

Supplementary material for

Generating annual estimates of forest fire disturbance in Canada: the National Burned Area Composite

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Text S1 Agency mapping of area burned

Two common approaches to creating burned area polygons are GPS tracking and manual delineation from remotely sensed imagery. Larger fires are mapped using airborne GPS, whereby a helicopter flies over the outline of the fire perimeter while GPS data are collected. Agency burned area mapping from remote sensing imagery most often involves on-screen digitisation of a single post-fire satellite image, but may involve more complex methods that use change detection and image thresholding of pre- and post-burn satellite data. Fire perimeters derived from aerial GPS may not be accurate as they often include omission and commission errors and typically do not remove unburned islands and water resulting in overestimation of area burned. Satellite-image derived perimeters tend to be more spatially precise and more cost-effective than those derived from aerial GPS but the quality of delineation is influenced by the date of image acquisition.

In the Yukon, manual digitisation of single-date post-fire Landsat imagery has been the predominant method of mapping burned area since 2004 (Table S1a). Although variable from year to year, unburned areas and water features can be removed from the Yukon fire polygons (Wright 2015). From 2004 to 2012, the Northwest Territories mainly employed GPS tracking from fixed-wing aircraft and helicopters to map burn perimeters and supplemented historical records with fire polygons derived from MODIS and Landsat image delineations (Table S1b). Manual delineation of Landsat imagery became the primary method of post-fire mapping in 2014.

Provincial agencies in western Canada have employed several techniques to map burned area. In British Columbia, fire polygons are derived from airborne GPS tracking and manual delineations of Landsat imagery (Table S1c). In Alberta, agency-derived fire polygons have been

mostly generated with on-screen digitisation and manual stereo-interpretation of digital aerial photographs based on softcopy photogrammetry and, to a lesser extent, airborne tracking from field surveys and image delineation from Landsat, Sentinel-2 and thermal infrared scanned imagery (Table S1d; Zhang 2018¹). The province of Saskatchewan has used airborne sketch mapping, field and airborne GPS tracking, and manual delineation of SPOT-4 and Landsat imagery (Table S1e). When fire polygons for this province are derived from satellite imagery, unburned forest islands and water features are delineated. Similar to the situation in British Columbia, the province of Manitoba employs mostly airborne GPS tracking and manual delineation of post-fire Landsat imagery to map burned areas (Table S1f). Water bodies are sometimes removed during a post-mapping geographic information system (GIS) exercise by overlaying hydrographic information.

In eastern Canada, most of the provincial agencies map burned area from airborne GPS tracking and interpretation of satellite imagery. From 2005 to 2011, airborne GPS tracking was the primary method of mapping fire polygons in Ontario, although in some of those years, fire polygons from aerial sketch mapping and buffered GPS point coordinates are the sources of burned area data (Table S1g). In Quebec, airborne GPS tracking and on-screen digitisation from Landsat images have been the primary methods and data sources used to generate fire polygons (Table S2h). Burn polygons from Landsat data were created from a time series data set in which unburned forest islands and water features were removed (Leboeuf and Fournier 2015). Quebec's has been the only provincial agency to use high spatial resolution satellite imagery from the RapidEye and QuickBird sensors to manually delineate fire perimeters (Table S1h). In the Atlantic provinces, the fire polygon records for most years did not include information about

¹ Zhang, J. 2018. Wildfire Resource Information Unit, Alberta Agriculture and Forestry, Edmonton, Alberta, Personal communications, Feb. 6, 2018.

data source or mapping method. Image delineation from Landsat, airborne GPS tracking and buffering geographic point locations were the primary sources of burned area data (Tables S1i, S1j, S1k).

Within Canada's national parks, fire attribution for data source and mapping method were not available until 2009, after which polygon delineations were described using Landsat satellite imagery and airborne GPS tracking (Table S11) (Zell and Kafka 2012). While Table S11 appears to indicate that Parks Canada actively maps area burned over National Parks, most do not capture such data. The burned area data where Landsat data were used mostly came from Wood Buffalo National Park.

