A comparison of coarse woody debris in post-harvest and post-fire island remnants a decade after disturbance in northern Alberta

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Forest Biology and Management

Department of Renewable Resources

University of Alberta

Abstract

Retention forestry is practiced widely throughout the world whereby forest structure is retained within cut-blocks at harvest sites. These practices are modelled on the propensity for fires to leave behind a variety of biological legacies or structural elements. However, the comparison of post-fire and post-harvest residual forest structure has received little attention. Coarse woody debris is an important component of forest structure often influenced by management. Here I compared coarse woody debris attributes in residual patches in harvests and wildfire disturbed locations in Alberta's boreal forest to determine how coarse woody debris was influenced by the different disturbances. Three wildfire disturbed areas included the Flattop Complex, M024 Complex, and the Utikuma Complex fires, while matching with three harvested regions. Within these areas, 30 sites were selected and sampled in 2021 based on a harvest or fire between the years of 2009-2011. These disturbances left residuals with a patch size >0.45 ha and >60% deciduous. Each site included a reference (larger matrix of forest bordering the same disturbance), a remnant (patch of forest isolated by the disturbance) and a disturbance (harvested or burned). Within these three locations an interior plot (not bordering a different matrix) and an edge plot (bordering a different matrix) were surveyed. Using forest inventory strategies and the line-intercept method coarse woody debris volume, decay class, species, and diameter was gathered during the summer of 2021 from 11.28 metre radius plots.

Overall, coarse woody debris attributes were similar between fire and harvest sites. The coarse woody debris volume of early decayed wood (decay class 1 and 2) for fire islands had an average volume of 42 m^3/ha; meanwhile, harvest islands averaged 31 m^3/ha. It was apparent that fire islands had a larger variability in early decayed coarse woody debris volumes, yet upon further analysis it was not evident that disturbance type influenced these values. A comparison of reference sites showed early decayed coarse woody debris around 27 m^3/ha for fire references and 40 m^3/ha for harvest references. The initial stand volume for both disturbance types in references and islands varied between 300-400 m^3/ha and was not an important predictor of coarse woody debris volumes. Distributions of size classes in both islands and references were similar in fire and harvest disturbance types. Species' distributions showed little variation between fire and harvest disturbances. This study found no evidence to support that edge and interior plots varied amongst each other or between disturbance types. The variability amongst the fires and the harvests surveyed was low and did not influence coarse woody debris attributes. Overall, a decade after disturbance, fire residuals and retention patches were found to be similar with respect to coarse woody debris attributes. This implies the long-term effectiveness of aggregate retention in ecosystem-based management strategies on coarse woody debris volume and attributes within the mixedwood boreal forests of northern Alberta.

Acknowledgements

I would like to show my deepest gratitude for the support I received from the Nock Lab. I want to thank my supervisor, Dr. Charles Nock, for providing the opportunity to join this research and his patience in working with me. I would like to thank Marcel Schneider for his massive contributions to our field season and his willingness to help at all stages of my research. Likewise, I want to thank Marcus Sommers for his consistent help and motivation throughout the thesis. Next, I would like to show gratitude towards Jéssica Chaves Cardoso for her encouragement and programming help. Lastly, I want to thank my American comrade, Rosanise Odell, for her constant support, not only in writing this thesis but throughout our international struggles. Even though we faced several barriers during our studies you all were fundamental to the completion of this thesis, and I will forever be grateful.

I am indebted to the everlasting support of my parents, brother, family and friends. Your prayers, encouragement and faith got me through the worst of the pandemic, this thesis and more than you can possibly know. I would like to specifically thank my parents for the sacrifices they have made and continue to make to see their children succeed; I will never be able to live up to your example. I want to thank my family at Bon Accord Community Church for their investment in my life and continual support throughout my Masters. Also, I would like to thank Cab Sav for her ability to keep me calm and sane throughout this process.

Lastly, but ever so greatly, I would be remised to not thank my Father. Above all else it is You who has impacted my life the most. Your constant presence, love, sacrifice and blessings has made me who I am and will form me into the man you drive me to be. With You anything is possible.

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Introduction

Boreal forest

The boreal forest, as defined by Burton et al. (2010), is a complex of forests growing in high-latitude environments where freezing temperatures occur for six to eight months out of a year. Although predominantly coniferous, the boreal has a substantial portion of mixedwood forest, which increases its structural and compositional diversity (Bergeron and Fenton 2012; Rowe and Scotter 1973). The boreal forest in Canada is far from uniform; the soil composition, moisture, climate, species, forest cover, density and structure can vary drastically across the country (Brandt et al. 2009; Brandt et al. 2013). Canada's high latitude and cool winters constrain three-quarters of its forested land and 58% of its total land to boreal forest (Millennium Ecosystem Assessment 2005; Dhar et al. 2018a; Brandt et al. 2013; Hassan et al. 2005). Nevertheless, these stands support thousands of species of living organisms (Kuuluvainen et al. 2012).

Fire

The boreal forest's structure and dynamics are strongly influenced by its relationship with fire (Packard 1993). The dominant mixed fire regimes in the boreal forest create stands with various ages and compositions (Rowe 1972; Burton et al. 2008; Kafka et al. 2001). These types of fire regimes are characterized by heterogeneous fire effects over a range of spatial and temporal scales (Franklin et al. 1997; Halofsky et al. 2011). The variation in stand size, age, structure and composition from numerous disturbances created a diverse habitat for a wide array of native species. The fluctuations in disturbance regimes over time are an integral part of the boreal forest's dynamics and demonstrate the resiliency of Canada's boreal forest (Gendreau-Berthiaume, Macdonald and Stadt 2018; Kuuluvainen and Aakala 2011; Shorohova et al. 2011).

Over the course of a fire, varying conditions and fuel forces the fire to move in dynamic, unique patterns (Kafka et al. 2001). These patterns develop differently depending on the severity of the fire. Wildfires are typically classified according to levels of severity, including ground fires, surface fires and crown fires. A ground fire is designated as low-severity and consists of matter below the ground burning. Surface fires are classified as medium-severity and includes the burning of leaf litter and fallen woody debris on the forest floor. Lastly, a crown fire means the fire would burn from canopy to canopy of the trees within the forest, resulting in extensive tree mortality. This type of fire is the most destructive and, likewise, classified as a high-severity fire. The destruction seen with these types of fires are the ones forest managers attempt to emulate through harvesting techniques.

Remnants created by fire vary in size, shape and level of preservation (Haines 1982; Eberhart and Woodard 1987; Kolden et al. 2012; Andison and McCleary 2014). The topography, soil moisture, weather, and connectivity of fuels are some of the major influences of forest island remnant formation (Rowe and Scotter 1973; Eberhart and Woodard 1987). Island remnants in the boreal are generally less than two hectares but can be as large as ten hectares (Delong and Kessler 2000). The size of an island is important because it influences the type of habitat it can support. As the remnant sizes decrease the type of habitat it supports changes, with skinny or small islands providing little interior forest habitat (Eberhart and Woodard 1987, Delong and Kessler 2000). Larger islands possess a greater capacity to preserve interior forest conditions for various species (Lindenmayer et al. 1999). Tree mortality, which represents island resilience, decreases as the size of the island remnant increases (Jönsson et al. 2007; Franklin et al. 1997; Matlack et al. 1993; Matlack et al. 1994). A remnant's area has an important influence on its ability to act as an effective lifeboat for species after a disturbance.

Island Remnant Importance

Decades of research has identified the important ecological role remnants play in the forests (Harmon et al. 1986; Spies and Cline 1988). The variation of burn patterns and wildfire regimes have led to the development of diverse biological and structural legacies (Franklin et al. 2000). Creating a lifeboat for organisms means preserving structural elements that fulfill the habitat requirements for various organisms, ameliorating microclimatic conditions caused by disturbances (Franklin et al. 1997). The retention patches in a disturbance act as a source of refugia, or an ecological lifeboat, for the forest-dwelling organisms and the original stand structure (Gasaway and DuBois 1985; Gandhi et al. 2001; Jönsson et al. 2007; Mori and Kitagawa 2014). Although the exact amount of retention necessary to achieve this life-boating effect is widely debated, it is suggested that >30% of the residual forest cover post-disturbance is required to maintain the original biodiversity (Cissel et al. 1999). Aside from the direct protection that species may receive, an island remnant preserves the genetic diversity that was present on the landscape before the disturbance (Xu et al. 2018). Fire refugia offer a safe-haven for fire-intolerant species and provide the ability to establish in the nearby disturbance (Eberhart and Woodard 1987). The retention patch serves as a base from which the protected organisms can reproduce and disperse into the disturbed location; meanwhile, it would maintain similar forest structure as the original forest which enhances the connectivity of the landscape (Franklin et al. 1997). This connectivity is important in linking pollinators or seed dispersers with the surrounding disturbance (Drever et al. 2006; Wiebush et al. 2020). The heterogeneity created by unburnt patches increase the diversity of habitat types displaying a greater assortment of flowing plants and pollinators (Adedoja et al. 2019; Wiebush et al. 2020). Hylander and Johnson (2010) observed invertebrate species using the refugia, which may indicate that small scale refugia are able to shelter a wide variety of species. Fisher and Wilkinson (2005) identified that the presence of unburnt remnants typically resulted in higher mammalian diversity. Both moose and many bird species benefit from overall remnants as they provide more opportunities for cover (Gasaway and Dubois 1985; Schieck and Hobson 2000; Berry et al. 2015; Franklin et al. 2019). The newly created edges also influence food supply which can be beneficial to large mammal species, such as grizzly bears (Larsen et al. 2019). Due to the ecological importance of island remnants as a source of nutrition and habitat following disturbances it is important to develop a comprehensive understanding of their responses post-disturbance. In Alberta, anthropogenic disturbances such as seismic lines, well pads, salvage logging and roads can overlap with harvested or burnt regions. When disturbance types overlap in an area, this can make attributing characteristics to a specific disturbance type difficult.

Boreal Forest Management

Two-thirds of the boreal forest is influenced by some sort of anthropogenic management (Gauthier et al. 2015 and Burton et al. 2010). Prior to European colonisation, Indigenous peoples managed the boreal forest through the intentional burning of wildfires to create travel corridors or to cultivate other desirable resources (Arno 1985; Williams 2000a; Kimmerer and Lake 2001; Lake and Christianson 2019). Contrary to Indigenous forest management, post-colonial management strategies have led to ecosystem degradation (Bergeron et al. 2002). The countries that are using a high-intensity management strategy, such as in Fennoscandia, have homogenized forest structure and high fire suppression strategies (Burton et al. 2010). Oftentimes this management strategy includes harvesting large diameter trees and removing coarse woody debris in the understory (Kuuluvainen et al. 2012).

Considering issues associated with traditional forest management in North America, forest industries are striving towards sustainable stewardship of their management areas to ensure long-term production and preserve biodiversity (Gustafsson et al. 2012). The concept of Ecosystem-Based Management was introduced in the twentieth century as an alternative approach to traditional forest management that aims to emulate natural disturbances (in Canada this would typically be wildfires) using harvesting techniques (Franklin et al. 2018). Forest managers implementing this management strategy are using retention forestry to balance economic, cultural and environmental objectives (Gustafsson et al. 2012). Retention forestry, as defined by Franklin et al. (1997), is the notion of putting more emphasis on what is retained as opposed to what is removed during harvesting. This involves leaving remnants in the forest after harvest to emulate the remnants that would be left after a disturbance. Creating these remnants are important for the preservation of habitat, forest structure and ecological processes (Franklin et al. 1997).

Coarse Woody Debris

Coarse woody debris is significant to the ecological functions in forested environments. In research as early as the 1940s coarse woody debris was found to increase biodiversity, carbon storage and nutrient cycling (Arnborg 1942; McCullough 1948; Harmon et al. 1986; Freedman et al. 1996; Stevens 1997; Jonsson and Kruys 2001). Although the importance of coarse woody debris was identified over half a century ago, forest management objectives did not create provisions for it until recent decades (Jonsson and Kruys 2001). By providing organisms with essential needs such as nesting, shelter, food etc., coarse woody debris allows species of bryophytes, saprobes, invertebrates, mammals, birds, reptiles, amphibians, vascular plants and fungi to survive in habitats that experience disturbances (Jönsson and Jonsson 2007).

Given the importance of coarse woody debris to forest structural diversity and as a key element of many forest species habitat, it is important to understand how anthropogenically disturbed stands and naturally disturbed stands may differ with respect to coarse woody debris. A study conducted in northern Quebec, suggested that post-fire islands have a significantly lower volume of coarse woody debris in the early stages of decay than retention islands in harvested locations (Moussaoui et al. 2016). This study emphasizes early decayed coarse woody debris because earlier decay classes are correlated to the recent disturbances (Angers et al. 2012). This study has highlighted that the initial volume of a stand plays a significant role in the production of coarse woody debris because stands with greater living volumes produce remnants with higher deadwood volumes (Ruel et al. 1995; Harper et al. 2005; Moussaoui et al. 2016). Similarly, in Quebec, larger retention patches with volumes from 60-300 m^3/ha were found to promote the longevity of island remnants in terms of the gradual input of deadwood (Moussaoui et al. 2016). To date, few studies have been conducted in the western boreal forest that compare coarse woody debris in locations harvested with a retention approach with locations disturbed by wildfire.

