires occurred in the Subalpine East during the same period. This underscores the impact of even single, large disturbance events. The second mitigating factor is that the total area disturbed in the Subalpine East since 1950 is very low. The 27,551 ha disturbed (Figure 10) represents the lowest rate of disturbance in the Foothills East (an average of only 0.2% per year since 1950). The third and final mitigating factor is that virtually all of the disturbance activity has been concentrated at the boundaries of the Subalpine East landscape. For instance, the large island of Subalpine East north of the Hinton town site with substantial harvesting activity is more precisely a transition zone between Upper Foothills and Subalpine natural subregions (Figure 11). In fact, in the revised version of the Natural Subregions of Alberta, this area was classified as Upper Foothills.

So, while Figure 10 may suggest that cultural disturbance activities have affected the Subalpine East more than any other landscape over the last half century, in fact, quite the opposite is true. Certainly the Subalpine East is generally the most difficult to access, the most challenging and expensive to develop, and the furthest from urban centres and travel corridors. Thus we would not expect cultural use of this landscape to be as high as either of the other two Foothills East landscapes.

The hypothesis that the Subalpine East is - overall - least affected by cultural activities is supported by the fact that neither the old forest patch sizes, nor the non-operating patch sizes have changed significantly since 1950 (see Figures 16 and 21). The single exception to this claim is the fact that 5% of the non-operating land has been converted to cultural use in the Subalpine East. However, keep in mind that this represents a loss of only 765 hectares, and a total of 23 patches. This is quite small considering that the Lower Foothills (which covers approximately the same area) lost 1,856 hectares and 83 patches of non-operating land. In any case, the decrease in non-operating land is almost all associated with the transition zones of the landscape.

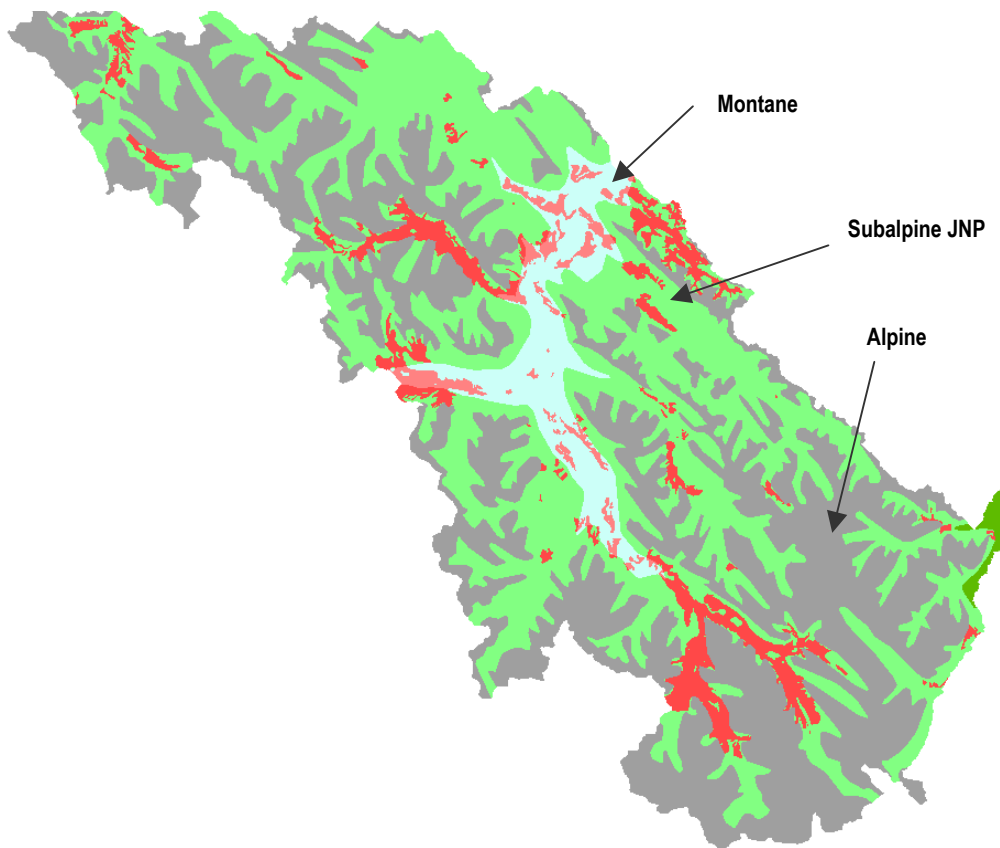
The impact of cultural activities on the Subalpine East is thus spatially variable. Close to transition zones with the Upper Foothills landscape the impact is quite high, while further away, the impact is virtually non-existent.

Subalpine JNP

The Subalpine landscape of Jasper National Park has the steepest terrain of the five landscapes. However, unlike the highly variable topography of the Subalpine East, the Subalpine of Jasper Park is frequently located within linear high-elevation valleys, and sometimes as upper slopes of Montane dominated valleys. Although very steep, the topography of the Subalpine JNP is not necessarily always complex. The Subalpine JNP is also dominated by (highly flammable), and spatially-continuous stands of spruce, although average fire cycles are the highest of any of the five landscapes (at over 150 years). No doubt the long fire cycle is due in part to the fact that lightning activity is extremely low, and the growing season and fire season are very short relative to the other four landscapes in this study.

The pattern of disturbance sizes revealed by this study suggests that small fires are rare, and the landscape is dominated by a high proportion of large, but not extremely large, fires. This is not completely unexpected, but generates some interesting hypotheses concerning fire behaviour on this landscape. For example, the low percentage of small fires may simply be related to the lack of ignition sources. On the other hand, there is a prevalence of self-contained valley corridors, within which fires are able to burn without substantial physical barriers. One can imagine that under extreme burning conditions, fires within such areas essentially burn the entire valley – especially those ignited in the valley bottoms which are able to always be burning uphill. Thus the size of fires during extreme burning conditions may only be limited by the size of individual valleys, which may explain why the largest fires here are much smaller than in either the Upper Foothills or Subalpine East. An image of the most recently disturbed areas within the Subalpine landscape of the Park in Figure 23 indeed shows entire valleys completely consumed by recent fire activity, but more detailed study will be required in future research projects to address this question more thoroughly.