References

Leboeuf A, Fournier RA (2015) A multisensor multiresolution method for mapping vegetation status, surficial deposits, and historical fires over very large areas in northern boreal forests of Quebec, Canada. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 8, 5199–5211. doi:10.1109/JSTARS.2015.2477780

Wright J (2015) 'Yukon fire history metadata, version 2015.01.' (Government of Yukon, Wildland Fire Management, Protective Services Branch, Community Services: Whitehorse, YukonYT, Canada)

Zell D, Kafka V (2012) 'Mapping recent fire history in Wapusk National Park and greater park ecosystem with Landsat imagery'. (Parks Canada Agency, National Fire Centre: Gatineau, QuébecQC, Canada)

Table S1. Proportion of burned area, as mapped by fire management agencies, by data source and mapping method, 2004 to 2016.

The burned area estimates were derived from Canadian National Fire Database polygon or point data available from the Canadian Wildland Fire Information System (<http://cwfis.cfs.nrcan.gc.ca/>). Values less than 0.1 are presented as 0.1. GPS = global positioning system, MODIS = Moderate Resolution Imaging Spectrophotometer.

S1a. Yukon (Yukon Territorial Government)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking		0.5	0.1	3.8	1.6	0.1						8.4	67.0
GPS point buffer													
Sketch mapping				1.8									
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation ^A			3.2										
Landsat delineation	95.4	97.5	95.4	94.4	98.4	99.9	100.0	100.0	100.0	100.0	100.0	91.6	33.0
MODIS delineation	4.6	1.9											
Hotspot buffering		0.1	1.3										
Undefined (%)													
Burned area (ha)	1 705 519	168 446	94 538	37 489	12 908	229 951	146 944	40 275	53 745	176 388	3158	150 571	20 325

^AIncludes SPOT-5

S1b. Northwest Territories (Government of Northwest Territories)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking				92.9	79.9	100.0	65.4	3.0	69.3		0.2	8.7	2.2
GPS point buffer													
Sketch mapping													
<i>Remote sensing (%)</i>													
Air photo delineation													
High High-resolution delineation													
Landsat delineation								42.6			99.8	91.3	97.8
MODIS delineation				7.1	20.1		34.6	54.4	30.7				
Hotspot buffering													
Undefined (%)	100.0	100.0	100.0							100.0			
Burned area (ha)	472 013	232 288	47 102	447 287	411 665	1702	346 876	298 679	288 531	437 371	3 412 092	649 187	254 095

S1c. British Columbia (British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking						0.4						0.1	24.5
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking	19.4	0.1	31.0	8.7	99.5	99.0	100.0	100.0	100.0	100.0	100.0	98.7	74.3
GPS point buffer													
Sketch mapping												0.6	0.9
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation ^A													0.3
Landsat delineation	76.2	43.8	68.0	91.3	0.5	0.6						0.5	
MODIS delineation													
Hotspot buffering													
Undefined (%)	4.4	56.1	1.0									0.1	
Burned area (ha)	183 075	24 868	120 024	25 633	13 472	237 822	290 347	12 790	98 374	17 699	359 137	264 138	99 257

^AIncludes thermal infrared scan images

S1d. Alberta (Alberta Ministry of Agriculture and Forestry)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking	6.5	2.3	2.2	0.8	4.4	3.2	1.5	0.1	0.3	4.0	29.7	0.5	0.1
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking	46.4	97.1	37.6	11.3	86.6	35.6	52.0	7.4	28.1	13.4	36.2	27.2	18.6
GPS point buffer													
Sketch mapping	5.2	0.4	0.3	0.1	0.4	0.1			1.6		0.1		0.1
<i>Remote sensing (%)</i>													
Air photo delineation	33.4	0.2	59.8	85.6	8.6	61.1	46.5	92.5	70.0	81.4	19.9	59.3	81.0
High-resolution delineation ^A	8.5		0.1	2.2						1.1	14.1		0.2
Landsat delineation										0.1		13.0	
MODIS delineation													
Hotspot buffering													
Undefined (%)													
Burned area (ha)	219 399	21 929	115 490	101 830	19 954	58 389	72 621	746 087	392 825	20 118	29 154	422 923	519 841

^AIncludes thermal infrared scan images, Sentinel-2

S1e. Saskatchewan (Saskatchewan Ministry of Environment)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking	0.1	7.7	2.9	13.4	14.3	1.3	0.1			3.6	0.1	0.1	0.1
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking	19.2	76.1	97.1	86.6	69.7	56.7	0.7	56.4	20.0		1.2	0.1	2.9
GPS point buffer													
Sketch mapping	58.7					4.3	0.5	11.3		0.1			0.1
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation ^A							43.2						
Landsat delineation							0.4		75.7	96.3	98.7	99.8	96.5
MODIS delineation					0.8								
Hotspot buffering													
Undefined (%)	22.0	16.2			15.2	37.7	55.1	32.3	4.3				0.4
Burned area (ha)	239 196	201 244	968 517	198 436	1 078 203	33 650	1 786 313	341 859	220 066	359 486	310 158	1 635 384	244 455

