Characterising anthropogenic disturbance patterns in the Alberta-Pacific Forest Industries forest management area

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Suite 1340, 10130 103 St. NW, Edmonton, Alberta T5J 3R2

Prepared by

Paul D. Pickell[1][*], Nicholas C. Coops[1] and David W. Andison[2]

[1] Integrated Remote Sensing Studio, Department of Forest Resources Management, University of British Columbia, 2424 Main Mall, Vancouver, British Columbia V6T 1Z4

[2] Bandaloop Landscape-Ecosystem Services, 1011 Hendecourt Road, North Vancouver, British Columbia V7K 2X3

[*] Contact: ppickell@interchange.ubc.ca, ph. (604) 822-6592

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Acknowledgements and Author Details

Executive Summary

The Alberta-Pacific Forest Industries (Al-Pac) forest management area (FMA) is rich with natural resources such as bitumen, natural gas and wood fibre. The extraction of these resources over Al-Pac's tenure has resulted in significant anthropogenic disturbance to the mixedwood, boreal forest. The primary causes of anthropogenic disturbance in the Al-Pac FMA are related to timber harvesting and energy development. Al-Pac has recently begun to pattern their activities after those of natural wildfire patterns in an effort to mitigate any negative unintended consequences associated with harvesting activities. However, the degree to which the cumulative interactions between the energy sector and forestry management on the landscape have in the past, or still are creating unnatural patterns is unknown.

The primary objectives of this exploratory research are as follows:

- characterise the disturbance patterns of energy and forestry related disturbances;

- characterise the disturbance patterns of more recent aggregated and historical dispersed timber harvesting; and

- compare the characterisations of anthropogenic disturbance patterns to patterns of a local, historical fire regime.

We used the decision-support tool NEPTUNE (novel emulation pattern tool for understanding natural events) to characterise the patterns of anthropogenic disturbance for the Al-Pac FMA. Aerially-derived Alberta vegetation inventory (AVI) data were supplemented with spatial layers for roads, seismic and utility lines and sampled for energy and forestry related disturbances using NEPTUNE. Four areas approximately 112,000 ha in size were stratified across the Al-Pac FMA by degree of anthropogenic management and sampled for energy, forest harvesting, and cumulative disturbance patterns.

The overall trend of the results indicate that anthropogenic disturbance patterns for the Al-Pac FMA are outside the historical range of variation (HRV) in terms of disturbance event size, the largest disturbed patch and the area in undisturbed forested residuals. Forestry related disturbances more closely approximated the HRV in terms of all metrics except the largest disturbed patch. Energy related disturbances contained few-to-no island remnants and were much smaller than the HRV. Aggregated harvests were only slightly larger on average than dispersed harvests, but contained less area in undisturbed total remnants and were significantly smaller than HRV. The results suggest that in order to better emulate historical benchmarks, future harvest events could be larger, contain one dominant disturbed patch, and retain more island remnants. Whether this is desirable or logistically possible is unknown. The results and our conclusions of these preliminary analyses provide us with the knowledge necessary to explore other lines of inquiry related to landscape scale patterning which will become the topic of future reports and publications from the on-going engagement between Al-Pac, FRI and IRSS at UBC.

Glossary of Terms

The following terms are used regularly throughout this report and are defined here for clarity and brevity. These definitions are sometimes modified from other authors of similar literature and cited herein.

Disturbance event. A discrete event in time and space which alters the physical environment and availability of resources (adapted from Pickett and White 1985).

Disturbed patch. A forested patch that has been physically altered by a disturbance event (Andison 2003).

Disturbance regime. The sum and pattern of disturbance type, frequency, size, and severity on a landscape (adapted from Woodwell 1983).

Historical range of variability (HRV). The range of variability for any given random variable that has been observed and is verifiable by a pre-industrial data source(s).

Island remnant. An undisturbed forested patch contained wholly within a disturbed patch (Andison 2003).

Landscape. An area of heterogenous ecological elements.

Matrix. All undisturbed forested features of a landscape not contained within the boundaries of a disturbance event (Andison 2003).

Matrix remnant. An undisturbed forested patch contained within a disturbance and physically adjacent to the surrounding matrix of the landscape (Andison 2003).

Patch. A polygonal area of irreducible or homogenous class elements.

Partial island. A partially disturbed forested patch with 6% or greater of canopy trees surviving.

Total remnants. The sum of island and matrix remnants.

1. Introduction

The Alberta-Pacific Forest Industries (Al-Pac) forest management area (FMA) is located in northeastern Alberta wholly within the mixed wood boreal eco-zone. The FMA holds significant deposits of natural gas and bitumen in addition to wood fibre resources. Although Al-Pac has been operating only since 1993, the landscape has a long history of extensive cultural disturbance activities in the form of both energy development and dispersed forest harvesting. For the past several years, Al-Pac has been shifting its harvesting patterns to more closely approximate natural disturbance patterns under the auspices of ecosystem-based management (EBM) ideals (Franklin 1993), which is resulting in a more aggregated harvesting pattern. However, over the long-term, the degree to which, or in what ways this strategy is creating more natural landscapes relative to previous disturbance activities is unknown. Furthermore, the cumulative impacts of forest harvesting and the energy sector combined have never been documented.

Prior to industrialisation in the late 20th century, the fire regime of the Al-Pac FMA was characterised by a 55-68 year mean fire return interval (Larsen 1997). The spatial extent of disturbances by this fire regime varied greatly, however the largest 1% of fires accounted for 97.7% of the total burned area (Cumming 2001a). Additionally, Andison (2003) found that the largest disturbed patch most frequently accounted for 71-100% of the total disturbed area of a fire. Thus, for the majority of fires occurring in this region, the largest disturbed patch accounted for most of the disturbed area. In the boreal mixed wood, Cumming (2001b) demonstrated that forest composition can explain burning patterns. The undisturbed live residuals for these fires tended to account for about 2-11% of the total disturbed area (Eberhart and Woodard 1987, Delong and Tanner 1996), although Andison (2004 and 2006) estimated that the residual area of boreal wildfires fires in Alberta and Saskatchewan, were 20-40%. These particular attributes of fire—event size, largest disturbed patch and residual patterning—are important for understanding historical disturbance patterns. These metrics may also be used to evaluate and monitor whether anthropogenic disturbances are falling within the historical range of variability (HRV).

