Island Remnants on Foothills and Mountain Landscapes of Alberta

Part II on Residuals

Alberta Foothills Disturbance Ecology Research Series
Report No. 6

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DISCLAIMER

foothills MODEL FOREST

research growing into practice.

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

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

The Foothills Model Forest mission: We are a unique 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

This research was possible only through the hard work and dedication of many individuals. First and foremost, Weldwood of Canada Ltd. (Hinton Division), Jasper National Park, the Canadian Forest Service, Alberta Newsprint Company, Weyerhaeuser Company Ltd., Alberta Sustainable Resource Development, and the Alberta Forest Products Association generously supported the natural disturbance research presented in this report.

The Foothills Model Forest (FtMF) 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 FtMF 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, Herman Stegehuis, and Bob Anderson 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 FtMF Board of Directors, and in particular Bob Udell, for their unrelenting belief in the Natural Disturbance Program.

Kim MacLean was instrumental in putting together the island remnants database and some preliminary analysis and reports. Christian Weik of the FtMF has also been instrumental in providing any and all forms of GIS support to our research program in general, and these data in particular.

To the numerous field crews who tirelessly cut and cored trees across the FtMF, and sanded and counted rings on those rainy days, thank you for your efforts. Also, thanks to Kris McCleary for constructive input and assistance throughout the process, and compiling the final version of the methods report as a companion to this report. Finally, many thanks to Dr. Bill Baker for providing valuable input during the early stages of this project.

EXECUTIVE SUMMARY

This sixth report in the FtMF Natural Disturbance Program research series describes "island remnants" as a second form of disturbance residual material to complement the "matrix remnants" introduced in the previous report in this series. The rules used to objectively define an island remnant are detailed, along with examples, some new terminology, and summaries of the pattern and composition of island remnants in west-central Alberta. Using an extensive and highly detailed set of data collected, mapped, and digitized over several years on historical fires, this report poses and answers a series of fundamental questions. Briefly, those findings are:

1. An average of 10-11% of the disturbed area of fires, events, or patches exist as island remnants, although the average is largely meaningless as a representative target. But this average is much higher than those found for similar studies in BC and Alberta. The range of island remnant area is 0- 30% of the area of the fire or event, and 0-50% of the disturbed patch.

2. The proportional area in islands does not significantly increase as the fire or event size increases. This is contrary to the findings from similar studies in BC and Alberta.

3. Discrepancies in the results from this study compared to others are likely a combination of differences in resolution, definitions, and methods.

4. Variation in the percent island remnant area for disturbed patches is at least as variable within fires as it is between fires.

5. Undisturbed islands only account for 16% of island area, moderately disturbed islands account for 74%, and heavily disturbed islands account for 10%. However, as fires or disturbed patches become larger, the proportion of island area that is moderately disturbed declines, while the proportion of island area that is undisturbed and highly disturbed increases.

6. Islands less than two hectares in size account for an average of 27% of the area in islands, and an average of 91% of the number of islands. This relationship also changes as fire / event size increases – larger fires have significantly more large islands.

7. Islands have highly convoluted shapes relative to all other disturbance spatial elements. This, plus the fact that most islands are very small, means that interior area is rare in island remnants.

8. Islands detached from the edge of the disturbance account for more than half of the island area on average, relative to islands that are still physically connected to the edge of the fire. The proportion of detached island area increases significantly as the fire / event size increases.

Although island remnants have been studied and described previously in western boreal forests, these findings are unique in their depth and breadth. One of the main reasons for this was the liberal, inclusive definition of islands adopted here, combined with the use of high-resolution, historical, aerial photographs. This highlights the importance of associating any identified patterns with the adopted methods, data, and definitions.

INTRODUCTION AND REPORT OVERVIEW

This report is divided into several related parts:

First, there is a general overview of the FtMF Natural Disturbance Program, and is common to all reports in this series.

Part 2 is the main body of the island remnants study, and includes background, methods, discussion, and a summary.

Appendix A provides all of the equations used within figures in the report.

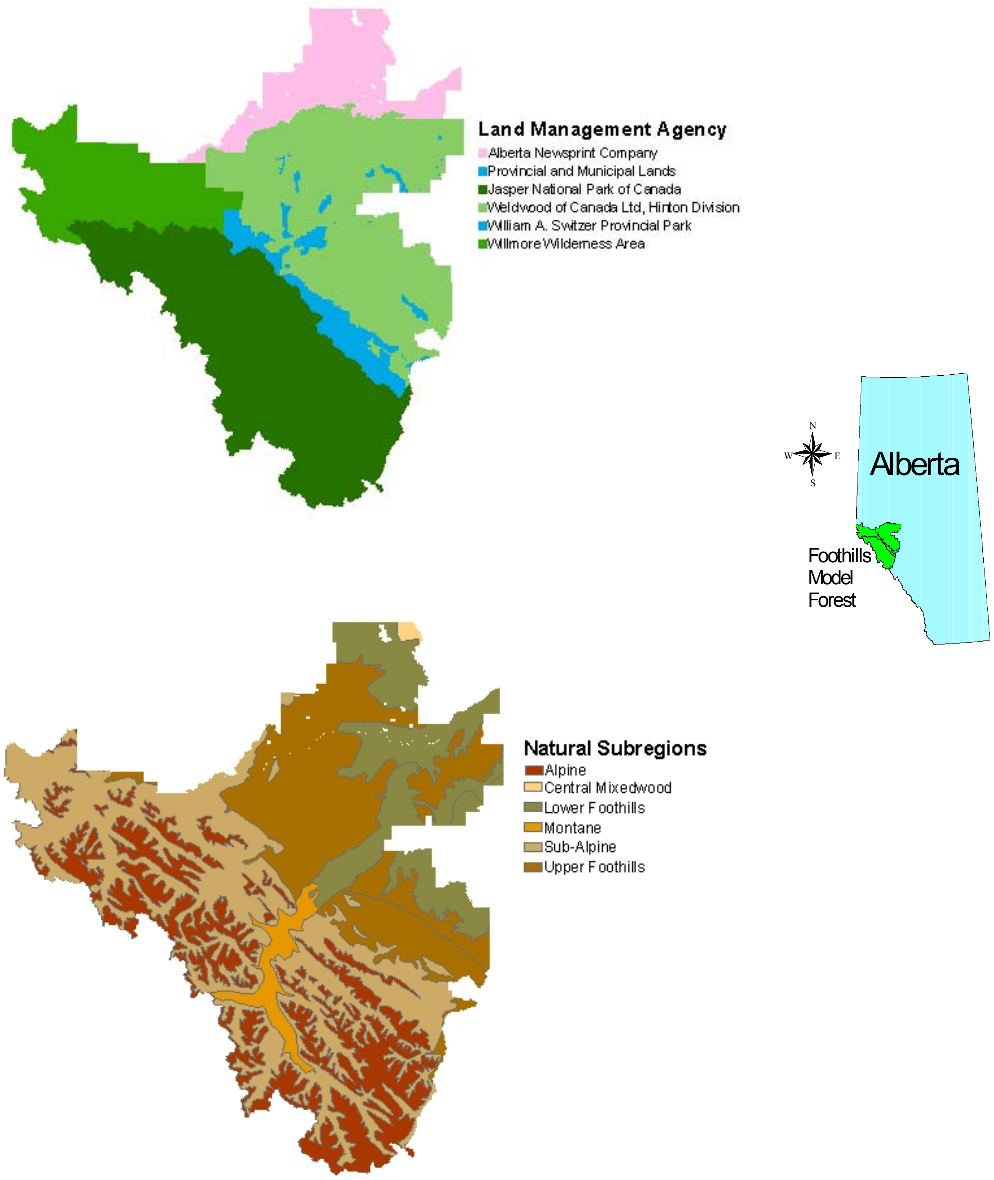
A glossary defines all of the technical terms used in this report.

Note that this report contains no methodological details. The data collected and methods used for this report have already been summarized in detail in:

MacLean, K., D. Farr, D.W. Andison and K. McCleary. 2003. Island remnants on foothills and mountain landscapes of Alberta: Methods. Alberta Foothills Disturbance Ecology Methodology Series, Report No. 1, November 2003. Foothills Model Forest, Hinton, Alberta.

Part 1: THE FtMF NATURAL DISTURBANCE PROGRAM

In 1995, the Foothills Model Forest (FtMF) 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 FtMF 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 Sustainable Resource Development (SRD), Jasper National Park (JNP), and Alberta Newsprint Company (ANC). The comprehensive research program is partitioned into over 40 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 link 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, our 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 different types of 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 ideally 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 must be conducted by professionals, openly peer-reviewed, presented at public meetings, conferences and tours, and published in FtMF NDP Quicknotes, internal reports, news updates, posters, and refereed journals. A communications plan has been developed for the FtMF 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 of disturbance to the land features (Forman and Godron 1986). 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 does allow some convenient scale distinctions to be made:

1) **Regional**

Several landscapes spatially related and commonly influenced by regional climatic patterns. The FtMF 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.

5) **Patch**

Contiguous areas of land that share common physical or biological characteristics. Age patches share year or year-range of origin (such as Old Forest), type patches depict areas of common tree species combinations, and Alberta Vegetation Inventory Patches define complex combinations of age, tree species, density and height, other vegetation, and other site factors. Relevant to this report, there are also *disturbance patches*, which have been affected similarly by a disturbance event, and *remnant patches*, which are any areas that have not been disturbed within a disturbance event.

6) **Island**

One type of remnant patch within a disturbance patch. There are no size limits on islands at this point, but they tend to be small. Islands may also be any combination of age, type and may be operable or inoperable.

7) **Matrix**

All undisturbed land outside the boundaries of disturbance events. Thus, any part of a landscape that is not within an event is matrix. *Matrix remnants* are undisturbed residual land within an event that are physically attached to the surrounding matrix.

The geographical terminology used in this document is as follows. The FtMF 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 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 SRD. Outside the boundary of the FtMF, 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 Jasper National Park, 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 FtMF, 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 ECOLOGY RESEARCH SERIES

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

For more information on the FtMF 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.

Andison, D.W. 2003. Patch and event sizes on foothills and mountain landscapes of Alberta. Alberta Foothills Disturbance Ecology Research Series, Report No. 4, March, 2003. Foothills Model Forest, Hinton, Alberta.

Andison, D.W. 2003. Disturbance events on foothills and mountain landscapes of Alberta. Part 1. Alberta Foothills Disturbance Ecology Research Series, Report No. 5, November, 2003. Foothills Model Forest, Hinton, Alberta.

Reports available in the methodology series:

MacLean, K., D. Farr, D.W. Andison and K. McCleary. 2003. Island remnants on foothills and mountain landscapes of Alberta: methods. Alberta Foothills Disturbance Ecology Methodology Series, Report No. 1, November 2003. Foothills Model Forest, Hinton, Alberta.

Part 2: ISLAND REMNANT PATTERNS

Perhaps the best-known attribute of natural disturbance patterns within forests is residuals, which are patches of partially or completely undisturbed vegetation within a disturbance. And while we already know that considerable residual material within forest fires of west-central Alberta exists between disturbed patches as "matrix remnants" (Andison 2003), residuals are often assumed to be synonymous with "island remnants". Islands are differentiated from other residual material in that they exist completely within the boundaries of individual disturbed patches.

Island remnant patterns within forest fires have been studied by DeLong and Tanner (1996) in northern BC, and Eberhart and Woodard (1987), and the Alberta Research Council (2001) in Alberta. This is the first study of residuals in the Alberta foothills. Given what we know about the variability of forest fire patterns, extrapolating findings for residuals from another landscape to this part of Alberta would be undesirable. There are also important methodological differences between this study and the others. The data used for this study was collected at extremely high levels of precision from aerial photos taken immediately after each natural fire. These data provide the ability to delve into far greater detail on residual patterns.

Our knowledge of the ecological relevance of island remnants is also better than that for most natural pattern attributes. We know, for instance, that islands are an important seed source for certain species and that they provide refuge for species that move poorly, or not at all, such as soil organisms. We also know that islands are critical habitat for birds and insects (Gandhi et al. 2001). Thus, we already have proof that island remnants are not only a natural phenomenon, but also provide many positive ecological benefits.

This is the first of two FtMF ND Program reports on island remnants, and the second of three on residuals. This one will focus on general questions of composition and structure. The next report will discuss specific spatial issues such as topographic and biological influences on island formation.

