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# Detection and analysis of post forest fire residuals using medium and high resolution satellite imagery

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# Detection and Analysis of Post Forest Fire Residuals Using Medium and High Resolution Satellite Imagery

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**September 2003**

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*Key Words:* Forest Fires, High-Resolution Satellite Imagery, Residual Forest Islands, IKONOS, Landsat ETM+

## *1. Synopsis of Research Objectives*

This project is a joint undertaking between the EOSL, Dr. Stan Boutin's Biodiversity group and Al-Pac Inc. At present, the geographic area of forest fires are not considered to be part of the landscape by major monitoring programs in the province such as the Alberta Ground Cover Characterization Program (AGCC). Currently, the AGCC blackens out the entire burned area within the external boundary of the fire. Consequently, no land cover classes are reported inside of burned areas. This approach does not allow for the characterization of post-fire forest fragments that are still alive within burn boundaries. The impact of this practice may be an overestimation of the overall extent of burned areas, and a lack of recognition of viable post-fire forest stands. Al-Pac, for one, has identified the ability to update fire and cutblock boundaries, and the residual timber volume left post-disturbance, as having important implications on Annual Allowable Cut (AAC) levels; and therefore the future timber value of an area. In general, large fires result in a net reduction in AAC and further adjustments to the AAC, involving bringing viable timber stands back into AAC calculations, are delayed several years after the fire has occurred. Hence this project has two main advantages, a) it will allow for the quantification of the actual amount of fiber that was lost in the fire, and hence provide accurate adjustments to the AAC if needed; and b) it provides comprehensive distributions of live vegetation inside of forest boundaries that can be integrated into biodiversity monitoring programs. This study uses IKONOS, and Landsat 7 ETM+ as data as data from these systems is already widely used in the forestry industry, and the NCE-SFMN biodiversity group. We expect that the outcome of this project will be the development and implementation of a protocol that will allow for the better estimation of a) the extent of fire scars at higher resolutions than before and b) the quantification of those forest resources that remain alive within these burned areas.

## *2. Progress made towards answering these questions or achieving these objectives*

This research employs medium and high-resolution IKONOS (4-m spatial resolution) and Landsat ETM+ (28.5 m spatial resolution) satellite imagery to detect and analyze the distributions of live post-fire residuals within two large area (>100,00 ha) fires [2001 Chisholm and 2002 House River] in Northern Alberta, Canada (Figure 1). This study differs from previous approaches to characterize fire-affected areas by focusing not on what the fire consumed but on detecting those forest patches that remained alive within the fire perimeter. Residual patch and shape level metrics are calculated to examine how the choice of satellite imaging sensor, minimum mapping unit and anthropogenic features influence residual area statistics, which has implications for the use of residual data in post-fire burn mapping and residual retention forest harvesting.

### *3. Key findings and deliverables; and 4. How the research contributes to advancement of knowledge in the field*

Land cover classifications, in areas affected by forest fire, need to move beyond descriptive and qualitative definitions (i.e. burnt area) and provide meaningful information on the features occurring within these disturbed areas. The goal of this research was to examine the use of high and medium resolution imagery for residual detection and to analyze the distributions of residuals within fire-affected areas. The results of this study do not only provide insight into the consideration that must be taken when employing residual data into subsequent ecological or secondary numerical analysis, but also serve as an important guideline for the use of data derived from remote sensing platforms into residual retention forest harvesting protocols.

### *Key Findings:*

Forest fires rarely consume everything in their path and tend to leave behind live irregularly shaped patches and/or linear rows of mature trees within the fire perimeter known as *residuals* (Rowe & Scotter, 1973) (Figure 2). The Chisholm and House River study areas are two areas undergoing different land use and land cover change dynamics and the residuals have been detected using two different satellite image sensors. The Chisholm fire was examined with an imaging sensor with a spatial resolution of 28.5 meters and the House River fire with a 4-meter spatial resolution. The residual forest classes examined at varying minimum mapping units were used to compare the impact of an areal-based sampling unit on patch level metrics. To investigate the amount of residual forest within the fires, residual area is analyzed as a function of class area and total landscape area for each of the minimum mapping unit classes.

To investigate the impact of changing minimum mapping unit (MMU) on residual area statistics, residual polygons from the Chisholm and House River Fire were queried into 10 classes at 10 minimum mapping unit intervals (0 - 0.01, 0.11 – 1, 1.1-5, 5.1-10, 10.1-20, 20.1-40, 40.1-60, 60.1-80, > 80 ha). These intervals were based on previously published data on post-fire residuals in the province of Alberta, Canada (Lee et al., 2002). To analyze similarities and differences in each study area and at the different class intervals, we calculate the total landscape area of each class (TLA), area of each individual class (CA), the number of patches (NumP) and the mean patch size (MPS) (McGarigal & Marks, 1994). Because the two study areas are undergoing different impacts of linear feature disturbances and are being observed at different sensor spatial resolutions, we calculate shape level metrics including edge density (ED) and areal weighted mean shape index (AWMSI).