The objectives of this exploratory research are to (i) understand in what ways, to what degree, and by way of what industrial activities do current anthropogenic disturbance patterns of the Al-Pac FMA compare to the historical disturbance regime and (ii) understand in what ways and to what degree do patterns of aggregated and dispersed timber harvesting compare to the historical disturbance regime.

2. Spatial analysis methods

2.1 Spatial data

To address the research objectives outlined above, several datasets were utilised to characterise anthropogenic disturbances in the Al-Pac FMA. Aerially-derived Alberta vegetation inventory (AVI) data (Alberta SRD 2005) were acquired from Al-Pac for four sample areas and supplemented with seismic line, utility line and road spatial datasets (M. Smith, personal communication, 7 December, 2011). These data were then processed and analysed using ArcMap 10 Geographic Information System software (ESRI, Redlands, Ca.). Seismic line features were buffered by a width attribute assigned within the dataset. When a seismic line feature lacked a width value, the mean width value of all seismic lines was used. Seismic features were then amalgamated into a single spatial layer class of SEISMIC. Utility lines and road features were buffered to 50 m right-of-ways. Unimproved roads and trails were excluded from this buffering process and analysis. Utility lines and road features were then amalgamated into a single spatial layer class of ROADS. Several classes of anthropogenic polygon features were then extracted from the AVI data. Harvest areas (MOD1='CC') were assigned to a class of BLOCKS, well sites (ANTH_VEG='CIW') and pipeline (ANTH_VEG='CIP') features were assigned to a class of WELLS and non-forested, permanent water (NAT_NON='NWF', 'NWL', and 'NWR') features were assigned to a class of WATER.

2.2 Spatial analysis tools

The decision-support tool NEPTUNE (novel emulation pattern tool for understanding natural events) was then used to describe several pattern metrics at the disturbance event level for each of the four sample areas (NEPTUNE User Guide 2009). In order to analyse disturbance patterns in NEPTUNE, each spatial layer had to be parameterised for two attributes: DIST_DATE, the year when the polygon became disturbed; and DIST_LEVEL, the severity of the disturbed polygon one of *fully disturbed*, *partial island* or *intact island*. Polygons of classes BLOCKS, SEISMIC, ROADS and WELLS were assigned to a common DIST_DATE to analyse the current state of the anthropogenic disturbance on the landscape. All polygons of classes SEISMIC, ROADS and WELLS were assigned *fully disturbed* for DIST_LEVEL. Polygons identified as harvest areas were assigned *fully disturbed* if the severity modifier attribute (MOD1_EXT) indicated greater than 95% removal of the canopy (MOD1_EXT=5) and *partial island* for less than 95% removal of the canopy (MOD1_EXT=1:4).

The aggregation of disturbed patches into disturbance events by NEPTUNE is determined by spatial and temporal proximity of these polygons. A spatial buffer width, analysis year range and tenure length are set *a priori* by the user. The spatial buffer width determines how close two disturbed polygons must be before they are considered separate events. The analysis year range determines how far in time two disturbed polygons must be before they are considered two separate events, and the tenure length assigned to each spatial layer is defined as

the amount of time (in years) that a disturbed polygon will remain disturbed. Once all attributes were parameterised, each spatial layer was analysed in NEPTUNE using a two year analysis range, tenure length of one year for each layer, a reporting interval of one year and a 200 m spatial buffer width. NEPTUNE creates disturbance events using the BLOCKS and WELLS layers, all other spatial layers contribute only to the total disturbed area (see NEPTUNE User Guide 2009 for more information on NEPTUNE processing).
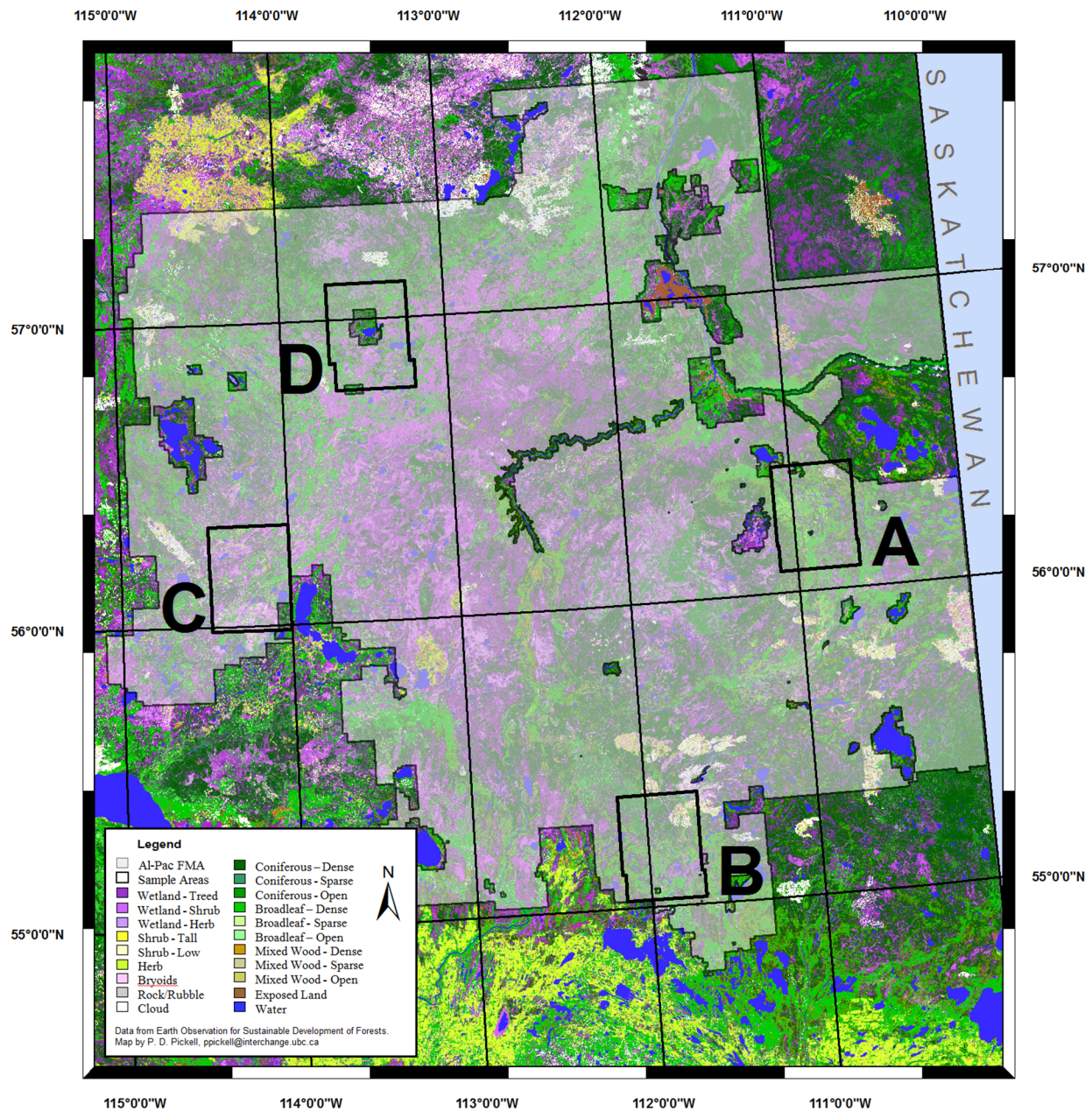