Objectives

The objective of this research is to compare the coarse woody debris volumes and attributes between post-fire and post-harvest island remnants, specifically in reference to the early decay stages of coarse woody debris. The early decay stages signify a more recent tree mortality that would correspond to the recent disturbance (Petrillo et al. 2016; Sittonen et al. 2000). This study sought to identify the influence of disturbances from 2009-2011 on coarse woody debris creation. The goal is to see how similar retention islands in forest harvest are to island remnants found in burned forests. In addition to volume, coarse woody debris attributes (decomposition stage, diameter and species) will be used to determine the similarity in function of the island remnants. I sought to answer two research questions: first, what are the similarities between harvest sites and fire sites in relation to coarse woody debris volume? And second, how does coarse woody debris size, decay class and species composition compare between harvest sites and fire sites? For the first question I predicted that harvest sites and fire sites would have equivalent volumes of coarse woody debris because of similar edge effects and other processes influencing tree mortality among patches. Likewise, for the second question I predicted that harvest and fire sites would have similar coarse woody debris attributes for the same reasons. Overall, I predicted that methods of forest island retention currently being used by the forest industry in boreal Canada would effectively replicate coarse woody debris structure found in fire refugia islands.

Methods

Site Selection

Harvest island information was gathered from partners in the NSERC Industrial Research Chair in ecosystem-based forest management (Tolko, Alberta-Pacific Forest Industries and Mercer International) who have operations in northern Alberta's aspen-dominated, mixedwood forests. The companies provided our team with the vegetation inventory, salvage logging data and island remnant polygon shapefiles of the sites. Digitized island remnants ≥0.45 ha and ≤10 ha was provided from industry partners and the fire islands were digitized using the ESRI base map with a 0.5 metre resolution that provided one meter or better satellite and aerial imagery. Then, we used cut-block maps to spatially locate the islands. Using the forest industries' vegetation inventory layer, we found the species composition data of each island's polygon. Harvest islands that experienced a fire in the years following the harvest were discarded from the possible field sites list. Some of the FMAs were salvage logged, but polygons provided by the forest industries allowed us to avoid sampling those zones. Fire island data was gathered from historical fire perimeter spatial data and the national dNBR raster layers to locate unburned/partially burned islands (Alberta Agriculture and Forestry 2021; Natural Resources Canada 2021). These patches were then digitized using sentinel 2 imagery at 10 metre resolution. Specifically, we used ESRI base map at 0.5 metre resolution to digitize the post-fire islands > 0.45 ha from the Utikuma, Flattop and M024 Complex fires. Table 1 lists their characteristics (Bourgeau-Chavez et al. 2020; Wildfire Science Documentation Report 2012).

Table 1. Characterisation of three fires surveyed. Fire weather data were from the closest stations to the fires from the government of Alberta Wildfire (2018) including Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Drought Code (DC), and Fire Weather Index (FWI).

Fire Name	Fire Start Date	FFMC	DMC	DC	FWI	Area within Burn Perimeter (ha)
MWF24 (M024)	13-Jun-09	90	24	123	14	10735
CWF056 (Flattop)	14-May-11	90	15	193	64	17000
SWF57 (Utikuma)	14-May-11	86	17	288	21	88702

We first focused on sampling retention patch sizes that were common and then sought to match fire island sizes so that the effect of disturbance was not confounded by that of island size. Knowing the harvest island threshold, we chose island sizes that overlapped between the two disturbances. Our islands were filtered to ≥0.45 ha and ≤5.0 ha. We compared the structure of the managed and disturbed forests a decade after the disturbances because retention forestry (patch retention) has been practiced by most of the industrial partners since ~2010. We selected the oldest locations harvested with this approach to evaluate whether locations disturbed by fire and harvest converge in structure over time. The dates of disturbances ranged from 2009-2011.

Because of the economic and ecological importance of aspen-dominated forest in Alberta, and the importance of aspen-dominated forests to partners in the NSERC IRC funding this research (Alberta Pacific, Mercer International), this study focused on deciduous-dominated stands in the mixedwood boreal forest. Specifically, islands were filtered to be ≥ 60% deciduous dominated. During final site selection sites adjacent to seismic lines, roads, well-pads and buildings were generally excluded, but this was not fully possible for seismic lines due to their ubiquitous presence in northern Alberta. A map of the selected sites appears in Figure 1.

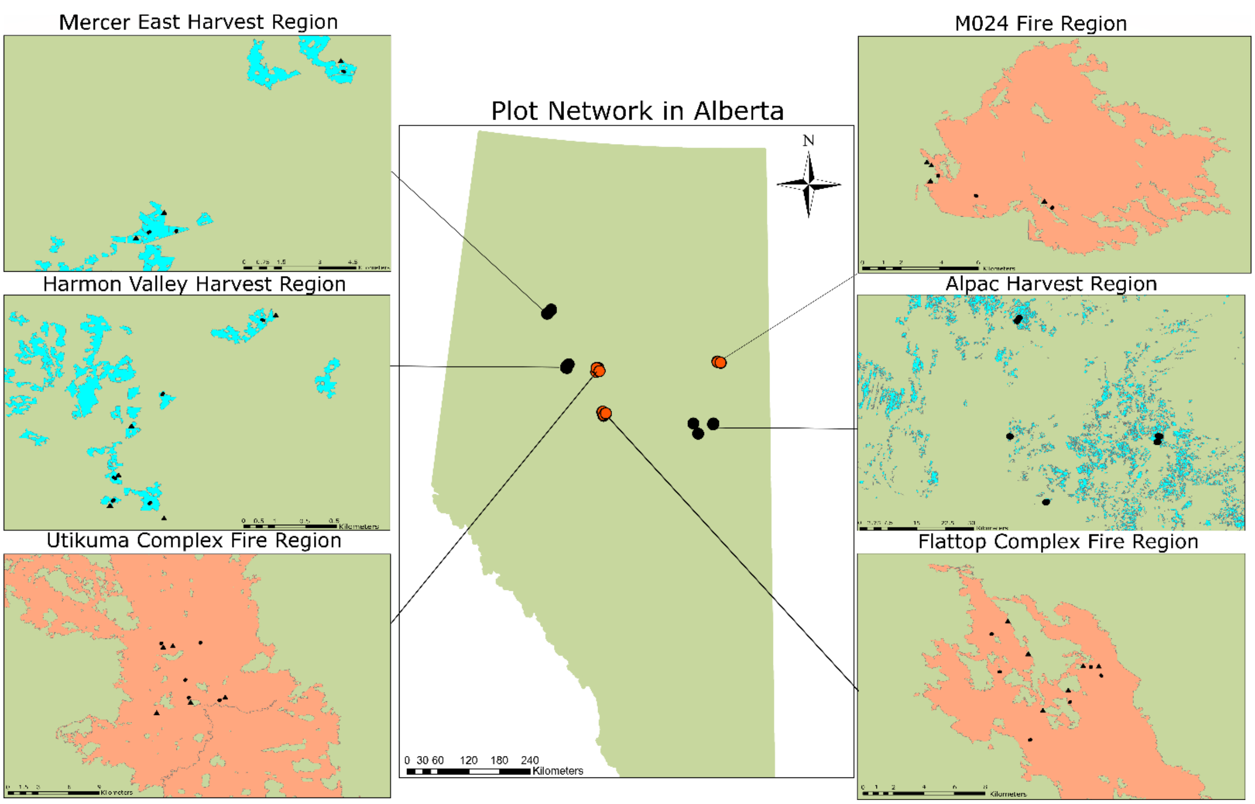

Figure 1. ArcMap of field sites located in northern Alberta. East Mercer harvest sites created in 2009-2010. Mercer-Harmon Valley harvest sites created in 2010. Utikuma fire sites created in 2011. Flattop fire sites created in 2011. Alpac harvest sites created in 2009-2012. M024 fire created in 2009. Map created by Marcel Schneider.

Plot Layout

A site consisted of a disturbed location, an island and a reference forest. A reference forest represented the closest continuous patch of undisturbed forest with a similar composition. Within each site we sampled six plots. Each of these islands were then paired with adjacent locations within the disturbance type (island, disturbed and reference forest). Each island, disturbance and reference were assigned an interior plot that did not border a different location and an edge plot that did. The island and disturbance plots were typically assigned to be adjacent to one another (Figure 2). The circular plots all had a radius of 11.28 metres (400 meter^2) (Provincial Growth and Yield Initiative 2015).

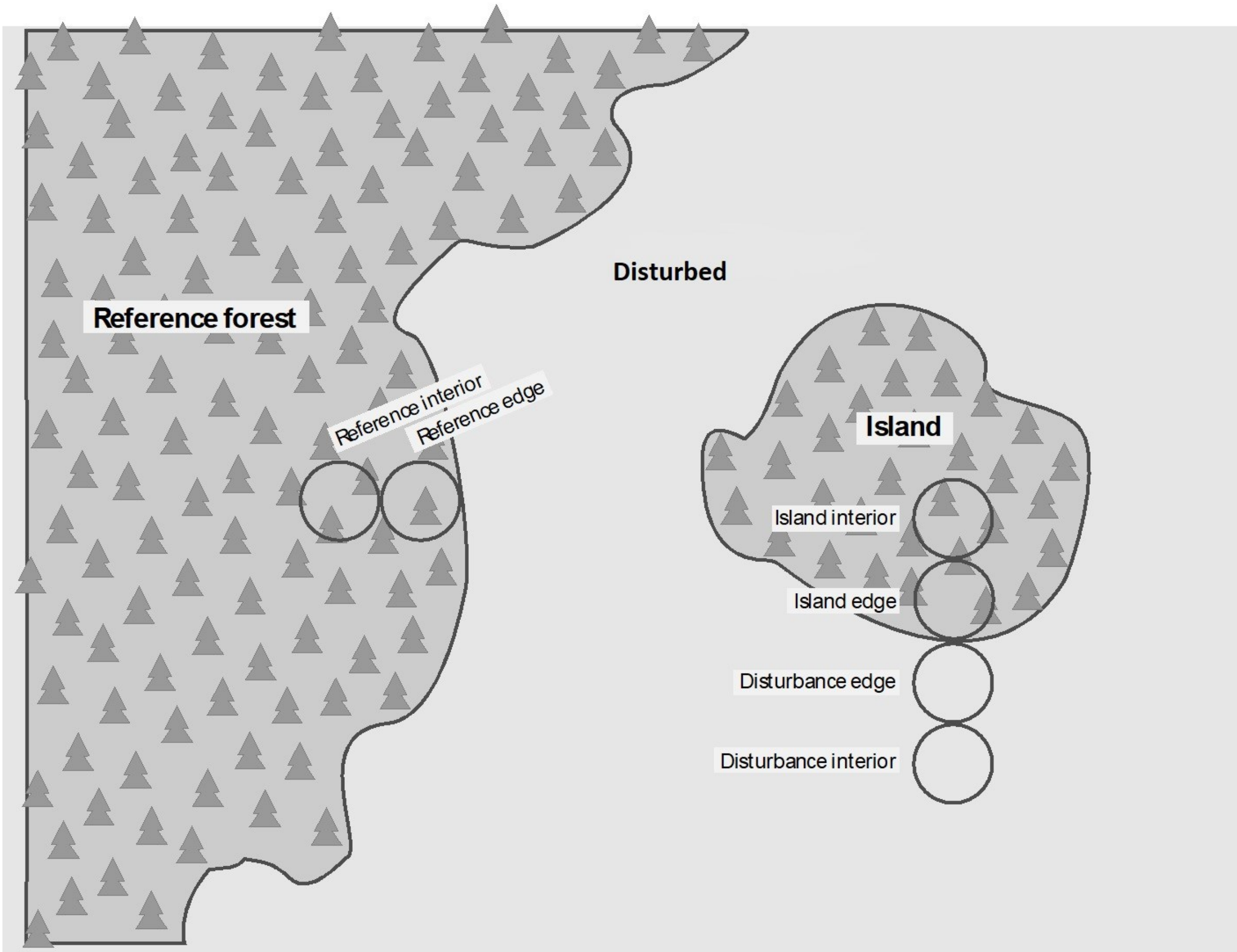

Figure 2. Sketch of a typical field site. Island (Remnant) location contained an interior and edge plot. Disturbed location (either fire or harvest) contained an interior and edge plot. Reference (used as control within larger matrix in same disturbance) contained an interior and edge plot. The centre point of each plot is 30 metres away from the centre of the accompanying plot.