Table 1 displays the results of the patch and shape level metrics for the 2001 Chisholm and 2002 House River fires, respectively. In both the Chisholm and House River fire, the largest minimum mapping unit (> 80 ha MMU) class has the largest amount of residual forest in each of the study areas. This class (> 80 ha) contains more residual forest contained than all classes combined (Figure 3). This indicates that large area patches do exist within both of the study areas. However, by examining the amount of residual forest in each of the classes in terms of the total landscape area, opposite trends are evident. For the Chisholm fire, the largest class (> 80 ha) still maintains the most amount of residual forest on the landscape, but in the House River fire, the smaller MMU classes (<0- 5 ha) actually contain more residual forest.

To investigate why the lower MMU classes contain more residual forest in the 2002 House River fire, it is useful to examine the number of residual patches and mean patch size. Analysis of the House River fire residual polygons shows that this fire contains a large number of small area patches. In total, these small patches comprise a large proportion of the total landscape. For example, the number of patches in the House river fire at the [< 0.1 ha] class size is 18,844 patches, while the largest MMU class [> 80 ha] contains only 4 residual patches (Figure 4). The trend toward smaller number of patches at higher MMU classes is also characteristic of the Chisholm Fire data, where the number of patches decreases from 6,771 in the lowest MMU class [< 0.1 ha] to only 51 patches at the highest MMU class [> 80 ha] (Table 1). For the 2002 House River fire, only the largest MMU class [> 80 ha] shows a significant increase in mean patch size that is explained by the large amount of residual forest contained within this class.

From the image classification point of view, the optimal spatial resolution is defined as the point where object size meets sensor spatial resolution (Woodcock & Strahler, 1987;Marceau, 1999). As the spatial resolution increases so too does our ability to infer smaller area residual patches using conventional pure-pixel based image classification techniques. Therefore, if a satellite image is used to detect residuals, but many of the residuals tend to occur as small or irregular shaped patches, the results may vary significantly if an area is imaged using a different satellite image sensors (Figure 9). For example, in conventional pure-pixel mapping approaches to image classification, if we use one type of imagery (i.e. Landsat TM imagery) to detect forest residuals, the sensor capabilities and classification method determine all the potential residual patches we include, while implicitly excluding smaller patches that occur at sub-pixel scales. Therefore when examining a study area with different imaging sensors, the one with the coarser spatial resolution may detect large area patches, but at higher resolutions, gaps in the forest canopy can appear. For example, the House River contains 18, 844 patches at the [< 0.1 ha] class size and only 4 patches at the [> 80 ha] class (Table 1). The House River fire captures more residual patches at the < 0.1 ha MMU class as this area is assessed using 4-metre spatial resolution IKONOS imagery. However, with a coarser data such as Landsat ETM+, it is possible that many of these individual residual forest patches would be classified as single congruent patches. Furthermore, if this area had been examined at an even coarser spatial resolution, many of these individual patches may have been classified as larger contiguous patches. This would lower any estimates of the number of patches and likely increase the amount of residual forest found in the larger minimum mapping unit classes. The physical size of the study area is also a significant factor and the House River fire study area for example is a smaller sized area than the Chisholm fire perimeter.

When attempting to make comparisons across areas using different satellite sensors, sensor spatial resolution and the selection of minimum mapping unit is important. However, the selection of a minimum mapping unit also influences estimates of total number and the distribution of residual forest islands (Table1). If a sampling unit of five hectares is used, this can affect our estimates of total number and the distribution of residual forest islands within the fire affected areas, as patches that are too small for the minimum mapping unit are not considered in the analysis, as the patch size falls below the defined threshold. In previous post-fire residual studies using aerial photography, Eberhart and Woodard (1987) explicitly defined residual forest patches as unburnt patches at least 1ha in size, while Delong and Kessler (2000) defined a residual as an older forest patch ≤10 ha based on field data. Such variations in MMU can complicate the process of making comparisons between study areas as establishment of a single minimum mapping unit (i.e. 10 ha) is not necessarily comparable across areas that have been viewed using different satellite imaging sensors. Therefore, sensor spatial resolution and MMU selection has implications for many land monitoring systems, which are potentially overestimating the total area burnt by fires, or underestimating the total amount of residual forest on the landscape.

