SHORELINE FOREST DISTURBANCE RATES IN NATURAL AND MANAGED FORESTS OF NORTHWESTERN ONTARIO

by

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the Degree of Master of Science in Forestry

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ABSTRACT

Landstrom, J.M. 2004. Shoreline Forest Disturbance Rates in Natural and Managed Forests of Northwestern Ontario. 76pp.

Key Words: change detection, disturbance events, fire, harvesting, natural disturbance pattern emulation, shoreline forest, variable width study buffer, and watershed.

The purpose of this study was to compare the rates of disturbance along forested shorelines between natural and managed forests of the mesic boreal region of northwestern Ontario. Comparisons were made between areas that experienced wildfire burns versus areas that were subjected to existing forest management reserve policies. A shoreline forest is the area of an upland forest region located adjacent to, and influenced to varying degrees, by aquatic and/or riparian environments. Since these areas have unique biotic and abiotic characteristics and serve important ecological functions, they may be more sensitive than upland areas to forest harvesting and fire suppression. Fire is an important factor for maintaining the unique habitat of shoreline areas, therefore, shoreline area management that differs from the natural disturbance regime may cause unexpected and unwanted consequences.

Shoreline forest disturbance rates were analyzed within disturbance events and watersheds using a variable width shoreline buffer to delineate the shoreline forest region. A disturbance event is a spatially aggregated and delineated collection of burn or harvest patches, whereas a watershed is an area of land within which all waters flow to a single river system. Remote sensing and geographical information systems technologies were applied to obtain new information about natural and artificial rates of forest disturbance. The band 5 subtraction change detection technique was 92% accurate in detecting forest disturbance patches from Landsat 5 and 7 Thematic Mapper satellite images.

Our results show that shorelines are disturbed by both fire and harvesting at a lower rate than the surrounding landscape, but that the magnitude of this difference depends on the analysis unit. The disturbance rate variability of harvested watersheds was much greater than that of their associated shoreline forests, indicating that shoreline areas are treated more uniformly than the watershed as a whole. The rate of disturbance within harvest events was both lower and more variable than the rate of disturbance within fire events and the rate of disturbance for burned watersheds and associated shorelines was not consistent across spatial scales. If the goal of forest management is to better emulate natural disturbance patterns, disturbance patches within harvest events or watersheds should be more aggregated and the disturbance rates within shoreline forests should be increased to slightly below the watershed disturbance rates.

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CONTENTS

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Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

TABLES

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FIGURES

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Figure Page

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INTRODUCTION

A shoreline forest is the area of an upland forest located adjacent to, and influenced to varying degrees by, aquatic and/or riparian environments. A shoreline forest differs from a riparian area, which is a transitional zone between aquatic and upland environments and contains distinct plant communities tolerant of flooding. Many shorelines exhibit a relatively discrete interface between open water and dry land occupied by forest but others have a riparian area varying from a narrow band of alder to large bogs, shore fens, or meadow marsh complexes (Racey 1998). Shoreline forests may contain riparian and upland vegetation and serve many important ecological functions, such as providing habitat for flora and fauna, influencing water temperature, water chemistry and shoreline hydrology, preventing soil erosion, and creating aquatic habitat from coarse woody debris (Allan 1995; Grizzel and Wolff 1998; Keim and Schoenholtz 1999; Naiman and Décamps 1997). In addition, shoreline forests may be exposed to increased sunlight, wind and soil moisture. These unique biotic and abiotic characteristics indicate that shoreline forests may be more sensitive than upland areas to forest management regimes, such as harvesting or fire suppression (Andison and McCleary 2002). Forest management buffers, in which harvesting is modified or eliminated, are commonly applied to shoreline areas in order to protect aquatic and shoreline ecosystem values (Keim and Schoenholtz 1999). In the boreal forest, fire is an important factor in maintaining the unique habitat of shoreline areas. Therefore,

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shoreline area management should be designed to maintain the natural disturbance regime (Andison and McCleary 2002).

The current philosophy toward maintaining biological diversity is to pattern forest management practices after the natural disturbances that shape the forest ecosystem (Delong and Tanner 1996; Hunter 1993). This approach is based on the hypothesis that natural ecological processes will be best maintained where forest management activities emulate natural disturbance (Delong and Tanner 1996). The assumption underlying this approach is that the biota of the boreal forest are adapted to natural disturbance and therefore, should be able to cope more easily with timber harvesting activities if they resemble the ecological processes caused by natural disturbances (Hunter 1993). It has been argued that natural disturbance regimes can serve as models for the frequency, size, and distribution of harvesting operations, as well as the type and amount of residual organic matter (Hunter 1993). However, not all elements of a natural disturbance regime can, or should, be mimicked by forest management.

Natural disturbances are defined as "relatively distinct events in time that disrupt ecosystem, community, or population structure and that change resources, the availability of suitable habitat, and/or the physical environment" (Parminter and Daigle 1997). For over a century fires have been efficiently suppressed in the boreal forest (Rowe and Scotter 1973; Zackrisson 1977). As a result, forest management has surpassed fire as the dominant disturbance agent shaping the pattern of forest age on the boreal landscape (Delong and Tanner 1996; Rowe and Scotter 1973; Zackrisson 1977). Prior to this, fire was the prime disturbance agent responsible for maintaining the

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diversity and long-term stability of the forest ecosystem (Zackrisson 1977). The impacts of forest management on forest patch structure and distribution need to be evaluated if we are to emulate natural disturbance (DeLong and Tanner 1996). In addition, there is a need to better understand the processes and patterns within shoreline areas in order to manage them effectively (Andison and McCleary 2002). Research has been conducted on the landscape scale effects of fire and harvesting on riparian ecosystems in western Canada and the United States (Andison and McCleary 2002; Bisson et al. 2003; Dwire and Kauffman 2003; MacDonald et al. 2004; Russell and McBride 2001; Sagers and Lyon 1997). Research on riparian systems in the boreal forest of Ontario, however, has generally been limited to stand level impacts and effects on aquatic systems (Lamb et al. 2003; Paterson et al. 1998; Steedman 2000; Steedman et al. 1998).

The purpose of this study was to compare the shoreline forest disturbance rates of natural and managed forests of a mesic boreal region within northwestern Ontario. Shoreline forest disturbance rates were examined within two analysis units: disturbance events and watersheds. A disturbance event is a spatially aggregated group of burned or harvested forest patches created within a defined period of time and delineated by a single polygon. A fire may result in many patches that collectively impact the environment as a single event. The forest pattern resulting from a fire includes both the disturbed forest patches as well as the residual islands and peninsulas. This mosaic of vegetation conditions influences the ecology of local forest and aquatic values.

The concept of a disturbance event can also be applied to a group of harvest patches to create an analogue for comparing fire and harvesting disturbance rates. Neighbouring harvest patches cut within a short period of time will influence the

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environment as a single event. The uncut forest between harvested patches creates within-event structure that can be compared to the residual forest of a fire event. Examining the collective impacts of burned or harvested patches as events is important for evaluating our ability to manage forest landscapes to emulate natural disturbance patterns. The disturbance event scale provides a measurement unit for identifying, managing and monitoring the patterns of landscape disturbance for natural disturbance pattern emulation.

A watershed, or catchment, is the entire surface area within which all waters flow to a single river system (Allan 1995; Heathcote 1998). The term watershed actually describes the boundary or high point of land separating two drainage basins but is used synonymously with catchment in North America (Allan 1995). Watershed management has emerged as an approach to ecosystem management (White 1996). Ecosystems are difficult to define or identify; however, watersheds are identifiable and meaningful ecosystem units with practical applications to natural resource management (White 1996).

Forests are characterized by patterns and processes distributed over a broad range of spatial and temporal scales (Lertzman and Fall 1998; Sample 1994). Therefore, it is important that the scale of analysis match the scale at which a process influences the landscape (Rempel et al. 1997). By examining forest patterns and processes over a range of scales we gain information about the appropriateness of different variables and the extent to which the variables and conclusions are scale dependent (Lertzman and Fall 1988; Waring and Running 1998). Shoreline forests should be analyzed at a range of spatial scales (e.g. 100, 1000, 4000 and 10,000ha watersheds) in order to explore the

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variability in the rates of disturbance. Watersheds provide ecological units at a variety of scales for identifying, managing and monitoring the patterns of landscape disturbance for natural disturbance pattern emulation.

SHORELINE FOREST MANAGEMENT IN ONTARIO

The goal of shoreline management is to protect water quality, fish habitat and biodiversity. In Ontario, the Crown Forest Sustainability Act (Government of Ontario 1994) requires that forest management emulate natural disturbance patterns. However, the federal Fisheries Act (Government of Canada 2002) calls for the protection of fish habitat to have priority in areas where forest operations may affect lakes or streams. The Timber Management Guidelines for the Protection of Fish Habitat (OMNR 1988) provide direction for the protection of fish habitat during the planning and implementation of timber management operations. These guidelines prescribe 30 to 90 metre shoreline management areas, referred to as areas of concern, around most streams and lakes. The purpose of areas of concern is to protect critical fish habitat by reducing erosion, sedimentation, water temperature increases and blowdown while maintaining vegetation to provide cover and food for fish and aquatic invertebrates (OMNR 1988). Within these areas of concern harvesting and silviculture activities must be modified for the protection of critical fish habitat and other aquatic values. Since critical fish habitat is difficult to define or identify, forested shoreline reserves, with little or no harvesting, are typically left around lakes and streams. Although shoreline management areas are intended to protect ecological values they may be creating shoreline forests with unnatural amounts of residual forest cover. Wildfire does not follow the boundaries of

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shoreline management areas and therefore, may result in different shoreline disturbance rates than harvesting.

NATURAL DISTURBANCE PATTERN EMULATION IN ONTARIO

In Ontario, the Forest Management Guide for Natural Disturbance Pattern Emulation (OMNR 2001) was created to support natural resource managers in developing and implementing forest management plans aimed at creating more natural forest landscapes than those that have developed under species-specific wildlife habitat guidelines. The guide provides direction for creating patterns of forest disturbances that more closely resemble wildfire. The application of the guide will not create forest landscapes that mimic the results of fire since fire is a physio-chemical process and harvesting is a mechanical process. However, in order to better simulate the results of wildfire, the natural disturbance emulation guide provides direction on the location and size of disturbances, residual stand structure, species composition of the forest and its age class distribution. The objective of the guide is to conserve biological diversity by applying a coarse ecological filter.

The forest management paradigm in Ontario has shifted from a species-specific management regime to the application of coarse and fine filters to conserve biodiversity within the forest environment (OMNR 2001). Previously, the forest was managed to create forest habitat conditions that were favourable to particular species of economic interest or species that were identified as being at risk. Over the years, the need for a broader, less species-specific approach to forest management has emerged (Rempel et al. 1997). A coarse filter aims to maintain a variety of forest conditions in order to satisfy

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the needs of a broad array of species, support interaction among species, and facilitate ecosystem processes. In contrast, a fine filter approach addresses the specialized needs of particular species. Applying both coarse and fine filters ensures that the landscape can satisfy the general needs of a large number of species and the particular needs of individual species with special requirements (OMNR 2001).

HYPOTHESES

My hypotheses were that (1) rates of disturbance within burned and harvested events and watersheds are the same as those of their associated shoreline forests, (2) rates of disturbance within harvested events and watersheds are the same as rates for burned events and watersheds, and (3) rates of disturbance for watersheds and associated shorelines are consistent across watershed size classes. The results of these analyses will provide quantitative data on the shoreline forest disturbance rates within the study area and examine how well timber harvesting spatially emulates wildfire.

Assuming that fire behavior is not influenced by shoreline forest conditions, we should expect the rate of disturbance within the event as a whole, and disturbance rate within the watershed as a whole to be the same as the disturbance rates within only the associated shoreline forests. Alternatively, if fire behaviour is altered within the shoreline forest, then the disturbance rates will be different than within the event or watershed. In addition, the percent area burned within the shoreline should equal some function of the percent area disturbed within the event as a whole. If harvesting practices emulate fire-disturbance-patterns, then this relationship between the shoreline

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and event (or watershed) disturbance rates should be the same when analyzing harvest disturbances.

CHANGE DETECTION

Integration of remote sensing and geographic information systems allows resource mangers to identify landscape-level ecological issues and to observe landscape pattern and structure at different spatial and temporal scales (Gluck and Rempel 1996; Pastor and Johnston 1992; Sample 1994). By examining forest disturbance patterns we gain insight into the processes shaping the forest landscape. Remote sensing is a popular approach to monitoring large-scale vegetation changes and can be used to examine both the spatial and temporal rates of forest disturbance. Change detection is a digital image analysis tool used to identify and locate differences in the patterns of temporal datasets obtained at times t_1 and t_2 (Armenakis et al. 2002; Singh 1989). Satellite-based change detection can produce reliable forest disturbance data for assessing temporal trends in disturbance patterns over large areas (Sader et al. 2003).

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STUDY AREA

The study area is a 2,600,000 hectare landscape, located immediately north of Thunder Bay, Ontario, on the northwest shore of Lake Superior (49°N, 89°W, approximately 350 metres above sea level) (Figure 1). It is located within the Superior and Nipigon sections of the Boreal Forest Region of Ontario (Rowe 1972). The variety of forest types and the rolling to rough topography within the study area (Rowe 1972) allowed us to examine fire and harvesting disturbance rates within a range of forest and shoreline conditions typical for the region.