DEFINITIONS

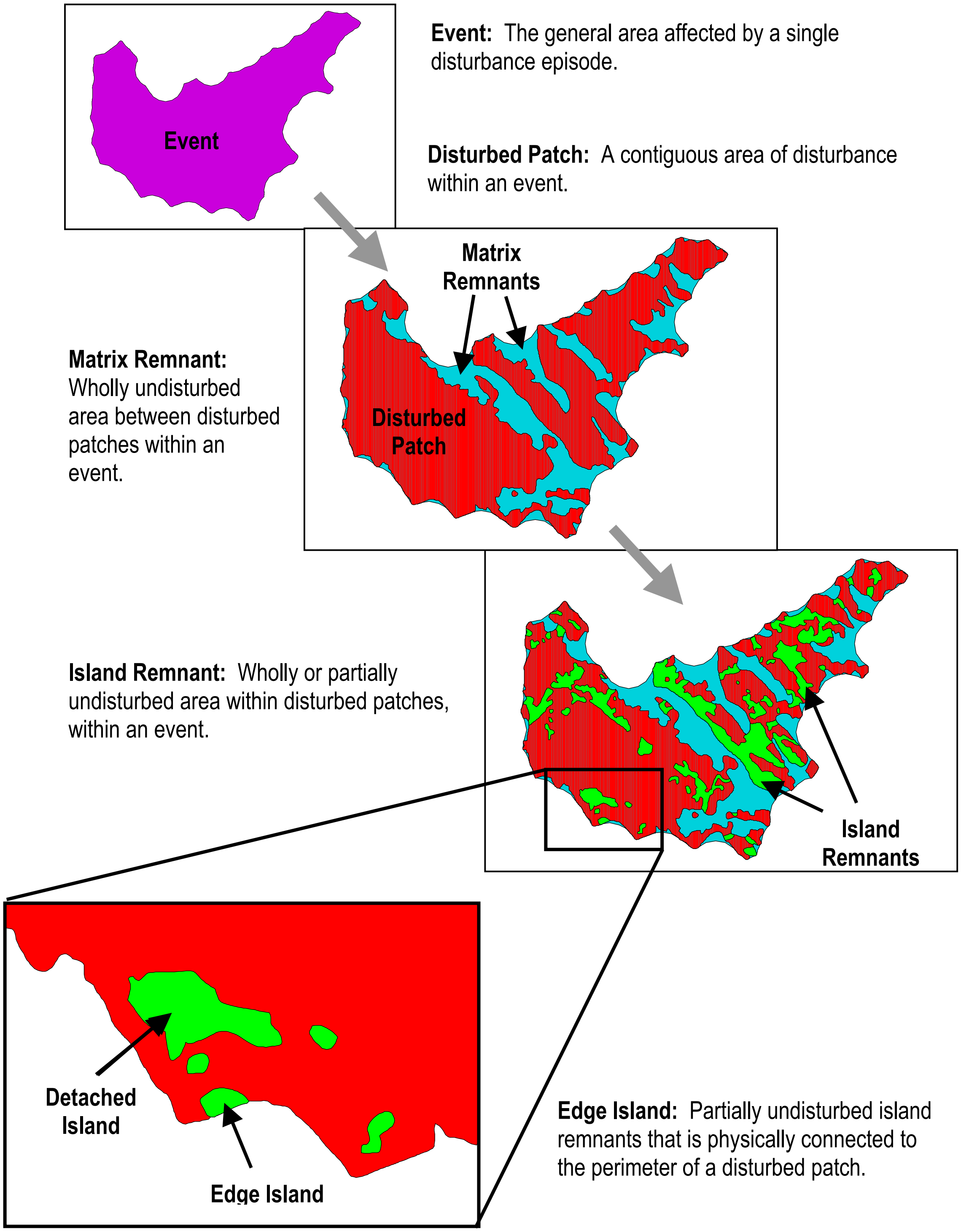
One of the keys to the successful integration of natural disturbance patterns into sustainable forest management is the ability to clearly define terms and spatial units. Although this report focuses on residual island remnants, it will reference several additional spatial units that require explanation.

The concept and an objective definition of a "disturbance event" was introduced and examined in detail in Report #5 in this series (Andison 2003). The simplest way of thinking of an event is the polygon represented by a simple line that would completely contain the multiple patches of a forest fire, as drawn on a map or aerial photos.

The two primary spatial elements within events are 1) disturbed patches, and 2) matrix remnants. Disturbed patches are defined by the exact boundary between any disturbed and un-disturbed areas. Thus, some fires can and do contain several disturbed patches if disturbed areas are not physically connected (Andison 2003). The area between disturbed patches is un-disturbed residual material called "matrix remnants". By definition, matrix remnants are ***always completely undisturbed***. Any areas partially disturbed adjacent to other disturbed areas would be included within the boundaries of a disturbed patch.

Any residuals within disturbed patches are defined here as "island remnants". Island remnants are ***always entirely contained within a disturbed patch***. This includes any partially disturbed areas that are still physically attached to the perimeter of a disturbed patch. Such areas are classified as island remnants as opposed to matrix remnants since they are technically inside the perimeter of a disturbed patch. An example of this phenomenon is illustrated in the bottom image of Figure 2. However, since these islands may differ physically and ecologically, a sub-category of islands is defined here. Islands that are physically isolated or separated from the edge of a disturbed patch will be called “detached islands”. Islands that are in physical contact with the edge of a disturbed patch will be called “edge islands”. In rare instances, a small, partially disturbed patch can exist in (spatial) isolation, and in this case the entire patch would be considered both a disturbed patch, and an island remnant. Figure 2 provides examples of all of these spatial elements, and the relationships between them.

Figure 2. Illustration of the Primary Spatial Units of a Disturbance Event



Event: The general area affected by a single disturbance episode.

Disturbed Patch: A contiguous area of disturbance within an event.

Matrix Remnant: Wholly undisturbed area between disturbed patches within an event.

Island Remnant: Wholly or partially undisturbed area within disturbed patches, within an event.

Edge Island: Partially undisturbed island remnants that is physically connected to the perimeter of a disturbed patch.

Detached Island: Wholly or partially undisturbed island remnant that is physically isolated from the perimeter of a disturbed patch.

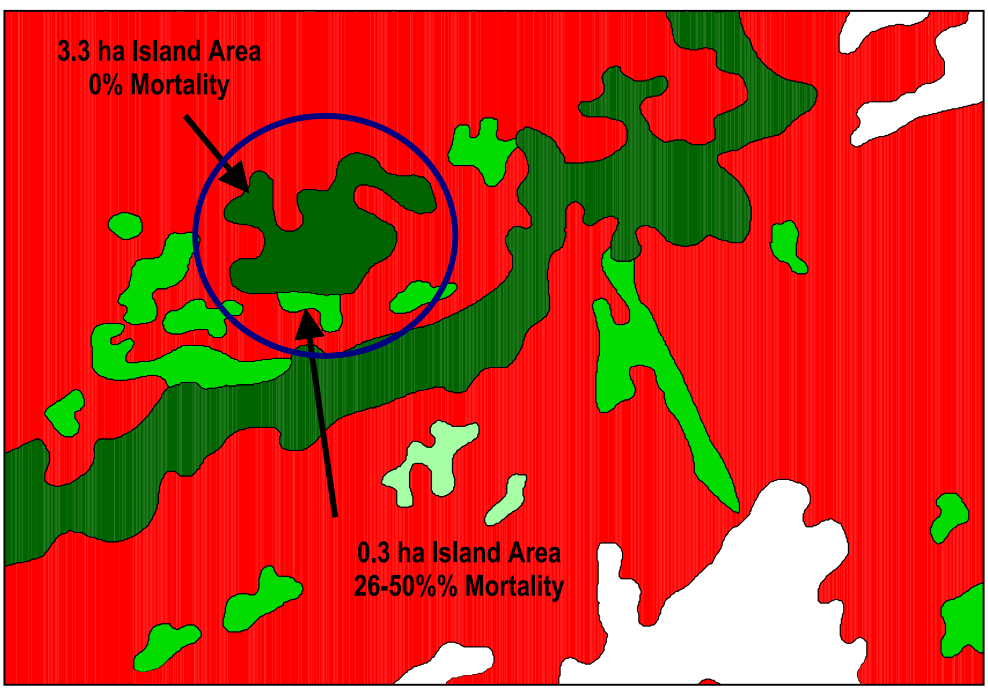
METHODS

A detailed description of how the raw data used for this report were collected is given in a companion FtMF report (MacLean et al. 2003), and will not be repeated here. However, it is worth summarizing several key elements. First, the data represent post-fire patterns of 24 fires ranging in size between 28 and 16,000 ha across the Upper Foothills, Lower Foothills and Sub-alpine natural sub-regions. Second, only fires that occurred prior to the aggressive initial attack era (circa 1970) were selected to minimize the influence of fire control. Only one fire in the dataset occurred after 1970, most fires occurred during the 1950's (see Andison 2003). Fires with any extensive fire control efforts were not accepted for the study. Third, all residual areas were assigned one of five mortality classes:

- 0 = no loss of crown (= 100% survival)
- 1 = 1-25% loss of crown
- 2 = 26-50% loss of crown
- 3 = 51-75% loss of crown
- 4 = 76-94% loss of crown

Patches with mortality greater than 94% were not considered residuals, but rather "individuals" (which will be addressed in a future FtMF report). Thus, the raw data do not necessarily represent individual islands, but simply spatial residual components that require subsequent assembly. For example, in Figure 3, the 3.3 ha of area that is mortality level 0, and 0.3 ha of area that is mortality level 2 represent the raw data. But because the data are spatial, they can, and are for any spatial analyses in this report, combined to create a 3.6 ha island that is, on average, mortality level 1 (1-26% mortality). A total of 4,507 island polygons were combined to create 4,269 island remnants.

Figure 3. Example of an Island Containing Multiple Mortality Classes.



Another methodological point to keep in mind is that in the vast majority of cases, photos at scales of at least 1:15,000 were used to identify patches and islands down to 0.001 ha in resolution using a magnifier stereoscope. However, in the interests of minimizing noise due to human error and allowing for differences in photo scale, I wanted to standardize minimum resolution. Thus, individual polygons less than $200m^2$ or .02 ha, and all events less than one hectare in size were eliminated from the dataset.

It is also relevant to understand that the analyses from this report take advantage of the methods and output from the previous report in this series on event patterns (Andison 2003). Again, the details will not be repeated here, but there are some highlights relevant to this report. For example, the algorithm used to define "events" as spatial entities identified 46 individual events ranging in size between 54 and 28,000 ha. Three out of the 24 fires generated multiple disturbance events, although, there was no indication that events generated from the same fire were in any way correlated to each other in terms of any patterns. Those 46 events contained a total of 246 disturbed patches.

In summary, the data used in the analyses to follow include a total of *4,507 original island polygons* collected at a very high level of detail, which combine spatially to create *4,270 island remnants* within *246 disturbance patches* (of which 175 are greater than five ha) within *46 disturbance events* generated from *24 individual fires*. Of those 4,270 islands, only 4,234 are larger than 0.02 hectares in size (representing the cut-off for inclusion in the analyses).

RESULTS

The results are presented as a series of logically sequenced questions. The first four questions relate to simple area summaries, and involve only the raw original island polygon data (see above). Subsequent questions relate to the spatial qualities of island remnants, and thus use the spatially aggregated island remnant data as described above, and illustrated in Figure 3. Details of the analyses such as regression equations or significance test results may be found in Appendix A.

Question 1: What proportion of the area of a fire exists as island remnants?

This is usually the first and most important question asked by both regulators and managers regarding island remnants since it relates directly to the issue of "how much?". Thus, it is important to be precise. As Report #5 in this series suggested, forest fires as spatial entities can be defined by either 1) the total area of the disturbed patches, or 2) the area of the greater "event", which includes the area of the disturbed patches, plus all areas of "matrix remnants" (see Figure 2). For example, suppose a forest fire consists of three disturbed patches 60 ha, 30 ha, and 10 ha, making a total of 100 hectares. Furthermore, suppose that within those three disturbed patches there were eight hectares of island remnants. Thus, the percent area in island remnants *relative to the disturbed patches* is (100 ha / 8 ha =) 8%. Now suppose that within this same fire, there are another 50 ha of matrix remnants in addition to the 100 ha of disturbed patches, for a total event area of 150 ha. In this case, the percent of island remnant area *relative to the event* is (150 ha / 8 ha =) 5.3%. There is no "right" way to make the calculation, but in the interests of clarity and consistency, I will calculate the area of island remnants both ways.

First, to allow the results to be compared directly to other island remnant studies, the calculation was made relative to the *disturbed patch area*. The calculation was also made using three different areas as the foundation or denominator: 1) the area of each disturbed patch, 2) the total area of all disturbed patches within each event, and 3) total disturbed patch area of individual fires.