Figure 1. Sample areas of the Al-Pac FMA.

2.3 Spatial language

One of the challenges of working with disturbance patterns is being consistent and complete with spatial terms such as *remnant* or *disturbance*. In this case, we adopted the disturbance pattern language developed by Andison (in press), which is predicated on the concept of the general area of influence of a wildfire. The language involves both mapped and generated spatial elements. The mapped elements include both *disturbed patches* and *island remnants* (Fig. 2). A buffering algorithm gathers disturbed patches into a single spatial entity called the *disturbance event*. The new undisturbed areas gathered within the event boundary are called *matrix remnants* (Fig. 2). *Total remnants* are the sum of island remnants combined with matrix remnants.
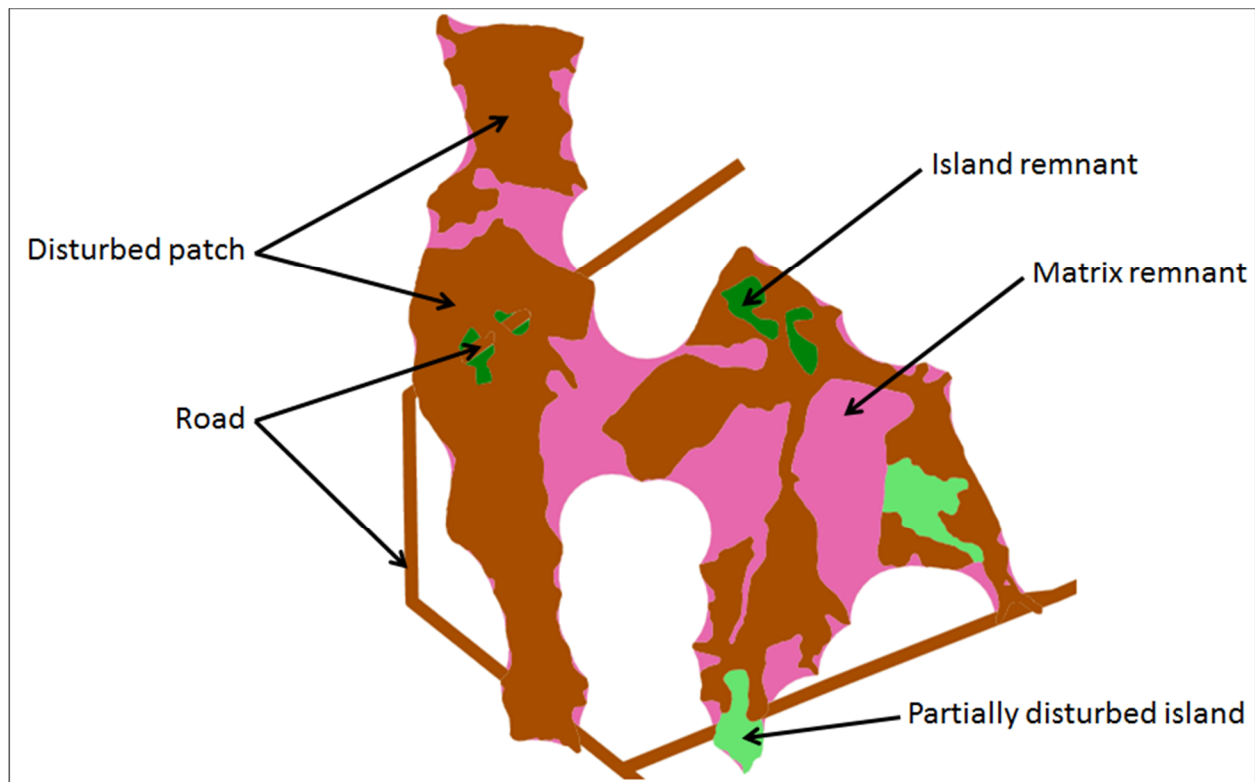
Figure 2. Composition of a harvest disturbance event as the result of the spatial buffering algorithm in NEPTUNE.

2.4 Spatial pattern indices

A number of ecologically-relevant pattern indices were derived from the NEPTUNE spatial outputs. The metrics included in our analyses included event size (ha), matrix remnants area, island remnants area (ha), largest disturbed patch area (as a percent of the total disturbed area within an event) and percent event area in matrix remnants, island remnants and total remnants.

2.5 Sample classes and areas

Each pattern index was analysed by disturbance event for four disturbance classes among four sample areas. The Al-Pac FMA was sub-sampled into four areas which were stratified by degree

of anthropogenic management (highest=A to lowest=D; see Fig. 1). Energy disturbances were analysed using only the SEISMIC, ROADS, WELLS and WATER spatial layers. Forestry disturbances were analysed using only the BLOCKS, ROADS and WATER spatial layers. Two analyses were performed on forestry-related disturbances. The first analysis amalgamated all harvest areas into forestry-related disturbances regardless of harvesting strategy. The second analysis discriminated two harvesting strategies: aggregated, single-pass harvests; and dispersed, two-pass harvests. The majority of aggregated harvesting has occurred since 2000 while the 1990's and earlier were dominated by dispersed harvesting strategies. To discriminate between aggregated harvests and dispersed harvests, we selected all harvest areas where MOD1_YR >= 2000 and assigned a class of *aggregated*; for all harvest areas where MOD1_YR <= 1999, we assigned a class of *dispersed*. All harvest areas in area D occurred during the 2000's, so there were no representative polygons for dispersed harvesting in this area by our definition.