Figure 1. Location of study area within northwestern Ontario.

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The time period selected for this study was based on available imagery for the area. Imagery was selected from September 1989, September 1996 and May 2001, creating a study period of approximately 11.5 years in which to examine the shoreline forest disturbance rates.

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METHODOLOGY

CHANGE DETECTION

Three satellite images from May 2001 (Landsat7 Enhanced TM), September 1996 (Landsat5 TM) and September 1989 (Landsat5 TM), were geographically registered to the Universal Transverse Mercator (UTM) coordinate system to correct for geometric errors within the data. Each of the images had 30-metre resolution, which had been resampled to 25 metres to facilitate the interpretation of area (i.e., 1 pixel equals 0.0625 hectares). Change detection was performed for each pair of images (i.e., 1989 to 2001, 1989 to 1996, and 1996 to 2001) to identify disturbances on the forest landscape (Appendix II). Band 5 subtraction was selected as the change detection technique because of its simplicity, ease of use and the clarity of the results (Howarth and Wickware 1981; Singh 1989). All image analysis was performed in PCI Geomatica V8.2 (PCI Geomatics Enterprises Inc. 2001). The change images were visually inspected to determine appropriate threshold limits for reducing the noise created by changes other than harvesting or fire, such as differences in season, stage of vegetation development, soil moisture, forest tent caterpillar (*Malacosoma disstria* Hubner) defoliation, sun angle, etc. A threshold is the boundary between pixels representing change and those representing no change (Jensen 1996). A threshold value of 70 was applied to the 1989 to 2001 and the 1996 to 2001 change images, while a threshold value of only 20 was applied to the 1989 to 1996 change image. The threshold values were identified through visual inspection of the change images and comparison with ancillary

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data. The 1989 and 1996 images were obtained in the same month, therefore there was less noise in the change image and a lower threshold value was required.

Landcover changes that are easily identified in satellite imagery immediately following a disturbance fade as regeneration occurs and the spectral values of the vegetation become more like those of a mature forest. Changes that were prominent in the 1989 to 1996 change image were less apparent in the 1989 to 2001 change image. In order to reduce the effect of fading landcover changes over time, the changed pixels from the three change images were combined into one cumulative disturbance image. The three change images were combined on a pixel by pixel basis by selecting the brightest pixel from each image. A sieve 3x3 filter was used to reduce the speckled appearance of the cumulative change image by selecting all polygons smaller than 3 pixels by 3 pixels and merging them with the largest neighbouring polygon. The sieve approach was used rather than a median or modal filter because the sieve maintains the integrity of the patch shapes, and does not smooth patch edges.

Burned and harvested patches were delineated from the cumulative change image using on-screen digitizing in Arcview 3.2 (ESRI 1999), while wetland and forest gap disturbances were removed from the data (Appendix III). Ancillary data, including the forest resource inventory (FRI) polygon layer, provincial landcover raster layer, provincial fire point and polygon layers, unclassified satellite images, and ground-truth data, where available, were compared with the change image to visually identify wetland and forest gap disturbances and to distinguish between burned and harvested patches. Several of the fires in the study area contained patches where harvesting and fire had occurred together, such as when a young plantation burned or salvage logging was

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performed following fire. Based on field observation, it was determined that the predominant disturbance type of these areas was fire. Therefore, under the assumption that the harvesting disturbances did not greatly influence the shape or size of the fire disturbances, the patches containing both disturbance types were retained and analyzed as fire disturbances.

The threshold values used to limit the change detection eliminated some pixels from burned areas that should not have been removed. However, the harvested areas did not appear to be affected. In order to recapture the lost pixels from the burns, the original change images were reprocessed using lower thresholds limits and then combined with the image created using the higher threshold values (Appendix IV). . Visual inspection of the change image was used to determine appropriate threshold values. A threshold of 30 was applied to the 1989 to 2001 and the 1996 to 2001 change images and a threshold of 10 was applied to the 1989 to 1996 change image. The change images were merged together, clipped to the fire boundaries, simplified with a sieve filter and then combined with the previously processed change detection data.

The accuracy of the change detection was assessed to quantify how well the disturbed forest patches were identified. Reference data were collected in the field using six road sections spread across the study area. One side of the road was sampled for each section, totaling approximately 142 km or 5669 pixels. Each road section was divided into multiple segments using ground control points referenced by GPS coordinates. The forest immediately adjacent to the road was observed and ground control points were collected at the beginning and end of every disturbance patch. Therefore, each road segment represented a patch of burned, harvested or undisturbed

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forest. New disturbance patches, which occurred more recently than the latest satellite image and old disturbance patches, which occurred prior to the earliest satellite image, were identified and removed from the sample. The length of each reference road segment was measured on-screen in Arcview (ESRI 1999). Within each road segment, the change detection forest patches were measured. Following the method of Congalton (1999), the reference and change detection data were compared to determine the omission and commission errors for disturbed and undisturbed forest patches.

Accuracy assessment was performed on approximately 142 km of forest adjacent to roadways within the study area. In total, 49 km of disturbed forest were assessed along with 93 km of undisturbed forest. The overall accuracy of the change detection was 95 percent. The omission errors were 6 and 4 percent for the disturbed and undisturbed forest, respectively. The commission errors were 8 and 3 percent for the disturbed and undisturbed forest, respectively, resulting in a 92% user's accuracy for disturbance.

SHORELINE STUDY BUFFER

A digital elevation model (DEM) with 20 m horizontal resolution and vertical resolution accurate to 5 m was used to produce a slope map for the study area (Appendix V). Visual examination of the slope map revealed a natural break point for two general slope classes, 0 to 30% (0 to 17 degrees) and greater than 30% (greater than 18 degrees). The buffer widths selected for these two slope classes were 50 m for slopes 0 to 30% and 100 m for slopes greater than 30%. In Ontario, the width of a timber management area of concern is dependent on the slope of the shoreline, where slopes less than 15%,

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16 to 30%, 31 to 45% and 46 to 60% require 30, 50, 70 and 90 m areas of concern, respectively. The shoreline study buffer widths were selected to be as consistent as possible with the area of concern recommendations given the limitation of the 25 m resolution of the change image.

The median of the slope grid was calculated using 3 x 3 cell blocks to smooth the slope classes. Stream, lake and wetland themes from the Natural Resources Values Information System were intersected with the slope map in order to divide the lines and polygons of the layers into segments and assign each segment a slope class. The segments were buffered 50 or 100 m according to their slope class and then overlaid to create one complete shoreline study buffer that was variable in width. The lakes, islands and wetlands were erased from the study buffer so that change in these areas would not be included in the measure of shoreline disturbance. However, 3 large fire disturbed islands were not removed because they were large enough to host fires indicative of natural forest disturbance rates found on the mainland.

Wetlands that are not connected to a lake or stream do not directly affect fisheries values and therefore were not included in the change database. Some wetlands may be connected to a lake or a stream but did not intersect in the GIS layers due to the resolution of the data. Therefore, a 50-m buffer around the lakes and streams identified the wetlands to be included in the analysis.

DISTURBANCE EVENTS

The Natural Disturbance Pattern Emulation (NDPE) extension (Elkie et al. 2002) in Arcview, was used to delineate the disturbance event boundaries from the change

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detection data (Appendix VI). This extension is a tool that was created to assist Ontario forest practitioners in planning operations that emulate the patterns created by natural disturbance. Initially, the change detection was combined with FRI data for the study area. The FRI was then processed through a forest inventory classification tool, the Strategic Forest Management Model Tool (SFMMTool 2.2, Watkins and Davis 1999), in Microsoft Access 97 (Microsoft Corporation 1996). The burned and harvested forest patches, identified by the change detection, were agglomerated into disturbance events which included the islands and peninsulas between individual patches. To be grouped into an event, disturbed patches had to be located within 200 m of each other (OMNR 2001). A residual island had be located at least 20 m from the edge of a disturbance, otherwise it was considered a peninsula (OMNR 2001). A residual peninsula was defined as undisturbed forest extending into a disturbance, with a base less than 400 m (for disturbances < 260 ha) or 1000 m (for disturbances > 260 ha) (OMNR 2001). Peninsulas were generally longer than they were wide at the base.

In Ontario, fires less than 10 hectares are not mapped. Therefore, in order to compare fire and harvesting disturbances, all harvest events less than 10 hectares were removed from the analysis. This accounted for approximately eight percent of the total area within harvest events.

For each disturbance type, the change detection, study buffer and water (lakes and wetlands) layers were clipped so that data outside the disturbance event boundaries were removed (Appendix VII). To create the disturbance event dataset the clipped change detection, study buffer, and water layers were combined into a single file with the disturbance events (Figure 2).

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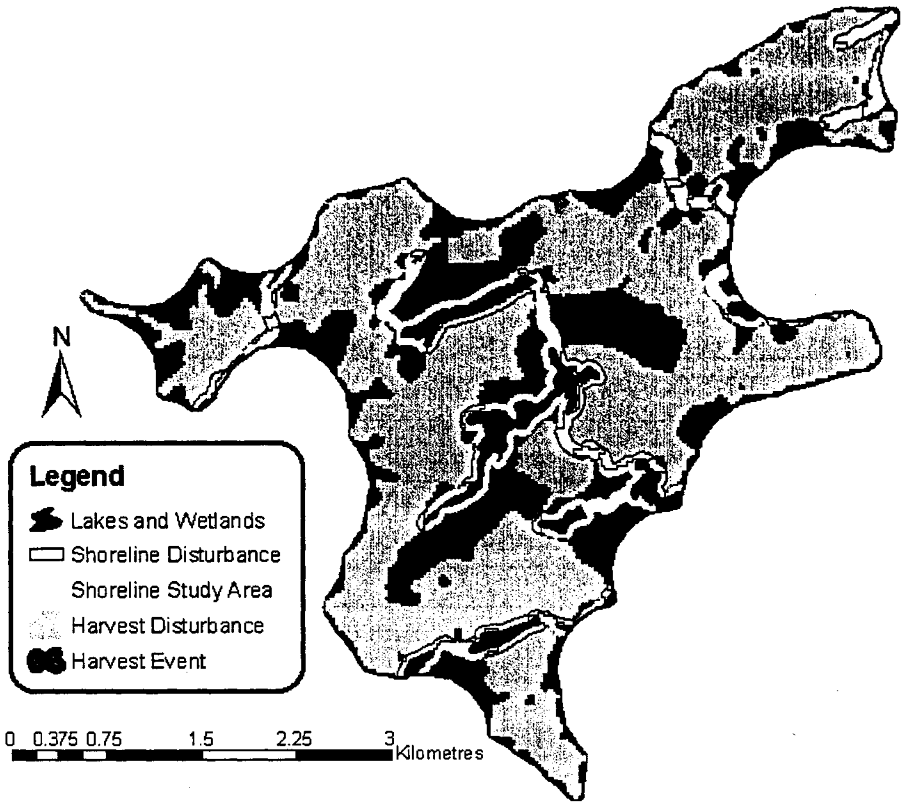

Figure 2. One harvest event including harvest disturbance patches, shoreline analysis areas, shoreline disturbance areas and water (lakes and wetlands).

WATERSHEDS

Watersheds of 100, 1000, 4000, and 10000 ha (± 30%), and nominally identified hereafter as 1, 10, 40 and 100 km^2, were identified from the 20 m DEM using standard procedures (Appendices VIII and IX). The 30% error range was selected to coincide with parallel research conducted under the Comparative Aquatic Effects Program within the Ontario Ministry of Natural Resources.

Watersheds bordering the edge of the study area were eliminated if the portion of the watershed within the study area was less than half the size of the lower limit for that class. Watersheds that were larger than 50% of the lower size class limit were retained

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with the assumption that they were large enough to provide a representative sample of the disturbance rate for that watershed size class.

For each of the four watershed size classes, the change detection, study buffer and water (lakes and wetlands) layers were clipped so that data outside the watershed boundaries were removed. To create the watershed data set the clipped change detection, shoreline study buffer, and water layers were combined into a single file with the watersheds (Figure 3).