Island remnants account for an average of 11% of the disturbed patch area within fires (Figure 4), 11% of the disturbed patch area within events (Figure 5), and 10% of the area of disturbed patches (Figure 6). In other words, the average proportional area of island remnants is identical regardless of which spatial unit is used as the reference point. Also common to all three estimates is the wide variation in proportional island remnant areas. For example, the proportional area of island remnants is less than 5% in 33% of the disturbed area of events, and zero 2% of the time. On the other hand, island remnants account for more than 20% of the area of (the disturbed area of) events 15% of the time (Figure 5).

The only difference between the three summaries of island remnants areas in Figures 4-6 is the shape of the distributions. The range of proportional area in island remnants is much wider for disturbed patches (Figure 6) than in either fires (Figure 4) or events (Figure 5). For example, 17% of the disturbed patches had no island remnants, compared to just 2% of all events, and none of the fires in the sample. Similarly, in 5% of all disturbed patches, island remnants accounted for over 30% of the area (Figure 6) compared to zero for both events and fires (Figures 5 and 4 respectively).

To allow the results to also be compared directly to previous natural disturbance pattern findings from the FtMF Disturbance Ecology Research Series, the calculation of area in island remnants was repeated relative to the total event area. As expected, the percentage of area in islands decreases (since the base number or denominator will always be higher). The average proportion of the total area of an event in island remnants is 7.5% (Figure 7), compared to 11% when the calculation was made relative to the disturbed patch area. The shape of the distribution is similar to that from the island area summary using the total disturbed area of the events (Figure 5). Thus, the only difference between using the disturbed area of events versus the total area of events as the base for this calculation is a negative shift of about 3.5% of the entire frequency distribution.

The output for the calculation is not shown here for disturbed patches or fires, but the patterns noted are identical to those found in Figures 4-6, with each one shifted to the left by 3-4%.

Figure 4. Percent of Disturbed Areas of Historical Forest Fires in Island Remnants

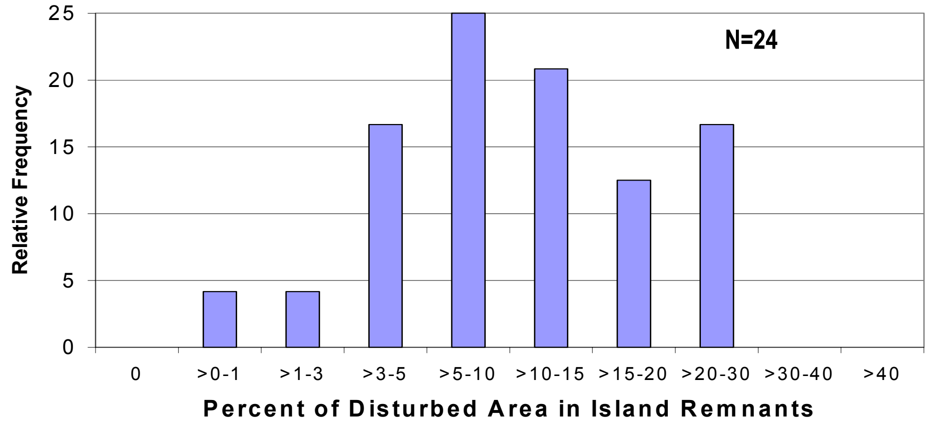


Figure 5. Percent of Disturbed Areas of Historical Events in Island Remnants

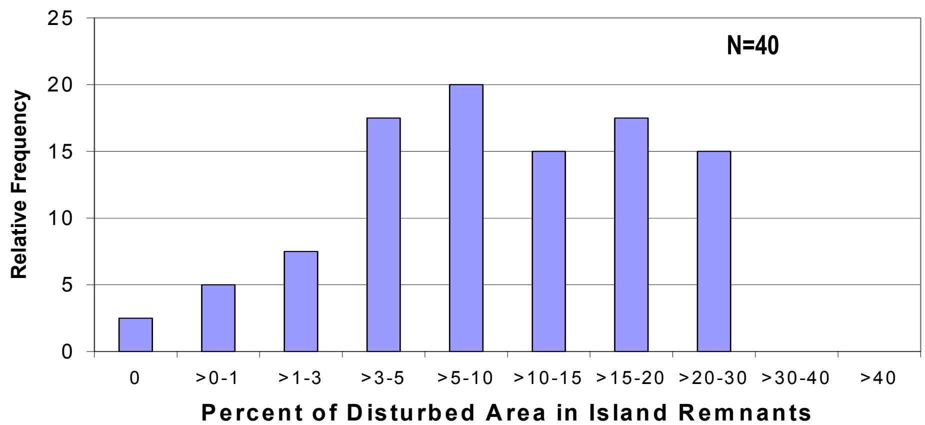


Figure 6. Percent of Disturbed Areas of Historical Disturbed Patches in Island Remnants

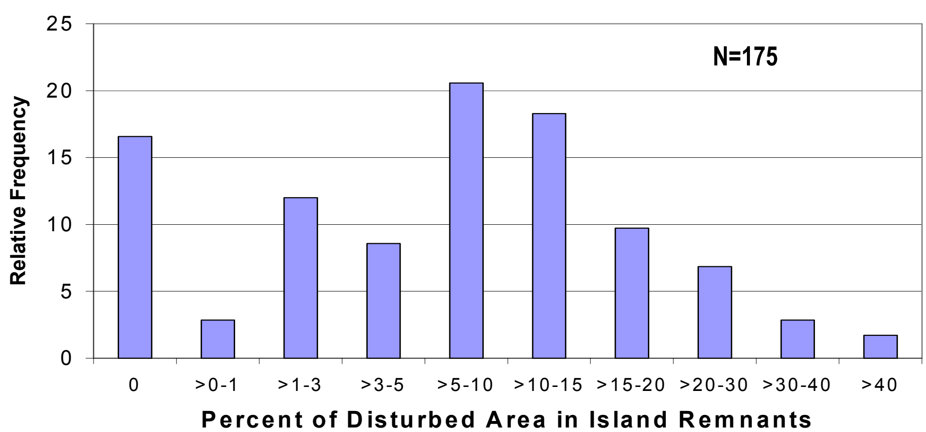
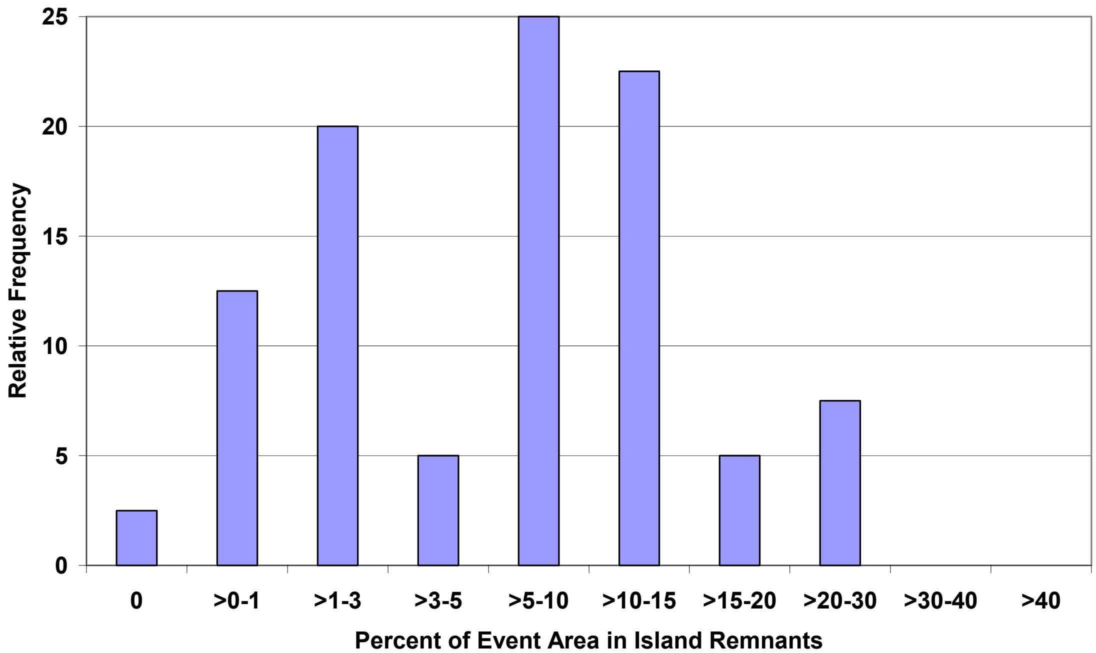


Figure 7. Percent of Historical Event Areas in Island Remnants



Question 2: Is the percent area in island remnants related to disturbance size?

Other island remnant research suggests that the proportional area of island remnants increases as the size of the fire increases (Eberhart and Woodard 1987, Delong and Tanner 1996). To test this hypothesis, the relationship between fire, event, and disturbed patch size, and the percent area in island remnants was tested using regression analysis. In each case, the line that best describes the relationship has a zero slope. In other words, there is no significant relationship between the fire, event, or disturbed patch size, and area in island remnants (Figures 8-10). This is true also for the proportional area of island remnants within the total area of events, except the best-fit line is at 7.5% (Figure 11) instead of 10 or 11% (Figures 8-10).

The variability of the proportional area in islands decreases as the size of the fire / event / disturbance patch increases. This is particularly notable for disturbance patches. For example, the standard deviation (common statistical measure of variation) of the proportional area in island remnants in disturbed patches less than 200 hectares is almost 12%, compared to just 6% for patches over 200 hectares. This also explains the large number of disturbance patches with no island remnants. As Figure 10 shows, most of the patches with no island remnants are very small. In fact, 26 of the 28 disturbed patches in the sample with no island remnants are less than 20 ha.