In many cases, harvest areas were positioned adjacent to a township boundary used to delineate the sample areas. Since the metrics derived from the NEPTUNE tool were dependent on the spatial proximity of disturbed polygons, it was necessary to identify polygons which were either cut off by the township boundary or were within 400 m of another disturbed polygon outside the sample area. To do so, we buffered each disturbed polygon by 200 m and manually eliminated any polygon which could potentially be amalgamated into a disturbance event and satisfied either of the two aforementioned criteria.

2.6 Statistical analysis

The distributions of the residuals for each pattern index were examined for normality and homoscedasticity using a Shapiro-Wilk test of goodness-of-fit and Bartlett test, respectively. Having found that all of the pattern indices were highly right-skewed and unresponsive to standard data transformations, we chose to use the non-parametric Kolmogorov-Smirnov (K-S) test to compare the distributions of the sampled anthropogenic pattern indices to the HRV. The statistic of the K-S test *D* is the maximum observed vertical difference between the sample cumulative distribution function (CDF) and the empirical cumulative distribution function (ECDF). For all of the analyses of this report, the ECDF was equivalent to the HRV.

2.7 NEPTUNE limitation

For sample area A, the disturbed polygons were too numerous, complex and irregular for NEPTUNE to process all at once. As a result a reduced set of indices were examined, which could be efficiently computed across all landscapes. These indices related to the discrimination between island and matrix remnants, though indices of total residuals (the sum of island and matrix remnants) were unaffected by this limitation. This result underscores the challenge of working with large, complex datasets which include multiple spatial layers for very disturbed landscapes. For example, we experienced processing times of <5 minutes for most analyses in NEPTUNE. However, the dense seismic networks of area A added a substantial amount of

processing lag, more than 24 hours for analyses that involved the seismic layer. In the case of area A, we had to manually split the analysis into four, 3-township-sized pieces in order to reduce processing lag when analysing energy disturbances. Future studies should be cautioned against do so, however, unless great care is taken to preserve the spatial proximity of potential event-creating polygons (i.e., well sites and harvest areas).

3. Results

3.1 Sample totals

In total, 2,201 anthropogenic disturbance events were sampled of which 836 were cumulative disturbance events (both disturbed forestry and energy features), 1,057 were energy-related disturbance events, 126 were forestry-related disturbance events, 108 were dispersed harvests and 74 were aggregated harvests. The patterns of these anthropogenic disturbances were compared to 87 unsuppressed, pre-industrial fires that occurred in the boreal eco-zones and represented the HRV (D. Andison, 2012, unpublished data).

3.2 HRV disturbance patterns

Previous analysis of 87 aerially-interpreted fires with no record of fire suppression (D. Andison, 2012, unpublished data) provided information for the HRV. All fires occurred between 1948 and 2004 of a geographic extent spanning from 110°0'W to 120°0'W and from 54°42'N to 60°1'N within the boreal shield, boreal plain, taiga plain and taiga shield ecozones of Alberta. The nature of the selection criteria for these fires, namely that there was no record of fire suppression and there were aerial photos available, severely restricted our sampling of the historical pre-industrial fire regime. The primary limitation of these data is that they do not represent the greatest range of fire attributes which have been

Event Size Cumulative Distribution

Forestry: p<<0.001, D=0.538
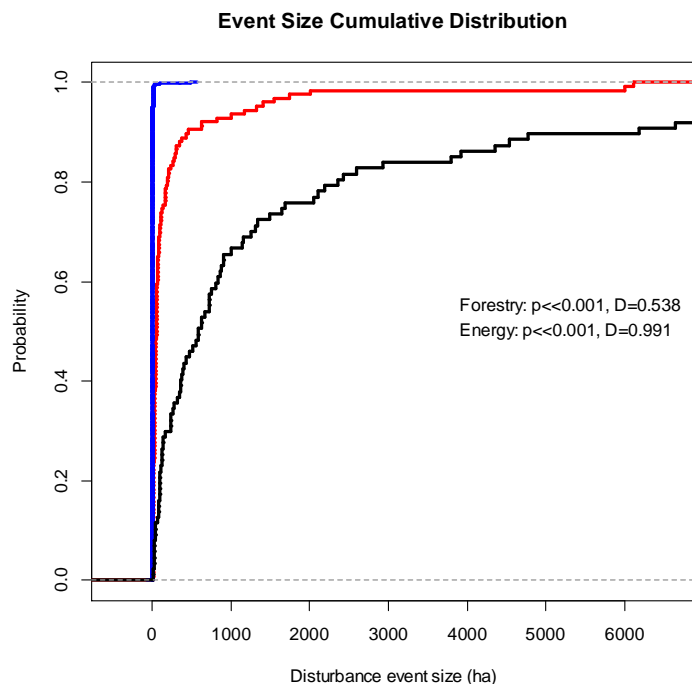Energy: p<<0.001, D=0.991