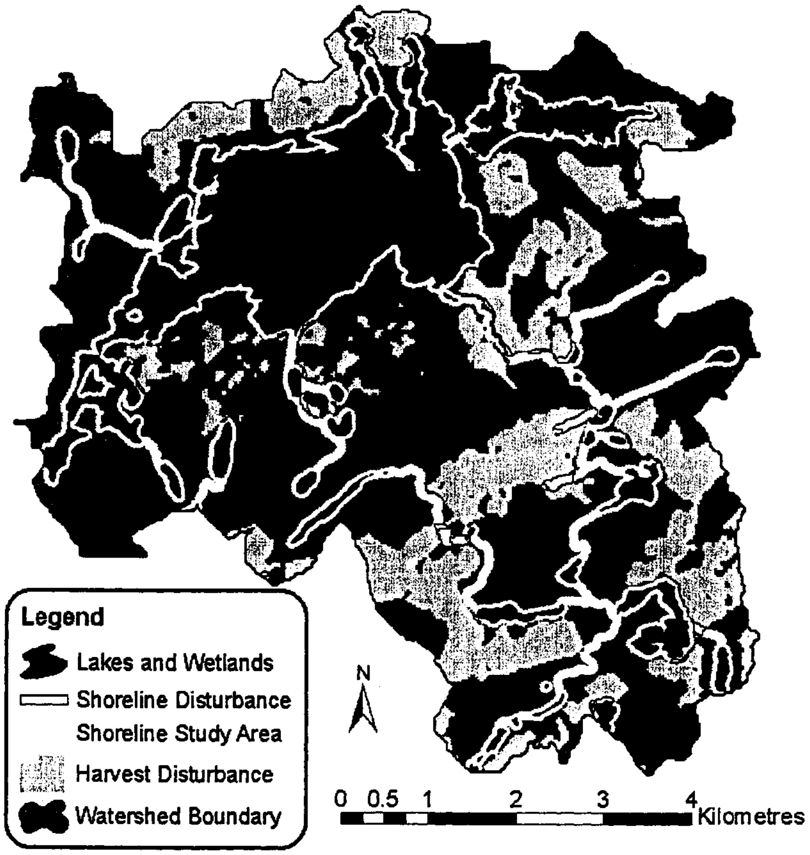

Figure 3. One 40km^2 watershed including harvest disturbance patches, shoreline analysis areas, shoreline disturbance areas and water (lakes and wetlands).

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ANALYSIS METHODOLOGY

All analyses were performed in SPSS version 11.5 (SPSS Inc. 2002). Statistical significance was defined as $\alpha = 0.05$ and Bonferonni corrections were applied where necessary to maintain this level of significance. The following analyses were performed for each of the analysis units (events and watersheds).

For each individual event the percentage of disturbed area was calculated as:

$$EPD = (ETDA / ETLA) \times 100,$$

where EPD (event percent disturbance) represents the percentage of the total area that is disturbed within a disturbance event, ETDA (event total disturbance area) represents the cumulative area of disturbance patches within a disturbance event, and ETLA (event total land area) represents the total land area within a disturbance event. Similarly, the percentage of shoreline forest area that was disturbed within each of the events was calculated as:

$$EPSD = (ESDA / ETSA) \times 100,$$

where EPSD (event percent shoreline disturbance) represents the percentage of the total shoreline area that is disturbed within a disturbance event, ESDA (event shoreline disturbance area) represents the cumulative area of disturbed patches in the shoreline area of a disturbance event, and ETSA (event total shoreline area) represents the total shoreline area within a disturbance event.

For each individual watershed the percentage of disturbed area was calculated as:

$$WPD = (WTDA / WTLA) \times 100,$$

where WPD (watershed percent disturbance) represents the percentage of the total area that is disturbed within a watershed, WTDA (watershed total disturbance area)

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represents the cumulative area of disturbance patches within a watershed, and WTLA (watershed total land area) represents the total land area within a watershed. Similarly, the percentage of shoreline forest area that was disturbed within each of the watersheds was calculated as:

$$\text{WPSD} = (\text{WSDA} / \text{WTSA}) \times 100,$$

where WPSD (watershed percent shoreline disturbance) represents the percentage of the total shoreline area that is disturbed within a watershed, WSDA (watershed shoreline disturbance area) represents the cumulative area of disturbed patches in the shoreline area of a watershed, and WTSA (watershed total shoreline area) represents the total shoreline area within a watershed.

The proportional data were not normally distributed; therefore, the Median test was used to test for significant differences between fire and harvest events (or watershed size classes). A Median test was used to test whether EPD and ESPD (or WPD and WPSD) were different between disturbance origin (i.e., fire and harvest). A Yates Continuity Correction was applied because the table used to calculate the χ^2-test statistic in the median test contained only two rows and two columns (Campbell 1988).

For each disturbance type multiple linear regression analysis was performed to test the hypothesis that shoreline areas are disturbed at the same rate as the disturbance events (or watersheds) to which they belong. Land, water, shoreline, and event (or watershed) disturbance areas were used to predict shoreline disturbance area. Distributional properties of the data were examined using standard methods. Where necessary logarithmic and square root transformations were used to improve the data fit. Partial correlations were calculated for the regression variables to determine the relative

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contributions of each to the linear model. Collinearity among variables was tested within each multiple linear regression model. Where collinearity existed, variables were removed to increase the power and interpretability of the model.

To help illustrate how the multiple linear regression analysis addresses the hypothesis of no difference between treatments, a linear regression line was fit to the data for each of the watershed classes to visually display the relationship between the watershed and shoreline disturbance areas. The expected disturbance area within the shoreline forests was defined by the watershed disturbance area. The assumption (null hypothesis) underlying this expectation is that fire and harvesting disturbances behave the same in the shoreline forest as in the watershed as a whole. Note that the regression lines were not forced through the origin and because these were for illustrative purposes only the regression lines were not statistically analyzed.

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RESULTS

EVENT LEVEL RESPONSE

In the 11.5 year period of the study, harvest events occurred more frequently than fire events, but were generally smaller in size (Table 1). The fire events occupied 37% of the total disturbed area while the harvest events occupied 63%. The total shoreline area occupied 11% of the total area within both fire and harvest events. The disturbed forest area represented 12% of the study area with 4.5% disturbed by fire and 7.5% disturbed by harvesting. The area of the shoreline study buffer within the disturbance events represented 1.3% of the study area with 0.5% disturbed by fire and 0.8% disturbed by harvesting.

Table 1. Total and median land, disturbance, shoreline and shoreline disturbance areas for fire and harvest events within the study area.

Event		Event Area (ha)	Event Disturbance Area (ha)	Shoreline Area (ha)	Shoreline Disturbance Area (ha)
Fire (n=23)	Total	116,271.3	96,088.6	12,731.1	8,788.9
	Median	269.1	191.1	58.3	37.5
Harvest (n=615)	Total	195,329.5	109,626.0	20,911.9	5,287.1
	Median	89.7	60.7	5.5	1.9

Disturbance rates for events and shoreline forests were significantly different for fire and timber harvesting events ($\chi^2 = 11.547$ and $\chi^2 = 11.551$, respectively, $df = 1$, $p < 0.001$), where disturbance rates within fire events and their associated shoreline forests were generally greater than in the harvesting events (Figure 4). The median disturbance

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rate within an event was 16.7 % greater in fire than in harvest events. Similarly, shoreline forest disturbance rates were 19.1 % greater in fire than in harvest events. Therefore, the event and shoreline disturbance rates within the harvesting events were less than what would be expected based on a fire disturbance regime. However, the difference between the event and shoreline forest disturbance rates within the harvesting events was similar to what would be expected based on a fire disturbance regime. The difference between the event and shoreline forest disturbance rates was –20.67% for fire, and –23.06% for harvesting (Figure 4).

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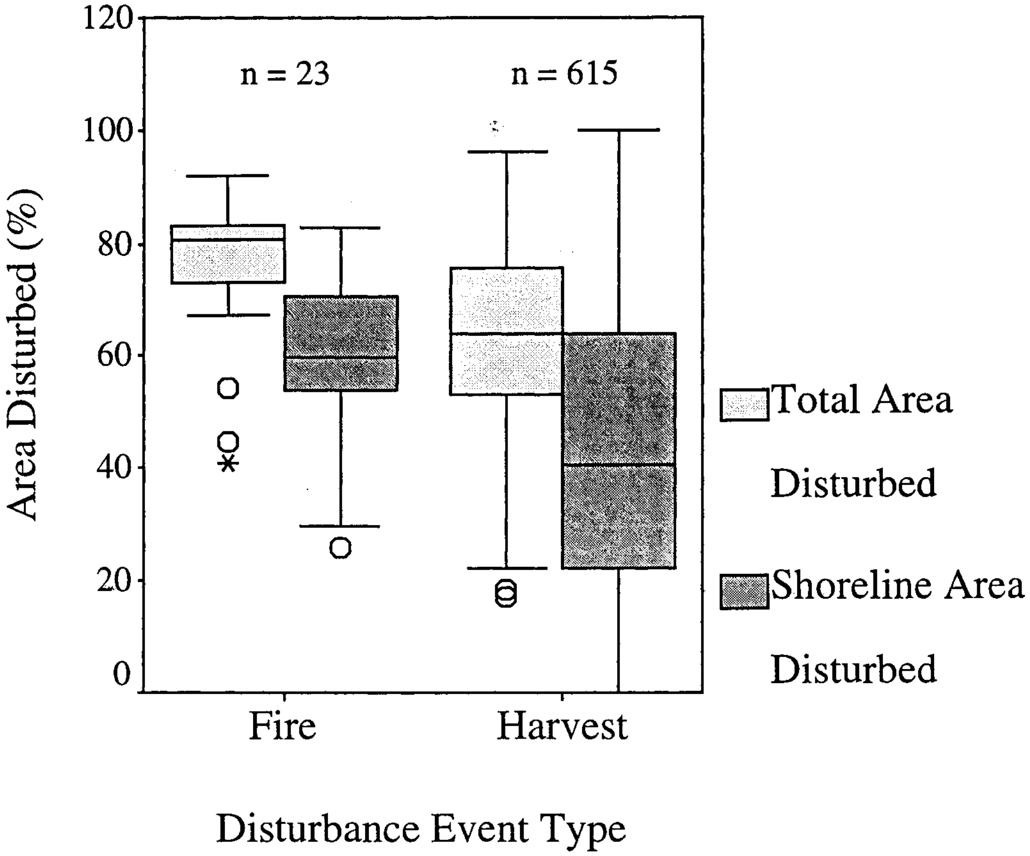

Figure 4. Disturbance rates for the fire and harvesting events for the 11.5 year study period. Boxes represent the 25 percent quartiles, horizontal lines within the boxes represent the group medians, and vertical lines represent the 95 percent confidence limits. The circles represent outlying values (between 1.5 and 3 box lengths from the upper or lower edge of the box) and asterisks represent extreme values (more than 3 box lengths from the upper or lower edge of the box).

Although the difference between event and shoreline forest disturbance rates was similar for fire and harvest events the variability was not (Figure 4). In the harvesting events there was greater variability in both the event and shoreline forest disturbance rates compared to the fire events.

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Collinearity was found within the harvest and fire event multiple linear regression models. Shoreline area was removed from the both models to reduce collinearity. Within fire events there was no relationship between shoreline disturbance and the area of land, overall disturbance and water (Table 2). The multiple linear regression fire model did not explain a significant amount of the variability in the shoreline forest disturbance area ($p > .191$); however, the harvest model did explain a small (23%) but significant proportion of the variability ($p < 0.001$), with disturbance and land area being significant variables. Disturbance area contributed the most information to the harvest model (Table 2). Shoreline disturbance area is positively correlated to overall disturbance area and negatively correlated to land and water area. Therefore, the greater the overall disturbance area relative to land area, the greater the area of shoreline disturbance.

Table 2. Regression parameters for the disturbance event multiple linear regression analysis. Response variable is shoreline disturbance area.

	Fire			Harvest		
	Slope	Std. Error	ρ^2	Slope	Std. Error	ρ^2
Land Area	-.519	.001	-.138	**-.207**	**.002**	**-.134**
Disturb. Area	.399	.243	.397	**.438**	**.058**	**.433**
Water Area	-.672	.021	-.179	.073	.033	.048
Intercept	25.080	18.193		-.186	3.889	
Adjusted R^2			.093			**.231**

Numbers in bold denote significant values

The low R^2 values for these models are supported by scatterplots comparing the event and shoreline forest disturbance rates (Figures 5 and 6).

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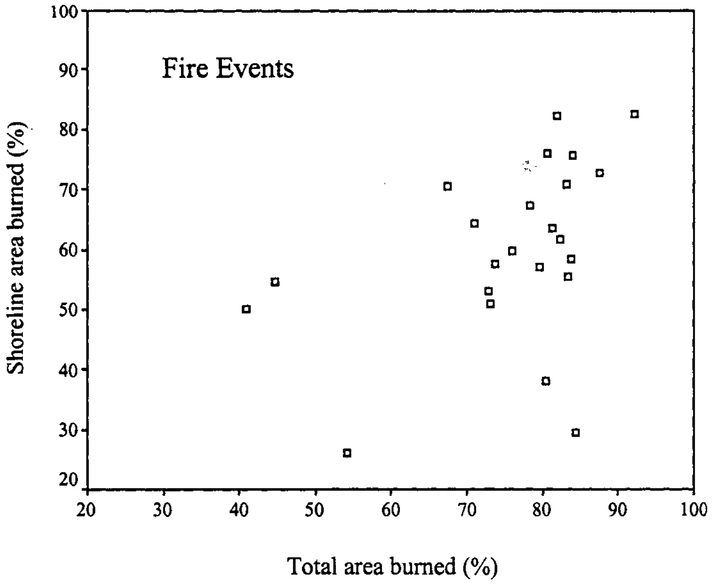

Figure 5. Fire event and shoreline forest disturbance rate distribution for the 11.5 year study period. The X-axis represents the overall rate of disturbance within the events and the Y-axis represents the rate of disturbance within the shoreline areas.