Coarse Woody Debris Survey

Coarse woody debris was defined as standing dead and downed woody debris. To quantify downed woody debris at each sampling location I used the line-intercept method by laying out six transect lines in each plot at 0, 60, 120, 180, 240 and 300 degrees which can be seen in Figure 3 (Warren and Olsen 1964; De Vries 1979; Kaiser 1983; Max et al. 1996; Lee et al. 1997). All downed woody debris ≥ 7.5 cm and > 1 m long that crosses the transect at any point was recorded and measured, then assigned a decay class and, if possible, the species identified (Vegetation and Soil Monitoring Program 2019). Decay class was determined using the 5-category class system based upon a modified form of Pyle and Brown (1998) seen in Figure 4. Downed woody debris included dead tree and shrub boles, large limbs and other woody pieces. Trees leaning > 45° from vertical were counted using this collection strategy. Bark not attached to a log, roots below the collar and logs in extremely advanced decayed states that were reduced to slightly elevated 'humps' on the ground without structural integrity were excluded from this survey. Standing dead tree information was gathered by identifying the dead trees within the plot, assigning a decay class, recording DBH and attempting to identify species to the best of our abilities. For this method, standing dead trees > 9.1 cm DBH were included (Provincial Growth and Yield Initiative 2015). Using this strategy trees that were leaning ≤ 45° from vertical and had no leaves above DBH were recorded.

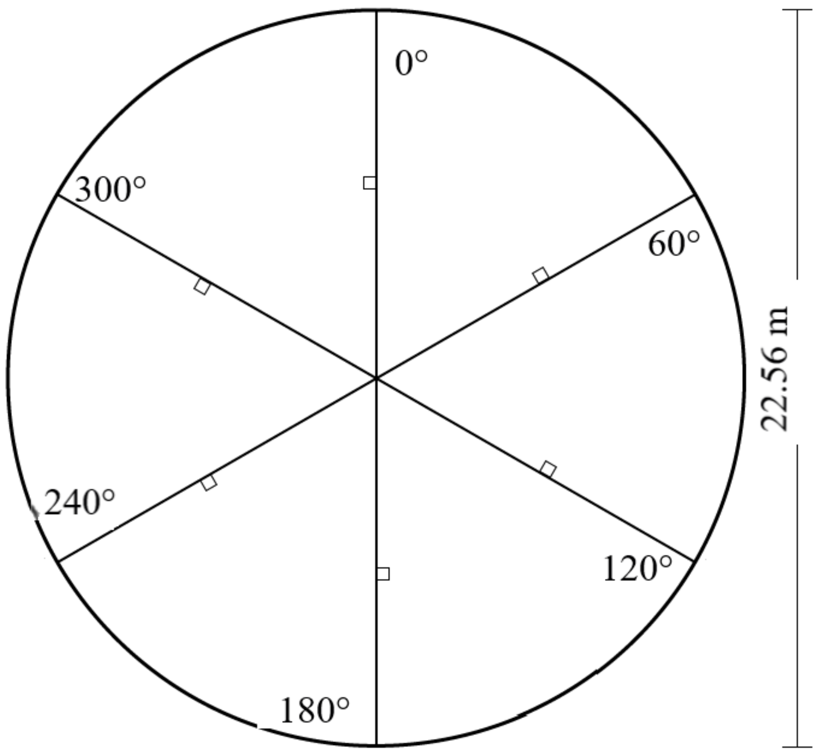

Figure 3. Line-intercept transect method. At each plot, six transect lines were laid out at 0, 60, 120, 180, 240 and 300 degrees. Each transect line was 11.28 metres in length, meaning the length of two back-to-back transects equaled the diameter of the plot (22.56 metres). These transect lines served as the basis for whether a log would be counted or not.

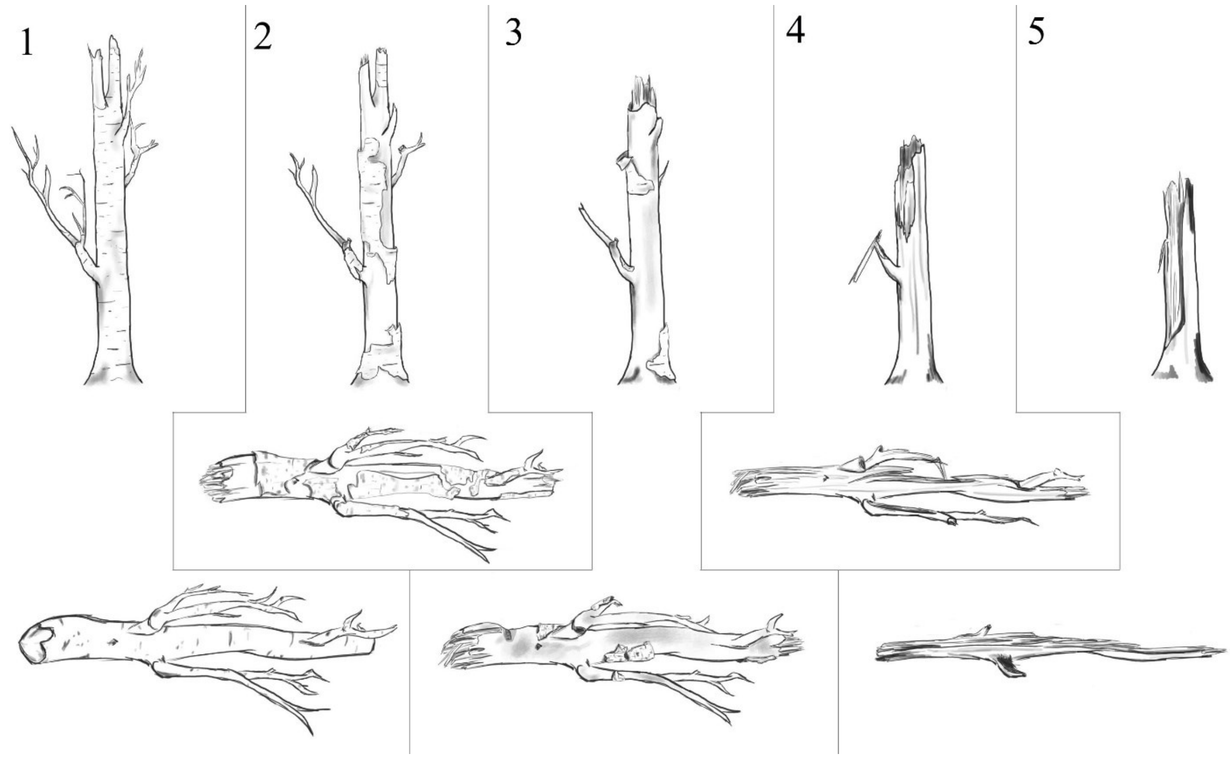

Figure 4. Illustration of the system of decay classification utilized for standing and downed coarse woody debris. Decay class 1: bark firmly attached, round and solid shape and fine branches remain. Decay class 2: bark present but decayed and not firmly attached, round and solid shape, some fine branches remain yet decayed. Decay class 3: bark generally absent unless *Betula* spp., round and firm shape, no fine branches left but larger branches still intact. Decay class 4: bark absent, oval or flatten shape that is no longer solid, no fine branches and larger branches not firmly attached. Decay class 5: bark absent, flat heap with no structural integrity, no large or fine branches. Adapted version of Maser et al. 1979. Sketch drawn by Lana Mrochuk.

As the focus of this study was on stand response to the fires and harvests occurring approximately one decade ago, data on coarse woody debris inventory was separated by decay class into recent deadwood (decay classes 1 and 2) and old deadwood (decay classes 3, 4 and 5), with the rationale that decay classes 1 and 2 would primarily reflect stand response to the events of interest. Previous work by Angers et al. (2012) and Petrillo et al. (2016) supports the assumption that the recent deadwood can be attributed to the disturbances that occurred in the last ten years. Angers et al. (2012) found that trembling aspen in the first two dead decay classes were dead for less than 10 years and that spruce in the same two decay classes averaged around 10 years. Using the aforementioned methods coarse woody debris volumes were estimated for recent deadwood, old deadwood (Appendix 4) and then combined for the total deadwood (decay classes 1-5) (Appendix 3).

Estimation of coarse woody debris volume

Huber's formula was used to estimate coarse woody debris volume from line intersect transect data using the diameter of each downed woody debris piece measured at the point of intersection with the transect line (Marshall et al. 2000).

$$\frac{\pi^2 \sqrt{1+\left(\frac{\%Slope}{100}\right)^2}}{8 * Slope\_length} * \sum_i^n Diam_i^2$$

This formula can be simplified to calculate coarse woody debris volume per hectare (m^3 / ha).

$$\frac{\pi^2}{8 * Horiz\_length} * \sum_i^n Diam_i^2$$

The calculation is made for each of the six transect lines in a plot. The volume of coarse woody debris volume per hectare for each plot is calculated as the average of the six transects in a plot. For standing dead volume per plot the volumes were gathered using the DBH applied to the species-specific equations developed by Lambert et al. (2005). The individual volumes for each tree were summed according to plot and converted to m^3/ha. Finally, the downed woody debris volume and the standing woody debris volumes were summed according to each plot to create a total coarse woody debris volume.

Stand attributes

Initial Stand Volume (ISV) was calculated as the summation of the current living volume and the recent deadwood volume (decay classes 1 and 2) (Moussaoui et al. 2016). The current living diameters were applied to the same species-specific equations developed by Lambert et al. (2005) from the data collected by Rosanise Odell through DBH forestry inventory methods. The values were summed by plot and converted to m^3/ha, then combined with the recent deadwood volumes to get the overall initial stand volumes for each plot (Moussaoui et al. 2016). Another stand attribute was the average Organic Layer depth (OL) of each plot collected by Marcel Schneider during his vegetation data collection in the same plots. Depths were sampled in each vegetation survey (three per plot) and were averaged. Island specific attributes, such as Island Perimeter (Prt) and Island Area (IA) were gathered from digitised islands on ArcGIS. The shape index was calculated using MacGarigal and Marks' (1995) equation.

Statistical analysis and model selection

Differences in coarse woody debris volume and mean diameter between post-fire and post-harvest sites were evaluated using a linear mixed effects model to include a random variable to account for the grouping in the data. The focus was on the recent coarse woody debris volume overall (reference, disturbance and island) and recent coarse woody debris volume of islands only. I wanted to separate islands to understand how fire islands and harvests islands compare independently of the disturbance and reference locations. Linear mixed models were created by exploring the effects of predictor variables/interaction of predictor variables. In all the models considered, the general area of sites (Alpac, Mercer Harmon Valley, Mercer West, S056

Complex, S027 Complex and M024 Complex) was treated as a random factor to account for potential non-independence among clustered sites. Models were created by exploring the effect of each variable and their interactions with each other. A stepwise model selection approach was taken by inputting a variable to see how it influenced the AIC value. Disturbance Type (DT) was the primary predictor used, although position of plot (Loc) (edge or interior) and location in a site (Loc2) (disturbed, reference or island) were considered as potential influences. Also, covariates, such as Initial Stand Volume (ISV), Region (Reg), Aspect (Asp), Island Perimeter (Prt), Island Area (IA), Shape Index (SI) and Organic Layer depth (OL) were included in island-specific models. Variables were split into base variables (DT, Loc and Loc2), characteristics of islands hypothesized to influence coarse woody debris creation, for example the shape of the island would influence the amount of area experiencing wind (Asp, Prt, IA and SI) and literature supported variables (ISV, Reg and OL). Once I found the factors that produced the most parsimonious model, I added interaction terms if they improved model fit. Models were compared using Akaike's Information Criteria (AIC) and the most parsimonious model chosen. Specifically, ΔAICc values were compared and those >2 were identified as less parsimonious (Burnham and Anderson 2002). Coarse woody volume debris was logarithmically transformed in all models to normalize residuals and homogenize variances. The most parsimonious models were evaluated to ensure assumptions of heteroskedasticity and uniformity were met. An ANOVA and post hoc test were conducted to assess how the predictor variables interacted with coarse woody debris (Moussaoui et al. 2016). Then, the top model was selected to explain the recent coarse woody debris volume overall (Table 2) and another one for the recent coarse woody debris volume of the islands (Table 3). All analysis was conducted using R Studio version 4.1.1.

Table 2. Candidate models tested for recent coarse woody debris volume accumulation in islands, references and disturbances using Akaike's information criteria and the most parsimonious model of the set. Predictor variables were location of plot within location (Loc2); location of plot in a site (Loc); disturbance type (DT); region of the province plot was located (Reg); initial stand volume in m^3/ha (ISV); organic layer depth in cm (OL). The number of parameters (K); Akaike's information criterion corrected for small sample sizes (AICc); Akaike's information criterion relative to the most parsimonious model (Delta AICc); Akaike's information criterion model weight (AICc Wt); Cumulative Akaike weights (Cum Wt); restricted log-likelihood of each model (Res LL).