^AIncludes SPOT-4

S1f. Manitoba (Manitoba Sustainable Development)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking										0.1	0.5	0.7	0.2
GPS point buffer												0.6	0.1
<i>Airborne mapping (%)</i>													
GPS tracking					61.9	74.8	66.0	99.7	67.6	20.8	7.7	26.8	79.1
GPS point buffer					1.3	25.2	0.8	0.3	1.2	0.1	5.6	2.5	0.1
Sketch mapping					2.1								
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation													
Landsat delineation									31.2	78.8	86.2	69.4	20.5
MODIS delineation					34.7		33.2			0.2			
Hotspot buffering													
Undefined (%)	100.0	100.0	100.0	100.0									
Burned area (ha)	25 069	66 339	169 323	317 877	151 415	2 879	196 389	128 188	218 994	1 120 097	38 448	67 967	38 369

S1g. Ontario (Ontario Ministry of Natural Resources)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking		87.6	97.1	87.5	96.0	31.8	92.0	91.0					
GPS point buffer		11.4	1.4	12.5	4.0	14.1	8.0						
Sketch mapping	79.5	1.0	1.5			54.1							
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation													
Landsat delineation								9.0					
MODIS delineation													
Hotspot buffering													
Undefined (%)	20.5								100.0	100.0	100.0	100.0	100.0
Burned area (ha)	1 581	41 539	147 867	39 221	988	19 763	15 280	633 149	147 754	53 024	5 359	42 686	99 692

S1h. Quebec (Ministère des Forêts, de la Faune et des Parcs)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													1.1
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking	41.3	27.9	3.5	41.6	100.0	1.3	1.7	0.2				29.5	36.4
GPS point buffer													
Sketch mapping		35.4	30.3	58.0									
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation ^A							72.7	4.1	69.6	4.9		70.5	
Landsat delineation	58.7	21.8	65.4			98.6	25.5	95.7	30.4	95.1	99.9		62.4
MODIS delineation													
Hotspot buffering													
Undefined (%)		14.9	0.8	0.4		0.1	0.1				0.1		0.1
Burned area (ha)	5 177	937 285	127 253	331 954	1 175	93 664	310 251	11 881	39 764	1 857 517	53 840	5 304	34 365

^AIncludes RapidEye and QuickBird sensors

S1i. New Brunswick (New Brunswick Energy and Resource Development)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking													
GPS point buffer											100.0	100.0	
Sketch mapping													
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation													
Landsat delineation													
MODIS delineation													
Hotspot buffering													
Undefined (%)		100.0											
Burned area (ha)		370									103	249	

S1j. Nova Scotia (Nova Scotia Department of Natural Resources)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking													
GPS point buffer										100.0	100.0	100.0	
Sketch mapping													
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation													
Landsat delineation			100.0	100.0	100.0	100.0							
MODIS delineation													
Hotspot buffering													
Undefined (%)													100.0
Burned area (ha)			21	14	1 742	642				270	536	494	743

S1k. Newfoundland and Labrador (Newfoundland and Labrador Department of Natural Resources)

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking								96.5	76.6				
GPS point buffer													
Sketch mapping													
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation													
Landsat delineation													
MODIS delineation													
Hotspot buffering													
Undefined (%)	100.0	100.0	100.0	100.0		100.0	100.0	3.5	23.4	100.0	100.0		100.0
Burned area (ha)	924	18 041	3 305	11 257		16 336	957	402	204 122	17 921	8 832		10 101

S11. Parks Canada

Source and method	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
<i>Field mapping (%)</i>													
GPS tracking													
GPS point buffer													
<i>Airborne mapping (%)</i>													
GPS tracking						100.0		1.6					
GPS point buffer													
Sketch mapping													
<i>Remote sensing (%)</i>													
Air photo delineation													
High-resolution delineation													
Landsat delineation							100.0	98.4	100.0	100.0	100.0	96.0	
MODIS delineation													
Hotspot buffering													
Undefined (%)	100.0	100.0	100.0	100.0	100.0							4.0	
Burned area (ha)	199 390	35 388	12 499	215 279	3 867	15 180	5 448	79 500	202 743	53 109	189 174	388 069	