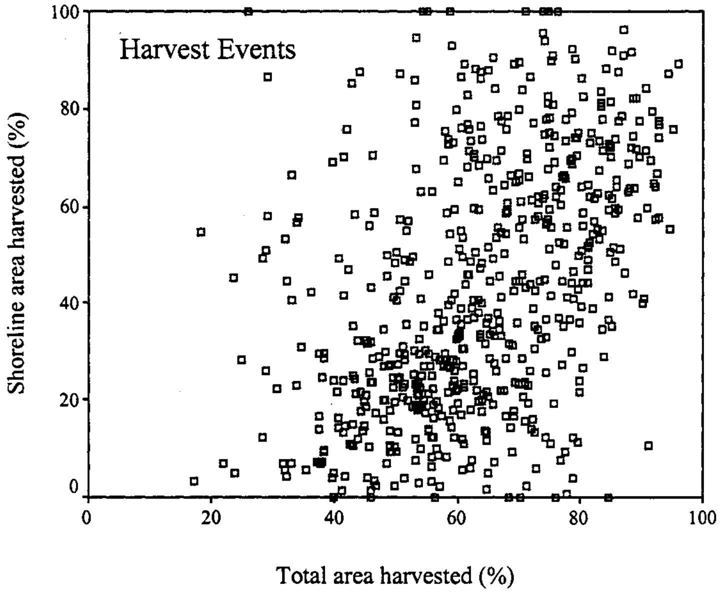

Figure 6. Harvest event and shoreline forest disturbance rate distribution for the 11.5 year study period. The X-axis represents the overall rate of disturbance within the events and the Y-axis represents the rate of disturbance within the shoreline areas.

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WATERSHED LEVEL RESPONSE

There were fewer watersheds in the larger size classes than in the smaller size classes; however, they represented greater total land area (Tables 3 and 4). The total land area of the harvested watersheds was larger than that of the burned watersheds; however, the median land and shoreline areas were very similar for the burned and harvested watersheds of each size class.

Table 3. Total and median land, disturbance, shoreline and shoreline disturbance areas for watersheds disturbed by harvesting within the study area.

Watershed Class		Land Area (ha)	Harvested Watershed Area (ha)	Shoreline Area (ha)	Harvested Shoreline Area (ha)
1km (n=2002)	Sum	211,934.1	42,083.5	34,160.4	2,453.8
	Median	103.8	14.7	11.8	0.8
10km (n=440)	Sum	418,866.3	47,511.7	61,220.7	2,403.4
	Median	950.3	73.0	129.5	3.5
40km (n=147)	Sum	513,542.9	43,068.6	77,407.5	2,225.4
	Median	3,368.8	207.8	526.0	9.6
100km (n=68)	Sum	592,234.1	47,276.5	86,131.9	2,243.3
	Median	8,441.6	512.4	1,164.0	19.7

Table 4. Total and median land, disturbance, shoreline and shoreline disturbance areas for watersheds disturbed by fire within the study area.

Watershed Class		Land Area (ha)	Burned Watershed Area (ha)	Shoreline Area (ha)	Burned Shoreline Area (ha)
1km (n=413)	Sum	42,341.1	27,589.2	3,972.7	2,153.3
	Median	104.0	72.6	6.6	3.5
10km (n=73)	Sum	69,201.8	30,865.0	7,288.0	2,789.9
	Median	918.2	416.8	110.5	32.1
40km (n=23)	Sum	79,231.8	27,944.3	9,888.4	2,322.7
	Median	3,358.4	453.2	404.5	57.7
100km (n=16)	Sum	138,227.1	20,760.2	16,808.2	1,591.9
	Median	8,393.7	859.0	997.3	64.5

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Fire disturbance rates were significantly different among watershed size classes (Figure 7) ($\chi^2 = 43.634$, df = 3, $p < 0.001$). Similarly, the shoreline fire disturbance rates were significantly different among watershed size classes ($\chi^2 = 28.411$, df = 3, $p < 0.001$). For the burned watersheds of all four size-classes, the watershed disturbance rate was greater than the associated shoreline forest disturbance rate (Figure 7); however, the actual difference between the median disturbance rates was small (about 5%) for the three largest size classes. The difference in the disturbance rates of the 1 km^2 watersheds was larger (17.5%) than in the larger size classes.

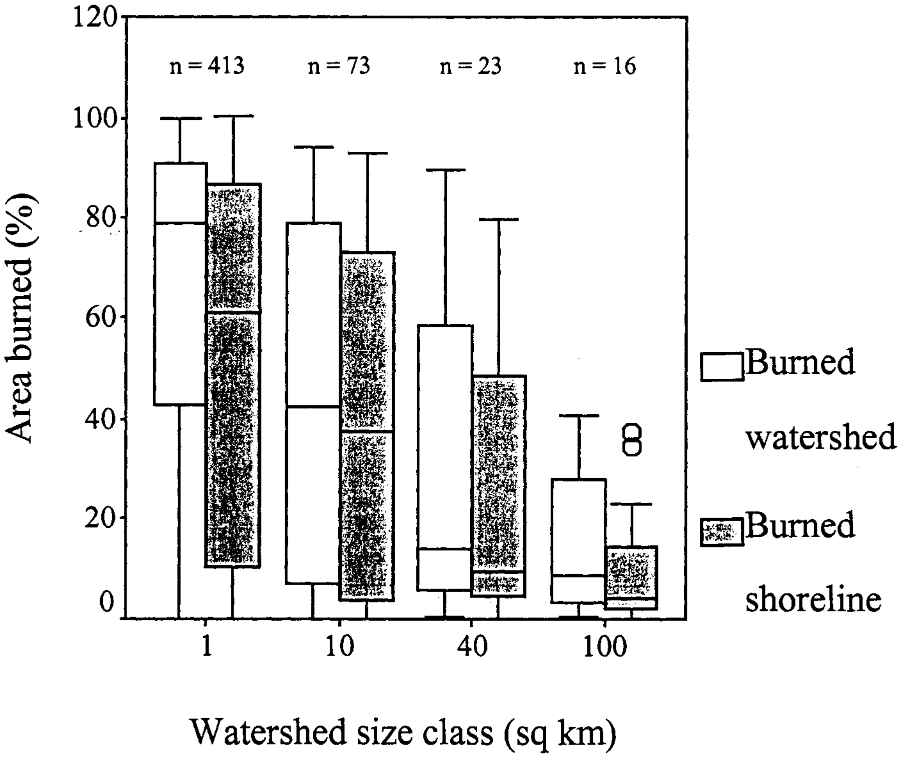

Figure 7. Watershed and shoreline disturbance rates over 11.5 years of study within burned watersheds. See Figure 4 for explanation of features.

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The median watershed and shoreline disturbance rates of the burned watersheds decreased with increasing watershed size class (Figure 7). In addition, the variability generally decreased with increasing watershed size class. Disturbance in the smaller watershed size classes may range from the entire watershed to a very small proportion; in contrast, the disturbance rates in the larger watersheds are less variable since the rates of disturbance are averaged over a larger area.

Disturbance rates for the harvested watersheds were significantly different between watershed size classes (Figure 8) ($\chi^2 = 121.440$, df = 3, $p < 0.001$). Similarly, the shoreline disturbance rates for the harvested watersheds were significantly different between watershed size classes ($\chi^2 = 37.525$, df = 3, $p < 0.001$). For harvested watersheds of all four size classes, the watershed disturbance rate was greater than the shoreline forest disturbance rate (Figure 8); however, the actual difference between the median disturbance rates was small (about 5%) for the three largest watershed size classes. The difference in the median disturbance rates of the 1 km^2 watersheds was larger (15%) than in the other watershed size classes.

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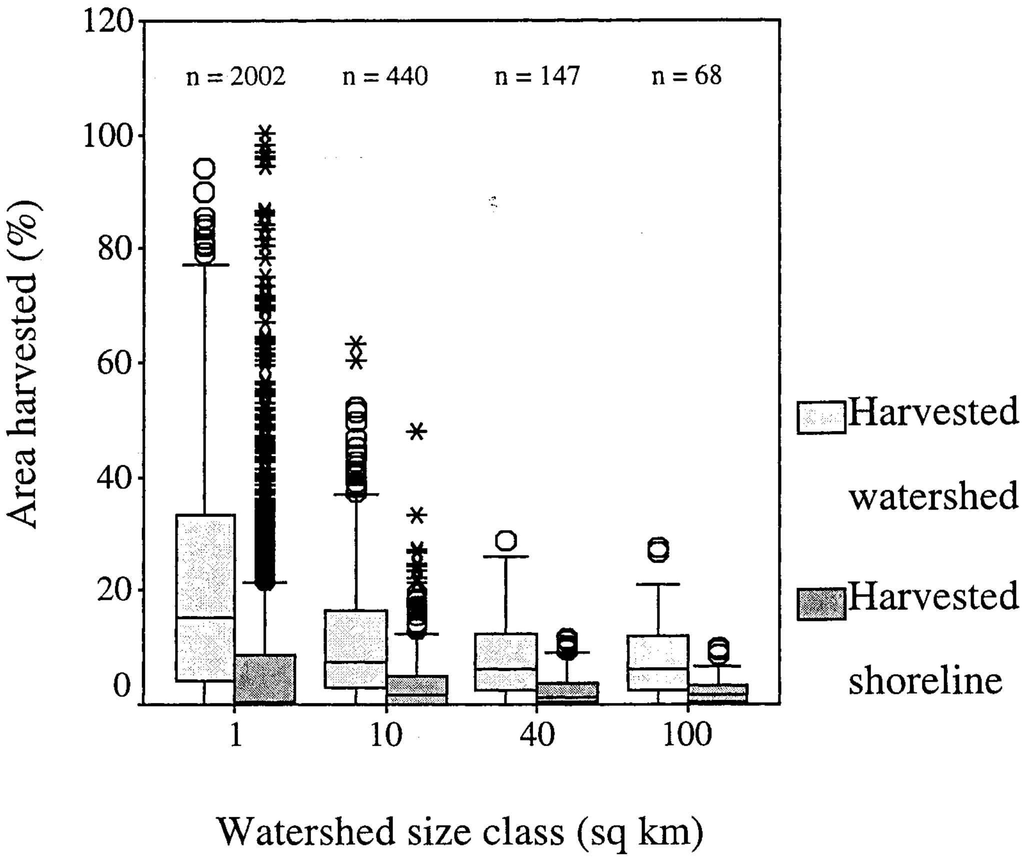

Figure 8. Watershed and shoreline disturbance rates over 11.5 years of study within harvested watersheds. See Figure 4 for a description of features.

The median watershed and shoreline harvest disturbance rates decreased with increasing watershed size class (Figure 8). In addition, the variability in disturbance rate generally decreased with increasing watershed size class. Similar to the burned watersheds the decrease in variability in the larger watershed size classes may be attributed to an averaging effect occurring over larger areas.

For the harvested watersheds, the disturbance rate variability was larger within the watersheds than in the shoreline areas for all size classes (Figure 8). This indicates that the harvest treatments within the shorelines were relatively more consistent than within the watersheds.

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The watershed and shoreline disturbance rates were very similar for the three largest size classes of harvested watersheds (Figure 8). The median watershed disturbance rates varied from 6.2% to 7.5% and the shoreline disturbance rates ranged from 1.4% to 1.7%. This indicates that forest management disturbed watersheds of different sizes at approximately the same rate. However, the 1 km^2 watersheds had a much higher median disturbance rate (15.1%) and a slightly lower median shoreline disturbance rate (0.49%) than larger watersheds. Compared to the larger watershed classes, the shoreline forests in the 1 km^2 size class were being disturbed at a lower rate than expected based on the watershed disturbance rate.

For each size class, the watershed and shoreline forest disturbance rates were consistently higher for fire and lower for harvest (Figure 9). This indicates that the forest disturbances caused by fire were more extensive within events than the harvesting disturbances. As watershed size increased the disturbance rates in the harvested areas became more similar to the disturbance rates in the burned areas; cumulative averaging effects dampen the variance as watershed size increases. The disturbance rates in the harvested watersheds most closely resembled the disturbance rates of the burned watersheds at the 100 km^2 scale.