Model	K	AICc	Delta AICc	AICc Wt	Cum Wt	Res LL
DT*Loc2	**8**	**208.33**	**0.00**	**0.90**	**0.90**	**-95.62**
DT*Loc2*Reg	14	212.76	4.42	0.10	1.00	-90.71
DT*Loc*Loc2	14	223.42	15.08	0.00	1.00	-96.04
DT+Loc2	6	224.10	15.77	0.00	1.00	-105.74
DT+Loc+Loc2	7	224.19	15.86	0.00	1.00	-104.68
DT+Loc+ISV	6	226.86	18.52	0.00	1.00	-107.12
DT+Loc2+Reg	7	226.96	18.62	0.00	1.00	-106.06
DT+ISV	5	227.71	19.37	0.00	1.00	-108.63
DT+Loc+Loc2+ISV	8	229.44	21.11	0.00	1.00	-106.18
DT+Loc2+ISV	7	230.05	21.72	0.00	1.00	-107.60
DT*ISV	6	230.46	22.13	0.00	1.00	-108.92
DT+Loc+Loc2+OL	8	231.04	22.70	0.00	1.00	-106.97
DT+Loc+ISV+OL	7	233.42	25.08	0.00	1.00	-109.29
DT+ISV+OL	6	233.92	25.59	0.00	1.00	-110.65
DT+Loc2+ISV+OL	8	236.32	27.98	0.00	1.00	-109.61
DT*Loc2*ISV	14	243.95	35.61	0.00	1.00	-106.31
DT*Loc*ISV	10	263.74	55.40	0.00	1.00	-121.02
DT*ISV*OL	10	272.87	64.53	0.00	1.00	-125.59
DT*Loc*Loc2*OL	26	295.71	87.38	0.00	1.00	-115.70
Null	3	301.18	92.85	0.00	1.00	-147.50
DT	4	302.90	94.56	0.00	1.00	-147.30
DT+Loc	5	304.64	96.31	0.00	1.00	-147.10
DT*Loc	6	307.96	99.63	0.00	1.00	-147.67
DT*Loc*Loc2*ISV	26	323.01	114.67	0.00	1.00	-129.35
DT*Loc*ISV*OL	18	356.34	148.00	0.00	1.00	-157.36
DT*Loc2*ISV*OL	26	358.91	150.57	0.00	1.00	-147.30

Table 3. Candidate models created to predict recent coarse woody debris (decay classes 1 & 2) volume in island remnants. Models tested using Akaike's information criteria and the most parsimonious model of the set. Predictor variables were location of plot within location (Loc2); location of plot in a site (Loc); disturbance type (DT); region of the province plot was located (Reg); initial stand volume in m3/ha (ISV); organic layer depth in cm (OL); shape index (SI); island perimeter (Prt); island area (IA); and aspect (Asp). The number of parameters (K); Akaike's information criterion corrected for small sample sizes (AICc); Akaike's information criterion relative to the most parsimonious model (Delta AICc); Akaike's information criterion model weight (AICc Wt); Cumulative Akaike weights (Cum Wt); restricted log-likelihood of each model (Res LL).

Model	K	AICc	Delta AICc	AICc Wt	Cum Wt	Res LL
Null	**3**	**79.69**	**0.00**	**0.68**	**0.68**	**-36.58**
DT	4	82.44	2.74	0.17	0.86	-36.76
DT+Loc	5	83.99	4.29	0.08	0.94	-36.30
DT+Loc+SI	6	85.91	6.21	0.03	0.97	-35.95
DT*Loc	6	87.13	7.44	0.02	0.98	-36.57
DT*Loc*SI	10	87.92	8.23	0.01	0.99	-31.07
DT+OL	5	90.49	10.80	0.00	1.00	-39.55
DT+Loc+OL	6	91.92	12.23	0.00	1.00	-38.96
DT+ISV	5	95.14	15.44	0.00	1.00	-41.87
DT+Loc+OL	6	96.65	16.96	0.00	1.00	-41.33
DT*OL	6	97.16	17.47	0.00	1.00	-41.58
DT+Loc+Prt	6	98.64	18.94	0.00	1.00	-42.32
DT+Loc+Asp	11	100.89	21.19	0.00	1.00	-35.88
DT+ISV+OL	6	103.34	23.64	0.00	1.00	-44.67
DT+Loc+ISV+Ol	7	104.73	25.04	0.00	1.00	-44.00
DT+Loc+Asp+Reg	12	105.58	25.88	0.00	1.00	-36.45
DT+Loc+IA	6	106.09	26.40	0.00	1.00	-46.05
DT+SI+IA	6	106.44	26.75	0.00	1.00	-46.22
DT*ISV	6	108.04	28.34	0.00	1.00	-47.02
DT+Loc+SI+IA	7	108.32	28.62	0.00	1.00	-45.79
DT*Loc*OL	10	114.40	34.70	0.00	1.00	-44.30
DT*Asp*Reg	19	119.47	39.77	0.00	1.00	-27.63

DT*Loc*ISV	10	137.83	58.14	0.00	1.00	-56.02
DT*Loc+Per	10	144.01	64.31	0.00	1.00	-59.11
DT*ISV*OL	10	147.80	68.11	0.00	1.00	-61.01
DT*SI*IA	10	160.89	81.20	0.00	1.00	-67.55
DT*Loc*Asp	26	165.90	86.20	0.00	1.00	-25.04
DT*Loc*IA	10	173.45	93.75	0.00	1.00	-73.83
DT*Loc*ISV*OL	18	228.93	149.23	0.00	1.00	-85.06
DT*Loc*SI*IA	18	248.94	169.24	0.00	1.00	-95.07
DT*Loc*Asp*Reg	36	326.13	246.44	0.00	1.00	-16.07

Results

Accumulation of coarse woody debris after harvest and fire

Exploratory data analysis between disturbance types revealed little variation in recent coarse woody debris volume between post-fire and post-harvest sites within references and islands (Figure 5).

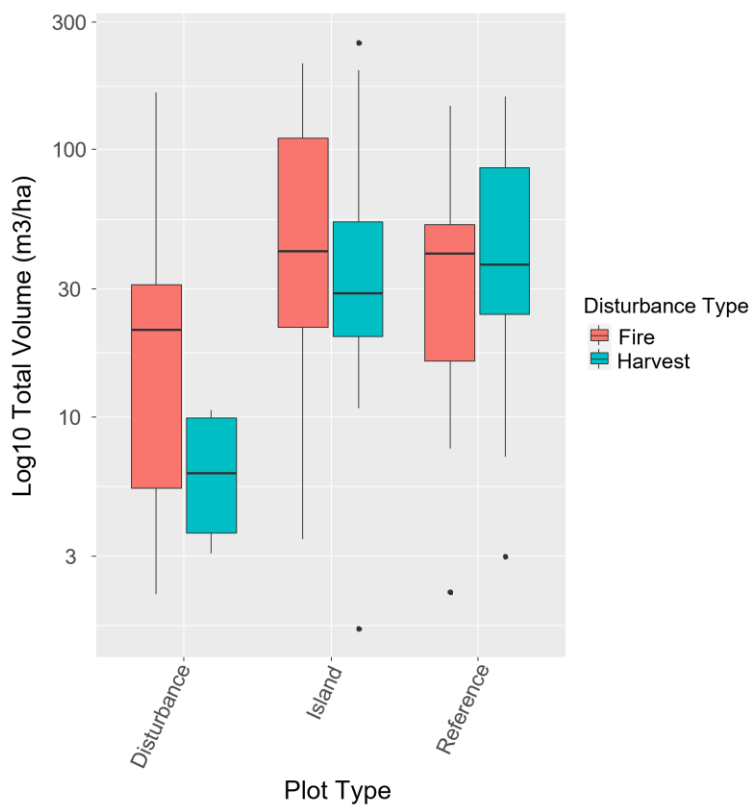

Figure 5. Boxplots show log10 of the total volume of decay classes 1 and 2 coarse woody debris compared between harvests and fires, according to the plot location.

The coarse woody debris volume of early decayed wood (decay class 1 and 2) for fire islands had an average volume of 42 m^3/ha and harvest islands averaged 31 m^3/ha. Fire islands had a larger variability in early decayed coarse woody debris volumes. Reference sites had an early decayed coarse woody debris volume around 27 m^3/ha for fire references and 40 m^3/ha for harvest references. The most parsimonious model explaining the volume accumulation of recent coarse woody debris identified the type of disturbance and the location of the plot (disturbance, island or reference) as influential covariates (Table 2). Figure 6 displays a post hoc test that shows recent coarse woody debris volume in a fire island differs from a fire disturbance, but it does not reveal any differences between corresponding locations (island-island, reference-reference or disturbance-disturbance) based on disturbance type (Table 4). There was slight evidence ($p = 0.07$) that a fire disturbed site had higher recent coarse woody debris volume compared to a harvest disturbance. This most parsimonious model for recent coarse woody debris volume explains 61% of the variance observed in the data (Table 4). The model created to isolate island specific sites/covariates did not provide evidence that disturbance type influenced recent coarse woody debris volume between post-fire and post-harvest island remnants.

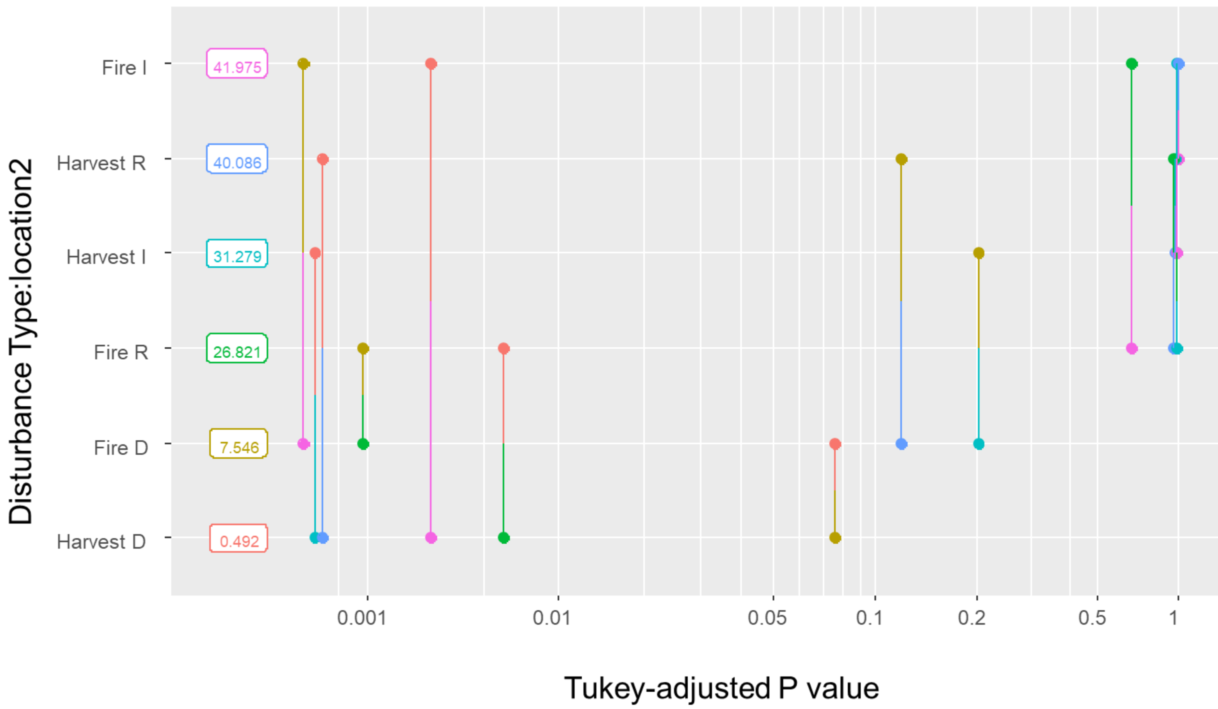

Figure 6. Tukey's test showing which groups in the sample differ. P-values on x-axis and different plots on the y-axis for the recent coarse woody debris volume model comparing all locations (islands, references and disturbances).

Table 4. Information for the most parsimonious model of the recent CWD volume for the log10 transformed data. Pseudo R^2 provides number on how well the predicted line fits the data points. List of fixed effects and their interactions with a p-value. The AIC value was 207.24 with a pseudo-R^2 total of 0.61.

Fixed Effects:	Est.	S.E.	t val.	d.f.	p
(Intercept)	0.93	0.15	6.15	6.19	0.00
Disturbance_TypeHarvest	-0.76	0.22	-3.49	6.56	0.01
location2I	0.70	0.12	5.61	130.94	0.00
location2R	0.51	0.12	4.13	131.30	0.00
Disturbance_TypeHarvest:location2I	0.63	0.18	3.49	131.01	0.00
Disturbance_TypeHarvest:location2R	0.93	0.19	4.88	132.00	0.00

p values calculated using Satterthwaite d.f.