Residual forest areas maintain very different natural shapes/variations in the study area that can affect the calculation of patch and shape level metrics. There are residuals that form large identifiable homogenous stands that have been surrounded by a larger fire affected area. These stands do not occur along the road, but form isolated patches within the fire-affected area. The second are relatively homogenous residuals that tend to be found at the perimeter of a linear anthropogenic feature. These residuals commonly occur along roads or seismic lines. Finally, there are residuals that do not seem to occur within a larger patch but tend to be found in a region that was not prone to burning such as a wetland (Figure 2). To investigate the complexity of the residual shapes in each fire, shape level metrics are computed to quantify residual landscape configuration. The areal weighted mean shape index (AWMSI) is a robust method used to measure the average patch shape or the average perimeter to area ratio for the residuals and can highlight if patches tend to from circular shapes or follow jagged patterns with rough edges (Saura, 2002). This information is important, considering that fire-affected areas do not always have clear transitions between deciduous and coniferous forest stands or, these stands can be modified by the presence and locations of anthropogenic linear features. The AWMSI shows opposite results in each of the study areas. In the House River fire, there are increasing complex patches at lower MMU classes, and a decrease in complexity at the higher MMU classes (Figure 5). Conversely, the AWMSI tended to increase for the Chisholm fire, until class seven [60.1- 80 ha] when the values increased the greatest. In certain areas of the fire perimeters, isolated stands maintain bona-fide boundaries between fire affected and residual areas, while in other regions there is a gradual transition from residuals to fire affected areas. Although forest ecologists can relate residual dynamics to fire and successional processes, such configurations may also be related to fire suppression techniques, via the creation of linear feature firebreaks that were used to extinguish the fire. Residuals shapes result not only from the way the fire moved across the landscape, but was also due to anthropogenic factors such as (i.e. roads, transmission lines, seismic lines) occurring within the fire perimeter (Figure 6).

Areas undergoing different land use and land cover change pressures can modify residual locations and shapes, making it difficult to compare results from studies that use varying minimum mapping units. Presently data collected on post fire residuals using photographic interpretations from aerial photography are used to devise forest-harvesting guidelines based on emulating natural disturbances (Lee et al., 2001). However, considering that much of the available data on residuals is based at certain minimum mapping units and different scales, it is not unlikely that residuals of a certain size are being biased. Forest managers deciding on how to harvest timber at a landscape scale need to be aware of the limitations of using data on post-fire residuals in forest management, considering that different areas are undergoing different natural ecological processes, fire histories and land use and land cover change dynamics.

If data on post fire residuals is used to characterize post fire environments without considering or understanding the limitations of the imaging sensor, and/or the rationale for choosing a given minimum mapping unit, the potential for poor forest management decisions may result. This is particularly true as is not known whether data derived on post-fire residuals in one area can be readily transferred into a forest management strategy in a different area, or for how long of a time interval data on post fire residuals can be used in support of forest harvesting practices. Furthermore, in areas that are under continuing linear disturbances, as it is typical in boreal Alberta, it will become increasing difficult to determine how the locations and distributions of post-fire residual are changing or will change in the future. For example, areas such as the Chisholm Fire study area that are undergoing increasing linear feature expansion are affected by a fire, they may show an even greater increase in the number of residual patches. Local weather conditions, the timing of year and image acquisition date, as well as the choice of satellite image and minimum mapping unit and influence of linear features can affect results and interpretations. Therefore, using such information into a management framework must occur using a precautionary approach that recognizes the shortcomings of the data.

Larson (1980) recognizes that variations in boreal communities exist in both wide geographical and local dimensions and Kellömaki (2000) notes that more research is needed on how boreal forests function in natural conditions at different scales. The mapping of fire-affected areas has been noted as a research area in need of improvement (Conard et al., 2001) and future satellite systems may be able to provide more detailed interpretations of residual forest cover, including information on forest species and compositional information. Therefore, an initial step towards developing meaningful characterizations of post-fire land cover will include developing residual classification schemes that are hierarchical in nature and will allow for increasingly flexible integration of information collected from various imaging platforms. Thorough investigations of post-fire areas will also require carrying out studies of post-fire environments in not only the province of Alberta, but also in other jurisdictions and countries in parts of the boreal forest ecosystem. Such a broad perspective may provide for an increasingly unified approach to sustainable forest management and therefore will require a much larger international focus and the ability to compare results in areas that are not necessarily undergoing the same linear feature expansion or forest harvesting practices that are occurring within the province of Alberta.