Figure 3. Cumulative distribution function (CDF) plot of event size (ha) for forestry (red line), HRV (black line) and energy (blue line). (Note that the largest values of the HRV distribution have been truncated.)
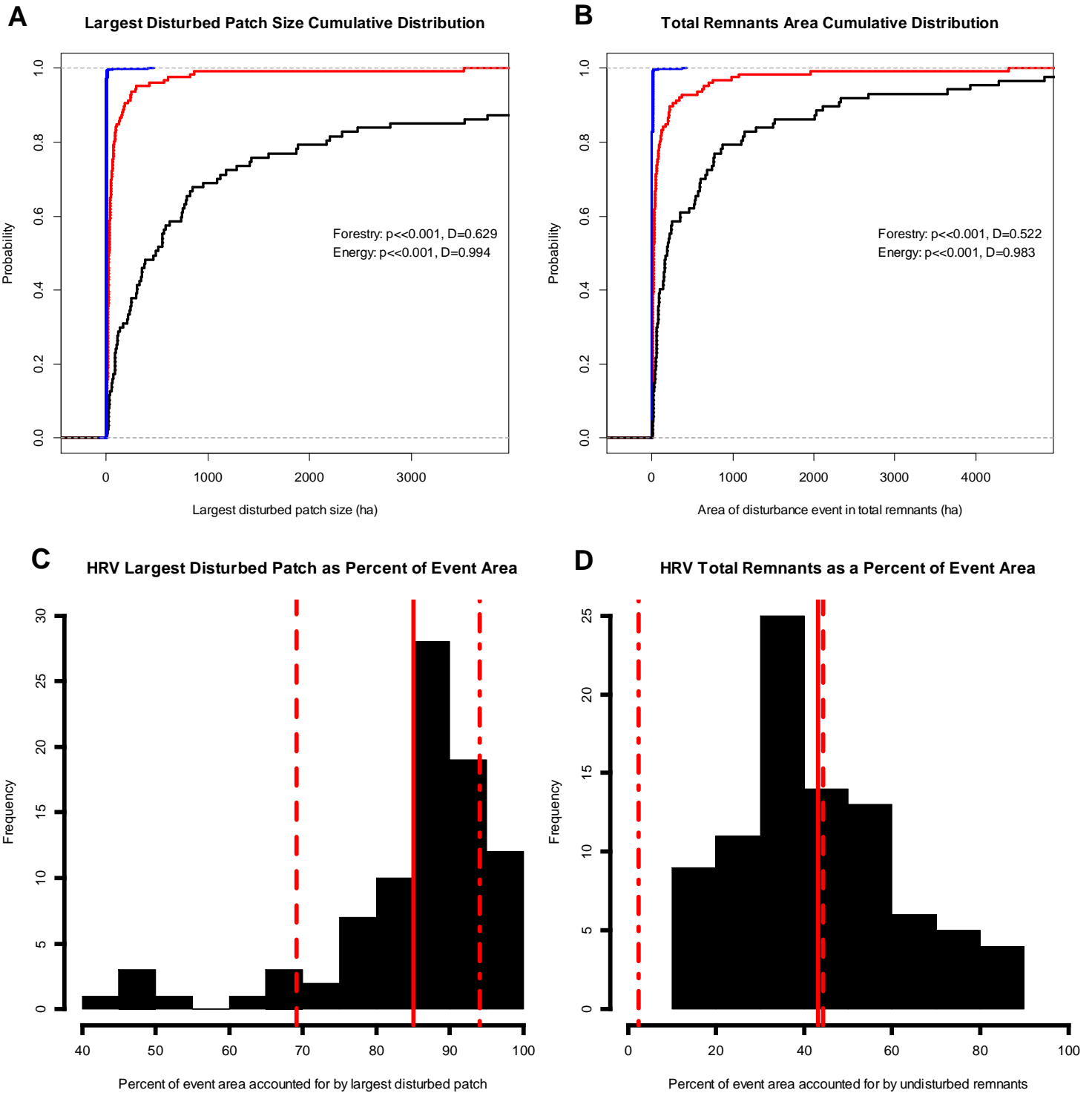
Figure 4. Cumulative distribution function (CDF) plot of largest disturbed patch for forestry (red line), energy (blue line) and HRV (black line) in terms of area (panel A) and CDF plot of total remnants for forestry, energy and HRV in terms of area (panel B); frequency distributions of largest disturbed patch as a percent of the total disturbance event area (panel C) overlain by the mean HRV value (solid line), mean forestry value (dashed line) and mean energy value (dashed-dotted line) and total undisturbed residuals for HRV as a percent of the total disturbance event area (panel D) overlain by the mean HRV value, mean forestry value and mean energy value. (Note that the largest values of the HRV distributions in panels A and B have been truncated.)

historically observed by mediums other than aerial interpretation. For example, Cumming (2001a) estimated the maximum fire size to be for lightning-caused fires in the interval of 1961-1998.

The sizes of our sampled historical fires were on average about 2,159 ha and ranged from 11.32 ha to 28,040 ha (Fig. 3). Most frequently, the size of the largest disturbed patch was less than 2,000 ha and on average accounted for 85% of the total disturbance event area (Fig. 4, panel B). The largest historical fires left as much as 24,700 ha in undisturbed forested residuals, but were more often around 1,000 ha on average. These residuals accounted for as much as 88% of the disturbance event area for some fires, but on average about 43% of the area of a historical fire could be expected to remain in undisturbed forested residuals (Fig. 4, panel D). On average, approximately 11.5% of the disturbed event area was in matrix remnants and 31.7% was in island remnants (Fig. 5, panels C and D).

3.3 Forestry and energy disturbance patterns

Anthropogenic disturbances tended to be small with a mean size of approximately 261 ha and 2.13 ha, respectively (Fig. 3). The largest forestry-related disturbance was 6,116 ha and the smallest was 2.67 ha. The largest energy-related disturbance was 491 ha and the smallest was 0.16 ha. The size of the largest disturbed patch for forestry and energy-related disturbances accounted for 69% and 94% of the total disturbance event area on average, respectively (Fig. 4, panel C). The size of the largest disturbed patch for forestry-related disturbances ranged from 2.07 ha to 3,514 ha. The size of the largest disturbed patch for energy-related disturbances ranged from 0.16 ha to 409 ha.

Forestry-related disturbances on average maintained greater proportions of undisturbed forested remnants than energy-related disturbances, approximately 44% and 2%, respectively (Fig. 4, panel D). On average, the total area in undisturbed remnants for forestry and energy-related disturbances was 134 ha and 0.78 ha, respectively (Fig. 4, panel B). Approximately, 20% of the total area of forestry disturbances was represented by matrix remnants and 24% by island remnants (Fig. 5, panels C and D). For energy disturbances, only 2.2% of the total disturbance event area was represented by matrix remnants and less than 1% by island remnants (Fig. 5, panels C and D).