Figure 23. Young Forest Areas (in red) in Jasper National Park.



Montane

The lack of very large disturbance patches in the Montane forest is consistent with what we know about the natural fire history of that landscape. Although the data have yet to be fully analysed, we know from our own data and the work of others (Tande 1979), that relatively frequent, low intensity fires occurred in this area in combination with high-intensity (stand-replacing) fires. Although topography is flat to gently rolling (providing few physical barriers to fire spread), the historical high frequency of fire activity on this landscape likely maintained a highly dynamic mosaic of forest ages and fuel types. This fuel-type mosaic would effectively prevent very large fires from occurring.

On the other hand, the low number of small fires is somewhat surprising, and may be in part due to the difficulties of identifying and differentiating between stand-replacing and stand-maintaining fire events (i.e., a data artefact). Or it may also be indicative of the high level of flammability and high occurrence of superior burning conditions in the Montane landscape. Future dedicated fire history work by the FMF Natural Disturbance Program in the Montane landscape will explore this and other related fire history issues in greater detail.

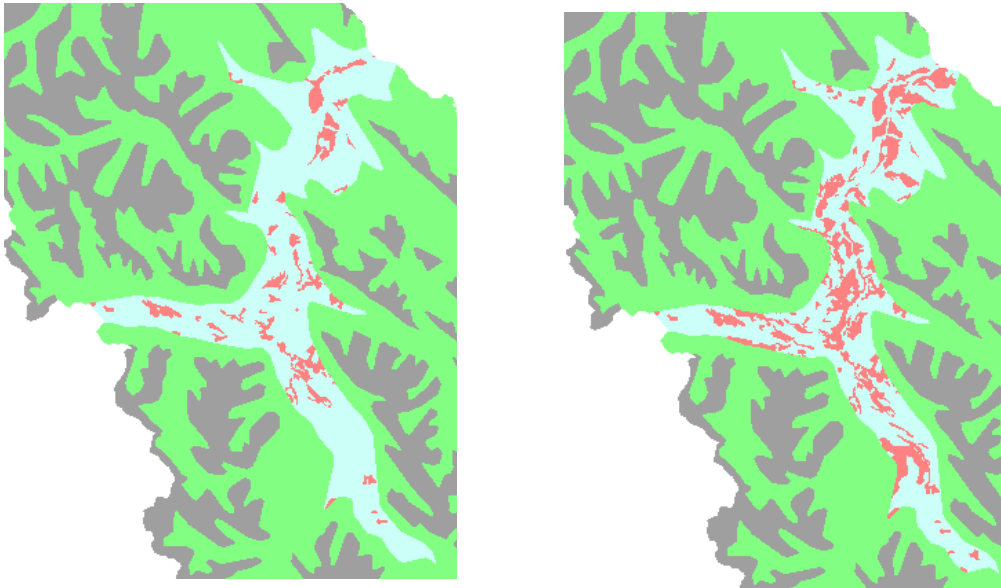
Jasper National Park – A Special Case

The 45-year comparisons of disturbance and old forest patch sizes were not completed for the two Park landscapes. If the same test criteria from the three eastern landscapes were used on the Park landscapes, the patch size distributions of the Park for 1950 and 1995 would change only slightly. This result is inevitable because the total amount of disturbance between 1950 and 1995 in the Park is very small (Andison 2000a). With little or no disturbance, patch sizes of both the oldest and youngest portions of the landscape would remain constant.

Thus, disturbance and old forest patch-size comparison for the Park is not only uninformative, but detracts from the more relevant disturbance regime shift in the Park over the last half century; the lack of disturbance activity. Other FMF Natural Disturbance Program research estimates that the average area disturbed in the Montane landscape since 1940 is less than 0.001% annually, compared to an average of 1.25% annually over the previous 100 years (Andison 2000b). With such a small amount of disturbance activity, comparative patch sizes become irrelevant.

However, absolute patch size comparisons are highly relevant. If one adopted a single cut-off age of 140 years to define “old forest” for the Montane landscape, it would include approximately 9,000 ha of the Montane in 1950, which would be the same 9,000 hectares of old forest in 1995 despite the fact that it is 50 years older (according to the rules used here). But if the same 140-year cut-off were applied in 2000, it would yield over 22,000 hectares of “old forest”. This would have substantial impacts on patch sizes of old forest. As the total amount of old forest increases, contiguous old forest patches are likely to significantly increase in size across the landscape, and in fact this phenomenon can be clearly seen in Figure 24. This is no doubt one of the factors contributing to the heightened levels of fire risk and significant habitat shifts that the Park is currently experiencing. The size, location, and functions of the Montane landscape makes it of particular importance to Park managers, and this old forest phenomenon will be explored in greater detail in future FMF Natural Disturbance Program research reports.

Figure 24. Forest Older than 140 Years in Jasper Park Montane (in red) from 1950 (left) and 2000 (right).



Part 4: SUMMARY

The previous section summarized many important points specific to the patterns of disturbance, old forest, and non-operating patches in each landscape in this study. This section discusses more general conclusions drawn from this study relevant to the management and monitoring of disturbance, old, and non-operating patch sizes across Alberta.

The Alberta natural subregions provide an ecologically relevant basis for differentiating landscapes according to disturbance regimes and their impacts in Alberta. Disturbance, old forest, and non-operating landscape patch size patterns are unique to natural subregions and consistent with what we know about the natural and cultural disturbance history, and the ecology, topography, and climate of these landscapes. Previous FMF Natural Disturbance Program research identified differences in fire cycles and age-class distributions using natural subregions. Monitoring should respect these differences, and extrapolating any patch size knowledge from one landscape to another for planning or monitoring purposes would not be recommended.