### *5. How the research and any products generated by the research, benefit participating partners and affiliates, and other organizations in Canada*

An outcome of the research partnership was a Sustainable Forest management fellowship for MSc Candidate Mark Kachmar. The main goal of this internship was to attempt to understand how to integrate satellite remote sensing techniques with operational forestry, specifically looking at the role of remote sensing in post forest fire timber salvaging and planning. Through this partnership, this research progressed from a technical challenge to a potentially beneficial practice that could aid post fire operational forestry. Without the communication and interaction with a partnering forestry company that was possible through this fellowship, I believe that such a progression would likely have not fully matured or been lacking in a real management context. During the course of my fellowship, I accomplished many secondary objectives including:

1) Understanding that practical work experience cannot be gained solely within the University, and thus, this internship made me realize the need to build communication and technological bridges that can overcome discourse and technical barriers that inhibit the dissemination and use of new technological tools in sustainable forestry, and;

2) Gaining insight and becoming aware of the logistical and operational challenges forestry company deal with on a day-to-day basis and;

3) Experiencing first hand the socio/cultural realities of working in isolated areas at a major pulp and paper mill in North America that I believe are important considerations for future employment options and careers.

### *6. Management/policy implications (i.e., practical applications of the research)*

This research has laid the foundation for improved methods for characterizing forest areas affected by fire. This research argues that the choice of methods must also be used relative to the landscape dynamics that are occurring in a specific study area, such that a given set of classification techniques needs to be carefully evaluated before implementing them in a new area under dynamic land cover forces, and requiring a unique management solution to an ecological or management question. The direct benefits of this research for are improved approaches to 1) Characterizing post fire land cover that can improve estimates of the area and extent of forest cover burnt by fire. The results are also important for future fuel mapping initiatives, as previous methods for assessing the land cover in fire-affected areas do not consider the fuel sources provided by live unburnt post-fire residuals. Finally, remote sensing should aim to produce accurate, transparent results that can be quickly disseminated and accessible to those agencies that could benefit from them. Data transfer however is not the only step, and data sharing includes education and training on the limitations and processes involved in generating land cover information using satellite imagery. Without such efforts and knowledge transfer, the effectiveness of using the resulting data products in support of natural resource management and habitat conservation is limited.

### *7. Any opportunities that emerged or problems that were encountered, and how these were addressed*

Mark Kachmar was awarded a 2002 industrial fellowship with Alberta Pacific Forest Industries Inc. during the course of this research project. The internship was to attempt to integrate satellite remote sensing techniques with operational forestry, specifically looking at the role of remote sensing in post forest fire timber salvaging and planning.
Through this partnership, my research progressed from a technical challenge to a potentially beneficial practice that could aid post fire operational forestry. Without the communication and interaction with a partnering forestry company, I believe that such a progression would likely have not fully matured or been lacking in a real management context. Mark Kachmar was also awarded the Space Imaging award from the American Society for Photogrammetry and Remote Sensing for the application of high-resolution satellite imagery.

### *8. Future follow-up or related research to be undertaken*

Thorough investigations of post-fire areas will also require carrying out studies of post-fire environments in not only the province of Alberta, but also in other jurisdictions and countries in parts of the boreal forest ecosystem. Such a broad perspective may provide for an increasingly unified approach to sustainable forest management and therefore will require a much larger international focus and the ability to compare results in areas that are not necessarily undergoing the same linear feature expansion or forest harvesting practices that are occurring within the province of Alberta.

### *9. Acknowledgement of those individuals or organizations who contributed substantially to scientific and technical aspects, or gave financial support*

We would like to thank the Sustainable Forest Management Network [SFMN] and Alberta Pacific Forest Industries Inc. [ALPAC] for their support of this research. I wish to also thank Dr. Elston Dzus for helping to facilitate the industrial fellowship at ALPAC, as well as Mr. Matthew Smith, and other members of ALPAC’s woodlands group, for their discussions, feedback and continuing support of this research project. I would also like to thank Dr. G. Arturo Sánchez-Azofeifa for his continuing support of this research and for encouraging me to work with Government and Industrial partners in Alberta. We would also like to acknowledge the American Society for Photogrammetry and Remote Sensing (ASPRS) and the Space Imaging Corporation for providing the IKONOS image data grant to support this research.

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List of Figures


Figure 1. Locations of the 2002 Crow Lake Ecological Reserve [affected by the 2002 House River fire] and the 2001 Chisholm Fire overlaid onto the Province of Alberta, Canada.