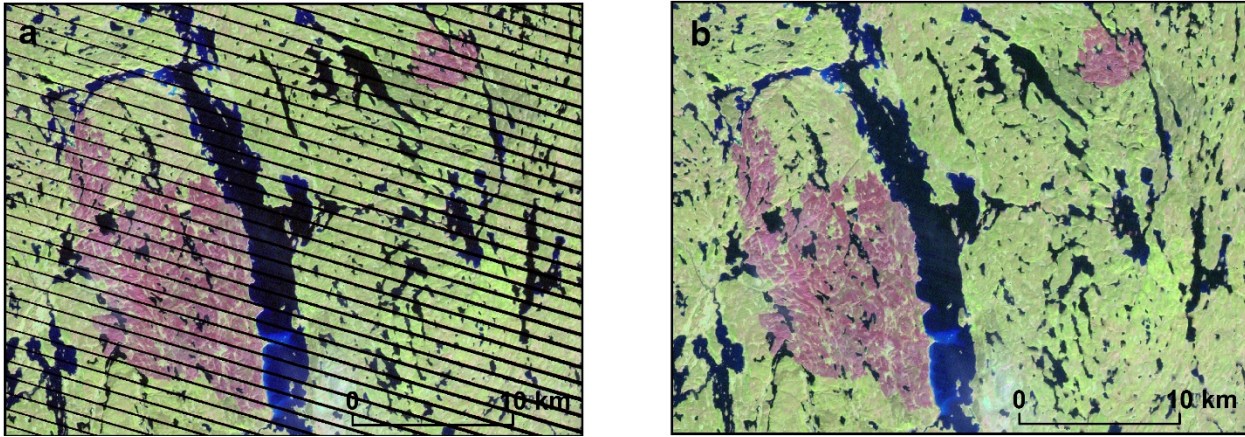


Figure S1. Landsat-7 Enhanced Thematic Mapper imagery for burned area mapping in the Multi-Acquisition Fire Mapping System. (a) Original image with data gaps related to Scan Line Corrector being turned off. (b) Pre-processing is used to interpolate the missing image values.

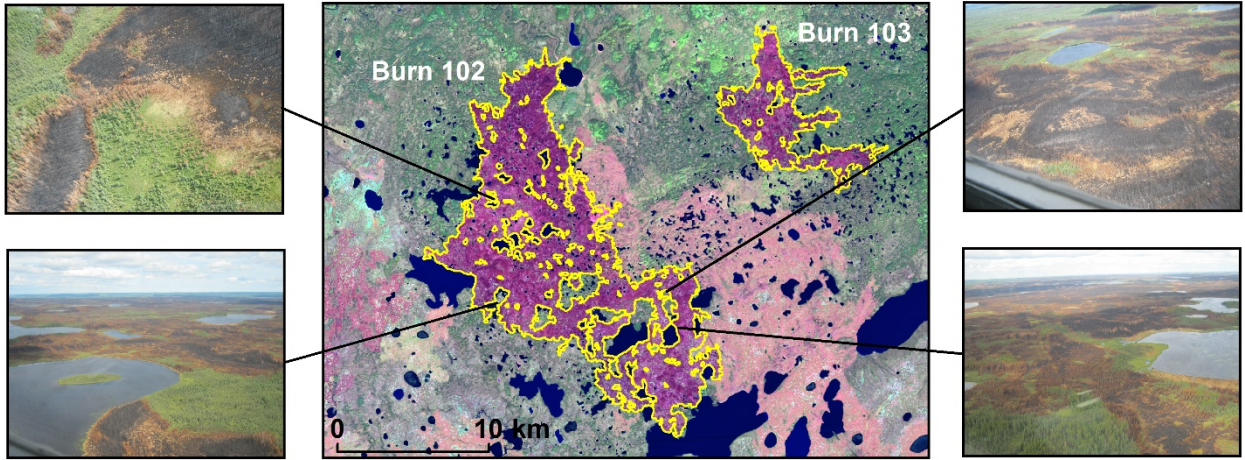


Figure S2. The final product from the Multi-Acquisition Fire Mapping System (MAFiMS) consists of polygon shapefiles representing individual fire events. In this example, aerial photographs of burn 102 illustrate the variability of a landscape burn in which islands of unburned forest are excluded from the delineation of the MAFiMS polygon. Photographs courtesy of Matt Coyle, Government of Northwest Territories.