The Alberta natural subregions provide a culturally relevant basis for management and monitoring purposes. Disturbance, old forest, and non-operating patch-size shifts over the last half century suggest dramatically different types and degrees of cultural impacts on each landscape. In fact, harvesting was the dominant cultural activity in only two of the five landscapes in this study.

Disturbance events are composed of one or more disturbance patches. For example, although the number of very small disturbance patches account for the vast majority of disturbance patches, only 5-10% of them are individual disturbance events. The rest are associated with larger disturbance events. The size distributions of disturbance events and patches are important to differentiate in both planning and monitoring systems.

The vast majority of disturbance patches on natural foothills landscapes are less than 10 hectares in size. However, most of the area disturbed is accounted for by a small number of very large disturbances. A small number of disturbance patches larger than 2,000, and in some cases over 10,000 hectares, historically dominated foothills landscapes. The impact of these large events on natural landscape patterns is substantial. Thus, even rare large fires that occur today have a tremendous mitigating impact on the current landscape pattern, and should be included in any monitoring programs concerned with landscape "health". Cultural disturbance activities in the foothills since 1950 have created a prevalence of disturbance patches between 10-40 hectares in most cases. This is a fairly typical trend of a disturbance size shift for boreal-type landscapes in Canada and elsewhere.

The dominance of cultural disturbances 10-40 hectares in size is noted above in all foothills landscapes, regardless of the level of harvesting. This suggests that there is a common cultural disturbance size footprint.

Despite the fact that they may leave similar footprints, the biological impact of short-term disturbances such as harvesting is likely fundamentally different than that of medium to long-term events such as residential and recreational development, road building, and mining. From a biological perspective, it would be reasonable to classify cultural disturbances according to their level of severity according to the number of years they are likely to exist. Thus harvesting, seismic lines, well-sites, mines, and road building are all potentially different "types" of disturbances, according to their most likely recovery time (to "natural" vegetation).

Most of the old forest area on a given landscape exists as large "patches" that a series of fires has left behind. However, the vast majority of old forest patches exist as small residual "islands" that are spatially isolated by a single disturbance event. Presumably both types of old forest provide important and perhaps distinct functions, and thus both are important to manage for and monitor.

Cultural activities over the last 50 years have affected old forest patch sizes in the foothills in two distinct ways: Patch sizes of old forests are declining. The rapid decline in the size of the very largest patches suggests that cultural activities are breaking apart these patches from within. This is classic "fragmentation", and is a widely recognized phenomenon. Little or no residual material has been left within cultural disturbance patches. Thus "island" old forest may be declining. This particular old forest phenomenon may be widespread, but is not well recognized. Harvesting is the cultural activity having the greatest impact on patch size changes of older forest, since it targets only merchantable wood. However, other non-targeted cultural activities are having a negative impact on older forest patch sizes as well.

Although the oldest forest is less fragmented than one might have predicted, the effects of fragmentation are evident throughout all merchantable forested areas. Thus, we know that fragmentation will be a characteristic of old forest in the Foothills East for several decades to come. Any efforts to mitigate fragmentation must therefore accept this as the starting landscape condition, and concentrate on how to reduce the impacts of future activities.

Non-forested patch sizes in the foothills are declining in such a way that suggests that non-selective cultural activities (such as road or seismic line building, mining, well site installation or rural development) are completely eliminating very small patches, and fragmenting larger ones. The net result is an overall decline in the amount of non-operating land, but a patch size distribution similar to that of a "natural" landscape.

Disturbance activities of any kind have been severely curtailed in Jasper National Park over the last several decades. This means the total area of old forest has increased, which in turn means the opportunity for larger contiguous pieces of old forest increases. This is particularly true of the Montane landscape and is one symptoms of the fire threat they now face. Forest fuel that was historically well mixed by an active fire regime is now becoming more homogeneous.

Part 5: INTERPRETIVE TABLES

The results presented here are potentially valuable information for planning, management and monitoring. Accordingly, Tables 1-6 provide a quick reference summary of the quantitative results. Each table represents how 100,000 ha of either disturbance patches, disturbances, or old forest area is distributed using ten patch size classes based on the analysis in this report. Comparison to other areas simply requires applying a multiplication factor. For instance, to arrive at a size-class breakdown for 30,000 ha of old forest for an Upper Foothills landscape, multiply the Upper Foothills columns of Tables 5 and 6 by 30%. Keep in mind that these tables assume that the total area of either disturbed area or old forest has already been determined through other means.

The figures presented in these tables should be considered medians. If nothing else, we have learned that natural patterns are highly variable, and if we were able to measure the same patch size distributions 100, 200 and even 300 years ago, we would come up with different numbers. Without those other landscape snapshots, it is difficult to judge the degree to which these numbers vary, and thus no ranges were attached to these numbers. However, using what we already know about the fire history, topography, and biology of the landscapes in question, the relative trends evident in these data are logically consistent.

Keep in mind that the old forest figures presented in Tables 5 and 6 refer to the oldest 15% of the forest, and not necessarily “old growth” or even the “old” seral-stage. The old forest tables also include all possible sources of old forest, both island remnant and patch. For example, likely all of the 10,023 old forest patches in Table 6 covering 4,901 ha (Table 5) are in the form of island remnants. Similarly, the 14,620 ha patch of old forest in Table 6 is likely just a patch that is bordered by several fires. However, using the breakdown estimated in Appendix B, 151 of the 283 old forest patches 10-39 ha in size in Table 6 are islands, and the other 132 are just patches. Similarly, an estimated 27 of the 95 patches 40-79 ha are islands, and the other 68 are patches.

Note also that these tables only account for the islands within events that are “old”, and should not be used to estimate the total numbers or areas of islands. That analysis is substantially different than the one presented here, and will be the subject of a subsequent report in this series.