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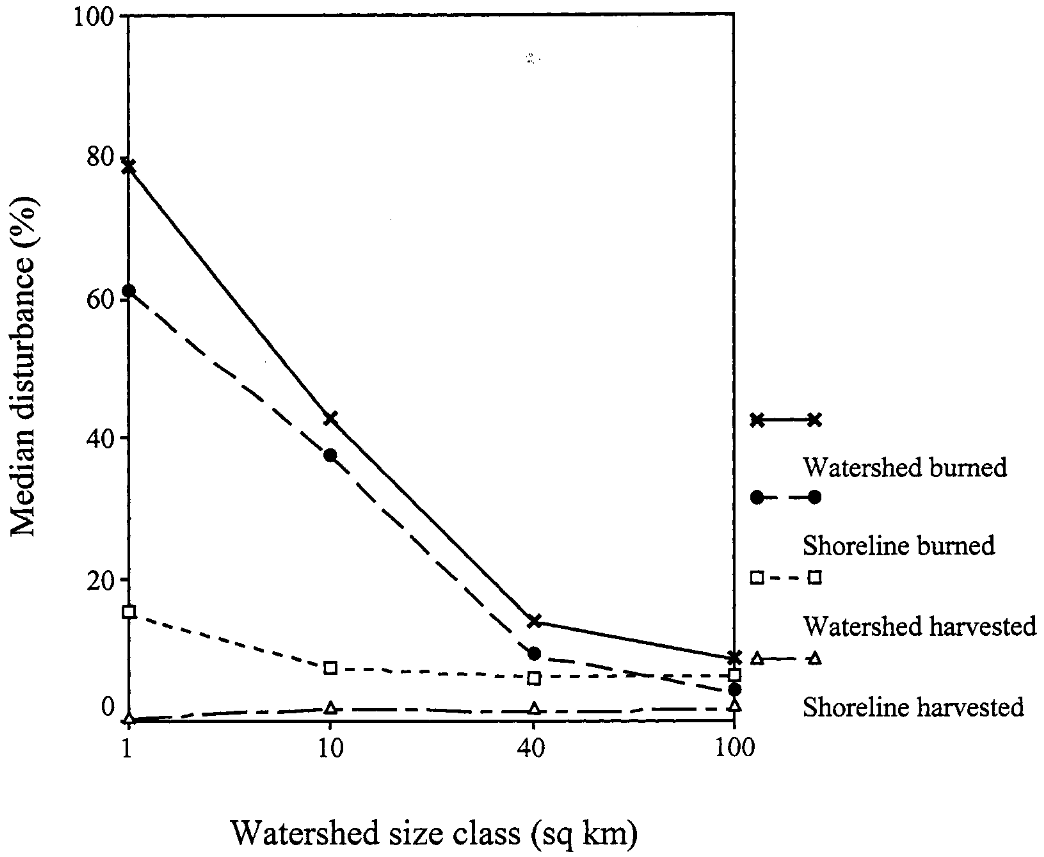

Figure 9. Median harvest and fire disturbance rates over 11.5 years of study within watersheds and shoreline areas for each watershed size class.

Within a watershed, the total area of shoreline disturbance is expected to be a function of the total disturbance area within the watershed, but the covariates total land, shoreline, and water area within the watershed will also influence the total area of shoreline disturbance. Multiple linear regression was used to evaluate rates of shoreline disturbance while accounting for significant covariables. Collinearity was present only in the 1 km^2 harvested watershed model. In all other models the variable inflation factors were low, the tolerances were close to one and even in low dimension

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eigenvalues with high condition indices, no two or more variables were correlated. All models were run with all four variables to provide a consistent comparison between models. However, the 1 km^2 harvested watershed model was rerun to examine any differences with shoreline area removed. Regression models of the shoreline forest disturbance rates were significant for burned and harvested watersheds of all watershed size classes (Tables 5 and 6). The R^2 values for burned and harvested watersheds were most similar in the 40 km^2 class (0.705 and 0.759, respectively) followed by the 10 km^2 class (0.797 and 0.641 respectively). Slope standard errors for the harvest disturbance area variable (Table 6) were lower than the standard error for the fire disturbance variable (Table 5).

The partial correlations for the linear models indicate that disturbance area was the most influential variable in all models except the 1 km^2 burned watershed model (Tables 5 and 6). In the 1 km^2 burned watersheds, shoreline area was the most influential factor. In the 100 km^2 burned watersheds the disturbance area and land area variables contributed equally to the linear model. In each of the other watershed classes shoreline area was the second most influential variable. In each of the linear models water area contributed the least information.

Shoreline area was a significant factor in the linear regression analysis for all of the watershed classes except the 100 km^2 fire disturbed watersheds (Tables 5 and 6). As shoreline area increased so did the shoreline forest disturbance area as indicated by the positive standardized coefficients of slope. Conversely, the land and water area variables had slightly negative influences on the shoreline disturbance rates for both fire and harvest disturbed watersheds.

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The only linear model for which water area was significant was the 10 km^2 fire disturbed watershed model (Table 5). Although the contribution was significant, the partial correlation of that variable indicates that the contribution was small. Similarly, land area was significant in six of the eight models but did not have a large effect for any of them.

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Table 5. Regression parameters for the burned watershed multiple linear regression analysis. Response variable is burned shoreline area.

	Shoreline Fire Disturbance Area[i]											
	1 km^2			10 km^2			40 km^2			100 km^2		
	Slope[ii]	Std. Error	ρ^2	Slope[ii]	Std. Error	ρ^2	Slope[ii]	Std. Error	ρ^2	Slope[ii]	Std. Error	ρ^2
Land Area	**-.135**	**.002**	**-.214**	**-.217**	**.001**	**-.395**	-.282	.001	-.446	-.583	.001	-.475
Shoreline Area	**.787**	**.004**	**.819**	**.460**	**.005**	**.689**	**.421**	**.005**	**.545**	.568	.005	.464
Fire Disturbance Area[iii]	**.434**	**.018**	**.661**	**.807**	**.023**	**.860**	**1.099**	**.059**	**.830**	**.869**	**.077**	**.475**
Water Area	-.017	.004	-.031	**-.138**	**.002**	**-.246**	-.083	.002	-.125	-.207	.002	-.238
Intercept	-.302	.226		.020	1.153		.075	4.468		7.486	6.181	
Adjusted R^2			**.740**			**.797**			**.705**			**.460**

[i] Square root transformation of shoreline disturbance area

[iii] Square root transformation of watershed fire area

[ii] Standardized Coefficients of Slope

Numbers in bold denote significant values

Table 6. Regression parameters for the harvested watershed multiple linear regression analysis. Response variable is harvested shoreline area.

	Shoreline Harvest Disturbance Area[1]											
	1 km^2			10 km^2			40 km^2			100 km^2		
	Slope[ii]	Std. Error	ρ^2	Slope[ii]	Std. Error	ρ^2	Slope[ii]	Std. Error	ρ^2	Slope[ii]	Std. Error	ρ^2
Land Area	**-1.274**	**.001**	**-.215**	**-.276**	**.000**	**-.342**	**-.229**	**.000**	**-.361**	**-.315**	**.000**	**-.563**
Shoreline Area	**1.407**	**.001**	**.236**	**.384**	**.001**	**.472**	**.429**	**.001**	**.580**	**.509**	**.000**	**.728**
Harvest Disturbance Area[iii]	**.505**	**.011**	**.502**	**.762**	**.009**	**.782**	**.721**	**.014**	**.806**	**.754**	**.015**	**.879**
Water Area	-.026	.002	-.027	-.034	.001	-.051	-.049	.000	-.097	-.068	.000	-.167
Intercept	**.924**	**.128**		**.599**	**.255**		-.175	.459		.290	.756	
Adjusted R^2			**.276**			**.641**			**.759**			**.842**

[1] Square root transformation of shoreline disturbance area

[iii] Square root transformation of watershed harvest area

[ii] Standardized Coefficients of Slope

Numbers in bold denote significant values

Without water area, the 1 km^2 harvest model produced similar results to the multiple linear regression model including all four variables. The main difference between the two models was that land area contributed a significant amount of information to the model without water area (Table 7).

Table 7. Regression parameters for the 1 km^2 harvested watershed multiple linear regression analysis. Response variable is harvested shoreline area.

Shoreline Harvest Disturbance Area[i]			
	1 km^2		
	Slope[ii]	Std. Error	ρ^2
Land Area	**-4.490**	**.001**	**-.133**
Harvest Disturbance Area[iii]	**.471**	**.011**	**.471**
Water Area	**-.087**	**.002**	**-.098**
Intercept	**.018**	**.066**	
Adjusted R^2			**.234**

[i] Square root transformation of shoreline disturbance area
[ii] Standardized Coefficients of Slope
[iii] Square root transformation of watershed harvest area
Numbers in bold denote significant values

Disturbance area was the only factor that significantly impacted the shoreline forest disturbance area for every watershed class in both burned and harvested watersheds (Tables 5 and 6). As the disturbance area increased so did the shoreline forest disturbance area as indicated by the positive standardized coefficients of slope for the disturbance area. The scatterplots (Figures 11 and 12) indicate that this relationship is linear and constant across watershed scales. The standardized coefficients of slope for the disturbance area were larger in the burned watersheds than in the harvested watersheds, indicating that shoreline disturbance rates are more influenced by fire than harvesting. Shoreline disturbance rates in the burned watersheds are only slightly below the expected disturbance rates, while the shoreline disturbance rates of the harvested

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watersheds are well below the expected rates (where the expected disturbance rates within the shoreline forests are defined by the watershed disturbance rates) (Figure 10). The assumption underlying this expectation is that fire behaves the same in the shoreline forest as in the watershed as a whole and therefore results in equal disturbance rates. One alternative hypothesis is that the moist environment within the shoreline forest will slow the progression of a fire; slopes less than one support an alternative hypothesis (Figure 10). Shoreline disturbance rates are more different from the expected disturbance rate in harvested watersheds than in burned watersheds. This pattern was evident for all watershed size classes except the 1 km^2 watersheds (Figure 10a, b). Therefore, across a range of scales, harvesting disturbances removed less shoreline forest than would have been expected based on a natural fire disturbance regime.

The linear models for the 1 km^2 watersheds explained significant amounts of variability in the shoreline rates of disturbance for both fire ($R^2 = 0.740$, $p < 0.001$) and harvesting ($R^2 = 0.276$, $p < 0.001$). A linear pattern was not as easily identified in the scatter plot comparing the 1 km^2 watershed and shoreline disturbance rates as would be expected from the high R^2 value (Figure 10a, b). The linear analysis of the 1 km^2 burned watersheds appears to be influenced by a large number of watersheds that contain disturbance but have little or no shoreline area and therefore no shoreline disturbance. Watersheds without shoreline area may result from small, unmapped streams such as seasonal or intermittent streams. This linear regression also appears to be influenced by a group of highly disturbed watersheds with large amounts of shoreline disturbance. This pattern with the 1 km^2 watershed class is consistent with earlier analyses in which

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the results for the 1 km^2 watershed class had larger differences between watershed and shoreline disturbance rates than those of the larger size classes (Figures 7-10).

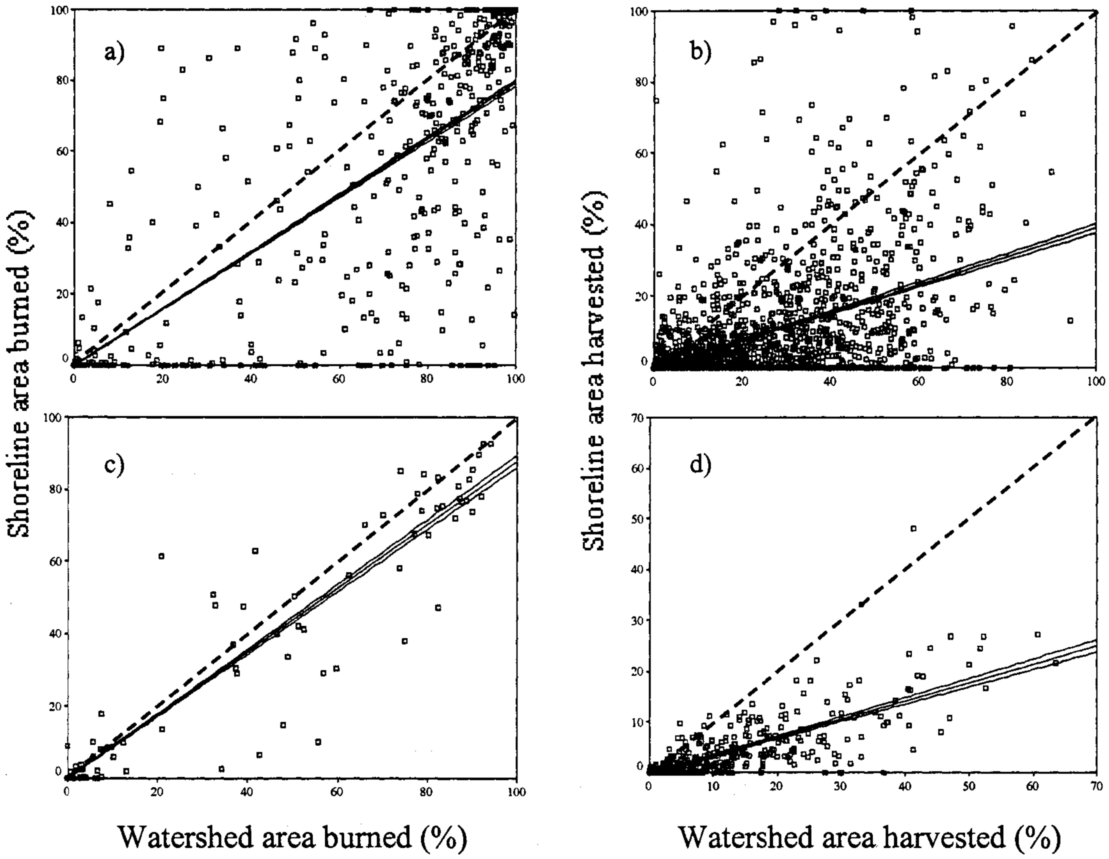

Figure 10. Fire and harvest disturbance rates for each watershed size class for the 11.5 year study period. The solid lines represent the regression and 95% confidence intervals. This figure illustrates the approach to testing the null hypothesis, but the actual test was conducted using multiple linear regression. The dotted lines (slope equal to one) represent a perfect match between the watershed and shoreline disturbance rates. The four graphs describe a) 1 km^2 burned watersheds, b) 1 km^2 harvested watersheds, c) 10 km^2 burned watersheds, d) 10 km^2 harvested watersheds, e) 40 km^2 burned watersheds, f) 40 km^2 harvested watersheds, g) 100 km^2 burned watersheds, and h) 100 km^2 harvested watersheds.