Table 5. Summary statistics for the most parsimonious model of the recent coarse woody debris volume within the log10 transformed islands only data. Pseudo R^2 provides number on how well the predicted line fits the data points. List of fixed effects and their interactions with a p-value. The AIC value was 79.16 and the model has a pseudo-R^2 total of 0.01.

Fixed Effects:	Est.	S.E.	t val.	d.f.	p
(Intercept)	1.59	0.07	21.25	5.94	0.00

p values calculated using Satterthwaite d.f.

Effect of initial stand volume on coarse woody debris accumulation

Recent coarse woody debris volume did not appear to be influenced by initial stand volume. Post-fire and post-harvest islands and references had an average initial stand volume between 300 m^3/ha and 400 m^3/ha (Figure 7). The post-fire and post-harvest disturbed sites averaged around 0 m^3/ha to 30 m^3/ha. The initial stand volume did not appear to influence recent coarse woody debris mean diameters. The most parsimonious linear mixed models created for volume accumulation and mean diameter did not include initial stand volume.

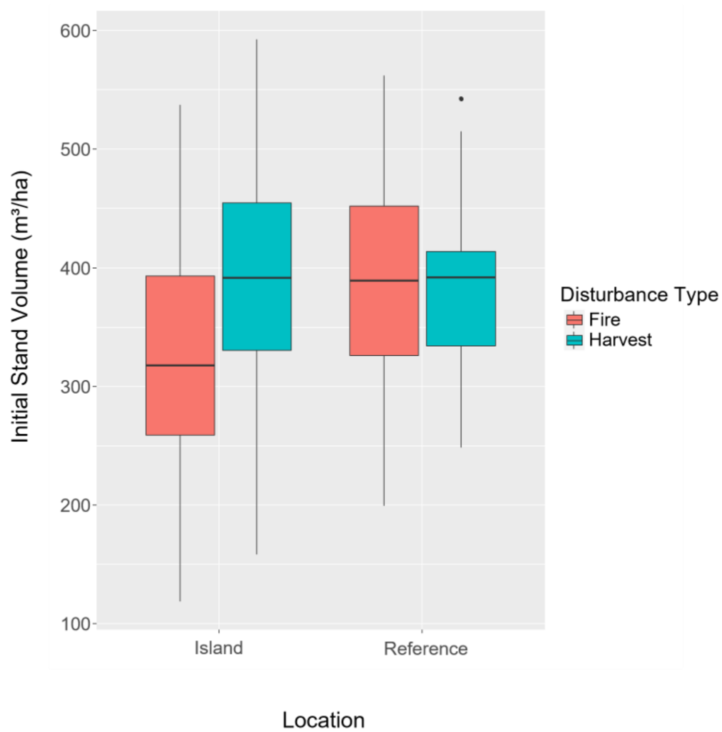

Figure 7. Boxplot comparison of the initial stand volume between harvests and fires, according to plot location. Initial stand volume was calculated by summing the living tree volumes and the dead decay classes 1 & 2.

Impact of fire and harvest on recent coarse woody debris diameters

It appears, in Figure 8, that the distribution of deadwood diameters is similar between harvests islands and fire islands. The null models created for coarse woody debris diameters for all plot locations (references, islands and disturbances) and the island specific covariates were identified as the most parsimonious (Appendices 1 and 2). Fire islands averaged 15 cm in diameter of early decayed coarse woody debris and harvest islands averaged 17 cm in diameter. Fire references had an average coarse woody debris diameter of 14 cm in early decayed trees and harvest islands averaged 17 cm in diameter.

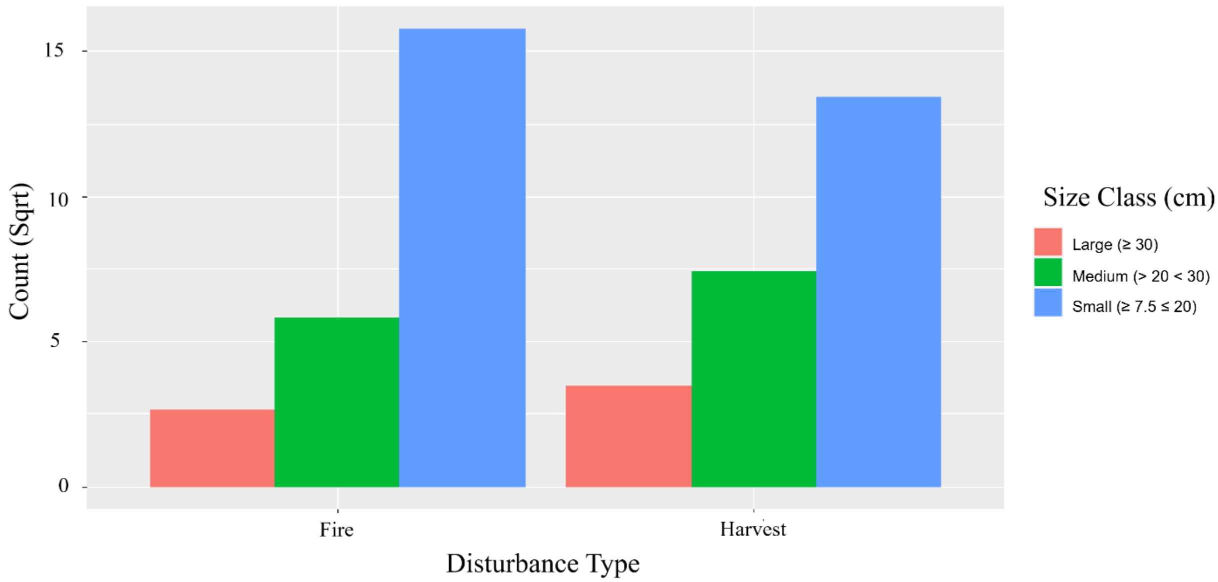

Figure 8. Bar graph displaying the distribution of recent coarse woody debris sizes between harvests and fires for islands only. The total counts have been square rooted.

Species diversity in post-fire and post-harvest island remnants

All the studied areas were >60% deciduous, but their understories varied. The recorded recent coarse woody debris species shows a similar distribution of dominant species, such as *Populus* spp. and *Picea* spp. although there appears to be more deadwood species diversity in fire sites compared to harvest sites (Figure 9). Due to the large quantity of unknown coarse woody debris species, a more detailed analysis was not possible.

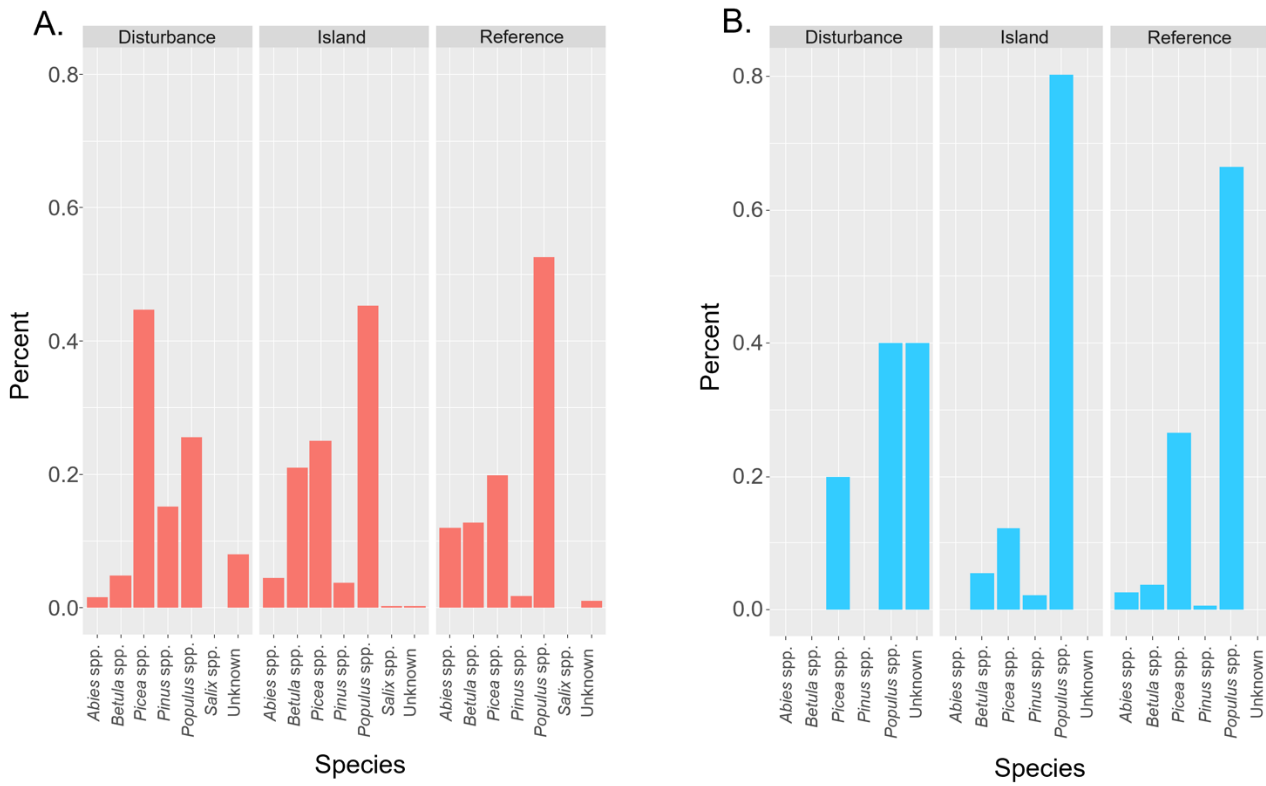

Figure 9. Bar graphs displaying the species composition of the recent dead trees in A. fire and B. harvests according to the plot location.

Discussion

Deadwood recruitment in post-fire and post-harvest island remnants

Coarse woody debris volume influences habitat quality and availability, which thereby influences the biodiversity the stand can support (Brassard and Chen 2006). The similarity between recent coarse woody debris volumes in post-fire and post-harvest stands suggests that the islands can function to support analogous levels of diversity regardless of the island's creation method. This finding contradicts the research of Moussaoui et al. (2016) in northern Quebec. Variation between our results may be because they conducted their surveys in black spruce forests with disturbances that occurred from 1-37 years prior to data collection. The references, which we used as controls, did not differ in recent coarse woody debris volume accumulation between post-fire and post-harvest island remnants. These result means our islands and references responded similarly to the disturbances, whether the disturbances surrounded the stand (island) or was adjacent to it (reference). Although not significant, the greater volumes seen in fire disturbances compared to harvest disturbances are to be expected. A fire disturbance consumes fine fuels and leaves behind larger woody debris, often not immediately killing all the living trees, while harvests cut and remove the larger logs and leave behind the fine woody debris (Brassard and Chen 2008). Nevertheless, the comparison of the recent coarse woody debris in a fire disturbance to a harvest disturbance can be misleading. The type of decay classification method used does not account for burned logs. For example, charred coarse woody debris created by a fire would be classified as decay class 3 because it does not present fine branching or bark. Little research has developed a method for addressing the decay classification of burnt logs. One such paper by Tinker and Knight (2000) used the concave trenches on the forest floor to indicate the presence of decay class 3-5 logs on the landscape. Unfortunately, this method would not work for plot surveys 10 years after the disturbance. Charring occurred in <1% of the collected data, but it is possible the fine branching or bark could have been burned and not shown signs of char years after the disturbance. Therefore, the estimated volume of recent coarse woody debris in fire disturbances may be higher than what is presented. Ultimately, this calculation does not influence the main comparison of the island remnants. Outside of the chosen model in Table 2 the additional covariates did not produce a more parsimonious model. This means the position of plot (Loc), Region of the province the plot was located (Reg), Initial Stand Volume in m^3/ha (ISV), Organic Layer depth in cm (OL), Island Perimeter (Prt), Island Area (IA), Shape Index (SI) and Aspect (Asp) were not linked to the recent coarse woody debris volume accumulation in this study. The similarity in recent coarse woody debris volumes between post-fire and post-harvest islands assists the idea that harvest islands can support equivalent amounts of biodiversity as fire islands and justifies the use of ecosystem-based management in the mixedwood forests of northern Alberta.

Initial stand volume influence on recent coarse woody debris accumulation

The forest stands we surveyed did not have initial stand volumes recorded before the disturbances occurred. Therefore, the calculation of the initial stand volumes provided insight into the original stand characteristics. A study investigating lichen and nonvascular flora within different types of residuals in Sweden supported the positive effects of residual stand structure on overall biodiversity (Perhans et al. 2007). Moussaoui et al. (2016) expanded on this finding stating that the greater initial stand volumes result in post-disturbance stands with greater deadwood volumes. They found that stands with an initial stand volume >60 m^3/ha would generate more coarse woody debris over time (Moussaoui et al. 2016). In my study, the initial stand volume did not influence recent coarse woody debris volumes. This is likely due to the similarity of the initial stand volumes between post-fire and post-harvest sites. Unlike the black spruce stands studied by Moussaoui et al. (2016), the deciduous dominated stands we studied were more dense averaging 300-400 m^3/ha within post-harvest and post-fire islands and references. This means the mixedwood boreal forest can act as a suitable location for forest managers to emulate post-fire residuals.