Table 1. Disturbance Patch Size Distribution by Area per 100,000 Hectares of Total Disturbance, for Five Landscapes in the Foothills Model Forest.

Size-Class (ha)	Landscape				
	Montane	Subalpine JNP	Subalpine East	Upper Foothills	Lower Foothills
<2	416	182	1,153	679	526
2-9.9	248	83	5,495	1,779	3,525
10-39	868	501	3,762	2,427	4,532
40-79	2,135	640	5,088	1,618	4,047
80-199	9,839	3,369	4,907	3,466	6,620
200-599	14,955	9,460	15,083	6,933	13,894
600-1,999	71,539	16,833	21,716	10,207	36,552
2,000-4,999	0	3,031	7,814	7,799	5,315
5,000-9,999	0	31,430	11,267	14,251	24,990
10,000+	0	34,471	23,715	50,841	0

Table 2. Disturbances Patch Size Distribution by Density per 100,000 Hectares of Total Disturbance, for Five Landscapes in the Foothills Model Forest.

Size-Class (ha)	Landscape				
	Montane	Subalpine JNP	Subalpine East	Upper Foothills	Lower Foothills
<2	360	168	1,246	506	508
2-9.9	43	25	776	239	477
10-39	28	20	127	78	162
40-79	29	10	64	21	54
80-199	51	19	27	20	42
200-599	36	19	29	14	28
600-1,999	51	12	16	8	22
2,000-4,999	0	1	2	2	1
5,000-9,999	0	3	1	2	3
10,000+	0	2	1	1	0

Table 3. Disturbance Size Distribution by Area per 100,000 Hectares of Total Disturbance, for Five Landscapes in the Foothills Model Forest.

Size-Class (ha)	Landscape				
	Montane	Subalpine JNP	Subalpine East	Upper Foothills	Lower Foothills
<2	108	36	277	133	131
2-9.9	76	19	1,561	412	1,035
10-39	210	87	1,242	523	1,257
40-79	913	227	2,185	668	1,958
80-199	2,778	692	2,761	997	2,779
200-599	4,727	1,951	3,736	1,532	3,848
600-1,999	58,734	11,077	17,812	6,810	29,491
2,000-4,999	32,453	7,853	15,630	8,798	20,431
5,000-9,999	0	19,846	12,834	12,187	21,768
10,000+	0	58,211	41,963	67,939	17,303

Table 4. Disturbance Size Distribution by Density per 100,000 Hectares of Total Disturbance, for Five Landscapes in the Foothills Model Forest.

Size-Class (ha)	Landscape				
	Montane	Subalpine JNP	Subalpine East	Upper Foothills	Lower Foothills
<2	46	22	185	76	69
2-9.9	6	4	136	42	77
10-39	5	3	59	23	43
40-79	7	3	22	10	20
80-199	10	4	18	7	16
200-599	7	4	6	3	6
600-1,999	22	6	9	5	11
2,000-4,999	11	3	9	3	6
5,000-9,999	0	2	1	1	2
10,000+	0	3	2	2	1

Table 5. Old Forest Patch Size Distribution by Area per 100,000 Hectares of Total Disturbance, for Five Landscapes in the Foothills Model Forest.

Size-Class (ha)	Landscape				
	Montane	Subalpine JNP	Subalpine East	Upper Foothills	Lower Foothills
<2	3,367	4,531	4,696	4,901	4,711
2-9.9	2,321	3,124	3,238	3,379	3,248
10-39	1,811	2,437	6,730	4,933	5,562
40-79	5,473	1,403	5,031	4,563	7,573
80-199	21,826	3,531	7,732	8,381	6,544
200-599	30,796	11,326	27,762	14,527	16,454
600-1,999	34,407	25,368	35,402	16,389	21,222
2,000-4,999	0	37,001	9,409	21,790	0
5,000-9,999	0	11,281	0	6,518	0
10,000+	0	0	0	14,620	34,685

Table 6. Old Forest Patch Size Distribution by Density per 100,000 Hectares of Total Disturbance, for Five Landscapes in the Foothills Model Forest.

Size-Class (ha)	Landscape				
	Montane	Subalpine JNP	Subalpine East	Upper Foothills	Lower Foothills
<2	10,074	10,151	9,900	10,023	9,963
2-9.9	772	778	758	768	763
10-39	152	153	398	283	330
40-79	121	31	111	95	164
80-199	255	20	82	80	74
200-599	109	48	95	53	58
600-1,999	49	30	41	17	24
2,000-4,999	0	16	3	11	0
5,000-9,999	0	2	0	2	0
10,000+	0	0	0	2	3

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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 do not claim these to be the “right” definitions, but rather the definitions used in these reports.

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 fraction – 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 patch – Contiguous area affected by a single disturbance event. Disturbance Patches combine to form Disturbance Events.

Disturbance rate - the percentage of area affected by disturbance over a given period. 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.

Event (or Disturbance event) – An area of land that is affected by the same disturbance. Events can be composed of multiple disturbance patches, as well as non-disturbed patches of forest and non-forest land.

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 small area which has survived more than one fire event, and therefore tends to be much older than surrounding areas of forest.

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

Fire severity - the amount of 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 – any area of a landscape that is void of tree growth, including water, meadow, brush, rock outcrop, swamp and bog.

Non-operating – term adopted for this report, but synonymous with the Alberta government term “non-productive forest land” and defined as: land not capable of meeting the specific productive and potentially productive growth time lines.

Patch - a contiguous area of the same type (defined by age, composition, structure, or other feature).

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.

APPENDIX A – DISTURBANCE PATCH AND EVENT SIZE METHODS

This appendix describes the data, methods, and assumptions used to estimate “natural” disturbance event and patch sizes. This effort would not be necessary if we had a sufficient number of historical natural fires to measure. However, fire control efforts over the past 30-50 years have affected not just the size of fires, but also the size and numbers of the disturbance patches within a fire. Fires prior to 30-50 years ago were mapped only in very general terms, if at all. Thus I attempted to develop unbiased natural fire and disturbance patch size distributions from alternative data sources as outlined below.