3.4 Cumulative anthropogenic disturbance patterns

When forestry and energy features were combined, anthropogenic events ranged from 0.16 ha to 11,120 ha (46 ha on average). The sizes of the largest disturbed patch ranged from 0.16 ha to 4,042 ha, but were only approximately 19 ha large on average. The area in total remnants (i.e., matrix and island) for these disturbance events was approximately 27 ha on average, but some events were as large as 6,565 ha. As noted previously, a software problem with the NEPTUNE tool did not allow for a discrimination in residual composition (i.e., island or matrix remnants), so our interpretations here are limited to total undisturbed residuals.
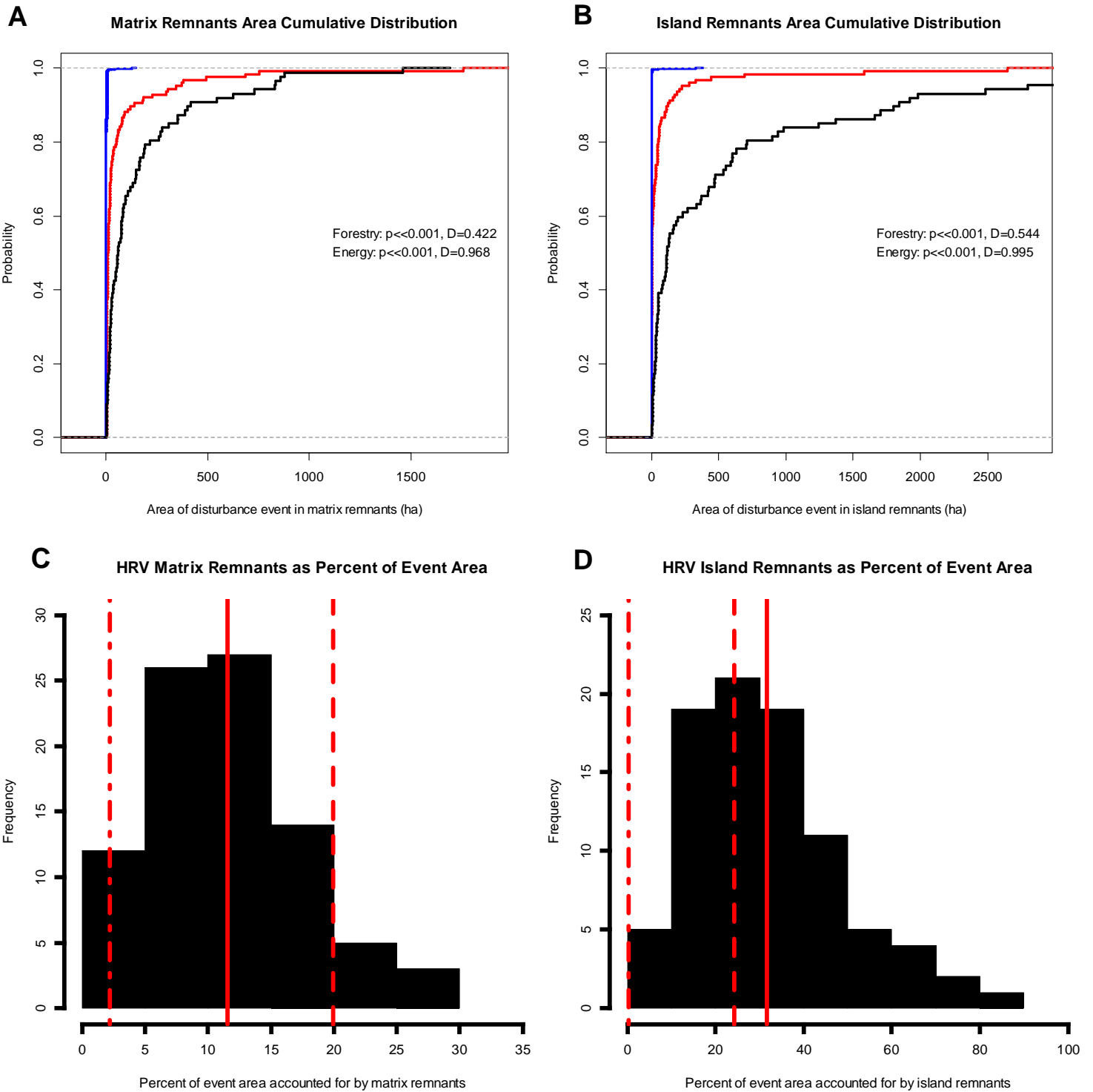
Figure 5. Cumulative distribution function (CDF) plot of matrix remnants for forestry (red line), energy (blue line) and HRV (black line) in terms of area (panel A) and CDF plot of island remnants for forestry (red line), energy (blue line) and HRV (black line) in terms of area (panel B); frequency distributions of matrix remnants as a percent of the total disturbance event area (panel C) overlain by the mean HRV value, mean forestry value (dashed line) and mean energy value (dashed-dotted line) and island remnants for HRV as a percent of the total disturbance event area (panel D) overlain by the mean HRV value, mean forestry value and mean energy value. (Note that the largest values of the HRV distribution in panel B have been truncated.)

3.5 Timber harvesting disturbance patterns

The sizes of aggregated harvests ranged from approximately 2.95 ha to 2,015 ha with a mean of 174 ha (Fig. 6, panel A). The largest disturbed patches for aggregated harvests ranged from 2.56 ha to 867 ha, with a mean of 83.5 ha and on average accounted for 70.5% of the total event size (Fig. 6, panel B). The total area in undisturbed remnants (i.e., matrix and island) for aggregated harvests ranged from 0.09 ha to 980 ha, with a mean of 74.8 ha and on average accounted for about 35% of the total event size (Fig. 7, panel A). Island remnants in these events tended to account for 16.8% of the event area while matrix remnants accounted for 18% on average (Fig. 7, panel B).
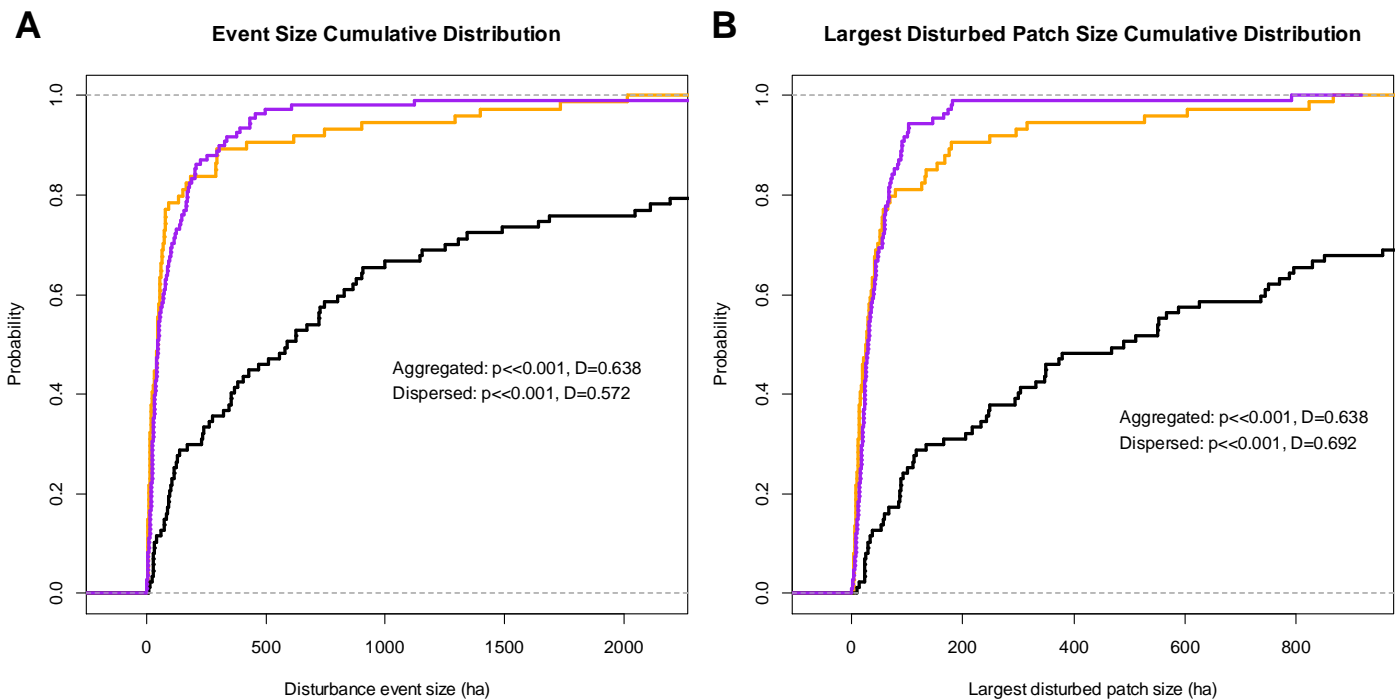