Influence of edge effects on post-fire and post-harvest island remnants

My study found that edge effects did not influence recent coarse woody debris volume accumulations or mean diameters. Harper et al. (2004) found contradicting results suggesting that the edges of post-fire and post-harvest sites exhibited more coarse woody debris volume than their interior sites. This study was conducted on black spruce forests in northern Quebec with a focus on disturbances ranging from 3-5 years old. Harper et al. (2004) identified that post-harvest edge effects extend up to 5 meters into the forest, while post-fire edge effects can extend up to 40 meters into the forest. It is likely that 10 years after the disturbance the edge boundaries for fire and harvests changed and influenced our sampling location. We determine the edge of an island or reference as the first visible line of living trees, but the original edge could have slowly died back to the edge we measured causing our collection to be skewed towards more interior conditions. It is, also, possible that the higher stand volumes in deciduous forests would prevent windthrow that often causes edge effects (Heithecker and Halpern 2007). The multi-directional transect lines would have been useful if windthrow had caused trees to fall parallel to one another, but that phenomenon was not observed in the field or in the plot photos. The increase in deadwood at the edges occurs because interior forest stands are not adapted to weather the same microclimatic conditions a forest edge experiences. Along these new edges the trees that remain, after initial windthrow, display crown dieback and reduced vigor, which causes mortality

(Jönsson et al. 2007; Steventon 2011). The research reported here shows that post-harvest edges effectively emulate post-fire edges, which supports the use of ecosystem-based management.

Deadwood diameter and species distributions in post-fire and post-harvest stands

The diverse ecological function of coarse woody debris at a variety of different sizes and species are necessary to support an ecosystem (Jönsson and Jonsson 2007). We found that the diameter distribution and the mean diameters between post-fire and post-harvest island remnants did not differ. Although fire and harvest disturbances have been recorded to generate different distributions of coarse woody debris, their remnants do not show a similar pattern (Brassard and Chen 2008). The equivalent distribution of recent coarse woody debris diameters means that post-harvest island remnants can provide a similar habitat and ecological structure as post-fire remnants.

Due to the decomposition state of many logs and snags it was not possible to assign specific species to every coarse woody debris entry. Therefore, it was difficult to compare differences in species composition between post-fire and post-harvest islands. Although this would have been an interesting observation without pre-disturbance compositions, it would be difficult to determine if the disturbance created the recent coarse woody debris distribution or if it was the original stand characteristics. Nevertheless, it appears that the post-fire island remnants displayed more recent coarse woody debris diversity than post-harvest islands. This has more to do with the differences between the preferences of fires and harvests than the disturbances themselves. Fire residuals typically contain more moisture, which means they contain tree species that tolerate moist environments, such as *Abies* spp., *Betula* spp., *Alnus* spp. and *Salix* spp. Unless the selection of harvest residuals mimics that of fire residuals, there will be some variation in recent coarse woody debris species.

Conclusions and Applications

Outside of species diversity, there is little evidence that coarse woody debris differs between residual patches of trees from fires and retained patches of trees in harvest sites in northern Alberta's mixedwood forests. It appears that harvest island remnants created through ecosystem-based management have been able to emulate structure of coarse woody debris in the natural disturbances, such as wildfires, within the 10 years post-disturbance. This is an important discovery because it supports the current application of forestry practices in western Canada as well as embracing adaptive management, but this finding does not mean the two island types will not diverge as time progresses. It is likely that fire edges will allow more tree mortality as time progresses causing the islands to differential as time continues. Another discovery from this study was the difficulties involved in the observational approach. These study sites were not optimal and other influences could have impacted the results due to the inability to control all aspects of the experiment. Meanwhile, an experimental approach, as attempted with EMEND, proved to be difficult in emulating wildfires because the controlled burns could only be conducted on non-fire conducive days, which would not simulate true wildfire conditions. Regardless of the approach it is important for researchers to continue studying this topic as the climate continues to change. Fires are predicted to become more common and their increase in frequency can threaten ecological systems that have adapted to mosaic formation (Hanes et al. 2019; Erni et al. 2017). Fires that ignite during a drought will reduce island size and abundance (Eberhart and Woodard 1987; Kolden et al. 2012). Therefore, adaptive management practices of leaving behind remnants would artificially act as the lifeboats flora and fauna need to survive a disturbance. To ensure forest industries select ecologically viable remnants the Government of Alberta has established protocols for each retention block. Island remnants should contain structural complexity and old-growth attributes, a continuum of deadwood structure and overall site quality (Government of Alberta 2022). Aligning the criteria for island creation using this type of adaptive management can preserve the ecological integrity of forest stands by maintaining coarse woody debris volumes and attributes to natural levels.

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Appendices

Appendix 1. Candidate models for recent coarse woody debris mean diameter (decay classes 1 & 2) using log10 transformed data. Models tested using Akaike's information criteria and the most parsimonious model of the set. Predictor variables were location of plot within area (Loc2); location of plot in a site (Loc); disturbance type (DT); region of the province plot was located (Reg); initial stand volume in m^3/ha (ISV); organic layer depth in cm (OL). The number of parameters (K); Akaike's information criterion corrected for small sample sizes (AICc); Akaike's information criterion relative to the most parsimonious model (Delta AICc); Akaike's information criterion model weight (AICc Wt); Cumulative Akaike weights (Cum Wt); restricted log-likelihood of each model (Res LL).

Model	K	AICc	Delta AICc	AICc Wt	Cum Wt	Res LL
Null	**3**	**-176.68**	**0**	**0.78**	**0.78**	**91.45**
DT	4	-174.09	2.59	0.21	1.00	91.22
DT+Loc	5	-165.88	10.80	0.00	1.00	88.21
DT+Ct	5	-162.03	14.65	0.00	1.00	86.28
DT+ISV	5	-161.53	15.15	0.00	1.00	86.04
DT+Loc2	6	-159.37	17.31	0.00	1.00	86.07
DT+Loc	6	-159.19	17.49	0.00	1.00	85.97
DT+Loc2+ISV	7	-153.42	23.26	0.00	1.00	84.22
DT+Loc+ISV	6	-153.28	23.40	0.00	1.00	83.02
DT+ISV+OL	6	-151.91	24.78	0.00	1.00	82.33
DT+Loc2+Reg	7	-151.70	24.98	0.00	1.00	83.36
DT+Loc+Loc2	7	-151.10	25.59	0.00	1.00	83.06
DT*Ct	6	-150.33	26.35	0.00	1.00	81.55
DT*Ct	8	-147.77	28.91	0.00	1.00	82.55
DT+Loc2+Ct	7	-146.73	29.95	0.00	1.00	80.88
DT+Loc+Loc2+ISV	8	-145.04	31.65	0.00	1.00	81.18
DT+Loc+ISV+OL	7	-143.66	33.02	0.00	1.00	79.35
DT*ISV	6	-143.50	33.18	0.00	1.00	78.13
DT+Loc2+ISV+OL	8	-142.96	33.72	0.00	1.00	80.15
DT+Loc+Loc2+OL	8	-141.13	35.55	0.00	1.00	79.23
DT*Loc2*Reg	14	-117.01	59.67	0.00	1.00	74.57
DT*Loc*Loc	14	-112.68	64.00	0.00	1.00	72.40
DT*Loc*ISV	10	-94.51	82.17	0.00	1.00	58.29

DT*Loc2*Ct	14	-92.86	83.82	0.00	1.00	62.49
DT*Loc2*ISV	14	-84.45	92.23	0.00	1.00	58.28
DT*ISV*OL	10	-81.64	95.04	0.00	1.00	51.86
DT*Loc*Loc2*OL	25	-15.88	160.80	0.00	1.00	40.08
DT*Loc*ISV*OL	18	25.19	201.87	0.00	1.00	8.89
DT*Loc*Loc2*ISV	25	33.19	209.87	0.00	1.00	15.55
DT*Loc2*ISV*OL	26	72.63	249.31	0.00	1.00	-2.51

Appendix 2. Candidate models for recent coarse woody debris mean diameter (decay classes 1 & 2) for islands only using log10 transformed data. Models tested using Akaike's information criteria and the most parsimonious model of the set. Predictor variables were location of plot within area (Loc2); location of plot in a site (Loc); disturbance type (DT); region of the province plot was located (Reg); initial stand volume in m3/ha (ISV); organic layer depth in cm (OL); shape index (SI); island perimeter (Prt); island area (IA); and aspect (Asp). The number of parameters (K); Akaike's information criterion corrected for small sample sizes (AICc); Akaike's information criterion relative to the most parsimonious model (Delta AICc); Akaike's information criterion model weight (AICc Wt); Cumulative Akaike weights (Cum Wt); restricted log-likelihood of each model (Res LL).

Model	K	AICc	Delta AICc	AICc Wt	Cum Wt	Res LL
Null	**3**	**-53.31**	**0**	**0.96**	**0.96**	**29.94**
DT	4	-46.60	6.72	0.03	1.00	27.79
DT+Loc	5	-39.24	14.07	0.00	1.00	25.37
DT+Loc+SI	6	-38.75	14.56	0.00	1.00	26.69
DT+OL	5	-37.01	16.30	0.00	1.00	24.25
DT+ISV	5	-36.49	16.82	0.00	1.00	24.00
DT+Ct	5	-33.94	19.37	0.00	1.00	22.72
DT+SI+Ct	6	-33.27	20.04	0.00	1.00	23.95
DT*Loc	6	-33.18	20.14	0.00	1.00	23.66
DT+Loc+OL	6	-29.52	23.79	0.00	1.00	21.84
DT+Loc+ISV	6	-28.93	24.39	0.00	1.00	21.54
DT*OL	6	-27.90	25.42	0.00	1.00	21.02
DT+ISV+OL	6	-27.15	26.16	0.00	1.00	20.65
DT+Loc+Ct	6	-26.60	26.71	0.00	1.00	20.38
DT+Loc+Per	6	-25.16	28.15	0.00	1.00	19.89
DT*Ct	6	-23.30	30.02	0.00	1.00	18.73
DT*Loc*SI	10	-21.70	31.62	0.00	1.00	24.78
DT+SI+IA	6	-20.45	32.86	0.00	1.00	17.54
DT*ISV	6	-19.72	33.60	0.00	1.00	16.94
DT+Loc+ISV+OL	7	-19.38	33.94	0.00	1.00	18.16
DT+Loc+IA	6	-17.76	35.55	0.00	1.00	16.19
DT+Asp+Reg	11	-16.74	36.58	0.00	1.00	24.26
DT+Loc+Asp	11	-14.40	38.91	0.00	1.00	23.09

DT+Loc+SI+IA	7	-12.55	40.77	0.00	1.00	15.08
DT+Asp+Ct	11	-10.39	42.92	0.00	1.00	21.09
DT*SI*Ct	10	-8.80	44.51	0.00	1.00	18.33
DT+Loc+Asp+Reg	12	-7.35	45.96	0.00	1.00	21.67
DT*Loc*OL	10	3.54	56.85	0.00	1.00	11.37
DT*Loc*Ct	10	10.04	63.36	0.00	1.00	8.12
DT*Loc*ISV	10	27.66	80.97	0.00	1.00	-0.69
DT*Asp*Reg	18	29.60	82.91	0.00	1.00	20.30
DT*Loc*Per	10	32.53	85.84	0.00	1.00	-2.34
DT*ISV*OL	10	38.57	91.88	0.00	1.00	-6.14
DT*SI*IA	10	45.32	98.63	0.00	1.00	-8.73
DT*Loc*IA	10	61.56	114.88	0.00	1.00	-16.85
DT*Loc*ISV*OL	18	146.83	200.14	0.00	1.00	-42.75
DT*Loc*Asp	26	149.38	202.69	0.00	1.00	9.81
DT*Loc*SI*IA	18	169.66	222.97	0.00	1.00	-49.73
DT*Asp*Ct	26	192.55	245.86	0.00	1.00	-11.77
DT*Loc*Asp*Reg	34	651.48	704.79	0.00	1.00	5.76