Figure 8. Percent of Disturbed Areas in Island Remnants Within Fires

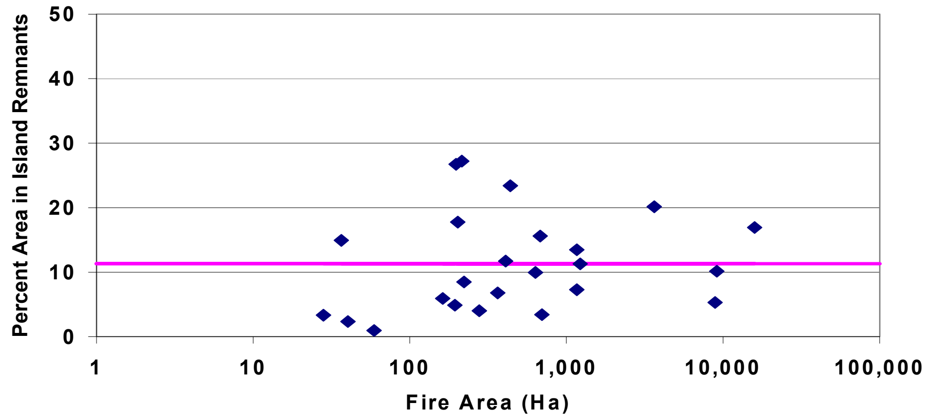


Figure 9. Percent of Disturbed Areas in Island Remnants Within Events

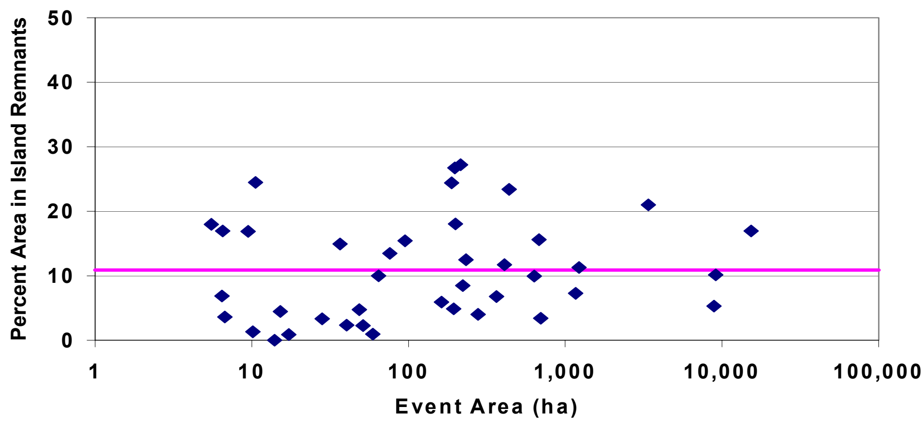


Figure 10. Percent Disturbed Patch Area in Island Remnants

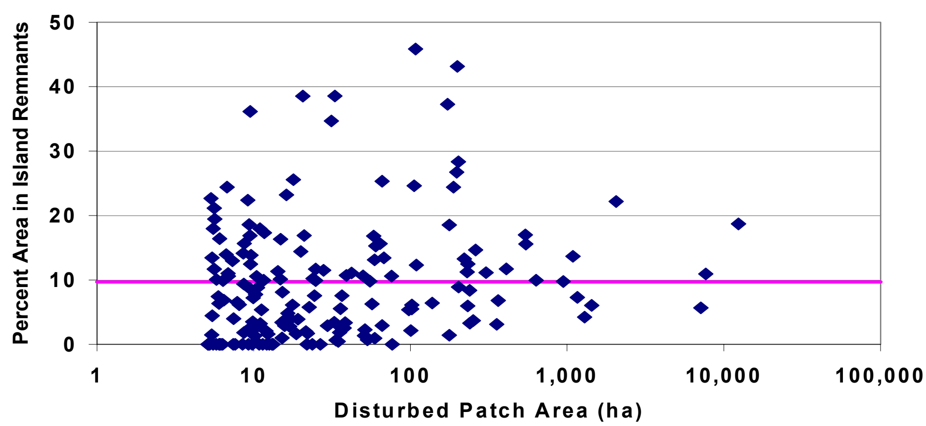
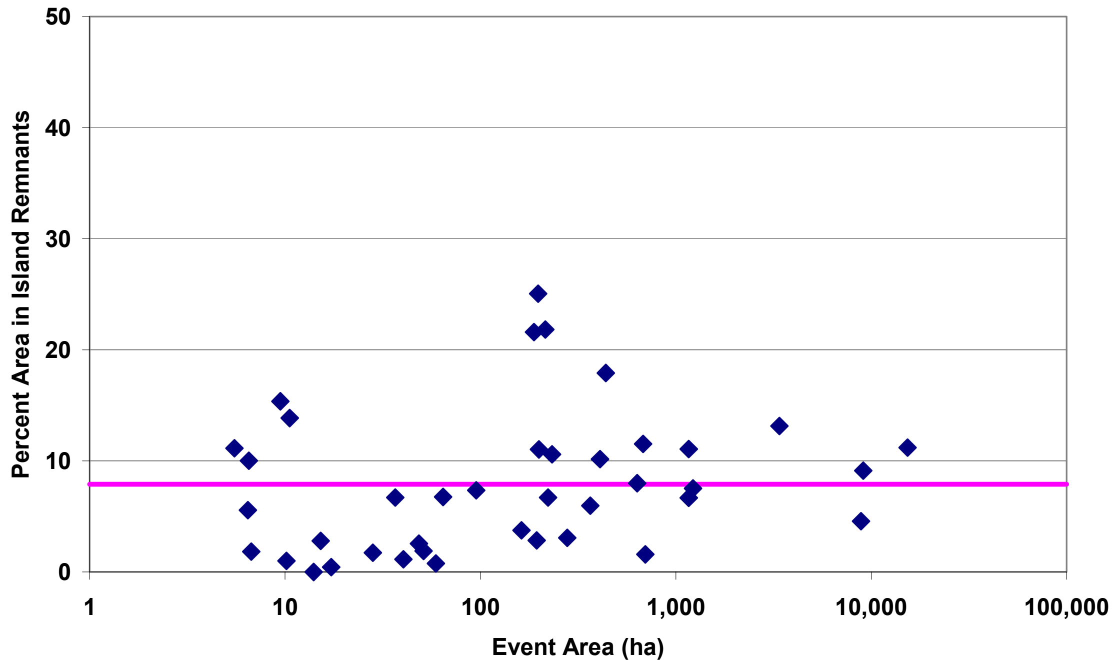


Figure 11. Percent of Event Area in Island Remnants

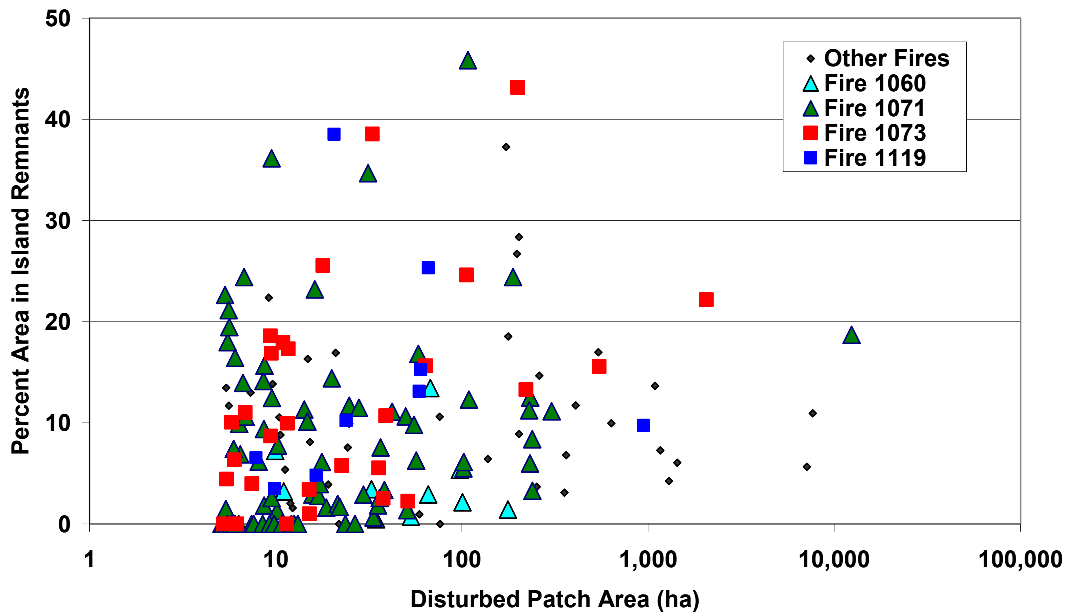


Question 3: Is the percent area in island remnants more consistent within individual fires than between them?

Each forest fire occurs under a unique set of biotic and abiotic conditions. The type, size, spatial arrangement and even the moisture content of available fuel, and the weather conditions during which the vegetation burns are all likely to be more similar within a single fire than between many different fires. Thus, it is reasonable to hypothesize that these unique conditions may translate into a unique and narrow set of burning patterns. Specifically in this case, the question is whether there is any consistency in the proportional area in island remnants between disturbance patches from the same fire or event.

No such evidence was found in these data. Of the 24 fires in the data, seven had only one disturbed patch (larger than five hectares), and 19 had less than five disturbed patches. Of the remaining five fires, paired tests reveal no significant difference between the proportional areas in island remnants by disturbed patch, of each fire. To illustrate, the data from Figure 10 is repeated in Figure 12, highlighting the disturbance patches from the four fires with the greatest number of disturbance patches larger than five hectares Even visually, these data do not suggest that disturbance patches from the same fire experience similar levels of island remnant area. In fact, the variation (indicated by the standard deviation) of the proportional area in island remnants was similar, or higher that for the entire dataset within three of the four fires shown in Figure 12.

Figure 12. Percent Disturbed Patch Area in Island Remnants For Selected Fires

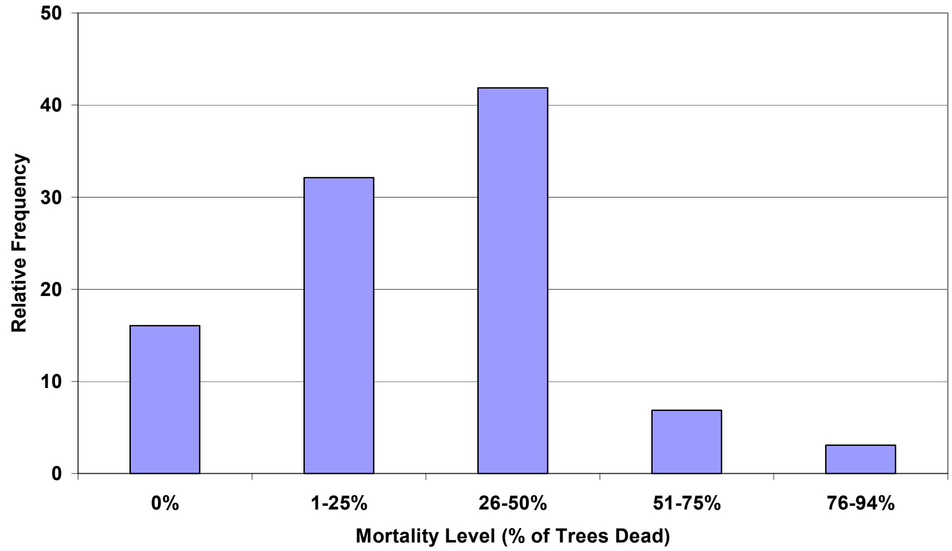


Question 4: What percentages of trees survive within islands?

Recall that in this study a polygon is technically an "island remnant" if at least 5% of the trees within it survived the disturbance. Recall also that each area of island remnant was classified into one of five mortality classes. Thus it is possible to summarize the area in island remnants for each fire, event, or disturbed patch by mortality class. Since it has already been demonstrated that island remnant patterns between fires, events, and disturbed patches are very similar, island mortality summaries are presented here only for events. Although not given, the mortality levels of islands for fires and disturbed patches are virtually identical to those for events.

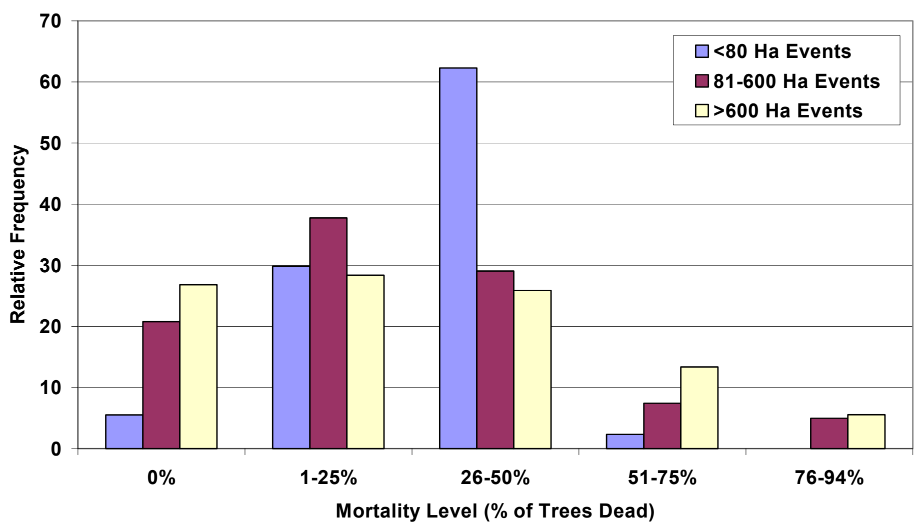
The vast majority of island remnants in fires in the Alberta foothills are disturbed to some degree, although very high mortality levels are rare. Overall, only 16% of the island remnant area in the FtMF dataset is completely undisturbed (Figure 13). Another 32% of island areas experience 1-25% mortality, and 26-50% mortality occur in 42% of island area (Figure 13). Islands with high mortality levels are the least common. Seven percent of island area experience 51-75% mortality, and only 3% of islands have 76-94% mortality (Figure 13).

Figure 13. Average Mortality Levels for Island Remnant Areas



Island mortality patterns shift dramatically as the size of the event or disturbance patch changes. In general, as the size of the event increases, the proportion of the island remnant area with intermediate (1-50%) mortality levels decreases (Figure 14). For example, 92% of all islands within events less than 80 ha experience between 1-50% mortality, compared to 67% for events between 80-600 ha, and 54% for events larger than 600 ha (Figure 14). In contrast, only 5% of the islands within events less than 80 ha in size are completely undisturbed, compared to 21% for events between 80-600 ha, and 27% for events larger than 600 ha (Figure 14). The increase in high mortality islands (between 51-94% mortality) also increases with event size from 2% for events less than 80 ha to 19% for events larger than 600 ha (Figure 14).