Figure 6. Cumulative distribution function (CDF) plot of event size (ha) for aggregated harvests (orange line), dispersed harvests (purple line) and HRV (black line) (panel A) and largest disturbed patch (LDP) size (ha) for aggregated harvests, dispersed harvests and HRV (panel B). (Note that the largest values for the HRV distributions in panels A and B are truncated.)

On average, the sizes of dispersed harvests were 154 ha in size, but ranged from 0.47 ha to 4,901 ha (Fig. 6, panel A). The largest disturbed patches of dispersed harvests were 48.9 ha in size on average, but ranged from 0.47 ha to 793 ha and tended to account for 60.9% of the total event size on average (Fig. 6, panel B). The area in undisturbed total remnants for dispersed harvests ranged from 0 ha to 2,755 ha, with a mean of 94.7 ha and on average accounted for 53% of the total event area (Fig. 7, panel A). The total area in island remnants ranged from 0 ha to 633 ha and accounted for 32.8% of the total event area on average. Matrix remnants tended to account for 20.2% of the total event area, and ranged from 0 ha to 2,122 ha on average (Fig. 7, panel B).
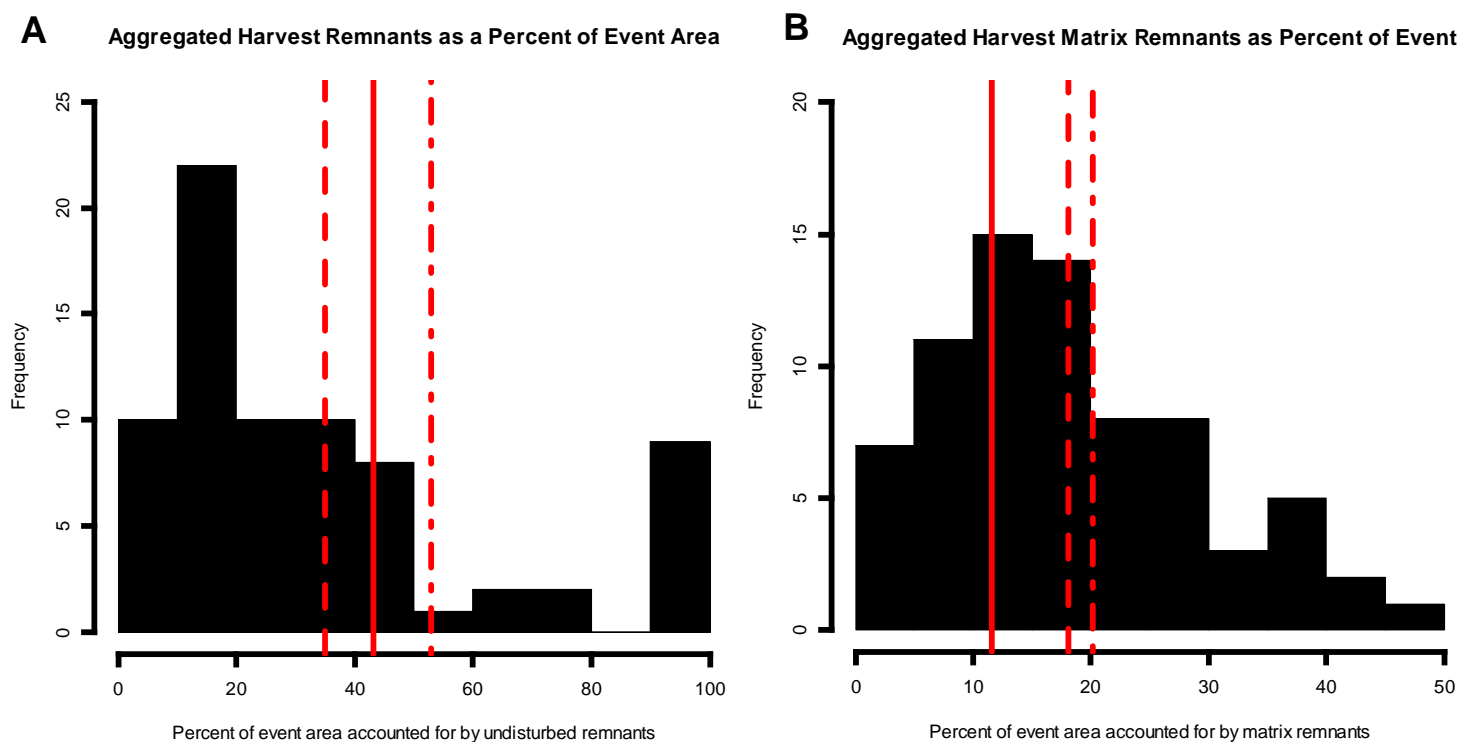
A Aggregated Harvest Remnants as a Percent of Event Area

B Aggregated Harvest Matrix Remnants as Percent of Event

Figure 7. Frequency distribution of aggregated harvest total remnants as a percent of the total disturbance event area (panel A) overlain by the mean HRV value (solid line), mean aggregated harvest value (dashed line) and mean dispersed harvest value (dashed-dotted line); and aggregated harvest matrix remnants as a percent of the total disturbance event area (panel B) overlain by the mean HRV value, mean aggregated harvest value and mean dispersed harvest value.