Step 1: Estimate young patch size distributions.

For both Weldwood and Jasper National Park there exists a “stand origin” map, which includes only the year of the last stand-replacing fire event. All cultural disturbance openings (such as roads, mines, and residential development) have been eliminated from this dataset, as have any natural disturbances since 1950 (of which there are few). The result is a “natural” snapshot of the FMF land base from 1950. For a more complete description of the stand origin data, including validation testing, please see Andison (1999).

Using the stand origin data from Weldwood and Jasper, the patches originating between 1890 and 1950 were isolated to represent an initial estimate of disturbance patch sizes. It is fairly safe to assume that young patches created prior to 1950 were only minimally influenced by fire control efforts, and thus are relatively “natural”. The area of the landscape represented by the 1890 to 1950 range varies from 19% to 32% depending on the Natural Subregion. Using data from a 60 year range to represent recent disturbance activity is less than ideal, but was necessary to ensure a large enough sample of patches was obtained. For example, patches between 1930 and 1950 cover only a very small percentage of the landscape, and include only several dozen patches – not nearly a large enough sample to represent landscape fire activity. Also keep in mind that none of the cultural disturbance activity over the last 100 years in the FMF is included in these data, and cannot bias the analysis.

Another risk of using a 60 year range of patch sizes to represent disturbance patches is that disturbances may overlay each other over that period of time. Without detailed field sampling, there is no way to assess the degree to which this may be true in this case. However, the spatial distribution of young patches (Figure 11) suggests that potential for spatial overlap is minimal. However, we can at least know that if any bias exists, it is negative. In other words, if anything, there are larger disturbance patches and fires than these data suggest.

These initial patch size figures were summarized by natural subregion, although same-aged patches were not split by natural subregion boundaries. For those patches that crossed natural subregion boundaries, the patch was associated only with that landscape in which most of the patch area existed. The other possibility was to present patch size results for each natural subregion as if these landscapes were physically unconnected. Although this would have been simpler, it is more landscape specific, less transferable to other parts of Alberta, and thus less valuable from an application point of view.

Step 2: Estimate disturbance patch size distributions.

Step one represents a preliminary estimate of disturbance patch size distributions using stand origin data. While stand origin maps well represent overall historical fire activity (as they are meant to), the level of resolution is unknown. Given the spatial complexity of even so-called “stand-replacing” fires, even high quality stand origin mapping exercises are at some point challenged to identify very small patches several years or decades later. In this step, highly detailed fire data is used to identify that resolution threshold of the stand origin data, and make an estimate of the proportion of (unidentified) very small disturbance patches.

Twenty-five historical fires between Rocky Mountain House and Grande Prairie were mapped between 1998 and 1999 ranging in size between 28 and 13,000 hectares. Fires were selected based on 1) the existence of aerial photographs within five years after the fire, and 2) presence of minimal or no cultural influence (including fire fighting). Each fire was mapped down to a resolution of about 10m (a clump of 3-4 trees) using five 20% mortality classes. The interpreted fires were digitized and assembled into a single spatial (ARC-INFO) data layer for processing, and exported into Excel spreadsheets for non-spatial analysis. Six fires were eliminated from this analysis because records indicated that each had bulldozer lines around the entire perimeter. Such fire lines have the potential to affect disturbance patch development since they would prevent moderate and low intensity fire spread from existing fire patches.

Using the disturbance patch size data, relationships were established between *disturbance patch sizes* and *fire sizes* in such a way that the number of patches of different sizes is predicted from the total size of the fire as follows:

As each fire tends to have one major disturbance patch, regression analysis was used to establish the following relationship to determine the size of the largest patch:

(a) **Total Fire Size = Largest Disturbance Patch x 1.342** (n = 19, R² = .99, SE = 442)

One problem with these data is that the range of the fire sample data only goes up to about 13,000 hectares, while our stand origin patch size data includes patches over 50,000 hectares. It is overly optimistic to expect that the extrapolation of this relationship holds up to 50,000 hectares, but without some estimate of the relationship beyond empirical data, this analysis is not possible. To be conservative, a factor of 1.25 was used instead of 1.372 in the equation above for patch sizes above 20,000 hectares. It is conservative in that it likely results in less smaller patches than actually exist. In any case, there were only two large patches in the stand origin dataset to which this rule applies.

The following relationships were also developed between Total Fire Size (TFS) and eleven patch-size ranges:

- (b) **No. of Patches 0-2 Ha. = 0.825 \sqrt{TFS}** (R² = .34, SE = 32.8)
- (c) **No. of Patches 3-10 Ha. = 0.388 \sqrt{TFS}** (R² = .45, SE = 16.0)
- (d) **No. of Patches 11-40 Ha. = 0.133 \sqrt{TFS}** (R² = .43, SE = 5.8)
- (e) **No. of Patches 41-80 Ha. = 0.047 \sqrt{TFS}** (R² = .43, SE = 2.0)
- (f) **No. of Patches 81-200 Ha. = 0.028 \sqrt{TFS}** (R² = .49, SE = 1.4)
- (g) **No. of Patches 201-600 Ha. = 0.0220 \sqrt{TFS}** (R² = .43, SE = 1.0)
- (h) **No. of Patches 601-2,000 Ha. = 0.0048 \sqrt{TFS}** (R² = .37, SE = 0.25)

Equations with slightly higher levels of significance are possible with much more complex equations, but the improvement was only marginal (R² values of 0.03 to 0.05) so the simpler equations were adopted. The sample size in each case was n=19.