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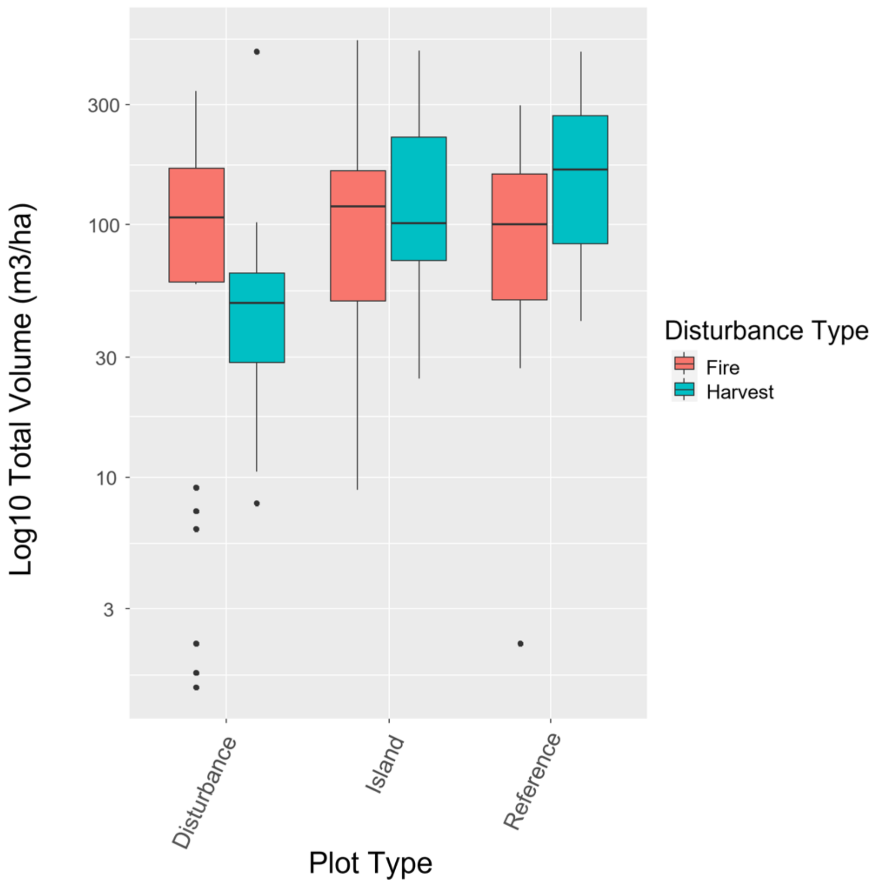
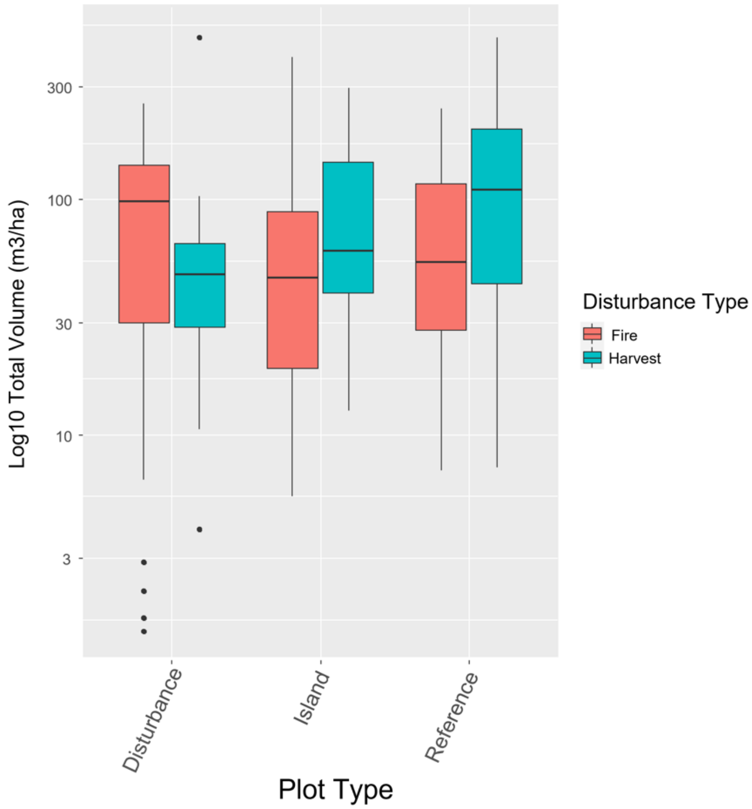
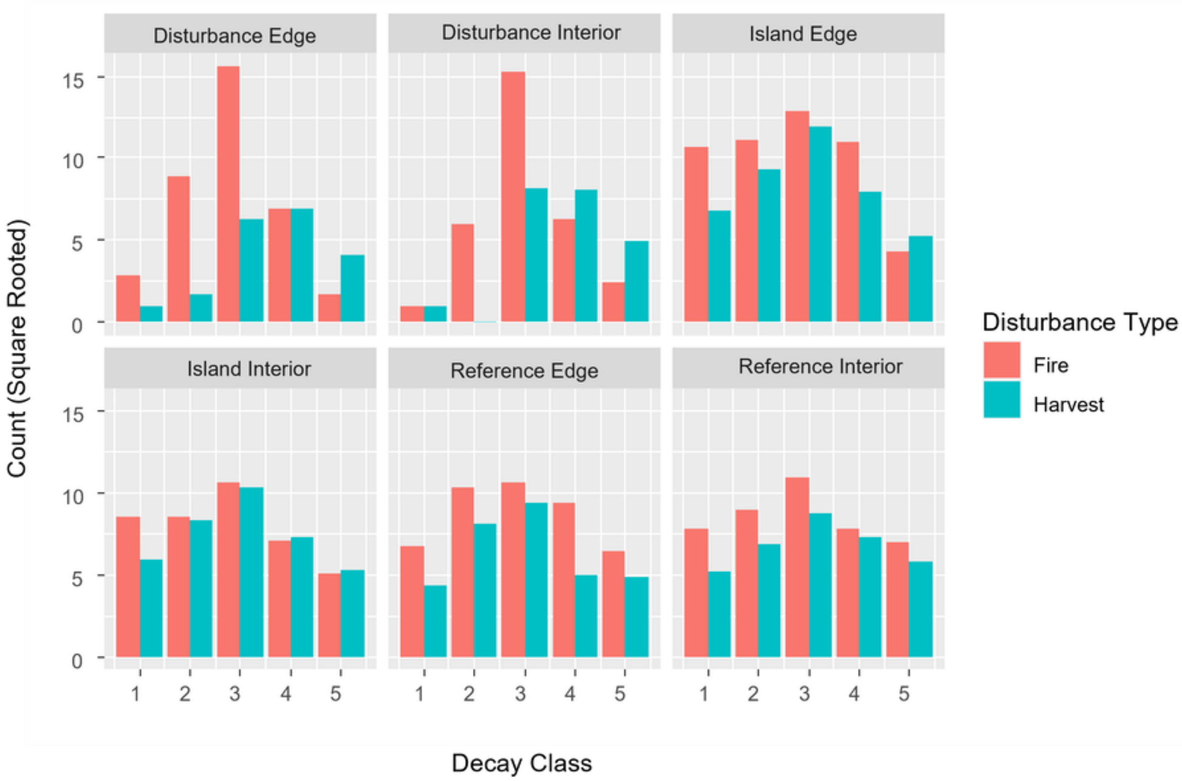


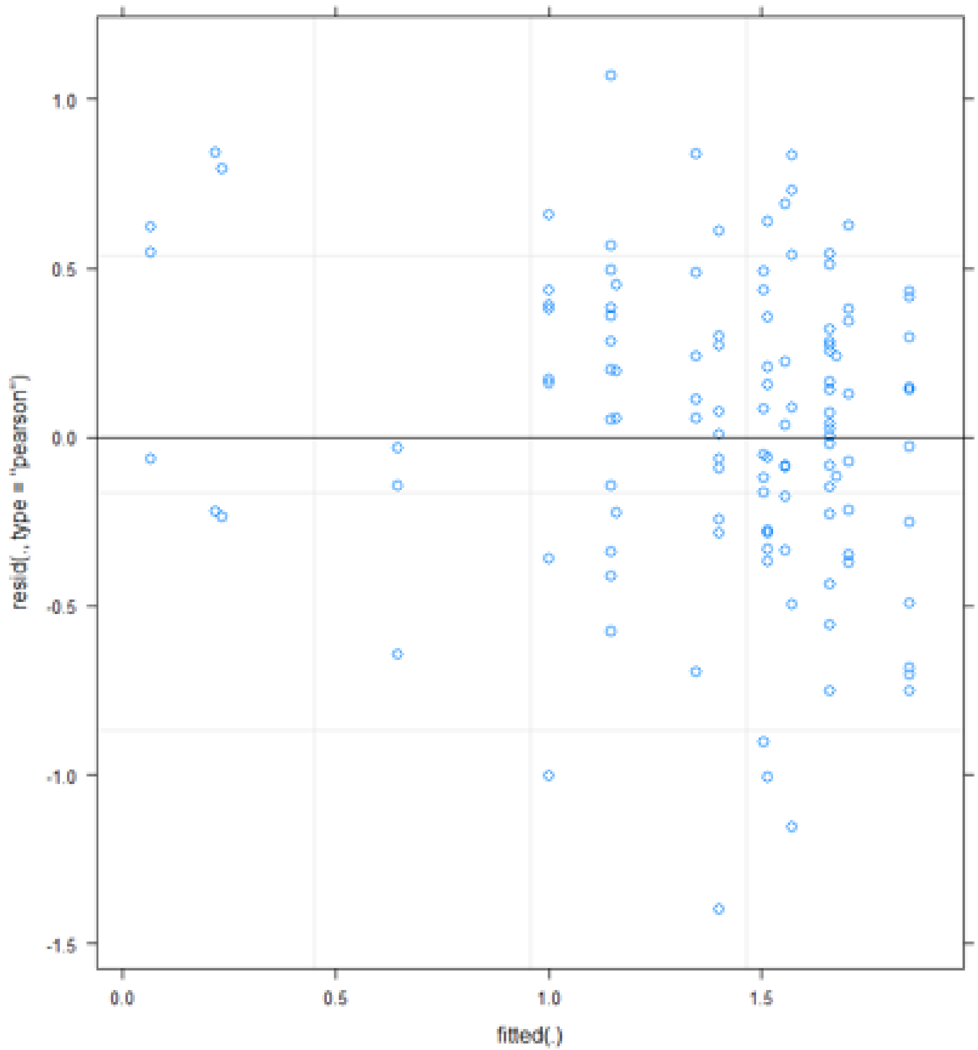
Appendix 3. Boxplots show debris of log10 transformed volumes of decay classes 1-5 compared between harvests and fires, according to the plot type.



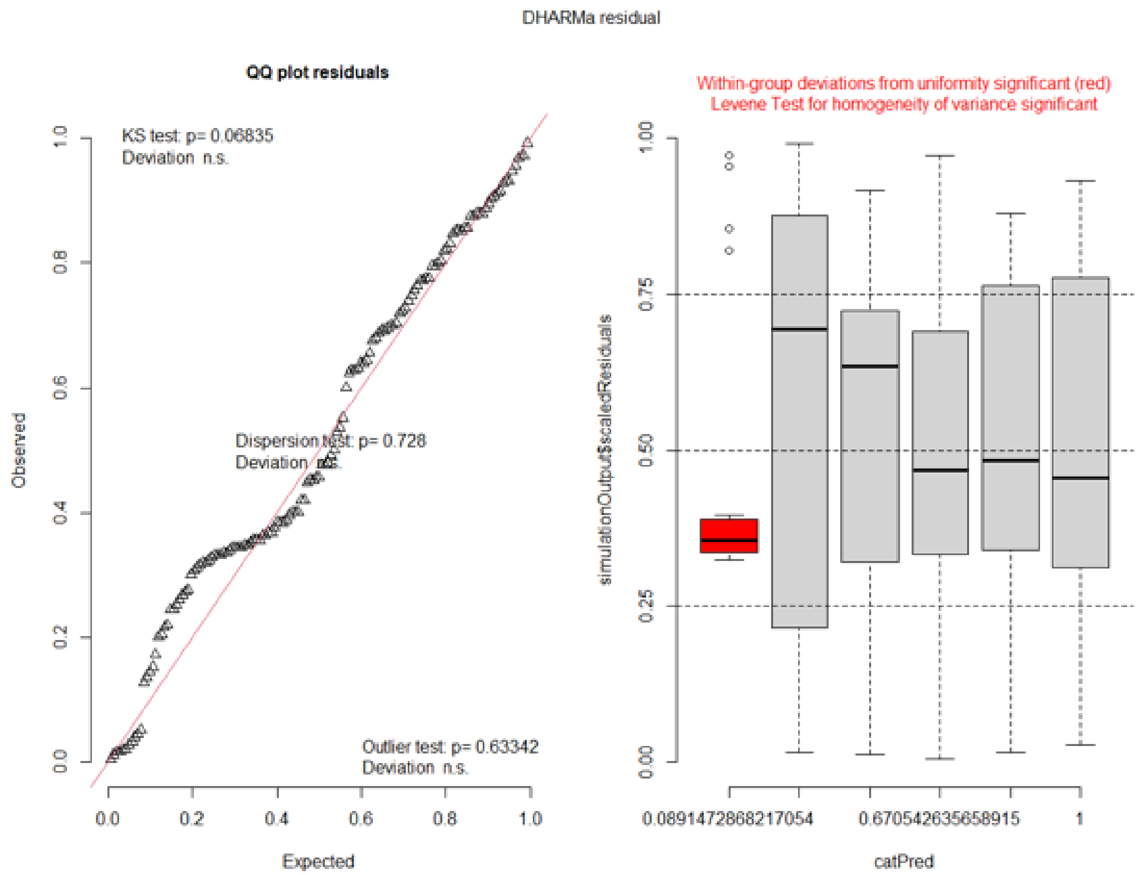
Appendix 4. Boxplots show log10 transformed debris volumes of decay classes 3-5 compared between harvests and fires, according to the plot type.