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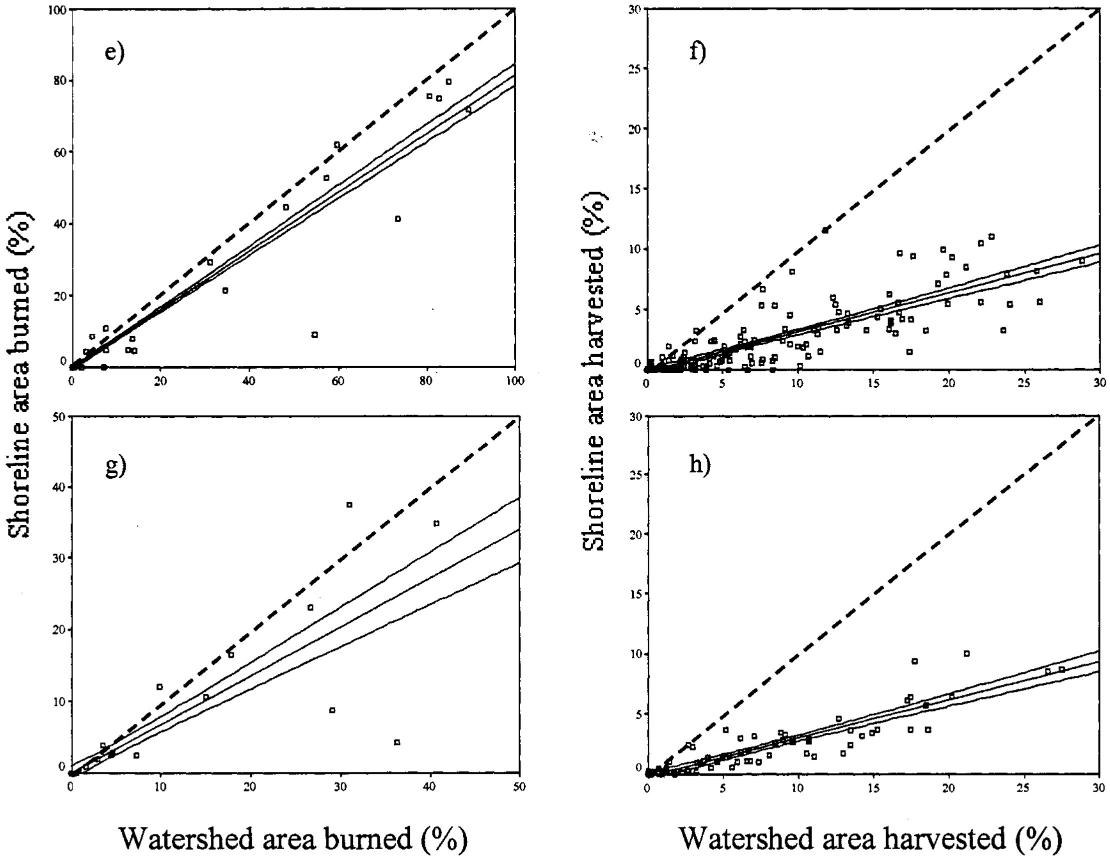

Figure 10 cont. Fire and harvest disturbance rates for each watershed size class for the 11.5 year study period. The solid lines represent the regression and 95% confidence intervals. This figure illustrates the approach to testing the null hypothesis, but the actual test was conducted using multiple linear regression. The dotted lines (slope equal to one) represent a perfect match between the watershed and shoreline disturbance rates. The four graphs describe a) 1 km^2 burned watersheds, b) 1 km^2 harvested watersheds, c) 10 km^2 burned watersheds, d) 10 km^2 harvested watersheds, e) 40 km^2 burned watersheds, f) 40 km^2 harvested watersheds, g) 100 km^2 burned watersheds, and h) 100 km^2 harvested watersheds.

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DISCUSSION

My first hypothesis was that rates of disturbance within burned and harvested events and watersheds are the same as those of their associated shoreline forests. The results of this study did not support this hypothesis. My results indicate that shorelines are disturbed by both fire and harvesting at a lower rate than the surrounding landscape. The magnitude of this difference depends on whether the analysis is conducted using events or watersheds as the defining boundary of the landscape. In a natural fire disturbance regime, the shoreline forest is burned at a slightly lower rate than the watershed as a whole. Shoreline areas tend to be wetter, steeper and have different species compositions than upland areas, therefore, the fuel moisture and availability, and fire behaviour may be affected (Andison and McCleary 2002; Dwire and Kauffman 2003; MacDonald et al. 2004; Russell and McBride 2001).

The results of this study support those of Andison and McCleary (2002), who found weak evidence suggesting that fire edges and island remnants formed slightly more often in shoreline areas than expected based on the occurrence on the landscape. Therefore, to better emulate natural disturbance, shoreline forest disturbance rates within harvested watersheds should be increased to slightly below the watershed disturbance rates. However, fire frequency and severity in shoreline forests may vary by region, forest and shoreline type (Dwire and Kauffman 2003) and therefore influence the relationship between watershed and shoreline disturbance rates. Similarly, the

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effectiveness of shoreline forests in protecting riparian and aquatic values may vary according to the width of the riparian zone (Lamb et al. 2003) and the type of shoreline vegetation.

Lamb et al. (2003) found that riparian vegetation communities may not be particularly sensitive to upland vegetation disturbance and suggested that most of the ecological services required by a stream can be provided by the riparian zone when it is relatively wide (e.g. 30-50 m). Other studies have indicated that lake water quality is not strongly influenced by shoreline buffer strips in response to catchment deforestation due to harvesting or wildfire burning (Carignan et al. 2000; Norris 1993; Steedman 2000). Therefore, it may be possible to increase disturbance rates within shoreline areas to create residual vegetation patterns more similar to wildfire without negatively impacting shoreline ecosystem values. In addition, increasing the rate of shoreline harvesting may have the economic advantage of increasing wood supply.

Although the use of shoreline buffers will result in lower rates of disturbance than those observed from fires, shoreline buffers may be required for the protection of other elements of the aquatic and forest ecosystems. Shoreline buffers can provide terrestrial and aquatic habitat, wildlife movement corridors, channel stabilization and aesthetic value (Andison and McCleary 2002; Grizzel and Wolff 1998; Macdonald et al. 2004; Machtans et al. 1996; Steedman 2000; Whitaker and Montevecchi 1997). In addition, limiting harvesting activities in shoreline areas reduces the potential of soil compaction, rutting and erosion caused by the use of mechanical machinery within riparian zones (Andison and McCleary 2002). Appropriate shoreline management regimes may best be identified based on local conservation and management concerns

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with consideration for both fine and landscape-level planning objectives (Macdonald et al. 2004).

The disturbance rate variability of harvested watersheds was much greater than that of their associated shoreline forests, indicating that shoreline areas are treated more uniformly than the watershed as a whole. It is likely that the variation in watershed harvesting rates was not reflected in the shoreline forest disturbance rates because of the forest management constraints on shoreline harvesting. However, this observation is not consistent with the results from the harvest event analysis in which the disturbance rates of the shoreline forests were more variable than in the events.

My second hypothesis was that rates of disturbance within harvested events and watersheds are the same as the rates for burned events and watersheds. The results of this study did not support this hypothesis. I found that the rate of disturbance within harvest events was both lower and more variable than the rate of disturbance within fire events. Given the various timber management guidelines constraining the timing, size, and placement of clearcuts it is not surprising that the rate of disturbance was lower for harvesting, but it was unexpected that the variance in the rates of disturbance for harvest events was higher than for fire events. Wildfires occur over short periods of time whereas harvesting events can take place over several years. Therefore, harvest events were captured at various stages of completion and this, along with factors such as road location and access, age and merchantability of vegetation and topography may have increased the variability of the harvest events.

My final hypothesis was that the rates of disturbance for watersheds and associated shorelines are consistent across spatial scales. While harvested watersheds of

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different size classes were disturbed at approximately the same rate, fire disturbance rates decreased with increasing size class. As watershed size increased, the rate of fire disturbance was averaged over a larger region, with that region containing more undisturbed area. Therefore, the disturbance rates of the burned watersheds decreased. In contrast, harvesting disturbance rates were more uniform across a range of scales because harvesting was more evenly dispersed across the landscape. Therefore, as the watershed sizes increased, harvest patches from nearby cuts were incorporated into the watershed disturbance rates.

Fire can be used as a model for forest management; however, there are considerable differences between the ecological effects of fire and timber harvesting. McRae et al. (2001) summarized how these differences affect biodiversity among disturbance scales, ecosystem types and harvesting practices. The scales of disturbance are different in that fire creates a much broader range of patch sizes compared to harvesting. In general, forestry practices do not result in the large numbers of small disturbances and the small number of extremely large disturbances created by wildfire. In Canada, the frequency of harvesting rotations is determined primarily by the age and size of the timber, typically ranging from 40 to 100 years. In contrast, stand replacing fires occur in the range of 20 to 500 years. Timber harvesting patches do not generally emulate the ellipse shape of wind driven fires, or the ragged edges and unburnt patches found in stand-replacing fires. The successional pathways and understory richness following disturbance also differ between fire and harvesting. There is no natural analogue for the road networks created during timber harvesting operations. Roads can cause erosion, reduce the areas available for reforestation, fragment the landscape and

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allow easier access by humans. Delong and Tanner (1996) compared the landscape patterns of wildfire and harvesting using a geographical information system. Their results were similar to those of McRae (2001), indicating that wildfire creates a more complex landscape spatial pattern with a greater range in patch size and more irregular disturbance boundaries.

Although there are many ecological differences between harvesting and wildfire, natural disturbance pattern emulation can be an effective tool for forest management (Delong and Tanner 1996; McRae 2001). It is important to identify which features of wildfire can and should be emulated in forest operations to create a socially acceptable compromise that is ecologically and economically sustainable (Delong and Tanner 1996; McRae 2001). An adaptive management approach is required to evaluate forest management regimes appropriate at the microsite, stand and landscape scales (Delong and Tanner 1996; McRae 2001).

Differences in the shape and residual stand structure of wildfires and timber harvesting patches demonstrate the importance of the disturbance event concept. It is widely accepted that wildfires create mosaics of disturbed and undisturbed patches. However, timber harvesting is more often thought of in terms of individual patches. If we analyze aggregations of harvesting patches as events, including the undisturbed forest between patches, we can more accurately compare not only the rates of fire and harvesting disturbance but also the shape, amount of edge and residual stand structure. The disturbance event is a convenient forest management scale for providing guidance on many aspects of emulating natural disturbances that cannot be adequately addressed at the stand or forest management unit scales.

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Watersheds can be used to analyze forest disturbance rates at a variety of scales and to evaluate the impacts on aquatic ecosystem values. The 10 and 40 km^2 watershed scales were the most effective of the four classes in which to compare fire and harvest disturbance rates. At the 10 and 40 km^2 watershed scales the linear models explained similarly high amounts of variation in the shoreline disturbance rates for both disturbance types. In contrast, the models for the 1 and 100 km^2 watershed classes presented less effective comparisons between disturbance types.

The Band 5 subtraction method proved to be an accurate and efficient approach to disturbance mapping. Band 5 subtraction, with some image editing, reliably extracted the forest disturbances from the satellite images. From a user's perspective, the change detection data was 92 percent accurate in identifying forest disturbances. One potential source of commission error for the disturbed forest can be found in wetlands. Wetland areas may have been classified as disturbance because the spectral signature of a wetland is similar to that of a recent clearcut. In some cases, tall road vegetation and dense residual vegetation made it difficult to identify the exact start and end points of a disturbance during reference data collection. This may have contributed to the omission and commission errors for both the disturbed and undisturbed forest areas. New roads and changes to the road right of way corridors may also have decreased the accuracy of the disturbance identification along the roadways.

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CONCLUSIONS

Forest harvesting restrictions have resulted in shoreline disturbance rates below those created by fire, and therefore, may be creating shoreline areas with unnatural age distributions and species compositions. These results support those of MacDonald et al. (2004), who found that there may not be a strong natural analogue to riparian forest buffers around lakes in the mixed-wood boreal forest. Harvest patches within events or watersheds should be more aggregated to better emulate natural disturbance patterns. As well, the shoreline harvest disturbance rates should be increased to slightly below the watershed disturbance rates. However, this study only compared fire and harvesting in terms of disturbance rates and disturbance rate variability and the recommendations presented here apply only to the emulation of the rates of natural disturbance. Many other factors must be considered in the emulation of the processes and patterns of natural disturbance while providing for the protection of aquatic and shoreline values. An adaptive approach to shoreline management (Delong and Tanner 1996; MacDonald et al. 2004; McRae 2001), incorporating variable width buffers prescribed based on local hydrologic conditions and conservation concerns may be a more effective alternative for meeting fine and landscape scale forest management objectives.

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APPENDICES

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APPENDIX I

TERMINOLOGY

Area of Concern – an area of value to users/uses which may be affected by forest management activities, requiring modifications to those operations usually prescribed (OMNR 1996).