The equations were then applied to the disturbance patch size data to determine total fire size (TFS), and from an estimate of TFS the probable breakdown of disturbance patch sizes for each fire was made. For example, one of the disturbance patches in our dataset was 7,190 ha. Applying the first equation, the total fire size (TFS) was estimated to be 9,649 ha. Using TFS, the number of patches 0-2 ha in size was estimated to be 79, 37 patches 3-10 ha, 13 patches 11-40 ha, and so on. If the sum of all disturbance

patches differed from the total fire size estimate, the patch size estimates were shifted proportionally (since the TFS estimate was much more significant than the individual patch size relationships).

The estimates of the numbers of patches for each fire were subtracted from the original inventory of patches in that class from the stand origin dataset, and the next smallest fire was estimated. This technique quickly created negative numbers for the smallest patches. In fact, the number of patches 0-1 hectares from the stand origin map was not even sufficient to cover the very first large fire. As expected, the number of “missing” patches was inversely related to their size by the end of the analysis, supporting the hypothesis that the stand origin mapping was not able to detect small patches of differently-aged forest many years after the event.

Positive numbers of patches occurred for all patches larger than 80 hectares at the end of this analysis. I interpreted this to mean that the stand origin mapping correctly identified all patches larger than 80 hectares in size. However, this also means that the final disturbance patch numbers do not account for all disturbance patches in fires less than 80 hectares in size. For that, I needed an estimate of the proportion of fires in each size-class below 80 hectares to complete the analysis.

Given the problems noted at the beginning of this section, historical records or maps could not be relied upon. Instead, I used the proportion of missing to estimated patches thus far as a proxy for the proportion of missing fires in each size class. For example, the 60 year patch size data identified 256 patches between 0-2 hectares. To this point, the analysis had identified another 2,506 patches 0-2 hectares in fires larger than 80 hectares based on equation (b) above. Thus, the ratio on minimum possible to correctly identified patches 0-2 ha in size is $(2,506+256)$ to 256, or 10.8 : 1. Similar ratios were estimated for patch sizes 3-10 ha (6.2 : 1), 11-40 ha (1.7 : 1), and 41-80 ha (1.4 : 1). Note that this assumes that the proportion of missing patch sizes below 80 hectares is identical to the proportion of missing fire sizes, which may not necessarily be true. For all we know, the proportion of fire sizes may be evenly distributed across the smallest four size classes. However, a proportional assumption is relatively safe given our current understanding of fire patterns and behaviour on other boreal landscapes across Canada.

Armed with proportions, I now needed an estimate of actual fire numbers on which to apply the proportions. In other words, an estimate of the total number of fires that the 60 year history used for the patch analysis represents. I already had the estimated actual number of fires larger than 80 hectares (99), but still needed a way to relate that number to the number of fires less than 80 hectares – to which the proportions above would be applied. Unfortunately, the young patch data could not be used to make this estimate since it would be a circular argument. Alternatively, I used provincial fire history records and Jasper National Park fire history records. Using an area much larger than the study area (about 7 million hectares), I used the average number of lightning fires per year between 1961 and 1999 (1982 to 2002 for Jasper Park). While cultural activity will have an effect on fire sizes, it should have much less of an effect on lightning-caused ignitions.

Knowing that the total forest area from which the young patch data was derived totalled 1.6 million hectares (1.1 million hectares in the Foothills East, plus $\frac{1}{2}$ million hectares in Jasper Park), I used the fire records to make an estimate of the number of fires that occurred across the 1.6 million hectares of interest, over a 60 year period (1,200 fires). I realize that this estimate of fire numbers is very rough, and there are many reasons why it might be inaccurate. However, it is unlikely that it is wrong by orders of magnitude, and thus serves at least as a first approximation to allow the patch and fire size analysis to be completed.

Assuming that the 1,069 young patches identified by the stand origin map that are less than 60 years of age across 1.6 million hectares represents about 1,200 fires, this means that $(1,200 - 99 =) 1,101$ of those fires are less than 80 hectares in size. (Recall that 99 was the number of fires identified larger than 80 hectares to this point). Now the four ratios noted above for the four size-classes less than 80 hectares can be applied to distribute these 1,101 “missing” fires. These numbers were used to complete the estimates of patch sizes. For example, the number of fires between 40-80 hectares over the last 60 years on the 1.6 million hectares was estimated to be 76 – which was plugged into equations (a) through (d). The number of fires between 11-40 hectares was estimated to be 94, which was plugged into equations (a) through (c). Below 10 hectares, I assumed that fires were single disturbance patches. None of our 25 sample fires were this small, so this is another conservative assumption.

The final proportion of disturbance patches is presented in Table A1. Note that the absolute numbers at this point are irrelevant. The point of the exercise was to try to develop an estimate of the *relative proportions* of historical disturbance patch sizes. I included the numbers to demonstrate that the two major assumptions required to build this table discussed above, end up having minor impacts on the outcome. For example, if the total number of fires used above doubles from 1,200 to 2,400, the percent of patches 0-2 hectares changes from 58.1 to 58.8 (for example). Other proportions show correspondingly small changes. Similarly, if I assumed that the 1,101 fires less than 80 hectares in size were divided equally among the four size-classes (instead of using the ratios above), the percent of patches 0-2 hectares would be 52.9% instead of 58.1%, which is by far the most significant change under that scenario. In any case, this assumption only changes the numbers of patches of the first four size-classes, and does not affect the numbers of patches larger than 80 hectares.

Table A1. Estimated Natural Proportion of Disturbance Patch Sizes.