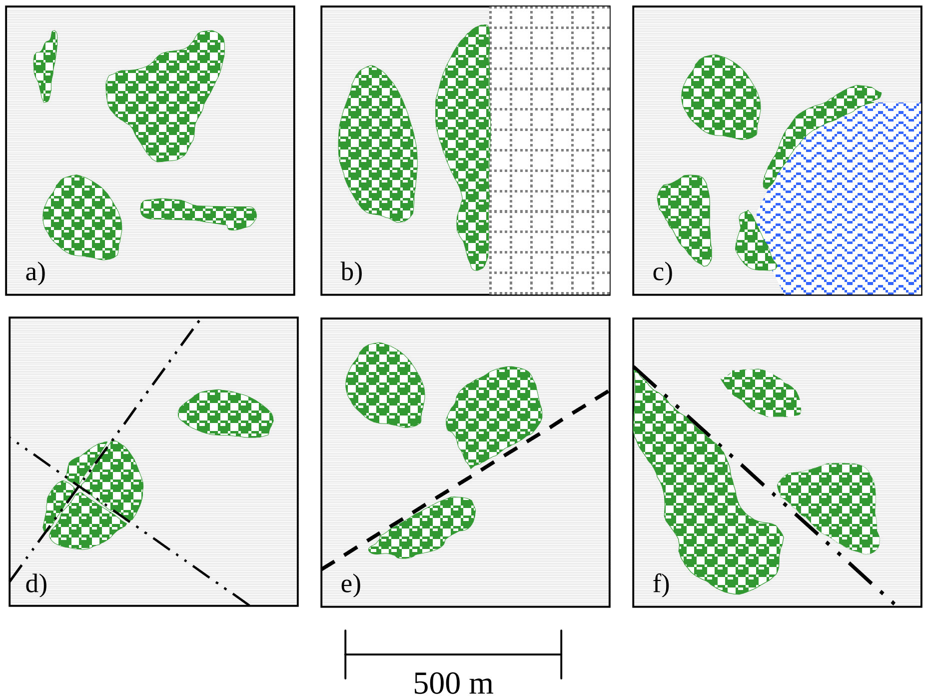



Figure 2. Bird's-eye-view pictorial representation of the locations and geometric shapes of unburnt [residual] forest patches located within the Chisholm (2001) and House River (2002) fire perimeter occurring as a) isolated forest islands; b) between agricultural fields; c) bordering lakes; d) along seismic lines; e) along road edges; and f) along transmission lines.