Aquatic environment – the biotic and abiotic elements of a stream, lake or wetland.

Band subtraction – a change detection technique in which the imagery of one date is subtracted from that of another (Jensen 1996). Used synonymously with image differencing.

Biodiversity (Biological diversity) – a qualitative description of a natural system including the number and types of different biological elements at different scales (Andison and McCleary 2002).

Catchment – an area of land within which all surface waters flow to a single river system (Heathcote 1998).

Change detection – a remote sensing tool used to identify differences between images obtained on different dates.

Critical fish habitat – Habitats which are needed to maintain the overall productive capacity of the fishery including spawning and feeding areas, highly productive

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nursery areas, essential refuges or cover, and any narrow migration routes (OMNR 1996).

Disturbance event - a closely aggregated group of burned or harvested forest patches created within a defined period of time, and delineated by a single polygon.

Disturbance rate – The percentage of an area affected by disturbance over a given time period (Andison and McCleary 2002).

Ecosystem – includes the living organisms of the forest, and extends vertically upward into the atmospheric layer enveloping forest canopies and downward to the lowest soil layers affected by roots and biotic processes (Waring and Running 1998).

Fire behaviour – how, how fast, where, and what an individual fire burns (Andison and McCleary 2002).

Fire suppression – anthropogenic limitation of the size or intensity of a fire.

Forest disturbance – any natural or anthropogenic event that alters the natural succession of a forest stand or stands (OMNR 2001).

Forest management – the practical application of scientific, economic and social principles to the administration and working of a forest for specified objectives (OMNR 1996).

Image algebra – the addition, subtraction, multiplication or division of image channels.

Landscape – The array of forest stands, grasslands, wetlands that form heterogeneous mosaics across the land (Forman 1995).

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Natural disturbance – a relatively distinct event in time that disrupt ecosystem, community, or population structure and that change resources, the availability of suitable habitat, and/or the physical environment (Parminter and Daigle 1997).

Pattern – any spatial or temporal behaviour that is not random (Andison and McCleary 2002).

Pixel – the smallest picture element of a digital image.

Radiance – the amount of electromagnetic radiation, reflected from the terrain and recorded by a remote sensor (Jensen 1996).

Regeneration – the natural or artificial renewal of a crop of trees (OMNR 1996)

Remote sensing – obtaining information about an object or phenomena without physical contact (Jensen 1996).

Riparian environment – a terrestrial area immediately adjacent to lakes, creeks, rivers, or streams (Andison and McCleary 2002).

Shoreline forest – an upland forest region located adjacent to, and influenced to varying degrees by, aquatic and/or riparian environments.

Shoreline Management Area – a distance from an aquatic environment in which land use activities are modified for the protection of fish and wildlife habitat, water quality, biodiversity and aesthetics (Naiman and Décamps 1997; Racey 1998).

Threshold – The boundary between pixels representing change and those representing no change.

Timber harvesting – the removal of trees for human utilization.

Watershed – the high point of land dividing two drainage basins. Used synonymously with catchment.

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Wetland – land that is saturated with water long enough to promote wetland or aquatic processes indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity adapted to a wet environment (National Wetlands Working Group 1988).

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APPENDIX II

CHANGE DETECTION

Change detection was performed on three geographically registered satellite images from May 2001 (Landsat7 Enhanced TM), September 1996 (Landsat5 TM) and September 1989 (Landsat5 TM). Each of the images had 30-metre resolution, which had been resampled to 25 metres. Change detection was performed in PCI Geomatica 8.2 (PCI Geomatics Enterprises 2001) using band 5 subtraction. In order to reduce the effect of fading landcover changes over time, the change pixels from the three change images were combined into one cumulative disturbance image.

Procedure:

1. Combine band 5 (mid infrared) from the three images into one PIX file.
2. Add several output channels (8-bit) to the PIX file. More output channels can be added as required.
3. Use the EASI Modeling function to perform a band subtraction for each pair of images. Subtract the earlier image from the later image and assign the result of each subtraction to an empty output channel.
4. If the original images are not identical in size or location the overlapping edges will be identified as change. Manually remove the edges using Image Edit or using a

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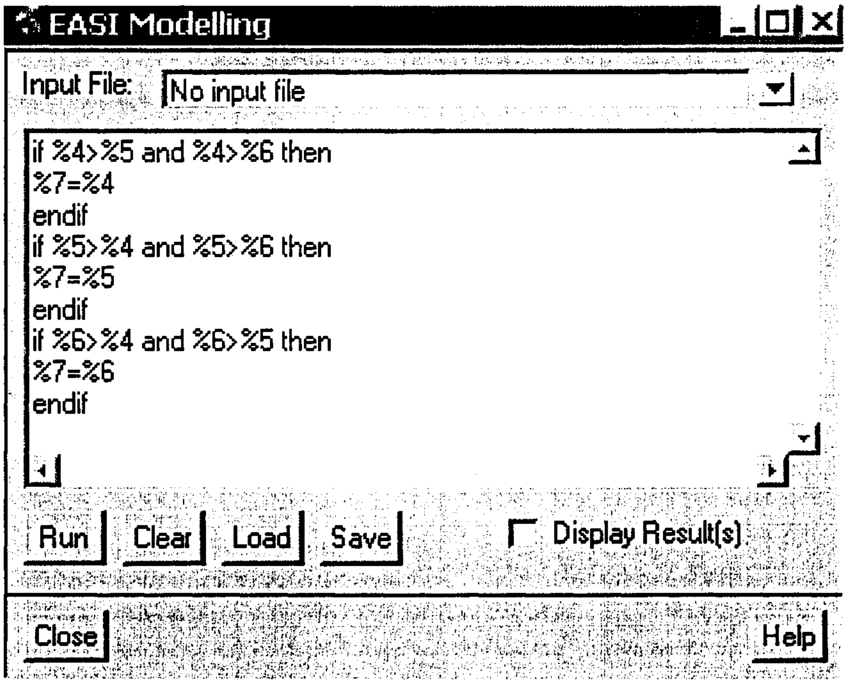
mask. To remove edges using a mask, create a mask of the exact study area, use the EASI Modeling function to select all of the pixels within the area of the mask, and save them to a new channel or file.

5. Visually inspect each pair of images to determine an appropriate threshold value for change. For each image, use the EASI Modeling function to select the pixels from the image that are above the chosen threshold and export them to an empty output channel.
6. Combine the three change images, using the EASI Modeling function, to select, on a pixel-by-pixel basis, the pixels with the highest value from the three images and assign the result to an empty output channel (Figure 11).



Input File: No input file

```
if %4>%5 and %4>%6 then
%7=%4
endif
if %5>%4 and %5>%6 then
%7=%5
endif
if %6>%4 and %6>%5 then
%7=%6
endif
```

Figure 11. Model for creating a composite image of three change detection images where, %4, %5 and %6 represent the channels containing the change detection images, and %7 is an output image channel.

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7. Apply a filter (e.g. 3x3 sieve filter) to the composite image and assign the result to an empty output channel.
8. Export the filtered composite image in a desired format (e.g. TIF).

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APPENDIX III

DISTURBANCE TYPE DELINEATION

Changes caused by fire and timber harvesting were identified from the cumulative change image, produced in Appendix II, using ArcView 3.2 (ESRI 1999) and ArcGIS 8.1 (ESRI 2001).

Procedure:

1. Convert the change detection image to a grid using Arc Toolbox or ArcView.
2. Convert the change detection grid to an Arc coverage using Arc Toolbox.
3. Convert the change detection coverage to a shape file in ArcView. By converting the change detection first to a coverage and then to a shapefile the polygon edges will remain true rather than being generalized as they would be if converted directly from a grid to a shapefile.
4. Compare the shapefile to the change detection image. If the shapefile is shifted use a shapefile shifter extension in ArcView to realign it with the original change detection image.
5. Load the change shapefile, fire polygons and points, landcover data for fire and harvest disturbance, FRI, original satellite images, and any available ground truth data into ArcView. Compare the change shapefile with the ancillary data to identify

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harvest and fire polygons. Create a new field in the table and assign each polygon an appropriate disturbance value.

6. Edit the change shapefile to split any polygons that overlap adjacent harvested and burned areas, and assign each new polygon a disturbance value.
7. Select all disturbance polygons and convert them to a new shape file in order to eliminate all unclassified polygons. Unclassified polygons represent landcover changes not caused by fire or harvesting, or changes outside of the study area.

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APPENDIX IV

ADDING ADDITIONAL CHANGE DATA

The threshold values used to limit the change detection eliminated some pixels from burned areas that should not have been removed. Therefore, PCI Geomatica 8.2 (PCI Geomatics Enterprises 2001) and Arcview 3.2 (1999) were used to add additional pixels to the burned areas of the change detection data from Appendix III.

Procedure:

1. Visually inspect the band subtraction images created in step 3 of Appendix II to identify the lower threshold values needed to recapture lost data from the burned areas. Repeat steps 5 to 8 from Appendix II using the lower threshold values.
2. Convert the change image to a grid in ArcView.
3. Reclassify the grid to contain only 2 values (0 = no change, 1 = change).
4. Convert the grid to a coverage and then to a shapefile.
5. Clip the change detection to the fire boundaries using the Geoprocessing Wizard in ArcView.
6. Union the new shapefile with the classified shapefile produced in Appendix III using the Geoprocessing Wizard in ArcView.
7. Assign appropriate disturbance values to the new polygons.

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APPENDIX V

VARIABLE WIDTH SHORELINE STUDY BUFFER

The variable width study buffer was created in ArcView 3.2 (ESRI 1999) using a DEM with 20-metre resolution and stream, lake and wetland shapefiles. The width of the study buffer was based on the slope of the shoreline. Shoreline areas with slopes of 0-30% and greater than 30% were buffered 50 and 100 metres, respectively.

Procedure:

1. Create a slope map from the DEM using the derive slope tool under the surface menu. The result will be a continuous grid of slope values.
2. Set the analysis extent to match the study area. Analysis extent is located under properties in the analysis menu.
3. Reclassify the slope grid into appropriate categories (e.g. 0 to 30% or 0-17 degrees and greater than 30% or over 18 degrees) using the reclassify tool under the analysis menu. Reclassifying the grid produces a value table that will allow the grid to be converted into a shapefile.
4. Smooth the slope grid by calculating the majority using the neighbourhood statistics function under the analysis menu.
5. Convert the smoothed slope grid to a shapefile.

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6. Intersect the streams with the smoothed slope shapefile using the Geoprocessing Wizard. A field called gridcode will indicate the slope category of each segment.
7. For each slope category, buffer the streams the appropriate distance using the buffer tool under the theme menu.
8. Merge the buffers of each slope category using the Geoprocessing Wizard.
9. Dissolve the boundaries between the buffers using the Geoprocessing Wizard.
10. Repeat steps 6 to 9 for the lakes and wetlands.
11. Merge the stream, lake and wetland buffers using the Geoprocessing Wizard.
12. Convert the lake and wetland shapefiles to coverages and then back to shapefiles. Converting a shapefile to a coverage creates topology for the islands.
13. Remove the lakes, islands and wetlands from the buffers using the erase function in the x-tools extension.

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APPENDIX VI

DISTURBANCE EVENTS

ArcView 3.2 (ESRI 1999) and ArcMap 8.1 (ESRI 2001) were used to prepare the change detection data from Appendix IV for the Natural Disturbance Pattern Emulation (NDPE) tool. Disturbance events were created in Arcview 3.2 using the NDPE tool (Elkie et al. 2002), an ArcView extension. A 200 m separation rule was used to identify the disturbance events.

Procedure:

1. Use the union function in the ArcMap Geoprocessing Wizard to combine the change detection shapefile with a FRI shapefile for the study area using.
2. Create three new fields in the shapefile for height, year of origin, and stocking. New values will be assigned to these fields while maintaining the data from the FRI in the original fields. If the original disturbance field is in numeric format create a new field and assign string values to represent the disturbance types.
3. Copy the FRI values from the original height, year of origin and stocking fields to the new fields.

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4. Select the disturbed records and edit the new height field to zero, the new year of origin field to a year later than the most recent cuts in the FRI, and the new stocking field to zero. This will allow the NDPE tool to identify these polygons as disturbed.
5. In ArcView, load the NDPEG tool extension and select step 1 from the NDPE drop down menu. Once step 1 is chosen the program leads the user through the set up procedure.
6. Select the appropriate Forest Unit field (e.g. FU_SFMM) and assign the forest types to appropriate categories.
7. Select the disturbance field and identify the variable representing fire. Leave the new and old cut categories blank. When repeating the process for the harvest events, leave the fire and old cuts categories blank.
8. Define the disturbance parameters in the disturbance analysis set-up screen (Figure 12). The disturbance parameters should correspond to the values assigned to the disturbance patches in step 4.