Patch Size (ha)	Estimated Historical Disturbance Sizes by Size-Class	
	Number	Percent
0-2	3,598	58.1
3-10	1,755	28.3
11-40	442	7.1
41-80	145	2.3
81-200	106	1.7
201-600	79	1.3
601-2,000	49	0.79
2,001-5,000	8	0.13
5,001-10,000	7	0.11
>10,000	4	0.06
Total	6,193	100

Step 3: Estimate fire size distributions

The previous analysis includes most of the steps necessary to estimate a fire (i.e., disturbance) size distribution. To develop the disturbance patch size distribution, estimates of numbers of fire events in each size class had to be made. Thus numbers of fires was simply a by-product of the analysis – with one exception. Fires larger than 10 hectares were still being represented by their largest patches, and not the actual estimate of the fire size. For example, a 190 hectare patch from our database would be the largest patch of a (190 x 1.342 =) 255 ha fire. Yet in the patch inventory, it was still being represented by the 81-200 size-class, when it should actually have been “promoted” to the 201-600 ha size-class. Thus a certain portion of fires in each size-class above 10 hectares needed to be promoted to the next class. All associated fire sizes below 10 hectares did not get promoted since I assumed that fires less than 10 hectares in size did not have multiple patches.

To estimate the number of fires in each size-class above 10 hectares that should be promoted, I applied the largest patch equation coefficient (1.342) to each patch in each size class, assuming that patch sizes were distributed evenly across the size-class range. Thus, if there were 3 patches in the 201-600 ha size-class, each one of the three would be 1.342 times larger, but only one (on average) would jump to the next size-class up. In the end, the total number of fires to estimate the proportions stays at 1,200, but about 1/3 of those larger than 80 hectares jump one size-class. The results are shown in Table A2.

Note that in this case the distribution of the fire sizes less than 80 hectares using the ratios in the previous section played a much more prominent role. Although the proportions of fire sizes above 80 hectares would not change, adopting a different assumption about the relative proportion of fire sizes less than 80 hectares would have a direct and dramatic impact on the estimates shown here.

Table A2. Estimated Natural Proportion of Fire Sizes

Patch Size (ha)	Estimated Historical Fire Sizes by Size-Class	
	Number	Percent
0-2	596	49.7
3-10	343	28.6
11-40	60	5.0
41-80	66	5.5
81-200	49	4.1
201-600	21	1.7
601-2,000	32	2.6
2,001-5,000	19	1.6
5,001-10,000	7	0.57
>10,000	7	0.60
Total	1,200	100

Step 4: Other Sources of Possible Errors

The main assumptions regarding the analysis have been discussed above. However, there is one other assumption made here that could affect the results. The analysis to this point assumes that at least the largest patches (larger than 80 hectares) were correctly identified, and thus I concentrated on “building” fires from available (and missing) patches – essentially arranging the disturbance patch inventory in space. An alternative possibility is that the patches from the stand origin data do in fact represent fire boundaries, but lack the internal detail. If this is the case, the analysis above would be applied assuming that patch size = fires size (as opposed to estimating TFS from equation (a)).

In fact, this analysis was done, although not presented here. The effect of the change is only marginally detectable in the disturbance patch size analysis. For example, the biggest difference is noted in the percent of patches 0-2 hectares, which shifts from 58.1% to 57.6%. As expected, there are fewer larger patches, but only fractions of percentages less in all cases.

The impact of this assumption change on fire size is more substantial. The percent of fires less than 10 hectares in size increases by about 2.5%, and the percentage of larger fires declines – in all cases less than 1%. This happens of course because a) the fires are smaller, and b) there is no size “promotion”.

Because virtually every fire history study dealing with fire size in the Canadian boreal forest has identified a negative exponential shape to fire size distribution, and visual assessments of the young patch data clearly identify clusters of patches that are undoubtedly related, the original estimate of fire size distribution under the assumption of clustering will be used in this report. However, it is important to keep this in mind as one possible source of error when considering the results.

One last assumption that I made in this analysis was that the relationship between fire events and fire patches is consistent across all five landscapes. With only 25 fires to work with, it was not feasible to divide the fire data into different natural subregions. It is possible that the disturbance patch – event relationship varies by landscape.

APPENDIX B – OLD FOREST PATCH SIZE METHODS

This appendix describes the data, methods, and assumptions used to estimate old forest patch sizes. The analysis deals with two main issues: resolution (i.e. the minimum size of old forest patches), and definition (i.e., what do we include?).

Step 1: Initial Estimate of Old Forest Patch Size Distributions.

Using the stand origin data from Weldwood and Jasper, the area representing approximately the oldest 15% of each of the five landscapes was isolated to represent an initial estimate of old forest patch sizes (recall that the stand origin data are from 1950, so fire control was an insignificant factor). Using this rule, the stand origin dates and percentage of landscape varied as follows:

- 1830 and older for the Montane (representing 15.5% of the forest land),
- 1690 and older for Subalpine JNP (representing 18.0% of the forest land),
- 1780 and older for Subalpine East (representing 17.4% of the forest land),
- 1808 and older for Upper Foothills (representing 13.4% of the forest land), and
- 1808 and older for Lower Foothills (representing 17.4% of the forest land).

Thus the “old” designation here refers only to the oldest 15% of the forest, and may not necessarily correspond to more precise definitions of “old growth”, or “old forest”. However, this relationship is unimportant for this analysis. Whether or not stands that originated from prior to 1800 are defined as “old growth”, or 1600, it will have nothing to do with the size and spatial arrangement of those patches, as long as in both cases it represents the same area of a given landscape. In the big picture, I am essentially interested in the decay of existing landscape forest patches by disturbance events into *old* patch sizes through time and over space. The biggest risk of using this method is that true “old growth” may in fact be a very small subset of the 15% arbitrarily chosen for this analysis. It is reasonable to assume that patch size distribution of the oldest 5% of a landscape will be different (and negatively biased) compared to one of the oldest 15% of the landscape. However, by the same token, “old growth” may include 30-40% of a landscape. The use of a standardized 15% allows these results to be applied to any landscape, with any amount of old growth.

These initial old forest patch size figures were summarized by Natural Subregion, although patches were not split by Natural Subregion boundaries. For those patches that crossed Natural Subregion boundaries, the patch was recorded for that landscape in which most of the patch area existed. The other possibility was to present patch size results for each Natural Subregion as if these landscapes were physically unconnected. Although this would have been simpler, it is also less transferable to other parts of Alberta, and thus less valuable from an application point of view.