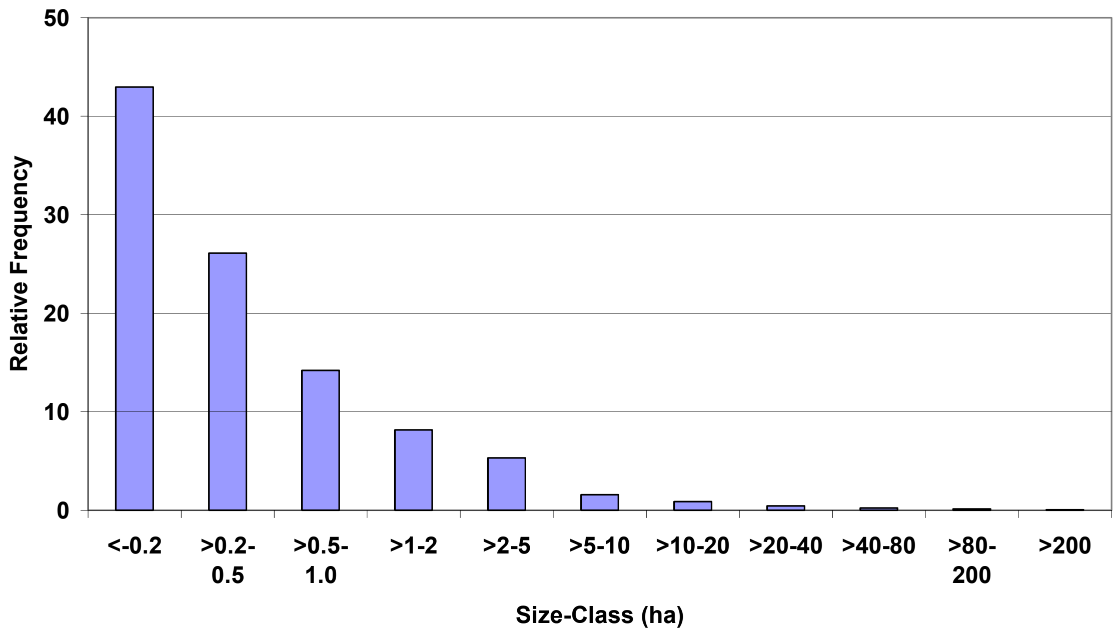
Figure 14. Average Mortality Levels for Island Remnant Areas Within an Event, by Event Size



Questions 5: How large are islands?

On average, island remnants tend to be very small in the Alberta foothills. Forty-three percent of all islands in the foothills sample were less than 0.2 ha in size, and 83% are less than one ha (Figure 15). Small islands also contribute substantially to the total area in island remnants. Islands less than 0.2 ha account for almost 4% of the total island area, and islands less than 1 ha in size account for over 18% of the total area in islands in the Alberta foothills (Figure 16). Islands larger than 10 hectares are rare (1.6% by density), but contribute just over one half of the total area in islands overall.

Figure 15. Sizes of Island Remnants in the Alberta Foothills By Numbers



Similar to island mortality levels, the island sizes shift significantly with the size of the event or disturbed patch. As one might expect, the proportion of small islands decreases as the size of the disturbed area increases. For example, small islands (less than 0.2 ha) contribute over 15% to the total island remnant area in disturbed patches 10-80 hectares in size, 7% in patches 80-600 ha, 5% in patches 600-5,000 ha in size, and just 1% to island area within disturbed patches over 5,000 ha (Figure 17). Similarly, in disturbed patches 10-80 ha in size, just 14% of the total area in islands is accounted for by large islands (>10 ha), compared to 36% for disturbed patches 81-600 ha in size, 40% for disturbed patches 601-5,000 ha in size, and 60% for disturbed patches larger than 5,000 ha (Figure 17). However, even within the very largest disturbed patches, small islands still dominate in terms of numbers. For example, within disturbed patches or events larger than 10,000 hectares, islands less than one ha in size account for over 68% of the total number of islands.

Figure 16. Sizes of Island Remnants in the Alberta Foothills By Area

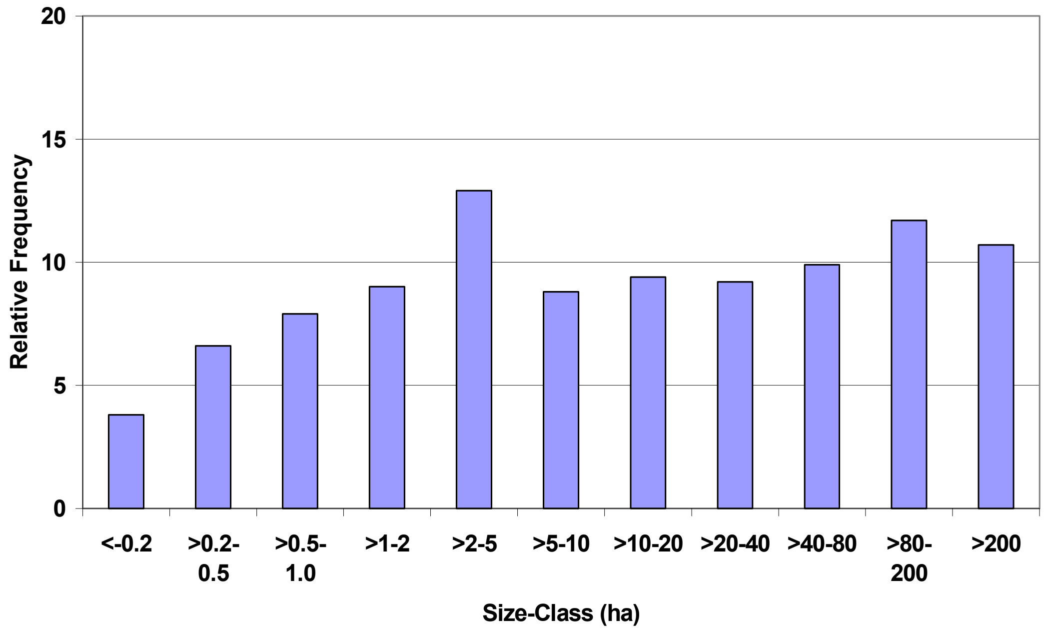
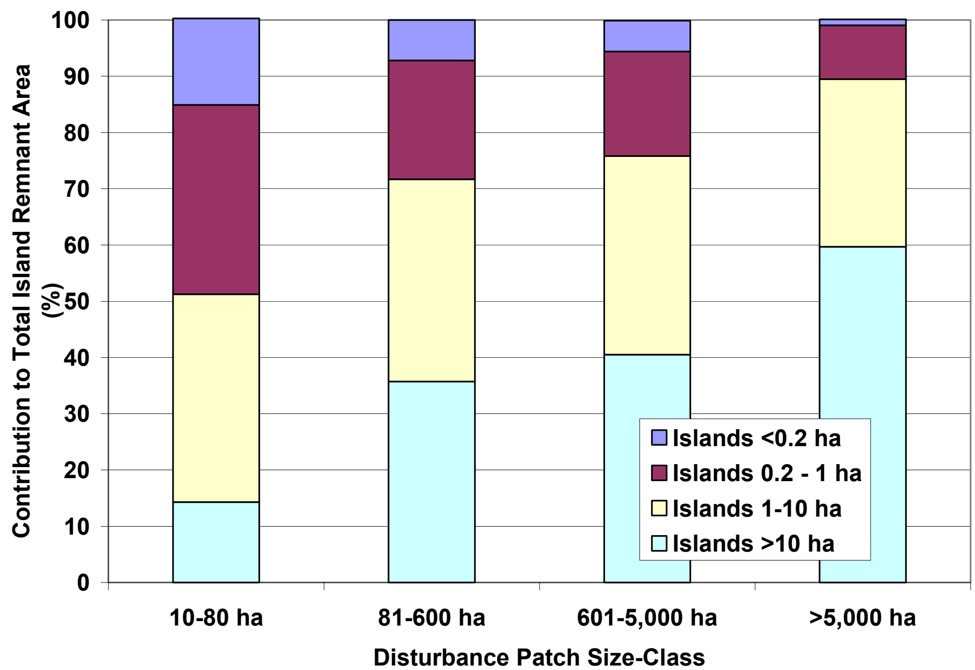


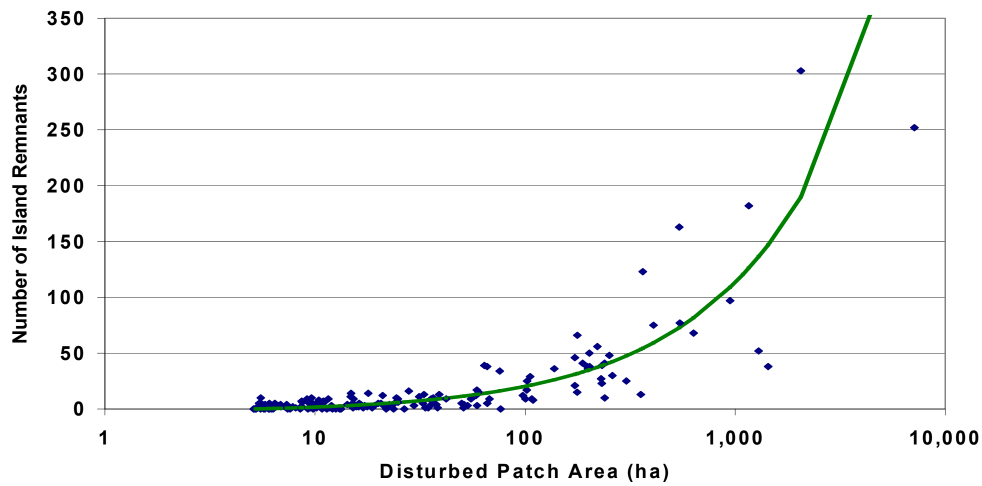
Figure 17. Breakdown of the Area of Island Remnants of Different Sizes by Disturbance Patch Size



Question 6: What is the density of island remnants?

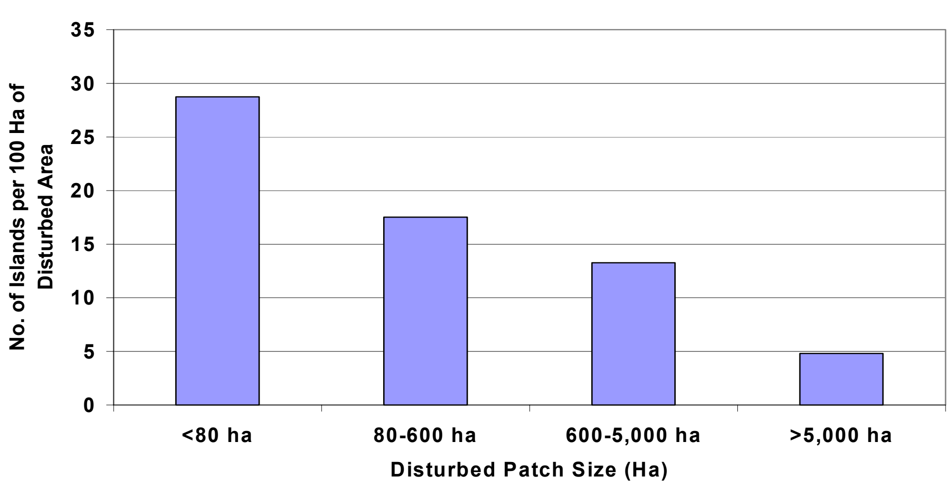
The *absolute density* of island remnants increases dramatically with both event and disturbed patch size. Disturbed patches less than 40 hectares in size average only four island remnants, patches 41-200 hectares in size average 19 islands, patches between 201 and 1,000 ha average 56 islands, and disturbed patches larger than 1,000 ha have 299 islands on average (Figure 18).

Figure 18. Number of Island Remnants per Disturbed Patch



Island remnant numbers can also be expressed in terms of *relative density*, or number per ha. Island relative density declines as disturbed area increases. For example, disturbed patches less than 80 hectares in size average 29 islands / 100 ha, disturbed patches between 81-600 ha average 18 islands / 100 ha, disturbed patches between 600-5,000 ha average 13 islands / 100 ha, and disturbed patches larger than 5,000 ha average only five islands / 100 ha. (Figure 19).