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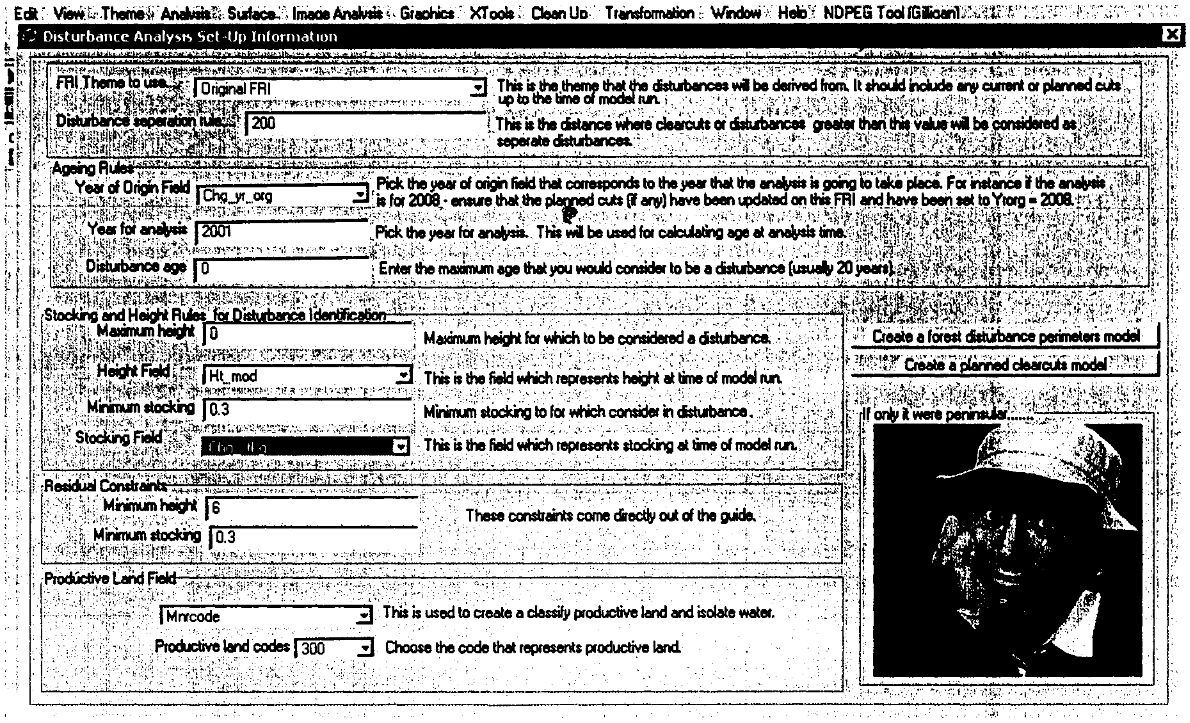

FRI Theme to use... Original FRI — This is the theme that the disturbances will be derived from. It should include any current or planned cuts up to the time of model run.

Disturbance seperation rule... 200 — This is the distance where clearcuts or disturbances greater than this value will be considered as seperate disturbances.

Ageing Rules

Year of Origin Field: Chg_yr_org — Pick the year of origin field that corresponds to the year that the analysis is going to take place. For instance if the analysis is for 2008 - ensure that the planned cuts (if any) have been updated on this FRI and have been set to Yrorg = 2008.

Year for analysis: 2001 — Pick the year for analysis. This will be used for calculating age at analysis time.

Disturbance age: 0 — Enter the maximum age that you would consider to be a disturbance (usually 20 years).

Stocking and Height Rules for Disturbance Identification

Maximum height: 0 — Maximum height for which to be considered a disturbance.

Height Field: Ht_mod — This is the field which represents height at time of model run.

Minimum stocking: 0.3 — Minimum stocking to for which consider in disturbance.

Stocking Field: [illegible] — This is the field which represents stocking at time of model run.

Residual Constraints

Minimum height: 6

Minimum stocking: 0.3

These constraints come directly out of the guide.

Productive Land Field

Mnrcode — This is used to create a classify productive land and isolate water.

Productive land codes: 300 — Choose the code that represents productive land.

Figure 12. Disturbance analysis set-up screen for the Emulating Natural Disturbance Patterns tool (Elkie et al. 2002).

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APPENDIX VII

DATA COMPILATION

The event and watershed boundaries were combined with the study buffers, change detection shapefile, and water layer (lakes and wetlands). The data was compiled separately for each analysis unit (i.e. fire and harvest events and each of the watershed classes). All clipping was performed using the clip function in the ArcView 3.2 (ESRI 1999) Geoprocessing Wizard. The files were combined using the union function in the ArcMap 8.2 (ESRI 2001) Geoprocessing Wizard. The union function in Arcview 3.2 was unreliable for large files and the union function in earlier versions of ArcMap ran out of memory on large files. The union function in ArcMap 8.2 is more reliable and considerably faster than the union function in Arcview 3.2.

Procedure:

1. Clip the change detection shape file from Appendix IV to the analysis unit boundaries.
2. Union the result from step1 and the analysis unit boundaries.
3. Clip the shoreline study buffers to the analysis unit boundaries. Add a new field to the clipped analysis unit layer and assign all records a single value.
4. Union the results from steps 2 and 3.

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5. Clip the water layer to the analysis unit boundaries. Add a new field to the clipped water layer and assign all records a single value.
6. Union the results from steps 4 and 5.
7. Remove all unnecessary fields, leaving only the analysis unit identification number, the disturbance code, the buffer code, and the water code.

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APPENDIX VIII

WATERSHED DELINEATION

The DEM preparation and watershed delineation were performed in ArcInfo 8.1. An Arc Macro Language (AML) script was used to delineate 1, 10, 40 and 100 km^2 watersheds (+/- 30%). ArcMap 8.1 and ArcView 3.2 were used to remove the watersheds that bordered the edge of the study area and were less than 50% of the lower size limit for the class.

Procedure:

1. Fill the DEM to remove sinks and level peaks.
2. Calculate the flow direction from the DEM (FLOWDIRECTION grid command). The flow direction procedure creates a grid of flow direction from each cell to its steepest downslope neighbour.
3. Calculate the flow accumulation from the flow direction (FLOWACCUMULATION grid command). The flow accumulation procedure creates a grid of accumulated flow to each cell by adding the weight for all cells that flow into each downslope cell.

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4. Determine the cell count range for each watershed size class. For example, the cell count for a 10 km^2 watershed class with a 30% range and a 20 m DEM would be calculated as:

$$
\begin{aligned}
1 \text{ Cell} &= 20 \text{ m} * 20 \text{ m} \\
&= 400 \text{ m}^2
\end{aligned}
$$

$$
\begin{aligned}
1 \text{ km}^2 &= 1000 \text{ m} * 1000 \text{ m} \\
&= 1{,}000{,}000 \text{ m}^2
\end{aligned}
$$

$$
\begin{aligned}
10 \text{ km}^2 &= 10 * 1{,}000{,}000 \text{ m}^2 \\
&= 10{,}000{,}000 \text{ m}^2
\end{aligned}
$$

$$
\begin{aligned}
\text{Cell Count} &= 10{,}000{,}000 \text{ m}^2 / 400 \text{ m}^2 \\
&= 25{,}000 \text{ cells}
\end{aligned}
$$

$$
\begin{aligned}
\text{Lower Cell Count} &= 25{,}000 * 0.7 \\
&= 17{,}500 \text{ cells}
\end{aligned}
$$

$$
\begin{aligned}
\text{Upper Cell Count} &= 25{,}000 * 1.3 \\
&= 32{,}500 \text{ cells}
\end{aligned}
$$

5. Create a reclassification textfile, for each watershed size class, containing the cell count range (e.g. 17500 32500 : 1). The values within the specified range are used to reclassify the flow accumulation in the watershed delineation AML script. The value listed after the colon indicates that all values within that range are assigned a value of 1 in the new grid.
6. Type the location of the AML script into ArcInfo.
7. Type in the menu location.

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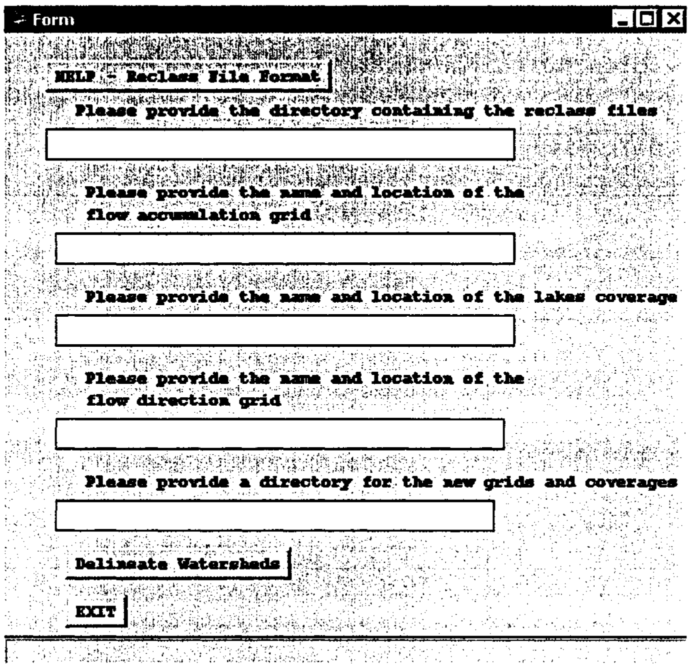
8. Type in the terminal directive.
9. Run the watershed menu to open the form.
10. Within the user interface form identify the name and location of each of the input files and the directory for the output coverage (Figure 13).



Please provide the directory containing the reclass files

Please provide the name and location of the flow accumulation grid

Please provide the name and location of the lakes coverage

Please provide the name and location of the flow direction grid

Please provide a directory for the new grids and coverages

Figure 13. User interface form for the watershed delineation AML script.

11. Load the watershed coverages and the study area boundary into ArcMap.
12. Select all watersheds that intersect with the study area using the select by location function in ArcMap.
13. In ArcView, clip the selected watersheds to the study area using the clip function in the Geoprocessing Wizard.
14. Update the area field using the ArcView X-Tools extension.
15. Eliminate all watersheds that are less than 50% of the lower size boundary for each watershed class. Small watersheds may result from cells trapped between

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watersheds or cells clipped at the study area boundary. Large watersheds may have been created in the centre of a circle of connected watersheds.

16. Create a new field and assign each watershed a unique number.

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APPENDIX IX

WATERSHED DELINEATION ARC MACRO LANGUAGE SCRIPT

```
/*wshed_delin3.aml
/*------------------
/*This aml will create the watershed (polygon) coverages containing
/*the watersheds for the specified area within the defined
/*size range
/*------------------------------------------------------
/*method by Darren McCormick and Kristine Strilchuk
/*Centre for Northern Forest Ecosystem Research,  OMNR
/*created by Kristine Strilchuk
/*updated April 2003
/*------------------------------------------------------

&echo &on

        /*record the time it takes to run the program
&sv start = [date -ampm]
        /*this will ensure reclass grids line-up with original flow accumulation
setwindow %.flow_acc% %.flow_acc%
        /*sets the workspace
&workspace %.reclass_files%
        /*creates a list of the textfiles
&sv reclass_list  [listfile *.txt -file]
        /*counts the list of textfiles and assigns to a variable
&sv reclass_num [token %reclass_list% -count]
        /*set variable to 1
&sv reclass_count = 1

        /*DELINEATION LOOP

        /*this will loop through the list of textfiles
&do &while %reclass_count% <= %reclass_num%
                /*set workspace
        &workspace %.all_dir%
```

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```
        /*start grid
    grid
        /*this will ensure reclass grids line-up with original flow accumulation
    setwindow %.flow_acc% %.flow_acc%
        /*extract the textfile name and assign to a variable
    &sv textfile [extract %reclass_count% %reclass_list%]
        /*assign the name of the coverage to a variable
    &sv txtlength [LENGTH %textfile%]
        &sv txtdelete = %txtlength% - 9

        &sv covname [SUBSTR %textfile% 6 %txtdelete%]

    /*reclassifies (or changes) the value of the input cells with the textfile containing
the reclass values

    reclass_%covname% = reclass (%.flow_acc%, %.reclass_files%\%textfile%,
NODATA, #, #)

    /*assigns unique values to sections of a raster linear network (reclass grid)
between intersection

    strmlink_%covname% = streamlink (reclass_%covname%, %.flow_dir%)

    /*converts a raster (grid) into a vector layer (line coverage)

    gridline_%covname% = gridline (strmlink_%covname%, data, thin, nofilter,
round, count, 1, #, #)

    /*exit out of grid

    quit

    /*removes the line or portion of a line (made from the reclass grid) that is
intersected with a lake
    /*this grid will be used for pourpoints; pourpoints can not be in a lake

    erase gridline_%covname% %.lakes_cov% erase_%covname% line

    /*create topology for the edited line coverage - updates the attribute table

    build erase_%covname% line

    /*restart grid

    grid
```

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```
          /*this will ensure grids line-up with the original flow accumulation grid

          setwindow %.flow_acc% %.flow_acc%

          /*convert the line coverage (vector) back into a grid (raster)

          linegrid_%covname% = linegrid ( erase_%covname%, count, #, #, 20, nodata)

          /*create the watershed grid with the new grid representing the pourpoint values

          wshed_%covname% = watershed (%.flow_dir%, linegrid_%covname%)

          /*conver the watershed grid inot a polygon coverage

          gridpoly_%covname% = gridpoly (wshed_%covname%, 0)

          quit
                    /*increment the count by one to loop t the next textfile
&sv reclass_count = %reclass_count% + 1

&end
          /*display time started and finished
&sv end = [date -ampm]

&echo &off

          &return
```