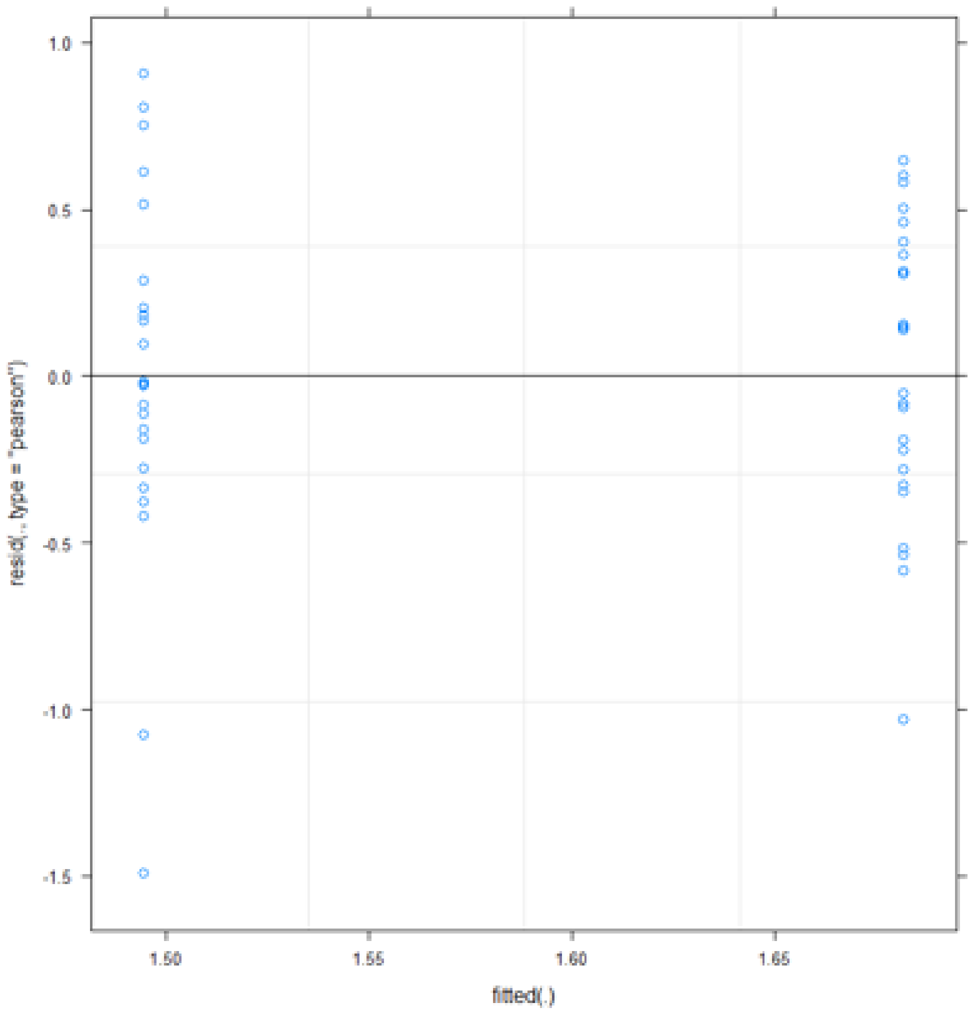
Appendix 5. Bar graphs show coarse woody debris log abundance of decay classes 1 and 2 compared between harvests and fires, according to the plot location.



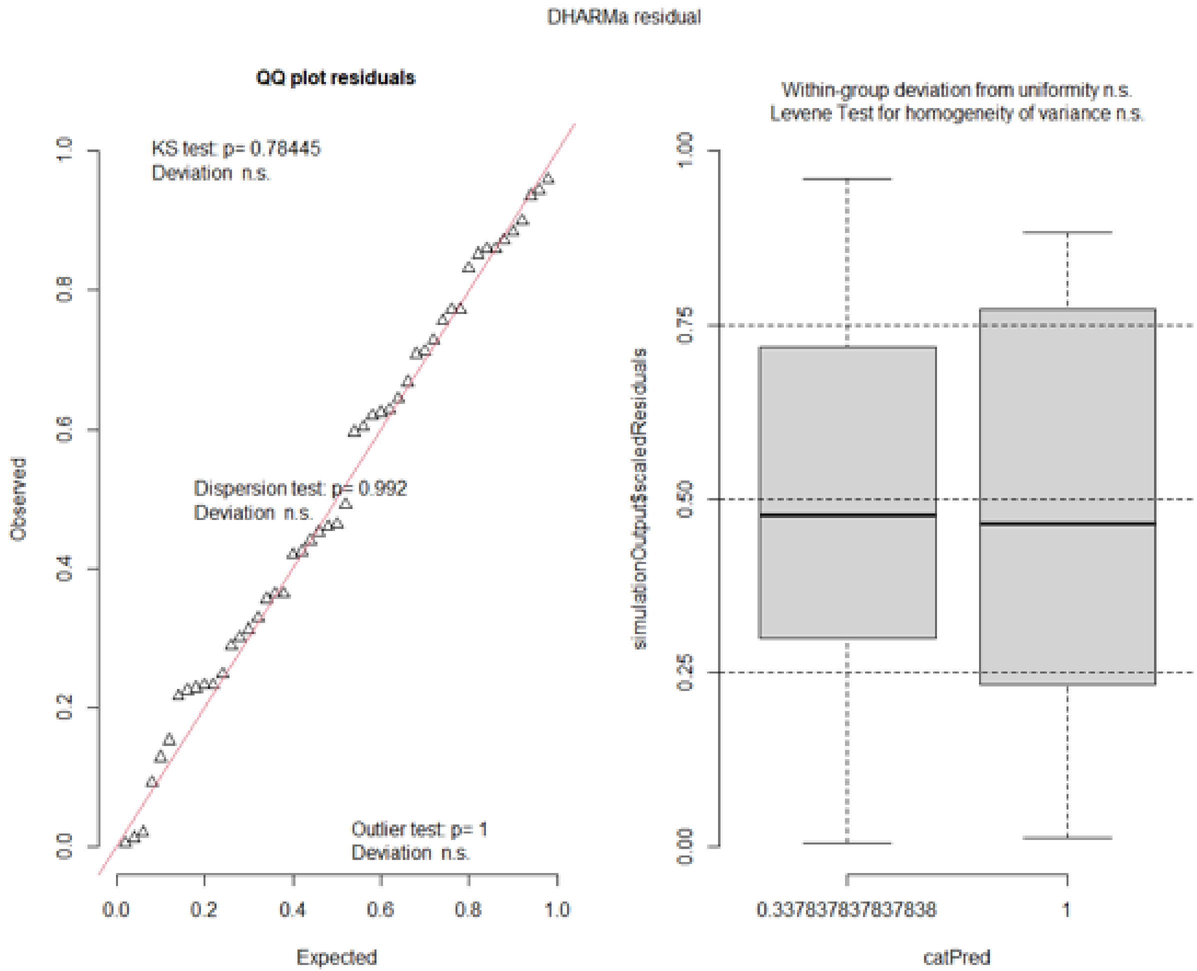
Appendix 6. Diagnostic plot of the residuals for chosen model in Table 1. Recent coarse woody debris volume modelled with Loc2 and disturbance type (DT). Plot tests for heteroskedasticity.



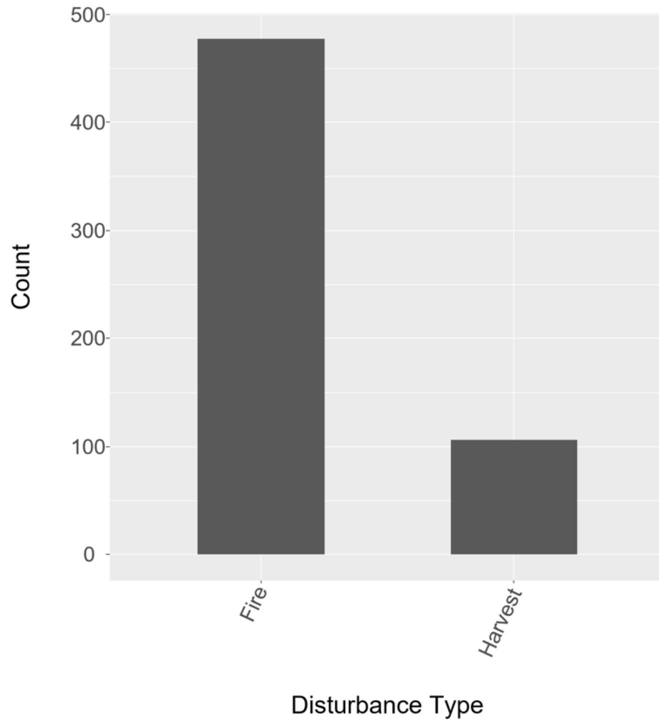
Appendix 7. DHARMa residual tests for selected model in Table 1 using disturbance type and Loc2. The QQ-plot is used to detect deviations from the expected distribution using the model. The Residuals vs Predicted plot displays the residuals against the predicted value. If there are data points outside of the simulated range they will be highlighted as red.



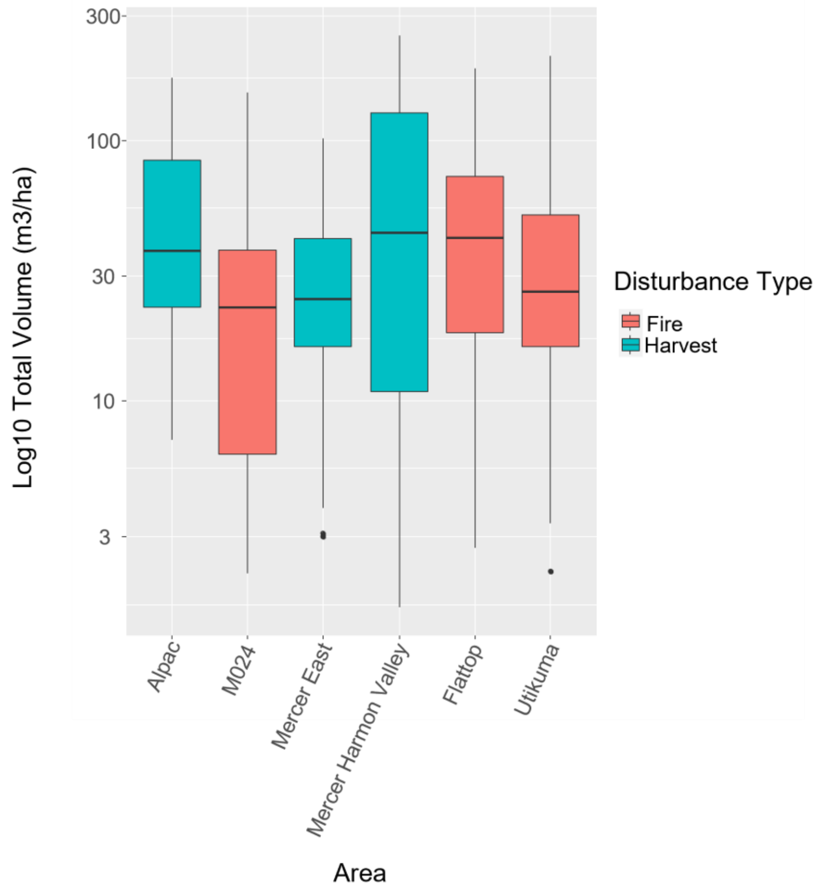
Appendix 8. Diagnostic plot of the residuals for selected null model in Table 5. Plotting the residuals against the fitted values allows for the detection of heteroscedasticity.



Appendix 9. DHARMa residual tests for the selected null model in Table 5. The QQ-plot is used to detect deviations from the expected distribution using the model. The Residuals vs Predicted plot displays the residuals against the predicted value. If there are data points outside of the simulated range they will be highlighted as red.



Appendix 10. Plot comparing total count of decay class 3 coarse woody debris between fire and harvest disturbances. Because the method of decay classification does not account for burnt logs it is possible that some of the decay class 3 logs in fires belong in the recent categorization.



Appendix 11. Plot showing the recent coarse woody volume accumulation transformed by log10 by the six disturbance areas (Alpac, Mercer East, Mercer Harmon Valley, M024 Fire, Flattop Fire and Utikuma Fire).