4. Conclusions and discussion

The disturbance patterns of anthropogenic activities on the Al-Pac FMA has positioned the landscape outside the HRV for several key pattern indices. However, there is a danger in considering such indices in isolation. For example, the size of the largest disturbed patch is critical to understanding the patterning and composition of the historical fire regime. In this case, the energy-related disturbances better approximated the HRV in terms of the percentage represented by the largest disturbed patch, however this result is an artifact of the size and configuration of energy disturbances on the landscape. As previously noted, well sites were the only energy features used to generate disturbance events. The distance between these features tends to be great enough such that a single well site was an event, hence a mean event size of about 2 ha. Consequently, there is only one patch for many of these disturbances and as a result the largest disturbed patch for these disturbances generally accounts for around 100% of the total disturbance event area. Additionally, energy-related disturbances were not effective at approximating the historical levels of undisturbed forested total remnants. In fact, the 75th percentile of all energy-related disturbances contained no remnants at all.

Forestry-related disturbances better approximated the historical levels of undisturbed total remnants as a percentage of the disturbance event area. A noticeable pattern of forestry-related disturbances was a high amount of matrix remnants. The mean distance between disturbed patches of harvest areas was likely a factor in the amount of matrix remnants of these disturbances, as were "leave blocks" from the old two-pass, or dispersed harvesting system. The dispersed harvesting method tends to leave large tracts of undisturbed matrix remnants between disturbed patches that either soon will, or previously was harvested. Thus, in the future, a more representative way of analysing the dispersed, two-pass harvesting pattern may be to include both passes as "disturbed".

When disturbed patches are smaller and less compact within the boundaries of a disturbance, more matrix remnants and edge tend to dominate the event. The higher density of edge and smaller disturbed patch sizes are characteristic of dispersed timber harvesting and energy sector disturbances. Although indices of fragmentation were not directly quantified in this report, these patterns indicate low amounts of undisturbed core forest which are available as functional habitat. A more recent argument has been made for larger, aggregated (i.e. single-pass) harvests that maintain greater amounts of undisturbed, live remnants (Van Wilgenburg and Hobson 2008) and allow roads to be removed sooner. However, forest managers are faced with an expectation to design timber harvests that maximize wood fibre extraction, which can be counter to the public negative perception of large, spatially contiguous harvest areas despite the potential ecological benefits.

The largest disturbed patch for aggregated harvests was nearly twice the size on average as dispersed harvests and better approximated the HRV in terms of percent of the total disturbance event area. It is noteworthy to point out that the largest disturbed patch for the bottom 50% of aggregated harvests tended to account for 20% more of the total disturbance event area than dispersed harvests, beyond which there was no significant difference between the two harvest systems. Aggregated harvests also better approximated the HRV in terms of total remnants as a percent of the total disturbance area than dispersed harvests overall, but still fell short of historical levels. Particularly, island remnants were severely underrepresented in aggregated harvests. Eberhart and Woodard (1987) demonstrated that the percent of disturbed area within the boundary of fires in northern Alberta decreased as the size of the fires increased. This suggests that historical fires maintained higher levels of undisturbed total remnants as the size of the event increased, although Andison (2004, 2006, and in press) found that remnant levels were constant across all fires in both Alberta and Saskatchewan.

It should be emphasized that these results represent the preliminary stage of a larger, on-going collaborative project that will produce more reports, published manuscripts and a thesis. Thus, any interpretation of these results should be done with due care. Perhaps the most important messages from the research involve the general trends rather than the specifics. For example, clearly forest management activities create more "natural" disturbance patterns than do those of the energy sector. Furthermore, Al-Pac's shift to single-pass aggregated harvesting is

manifesting patterns that resemble the pre-industrial fire regime. The results do suggest that larger aggregated harvests that retain greater amounts of island remnants within harvest areas than matrix remnants between them are more "natural" based on historical data. However, doing so will also only further increase the gap between the disturbance patterns of forest management and the energy sector. Thus, it seems an equally critical element of creating more resilient landscapes is to encourage and foster a coordinated approach to anthropogenic disturbance activities. This is particularly true in Alberta where

As to the specifics, as with any innovative research, we are still learning. For example, as mentioned earlier, it may be more representative to combine both harvesting passes in a two-pass system when comparing disturbance patterns. From a technical perspective, these results also underscore the challenges associated with summarising and understanding pattern metrics. Interpreting a single metric in isolation is problematic and as a result, on-going research will continue to focus on understanding the use and interpretation of combinations of metrics. This research also raises many new pattern-related questions such as the effects of event size and remnant composition of anthropogenic disturbances on landscape scale patterning, specifically edge density and connectivity of undisturbed forested remnants as these are important considerations for conservation planning.

Although this study did not directly quantify edge density or sizes of patches, these variables are likely a contributing factor to habitat quality and undisturbed remnant accessibility. The distribution and configuration of undisturbed or partially disturbed remnants throughout a disturbance event may have important feedbacks at local scales for low-dispersal flora and movement of small mammals. By contrast, there may be organisms that are adapted to disturbed conditions and it may be just as important to maintain these conditions in the appropriate configuration, severity and proportion on the landscape to allow for the persistence of these species (Nonaka and Spies 2005). General island biogeography theory predicts that smaller islands (i.e., undisturbed remnants) support fewer species (MacArthur and Wilson 1967). Therefore, interpreting these results in a strict sense of proportional areas may not be sufficient to maintain historical biodiversity levels. The historical size distributions of island and matrix remnants may be just as critical as maintaining proportional areas in undisturbed remnants. However, the merits of invoking such theory are limited by its application. For example, island remnants which remain following any type of disturbance in a forested system are not truly analogous to islands of the archipelagos which MacArthur and Wilson studied. Though some attributes of island remnants are analogous to islands of the seas such as structure and living organisms (i.e., trees and vegetation), these attributes are degraded over time as successional trends convert disturbed areas back into forest. These and other questions will be explored in more detail as part of the on-going collaborative research between Al-Pac, FRI and IRSS at UBC.

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