The estimation of old forest patch sizes for the 1995 landscape snapshot included the influence of harvesting, other cultural “clearing” activities (such as mining or land conversion), and any roads or other major linear features that the Alberta Vegetation Inventory identified.

Step 2: Estimating Old Forest Island Remnants

Step one represents a preliminary estimate of old forest patch size distributions using stand origin data. While stand origin maps represent well overall historical fire activity (as they are meant to), the level of resolution to which this is true is unlikely to pick up very small old remnant islands within the forest matrix. Given the spatial complexity of even so-called “stand-replacing” fires, even high quality stand origin mapping exercises would be challenged to identify very small patches several years or decades later. In this step, highly detailed remnant island data is used to estimate of the proportion of (unidentified) very small remnant islands patches.

Twenty-five historical fires in the foothills area were mapped between 1998 and 1999 ranging in size between 28 and 13,000 hectares. Fires were selected based on 1) the existence of aerial photographs within five years after the fire, and 2) presence of minimal or no cultural influence. Each fire was mapped down to a resolution of about 10m (i.e., a clump of 3-4 trees) using five 20% mortality classes. The interpreted fires were digitized and assembled into a single ARC-INFO data layer for processing, and exported into Excel spreadsheets for non-spatial analysis (MacLean et al. 1998). Six fires were eliminated from this analysis because records indicated that each had bulldozer lines around the entire perimeter. Such fire lines are expected to particularly impact on disturbance patch development since they would prevent moderate and low intensity fire spread along the perimeter of the largest patch.

The island remnant dataset included a total of 4,508 islands ranging in size from less than 1 ha to over 100 ha across a disturbance area of 40,421 ha. The breakdown of island sizes shown in Table B1 was thus assumed to be the universal breakdown of island remnant sizes across all landscapes and applied to that portion of the landscape that is not old forest. For instance, the total forest area of the Montane landscape is 62,345 ha, of which I classified 9,645 ha as “old”. The remaining 52,700 ha of not-old forest is the only forest area eligible to have island remnants, since by definition island remnants must be older than the surrounding matrix forest. Thus, we would expect 52,700 ha of not-old forest to have $(4,112 \text{ islands} < 2 \text{ ha across } 40,421 \text{ ha}) \times (52,700 \text{ ha} / 40,421 \text{ ha}) = 5,361$ islands less than 2 ha in size in the Montane in this example.

Table B1. Distribution of Remnant Island Sizes from Island Remnant Dataset

Island Size	Number of Islands
<2 ha	4,112
2-10 ha	315
10-39 ha	62
40-79 ha	11
80-199 ha	6
200-599 ha	2

Obviously, not all island remnants will be “old”. A patch of 30 year old forest left unburnt within a recent fire is still defined as a remnant island in the same way a 300 year old island would be. Also, islands have a greater chance of not surviving over time. Thus “not old” islands are expected to be more common than “old” islands across the landscape. To estimate the proportion of islands that are “old”, I used the proportion of old forest across the landscape. This assumes that an old island has the same chance of survival as any other category / patch of old forest. So in the example above, we expect to find $(5,361 \text{ total islands}) \times (9,645 \text{ ha old} / 62,345 \text{ total ha forest}) = 829$ island remnants < 2 ha in size that are classified as “old” in the Montane.

Step 3: Integrated Estimate of All Old Forest Patches

We know old forest exists in larger patches which more recent fires burnt around and/or up against, as well as much smaller islands entirely within more recent disturbances. However, the mechanisms are less important than the outcome at this point. Ultimately, the important issue is to derive an accurate estimate of the patch size distribution of *all* old forest – regardless of what it is called. In this case we have one dataset at the landscape scale which identifies all old patches, and one that focuses on island remnants (which tend to be relatively small). So while it is recognized that both datasets are incomplete, there will be overlap between them, and it is possible to logically link them to generate a single patch size distribution which represents all forms of old forest.

We already know (from Appendix A) that the stand origin map has important resolution limitations, which fall roughly along the line between patch and island. In other words, the stand origin data will provide good estimates of the numbers of old forest patches, but likely not be able to identify most of the islands of old forest. Using this logic, I converted both datasets into absolute numbers of old forest patches for each of the five landscapes, and adopted the highest number of the two to represent a combined estimate of old forest. For example, Step 2 estimated that there were 829 old island remnant patches <2 ha in size in the Montane, and the stand origin data identified only 15 patches <2 ha in size. In this case, I assumed that 829 was the more correct number, and the difference was due to the resolution limitations of the stand origin map. Similarly, the island remnant data estimated 13 old patches 10-39 hectares, while the stand origin data identified only 6. Again, the island remnant estimate of 13 was used to represent the combined total number of old forest patches for that size-class. However, the island remnant data only estimated two old patches between 40-79 hectares, and the stand origin data found 10. In this case, I adopted the estimate of 10, and assumed that the stand origin data was accurate.

It is interesting to note that the minimum patch size at which the stand origin data was deemed valid (around 40 hectares in most cases) is the same point at which the young patch data was thought to be valid from Appendix A.

Step 4: Other Sources of Possible Errors

There are several places in this analysis where my assumptions may be questioned. First, I chose to represent that portion of islands that were “old” by the portion of old forest in each landscape. For various reasons, this may not be true – islands may for some as yet unknown reason either be more or less likely to survive to be “old”.

The second potential source of error is that the method of combining the two estimates of old forest patches likely catches all of the very small and very large patches, but may under-represent the number of intermediate-sized patches. For example, stand origin data may still miss some 40 ha patches, but the island remnant data may not allow for them either. I have no way of validating this technique, so the impact of such an error is unknown.

The third possible source of error in this analysis is that I applied the sizes of the entire island remnant dataset evenly across all five landscapes. It is possible that the relative frequency of island sizes varies by natural subregion. The sample size of the island remnant data is not large enough to test this hypothesis at this time.