Figure 19. Island Density Per 100 Ha of Disturbed Area, by Disturbed Patch Size



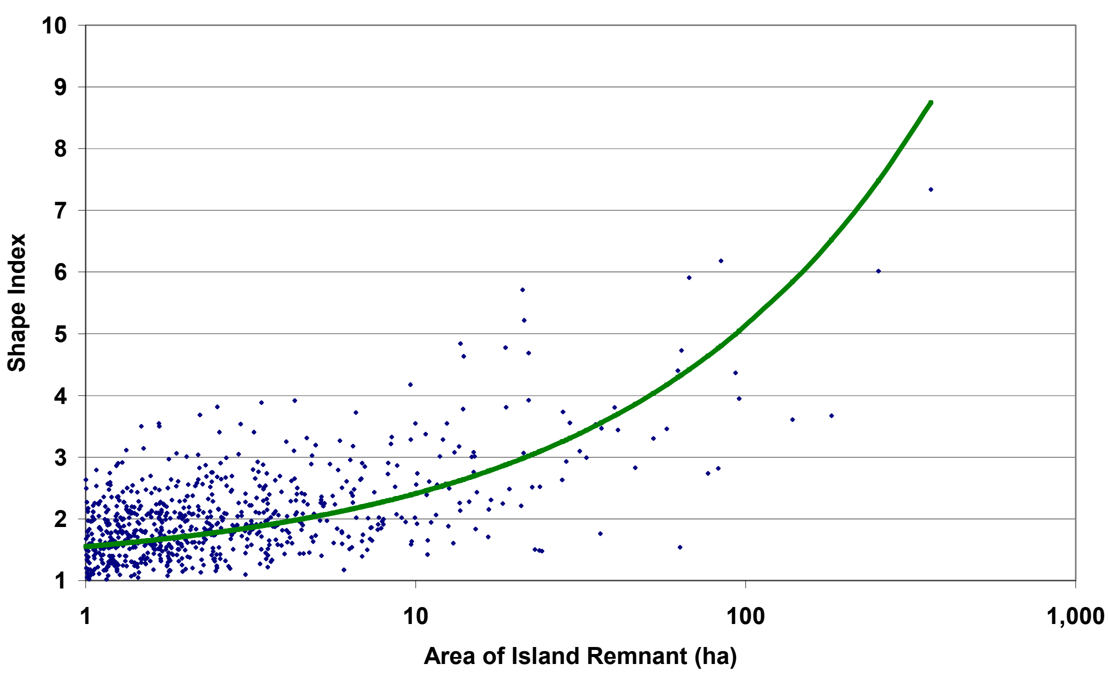
Question 7: What are the shapes of island remnants?

Shape is defined here as the actual perimeter for a given polygon, relative to the perimeter of a circle of the same size (which is the simplest possible shape). Thus, a "shape index" of 1.5 means that the perimeter of the polygon is 1.5 times as long as that which would be required for a perfectly circular polygon of the same size.

The shape of island remnants becomes more complex as they increase in size. On average, islands less than one ha in size have a shape index of 1.3, islands between one and 10 have a shape index of 2.0, islands 10-80 ha have a shape of 2.9, and islands larger than 80 hectares have an average shape of 4.7 (Figure 20). For reference, the shape of disturbed patches larger than 5,000 ha from these same data are 4.9. So islands larger than 80 ha are the same shape as disturbed patches larger than 5,000 ha. In other words, islands are highly convoluted polygons given their size.

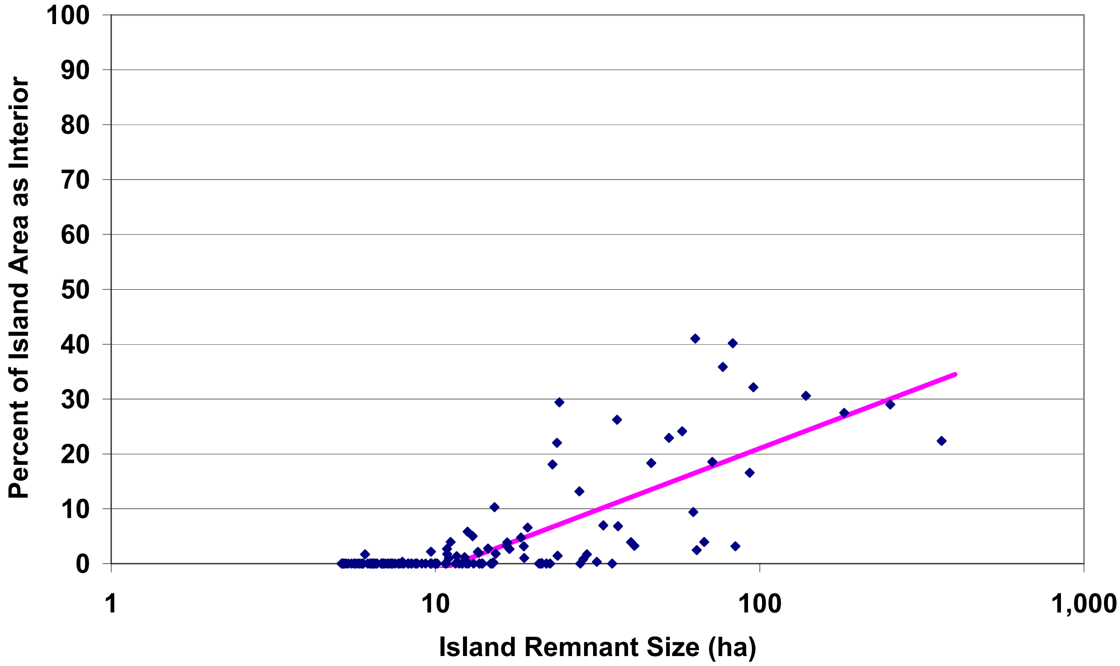
No difference in shapes for islands of different mortality levels was found.

Figure 20. Island Remnant Shapes



One of the implications of complex shapes is a decrease in core or interior area. Assuming a 100m buffer defines “interior” forest in most cases, island remnants less than 10 ha in size have no interior, and for islands 100 ha in size, average only about 21% interior (Figure 21). It is not uncommon for islands larger than 25 ha to have no interior or core area. For reference, a 100m buffer on a 20m circle would generate 36% interior area, and on a 100 ha circle a 100m buffer would leave 68% interior area.

Figure 21. Percent of Island Area Considered Interior Using 100m Buffers

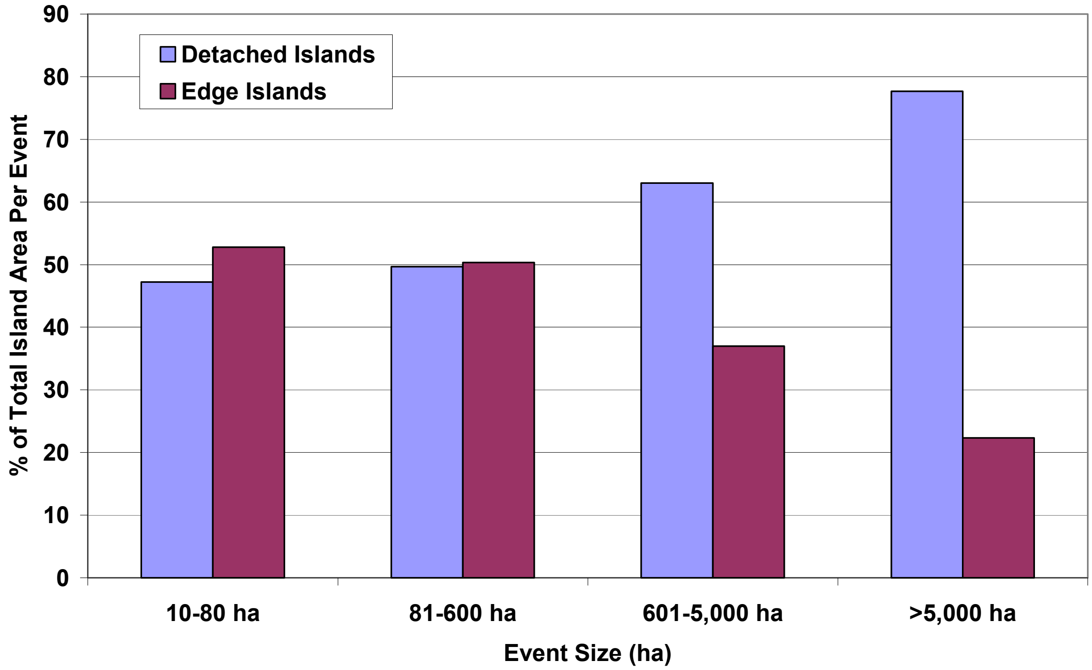


Question 8: What proportion of island remnants are ‘detached’ versus ‘edge’?

Recall that in this study there are both “detached” islands that are physically disconnected from the surrounding un-burnt landscape matrix, and “edge” islands, which are partially burnt residuals physically attached to the surrounding un-burnt matrix. The distinction is important from a taxonomic perspective since it is also possible to define such areas as part of feathered edges.

Overall, edge islands account for about 56% of the total area in islands in this dataset, compared to 44% by area for detached islands. However, this relationship is strongly linked to event / disturbed patch size. For example, on average, edge island area dominates within events less than 80 ha in size (53% to 47% for edge and detached island proportions respectively), and the proportions of the two island types are virtually equal within events 81-600 ha in size (Figure 22). However, for events 601-5,000 ha in size, detached islands account for 63% of the total island remnant area, and for events greater than 5,000 ha, the detached island area averages almost 78% of the total area in island remnants (Figure 22).

Figure 22. Percentage of Island Area by Island Type by Event Size



Although not shown, no relationships between island type and other factors were found. The size-class distributions of the two types of islands are not significantly different. Nor do the shapes of the two island types differ. The only real difference between edge and detached islands is the mortality levels. Mortality levels within detached islands ranges between 0-94%, while, by definition, it is not possible for edge islands to be completely intact. If they were, they would not be part of the disturbed patch to begin with, but rather part of the surrounding un-burnt landscape matrix.

DISCUSSION

The findings from this study not only suggest that island remnants are far more complex spatial elements than previously thought, but also that the island patterns noted are inconsistent with previous research. Both the link to previous studies, and observations on new island remnant patterns will be fully explored here.

The Relationship to Previous Island Remnant Studies:

There are two noteworthy differences between the conclusions reached in this study, and those from others.

1) This study suggests significantly higher average levels of island remnant areas. Island remnants accounted for an average of 2-7% of the total area of the fire for an Alberta study (Eberhart and Woodard 1987) and 3-9% for a sub-boreal BC study (Delong and Tanner 1996) respectively, compared to 10-11% suggested by this study.

2) Both Eberhart and Woodard (1987) and Delong and Tanner (1996) identified significant, positive relationships between fire size and the percentage area in island remnants. This study suggests that proportional island remnant area is independent of fire, event, or disturbed patch size.

There are three possible explanations for the differences in the patterns noted. First, it is possible that fine-scale fire patterns manifest themselves differently on different landscapes. Island remnant patterns may simply be unique landscape attributes.

The second possible explanation for the discrepancy in the findings is that both previous studies adopted a narrower definition of a "residual" with respect to mortality levels. For example, the Delong and Tanner (1996) study used aerial photos many years after the fire, which would have made identification of partially disturbed islands difficult. By expanding the definition in this study to include virtually any area within a fire event that had been partially or mostly killed by the fire, higher measured overall levels of residual are a likely result. And since small fires have much higher levels of partially burned islands than large fires (see Figure 14), if partially disturbed islands were excluded from the calculation, a trend of increasing proportional area of islands would be apparent in the FtMF data. Similarly, the inclusion of all "edge" islands in this study may be more generous than the definitions of islands adopted by the other studies. Again, this would not only lower the overall estimate of island area, but also bias the sample such that larger fires (or events, or disturbed patches) would show proportionally higher island remnant areas than small fires (see Figure 22).

The third contributing factor for the different island remnant patterns noted by other studies is a difference in the minimum resolution. This study measured islands down to 0.02 hectares using photos taken, in most cases, within two years after the fire. The Alberta study measured only those islands larger than one hectare (Eberhart and Woodard 1987). Although the BC study adopted a 0.2 ha cut-off, it relied on aerial photos taken many decades after the fires, which would make identification of small islands difficult. In this study, we found that islands less than two hectares account for over 26% of the total area in islands (see Figure 16). Furthermore, these small islands contribute a far greater area to the total island remnant area for small fire events relative to large fires. Thus, if we reset the minimum resolution of the FtMF dataset to two hectares, a significant positive relationship between proportional island remnant area and fire / event / disturbed patch size would be evident, and the overall proportional area of island remnants would decrease significantly.

If one combines the impacts of these last two factors (differences in resolution and island definition), the findings from this study would have been much more similar, if not identical to those of the other two discussed here. This reveals a fundamental point about studying and understanding natural patterns; ***definitions and assumptions must be clearly and consistently linked to the results***. Technically, the findings from all three studies are correct in that no errors were made, the data were collected in a rigorous manner consistent with the objectives, and the appropriate statistical tests were performed.