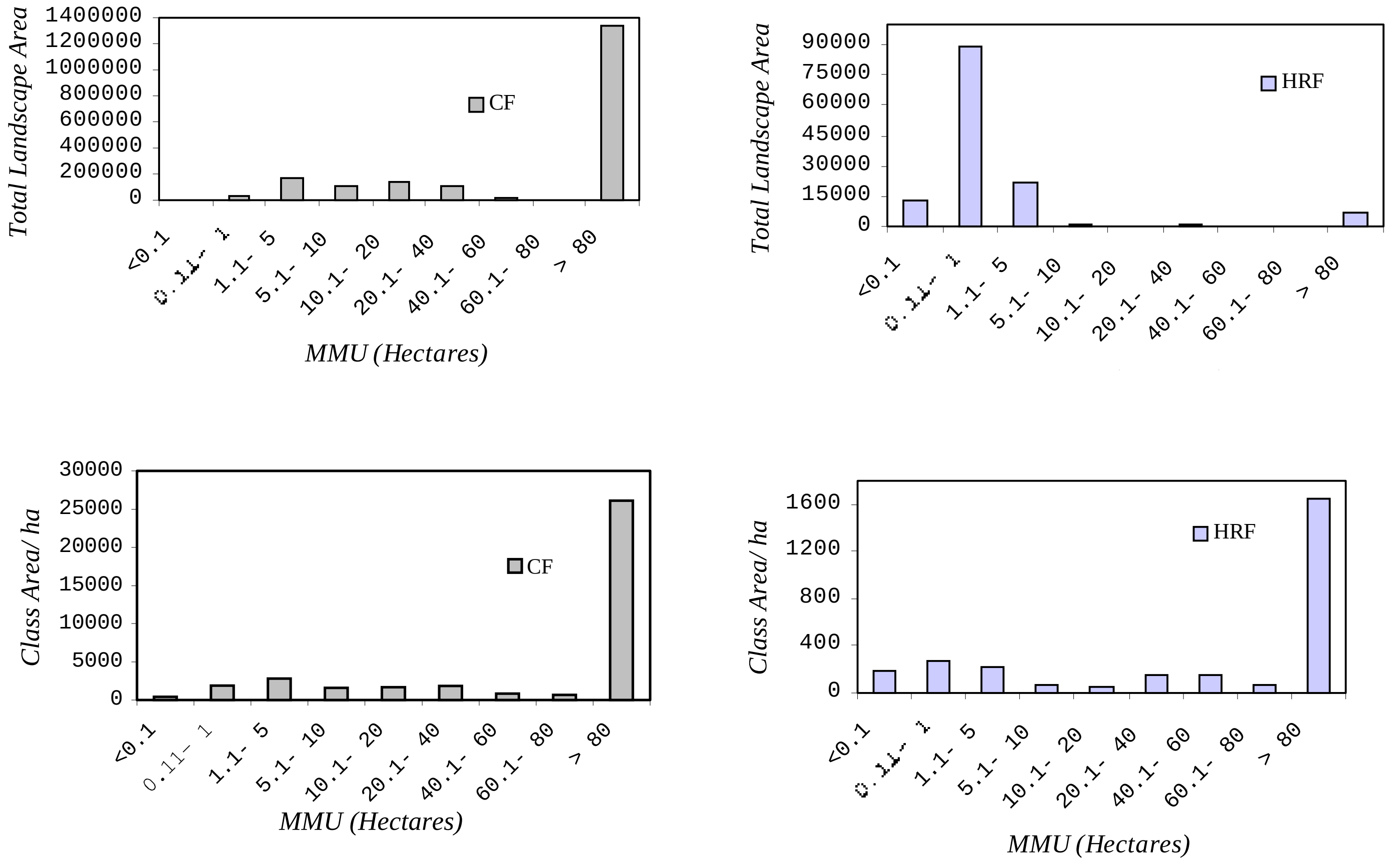
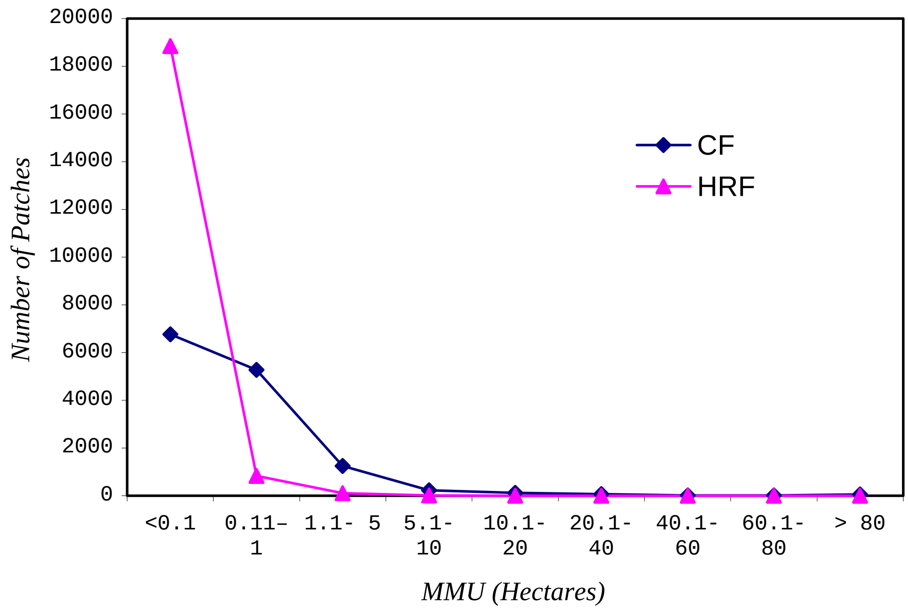



Figure 3. Total Landscape (top) and Class Area (bottom) calculated as a function of minimum mapping unit from a classified Landsat ETM+ image acquired over the perimeter of the 2001 Chisholm fire and from a classified IKONOS image acquired over the perimeter of the 2002 House River Fire