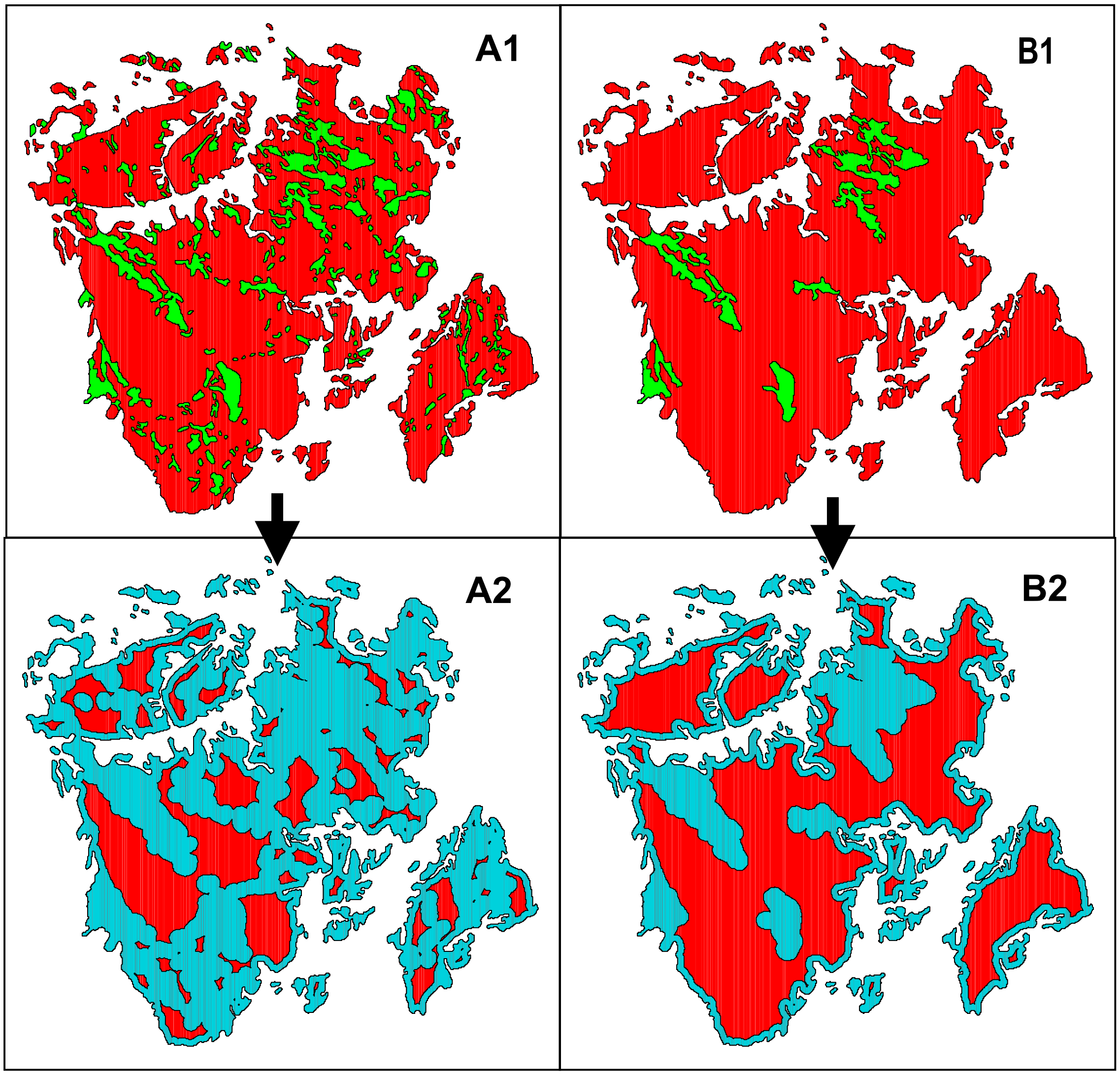
This suggests that general level statements about the relationship between proportional island remnant area and fire / event / disturbed patch size are not particularly meaningful. For example, the conclusion that "proportional island remnant area increases with fire size" is as legitimate as "proportional island remnant area is constant across all fire sizes" since the most important part of each statement is left unsaid. Thus, more precisely, both of the following statements are true:

1) The proportional area of all types and forms of un-burnt material greater than 0.02 hectares in size within disturbed patches, events, or fires is unrelated to the disturbed patch, event, or fire size.

2) The proportional area of mostly un-burnt material greater than two hectares in size within fires increases significantly with increasing fire size.

The same argument could be made for the average proportional area of island remnants within a fire (e.g. is it really 3%, 7% or 11%?). In fact, the relative value of these seemingly conflicting statements can only be evaluated by making the link back to our methodological assumptions, which inevitably leads to assumptions about ecological function. For example, minimum island size is almost certainly a relevant factor for habitat, forage, and predator cover functions. Islands less than two hectares likely could not deliver these functions effectively, so a two hectare resolution is appropriate. However, even very small islands function as sources of seed for species that disperse over short distances, and thus a two hectare resolution representing this function will not be suitable. To demonstrate, assume that the maximum dispersal distance for white spruce is two tree lengths, or about 50m. Imposing a 50m buffer outwards from all islands and edges within a 680 ha fire from the FtMF dataset yields an area of 517 ha, or 76% of the fire area (A2 in Figure 23). If all islands less than two hectares are eliminated from the raw data, and the calculation is repeated, the same 50m buffer covers only 316 ha, or 46% of the fire (B2 in Figure 23). In other words, small islands increase the potential for post-disturbance white spruce invasion significantly. One may conclude from this that small islands play a critical ecological role in post-disturbance vegetation dynamics.

Figure 23. Example of Buffered Residual Patterns With and Without Islands Less Than Two Hectares.



Thus, if the research objective is to understand the function of residual islands as seed sources, then clearly small islands are important to capture. If the research objective is to understand how residual islands function as habitat and forage, then lower resolution limits are appropriate since the additional effort to capture the number, location, and size of very small islands is disproportionately large. In the case of the FtMF natural disturbance research program, the objective is to understand natural patterns as holistic, coarse, biological "filters", and thus all possible types and sizes of residual islands are relevant.

New Island Remnant Patterns

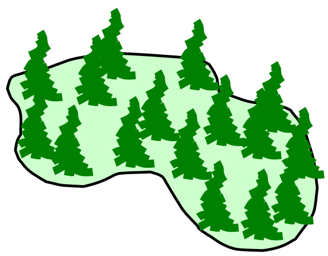
Several significant island remnant patterns not noted by other studies were identified in this research.

Perhaps the most surprising finding was the wide variation in island remnant areas within single fires. Recall from Figure 12 that the variability in the percentage of island remnant areas within disturbed patches was in most cases at least as high *within* fires as it was *between* fires. This suggests that the average fire weather conditions over the course of an individual burning event are not particularly good indicators of survival levels. It is not difficult to imagine, and demonstrate, that each wildfire burns under a unique set of fuel and weather conditions. However, either this is not as important as we think, or this difference does not translate into unique and predictable levels of island remnant areas. The only other explanation for this variation is either 1) fuel-type and topography changes (which will be explored in the next report in this series), or 2) variability in fire weather conditions within individual fires over time.

The shift in the pattern of island mortality with increasing disturbance size was also unexpected. If anything, a reasonable hypotheses would be that larger fires would, on average, burn hotter and thus would be less likely to leave islands with low mortality levels. In contrast, the FtMF data suggests that small fires have the lowest proportional areas of islands with low levels of mortality, and the largest fires have the greatest. One possible explanation for this phenomenon is that as fires increase in size, they tend to move faster across the landscape, increasing the chances of completely "skipping" a given area. The diurnal changes in fire behaviour common to larger fires may also play a role in allowing more intact islands to exist.

The variation in island remnant mortality level raises another interesting point. Most island remnants in this study were partially disturbed - a phenomenon not previously noted. However, one must be careful not to equate the ***area disturbed*** of a fire with the ***mortality level*** of a fire. All of the results in this study are reported by area. But, since not all islands have 100% mortality, the percentage of trees killed by a fire will always be lower than the percentage of area affected by fire as represented by island remnants. For example, by multiplying the observed average proportions of island area by the average survival levels, one ends up with a tree mortality level equal to about 73% of the area of islands. So although an average of 11% of each fire, event, or disturbed area exists as residual island remnants, that area represents only an average of (11% x 73% =) 8% of the trees within a fire. Similarly, 20% by area in island remnants would equate to (20% x 73% =) 14.6% of the trees (Figure 24).

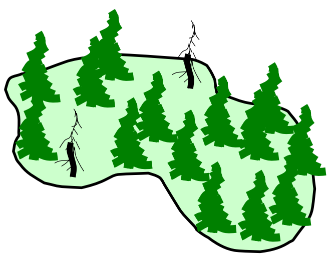
Figure 24. Relationship between the proportional area of island remnants, to proportional mortality levels, assuming that island remnants account for an average of 11% of the area of disturbance events.



Island Mortality = 0% / Survival = 100%

On average, these islands represent:

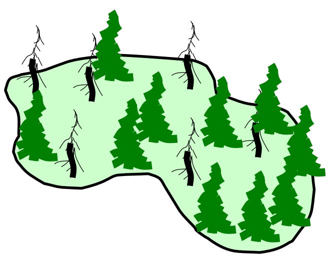
- 16% of island remnant area.
- (16% x 11% total island area) = 1.7% of event areas.
- (100% survival in 1.7% of the area) = 1.7% of the trees.



Island Mortality = 1-25% / Survival = 87% (on Average)

On average, these islands represent:

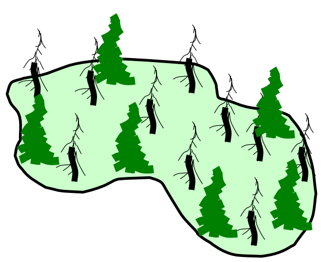
- 33% of island remnant area.
- (33% of 11% total island area) = 3.6% of event areas.
- (87% survival in 3.8% of the area) = 3.1% of the trees.



Island Mortality = 26-50% / Survival = 62% (on Average)

On average, these islands represent:

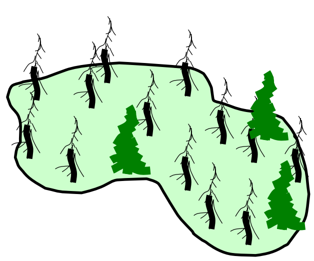
- 41% of island remnant area.
- (41% of 11% total island area) = 4.5% of event areas.
- (62% survival in 4.5% of the area) = 2.8% of the trees.



Island Mortality = 51-75% / Survival = 37% (on Average)

On average, these islands represent:

- 7% of island remnant area.
- (7% of 11% total island area) = 0.8% of event areas.
- (37% survival in 0.8% of the area) = 0.3% of the trees.



Island Mortality = 76-94% / Survival = 15% (on Average)

On average, these islands represent:

- 3% of island remnant area.
- (3% of 11% total island area) = 0.3% of event areas.
- (15% survival in 0.3% of the area) = 0.05% of the trees.

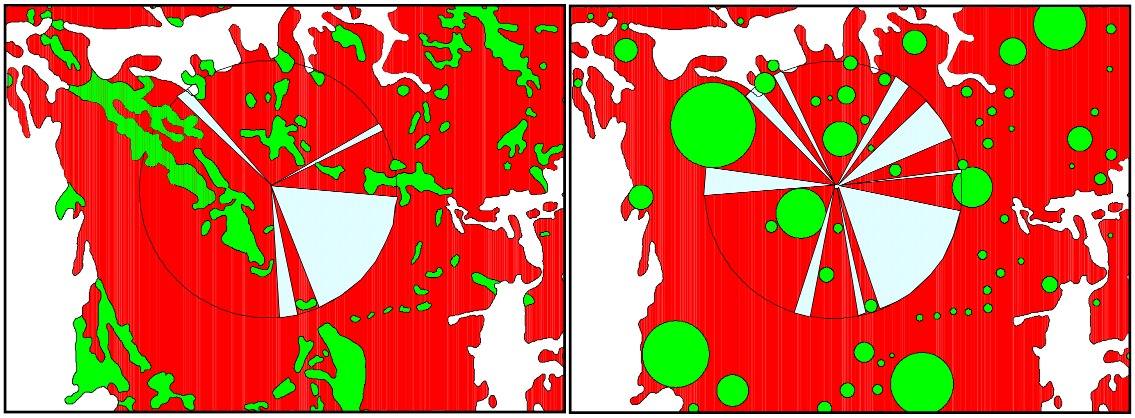
Total Average Island Area = 1.7% + 3.6% + 4.5% + 0.8% + 0.3% = 10.9%
Total Average Tree Density = 1.7% + 3.1% + 2.8% + 0.3% + 0.05% = 8.0%

The increase in island remnant size with fire size may also be related to the speed of a fire. As forest fires move more quickly, perhaps with more constant wind direction and speeds, they may be more likely to skip over or around larger areas, and less likely to burn back on themselves. It is also possible that the larger island remnants associated with larger fires is simply a function of spatial probabilities and fuel-type. Larger fires have a greater chance of encountering significant areas of low flammability (such as hardwoods or immature forest). The relationship between island size and location, and fuel-type will be explored in the next report in this series.