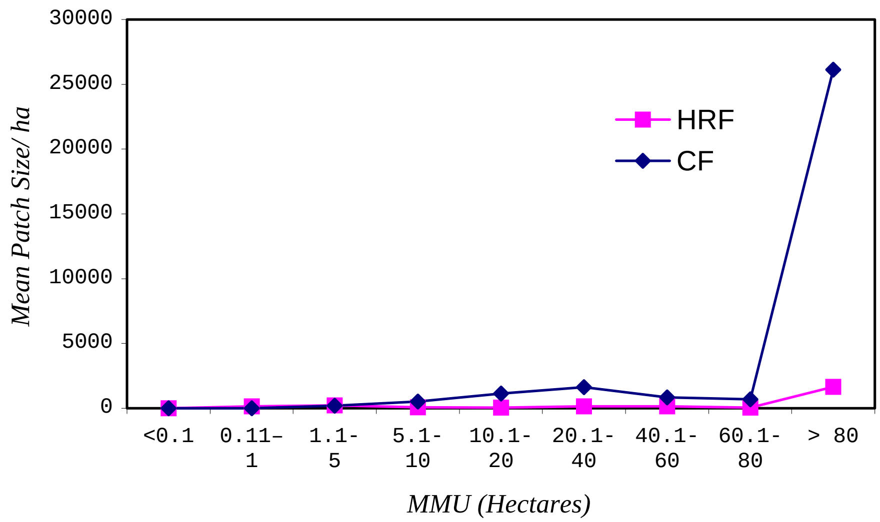




Figure 4. Number of Patches and Mean Patch Size calculated as a function of minimum mapping unit for the perimeter of the 2001 Chisholm and 2002 House River Fires.

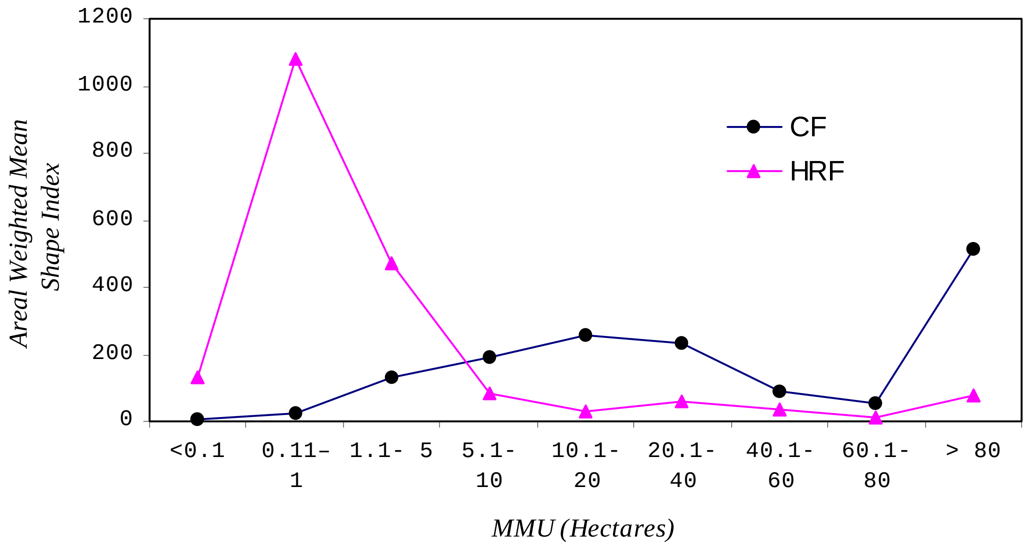



Figure 5. Areal Weighted Mean Shape Index calculated as a function of minimum mapping unit for the perimeter of the 2001 Chisholm and 2002 House River Fires. Mean Patch Fractal Dimension calculated as a function of minimum mapping unit for the perimeter of the 2001 Chisholm and 2002 House River Fires.

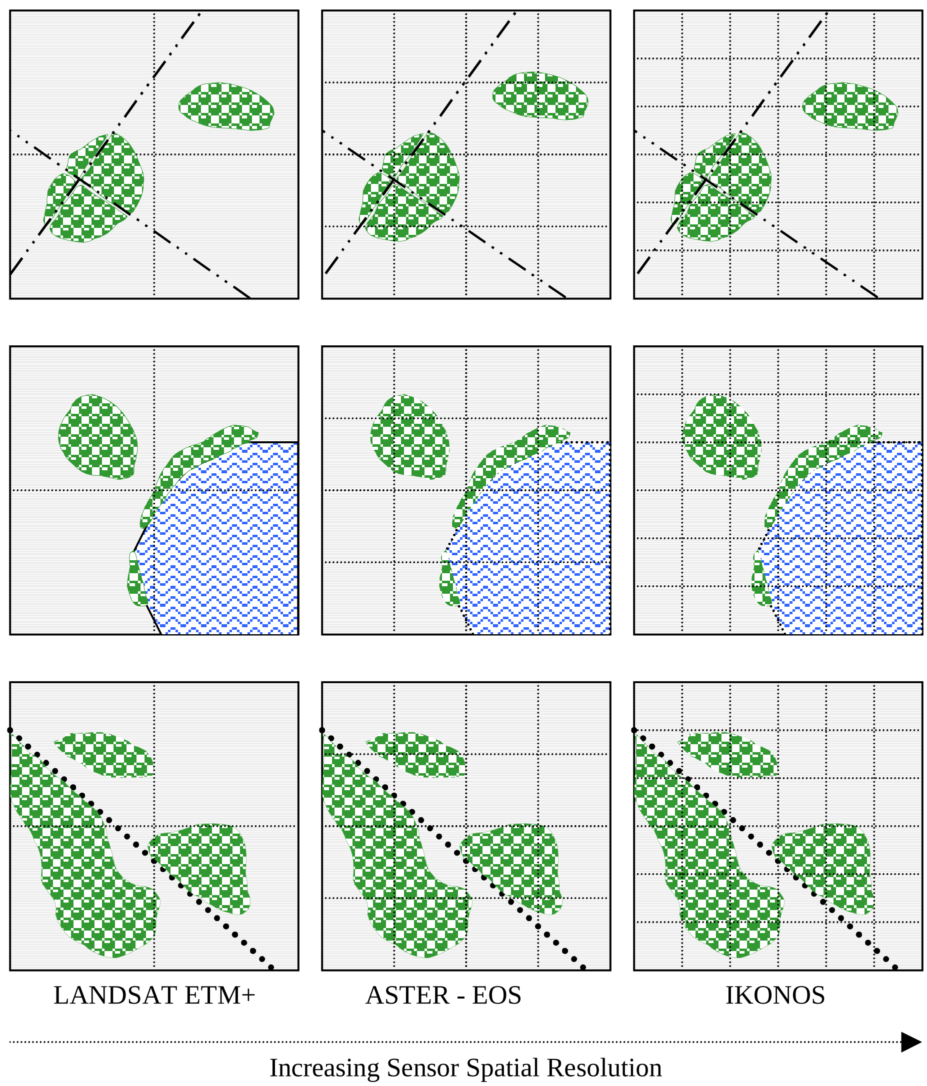



Figure 6. Pictorial representation of the effect of increasing sensor spatial resolution on different sized residual forest patches affected by a) seismic lines; b) bordering lakes; and c) roads overlaid onto a grid representing sensor field of view at 28.5, 15 and 4 - metre sensor spatial resolution perimeter.

Table 1. Residual forest patches metrics as a function of minimum mapping unit for the 2002 House River fire derived from a supervised maximum likelihood classification on a 4 m resolution IKONOS image.

| House River Fire Residual Data Statistics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Metrics** | **<0.1** | **0.11– 1** | **1.1- 5** | **5.1- 10** | **10.1- 20** | **20.1- 40** | **40.1- 60** | **60.1- 80** | **> 80** |
| | | | | | | | | | |
| **Class Area (ha)** | 190.8 | 263.6 | 218.8 | 74.2 | 50.9 | 155.5 | 155.7 | 61.0 | 1643.9 |
| **TLA** | 12595.5 | 89344.9 | 21446.7 | 816.5 | 203.5 | 777.4 | 467.1 | 61.0 | 6575.4 |
| **Number of Patches** | 18844.0 | 835.0 | 103.0 | 11.0 | 4.0 | 5.0 | 3.0 | 1.0 | 4.0 |
| **Mean Patch Size (ha)** | 3.3 | 149.2 | 212.6 | 74.2 | 50.9 | 155.5 | 155.7 | 61.0 | 1643.9 |
| **AWMSI** | 131.0 | 1079.8 | 469.1 | 82.4 | 32.5 | 61.3 | 34.5 | 9.5 | 75.6 |

Table 2. Residual forest patches metrics as a function of minimum mapping unit for the 2001 Chisholm Fire derived from a supervised maximum likelihood classification on a 28.5 m resolution Landsat ETM+ image.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Class Area (ha)** | 423.2 | 1887.9 | 2790.5 | 1594.0 | 1669.8 | 1828.4 | 840.7 | 679.3 | 26116.9 |
| **TLA** | 423.2 | 28319.1 | 175801.5 | 113174.0 | 133580.0 | 104217.4 | 14291.7 | 6792.5 | 1331960.6 |
| **Number of Patches** | 6771.0 | 5278.0 | 1244.0 | 224.0 | 117.0 | 66.0 | 17.0 | 10.0 | 51.0 |
| **Mean Patch Size (ha)** | 0.2 | 8.4 | 192.9 | 528.5 | 1144.4 | 1618.1 | 840.7 | 679.3 | 26116.9 |
| **AWMSI** | 3.4 | 22.8 | 133.6 | 192.3 | 255.5 | 232.7 | 90.8 | 55.4 | 511.9 |

Total Landscape Area (TLA)
Areal Weighted Mean Shape Index (AWMSI)