The shifting relationship between detached and edge island area with disturbance event size is not particularly surprising, and this pattern is our first hint of the spatial dynamics of islands. Consider that if a) the area of island remnants remains constant across all fire or event sizes (which we know to be true), and b) islands within a fire have an equal chance of forming in any given location, then the proportion of island numbers and area that are physically attached to the edge of a disturbed patch will diminish relative to the number and area of unattached residuals. In other words, the percentage of a given fire or disturbed patch within X meters of the edge will increase as the fire or disturbed patch gets larger. Since edge islands must be attached to the edge of the fire, the chances of edge islands forming relative to isolated or detached islands decreases. Thus, the fact that the area of edge islands decreases relative to detached islands is one indicator that island location may not be related to the distance from the edge of the fire.

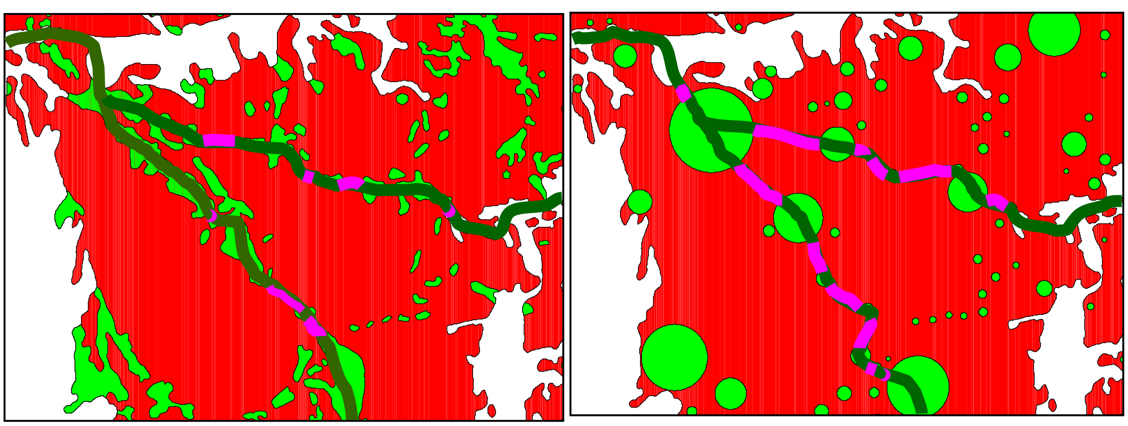
Shape is a quality of island remnants not previously described. Given the fact that so few studies of island remnants exist, this is understandable. The first, and presumably the most important island remnant issues to study and quantify are area, and size. Furthermore, one would not anticipate that shape would be a significant factor for islands since they are so small. However, the highly convoluted shapes of islands noted in this study suggest that shape may be more relevant than first thought. Consider, for example, the difference between simple and convoluted island shapes on line-of-sight – perhaps as it relates to predator-prey relationships. Residuals of simpler shapes will almost always allow higher levels of visibility from a given location within a disturbance than would residuals of more convoluted shapes. Figure 25 illustrates this phenomenon for a single randomly chosen location within one of the fires used in this study. In the left frame in Figure 25, the actual size, location, and shapes of islands results in about 22% of the perimeter of a 500m radius being theoretically visible. By simplifying the shapes of each island to circles, but maintaining the size and location, about 34% of the perimeter of the same circle is theoretically visible (right frame of Figure 25) – a 50% increase in visibility. Similar differences are found in other fires, and other random point locations.

Figure 25. Illustration of the Relative Influence of Naturally-Shaped Islands (Left Frame) Versus Simply-Shaped Islands (Right Frame) on the Visibility of the Perimeter of a 500m Circle.



Similarly, if islands are important for protection as so-called protective “corridors” and/or “stepping stones”, crossing through a fire is safer with convoluted islands than with simply shaped islands. To demonstrate, in Figure 26, I outlined two routes across a fire that affords the greatest level of protection. With the actual, complex shaped islands, a total of about 500m of the crossing distances are unprotected (i.e., no islands) (Figure 26, left frame). When the island shapes are simplified to circles, the unprotected crossing distance increases to more than 1,500 m (Figure 26, right frame). Again, similar differences are found in most fires in the FtMF data.

Figure 26. Illustration of the Relative Influence of Naturally-Shaped Islands (Left Frame) Versus Simply-Shaped Islands (Right Frame) on the Level of Exposure of Crossing a Disturbance.



The examples in Figures 25 and 26 are over-simplified, but are only meant to demonstrate that island shape may be an important descriptor (i.e., with biological meaning) worth considering.

The other inevitable result of high shape complexity is that interior area decreases (as shown in Figure 21). Combined with the fact that the vast majority of islands are very small (98.4% are less than 10 ha), this means that it is extremely rare for a given island to have interior forest. And even above 10 ha, the interior area of islands remains a minor spatial component, averaging only 15% by area for 50 ha islands, and 21% for 100 ha islands. On the other hand, the fact that interior island area is so rare may mean that its ecological significance is magnified where they do occur. Consider that islands large enough to have interior occur only on larger disturbances, where the distance from one edge of the burn to another is greatest. Having just a very few islands with even small interior areas may be quite important to some species under such circumstances.

The explanation for the highly complex shapes of islands is not obvious from these data. It is possible, that islands are responding to a different combination of influences than are fire edges. For example, their tendency to be elongated is consistent with wetland / riparian features on this landscape. We do know from previous FtMF research that island remnants are slightly more likely to occur in riparian zones (Andison and McCleary 2002), although such relationships are weak at best. The next report in this series will explore this hypothesis on the rest of the landscape.

Another compelling argument is that islands are convoluted because they represent rare, transitional burning properties of so-called stand-replacing fires. Keep in mind that forest fires in boreal landscapes of Canada are among the largest and most severe anywhere in the world. On the other hand, we already know that tree survival – even within very large fires - can be substantial in the form of both matrix remnants (Andison 2004) and island remnants. Furthermore, we also determined in this study (see Figure 13) that over 84% of the area in island remnants only *partly* survived the fire (versus 0% for matrix remnants). This suggests that fire effects are not necessarily always either “on” or “off”, but can sometimes be intermediate. In other words, island remnants are the only spatial element that captures partial mortality – and thus the only physical manifestation of intermediate levels of fire severity in otherwise very severe fires. Following this same logic, islands are created by a unique combination of burning conditions such as lower fire intensity and speed. This in turn may mean that during these times, fires burn in a more spatial convoluted pattern in response to very local changes in topography, fuel-type, and micro-climate. Burning during the night, or during short-term marginal fire weather conditions, are the most obvious examples of this phenomenon.

CONCLUSIONS

The findings from this study suggest that island remnants are far more complex spatial elements than previously thought. Briefly, this study has found:

1) An average of 10-11% of the disturbed area of fires, events, or patches exist as island remnants, although the average is largely meaningless as a representative target. But this average is much higher than those found for similar studies in BC and Alberta. The range of island remnant area is 0- 30% of the area of the fire or event, and 0-50% of the disturbed patch.

2) The proportional area in islands does not significantly increase as the fire or event size increases. This is contrary to the findings from similar studies in BC and Alberta.

3) Differences in the results from this study compared to others are likely a combination of differences in resolution, definitions, and methods.

4) Variation in the percent island remnant area for disturbed patches is at least as variable within fires as it is between fires.

5) Undisturbed islands only account for 16% of island area, moderately disturbed islands account for 74%, and heavily disturbed island account for 10%. However, as fires or disturbed patches become larger, the proportion of island area that is moderately disturbed declines, while the proportion of island area that is undisturbed and highly disturbed increases.

6) Islands less than two hectares in size account for an average of 27% of the area in islands, and an average of 91% of the number of islands. This relationship also changes as fire / event size increases – larger fires have significantly more large islands.

7) Islands have highly convoluted shapes relative to all other disturbance spatial elements. This, plus the fact that most islands are very small, means that interior area is rare in island remnants.

8) Islands detached from the edge of the disturbance account for more than half of the island area on average, relative to islands that are still physically connected to the edge of the fire. The proportion of detached island area increases significantly as the fire / event size increases.

This is a remarkable list of island remnant patterns either not previously noted by, or in conflict with, other studies. This contrast reflects both the novel nature of residual pattern studies, and the influence of subjective observation on the nature of conclusions. Consider that within the scientific method, it is not the question itself that is objective or impartial, but rather the *answer* to the question that is. In this case, it is impossible to separate the results of a study of island remnants from the data, methods, and assumptions adopted. There is no “right” way to define or measure islands (*i.e.* to ask the question), so the results from this, or any other study, must be considered within their own subjective context. In this study, I adopted a very generous, inclusive definition of islands because the Foothills Model Forest Natural Disturbance Program is committed to describing all types and scales of residuals as so-called coarse biological filters. So, I considered any forest material that survives a fire to any degree, regardless of its location, size, or orientation, as technically a residual of that fire. If one or more type of residual were not included here, they would have to be described somewhere else. For example, if edge islands are not counted as islands, they still have to be accounted for, perhaps as “feathered edge residuals”, with the appropriate change in disturbance patch shapes (from Report #5 in this series) to account for the change in the original question being asked. Alternatively, one could capture the pattern of all residuals using a buffer, or a nearest neighbour analysis. The important thing is to capture the pattern (of un-burnt material within patches) in some way – the method used to do so is simply a matter of communication.

Perhaps the most important lesson is that it is critical to be consistent and clear with definitions and assumptions when studying and interpreting patterns. Clarity is important for interpreting and comparing findings from one study to another. Defining terms in different ways is a common occurrence with scientific studies, but comparing results between studies is not a problem if terms and assumptions are clearly defined each and every time. Consistency is important when translating these findings to forest management and monitoring initiatives. Consistent spatial definitions ensure that there is a direct link between the science of measuring historical patterns, and the applied management and monitoring tasks. For example, it would not be appropriate to use the findings from this study as benchmarks for a management application that does not recognize partially disturbed islands.

Another benefit of clarity and consistency is the ability to seamlessly combine research results from different scales. For example, the results from Report #5 on events can be combined with the results from this project to create a complete depiction of within-fire residuals. For example, the data from Figure 11 from Report #5 and Figure 5 from this report could combine to generate a frequency distribution of the total residual area for historical fire events. Between the two reports, all of the substantial spatial elements within a disturbance event larger than individual trees are described and quantified. One can always argue with the definitions or assumptions, but it *does* represent a complete list of the attributes of residuals.

WHAT IS NEXT?

Now that the non-spatial descriptions of all possible types of residual material within forest fires in west-central Alberta have been described, the next logical issue is that of the influence of spatial controls. For example, what proportion of island or matrix remnant area exists as bog, swamp, wetland, and other non-forested land? Is there a significant relationship between specific biotic and abiotic conditions and the presence or absence of residual material? Report #3 (Andison and McCleary, 2002) explored this phenomenon for riparian zones, but the analysis has yet to be expanded to the context of the full landscape. The next report in this series will explore these and other spatial questions of all types of residuals (island and matrix remnants combined).

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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, located within a disturbed patch.

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 event. 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 – Equations Used in This Report

Figure 8: All fires were used.

$PctFireAreaAsIslands = 11.01 + 0.0002(FireArea)$ n=24, R^2 = 0.01, Not Significant.

Figure 9: Only those events larger than 5 ha were used.

$PctEventAreaAsIslands = 10.5 + 0.0002(EventArea)$, n=40, R^2 = 0.01, Not Significant

Figure 10: Only those events larger than 5 ha were used.

$PctDisturbedPatchAreaAsIslands = 9.56 + 0.0005(DisturbedPatchArea)$

n=175, R^2 =0.003, Not Significant

Figure 11: Only those events larger than 5 ha were used.

$PctDisturbedPatchAreaAsIslands = 7.34 + 0.0001(DisturbedPatchArea)$

n=40, R^2=0.01, Not Significant.

Figure 18: Only those disturbed patches larger than 5 ha were used.

$\#ofIslands = -2.24 + 0.95(EventArea)^{0.7}$ n=175, R^2=0.76, Significant

Figure 20: Only those islands larger than 0.08 ha were used.

$IslandShape = 1.15 + 0.40\sqrt{(EventArea)}$ n=4,564, R^2=0.52, Significant.