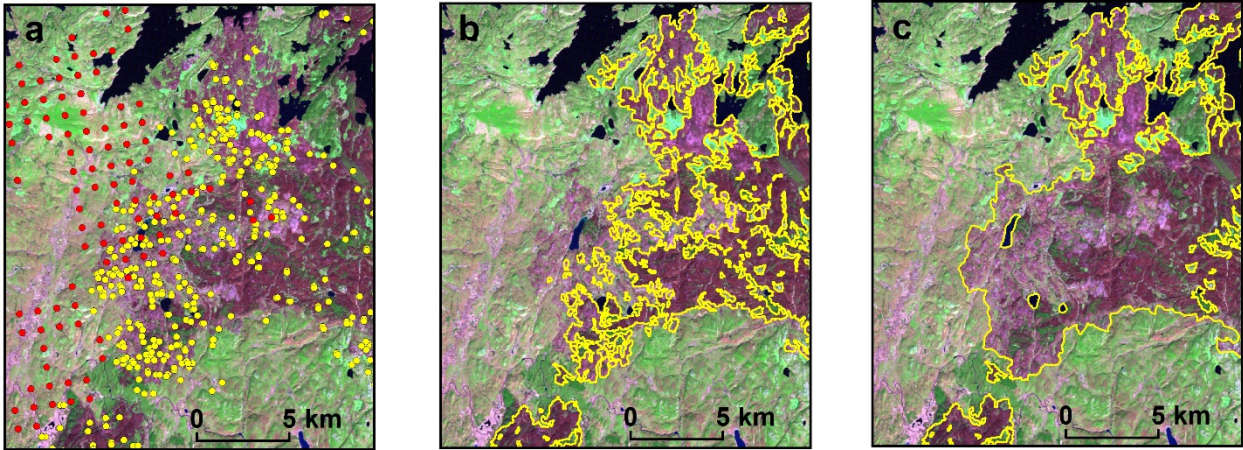


Figure S3. (a) MODIS hotspots (in yellow) overlaid on a Landsat image of a forest fire that occurred in 2010, which burned over a previous fire that occurred in 1998, represented by Advanced Very High Resolution Radiometer hotspots (in red). (b) Omission mapping errors within the burn-over-burn area. (c) Post-editing of the omission errors was used to correct delineation of the 2010 fire event.

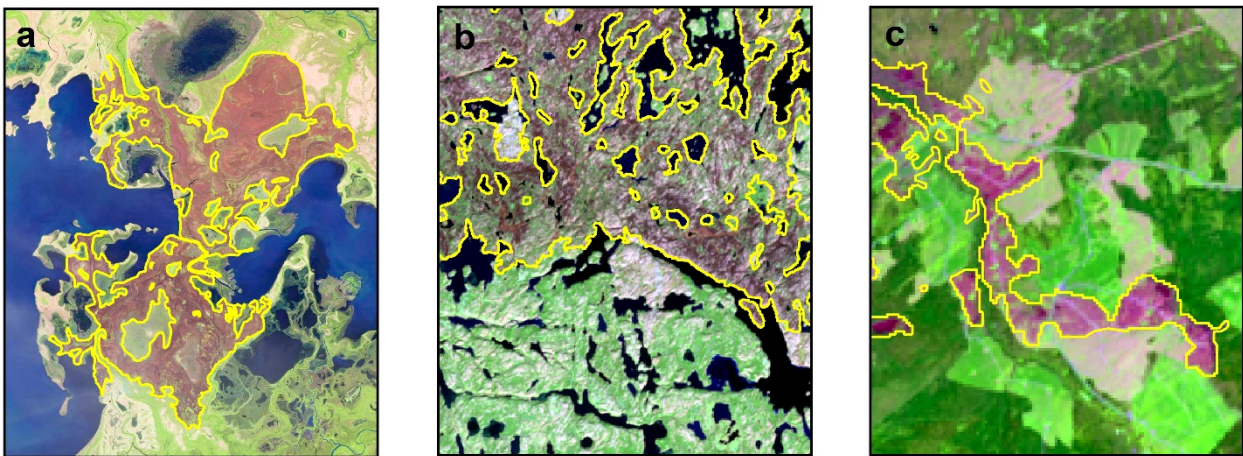


Figure S4. Post-editing was required to improve delineation of the burned area in more challenging areas: (a) wetland vegetation, (b) rocky outcrops, and (c) forest cutblocks.

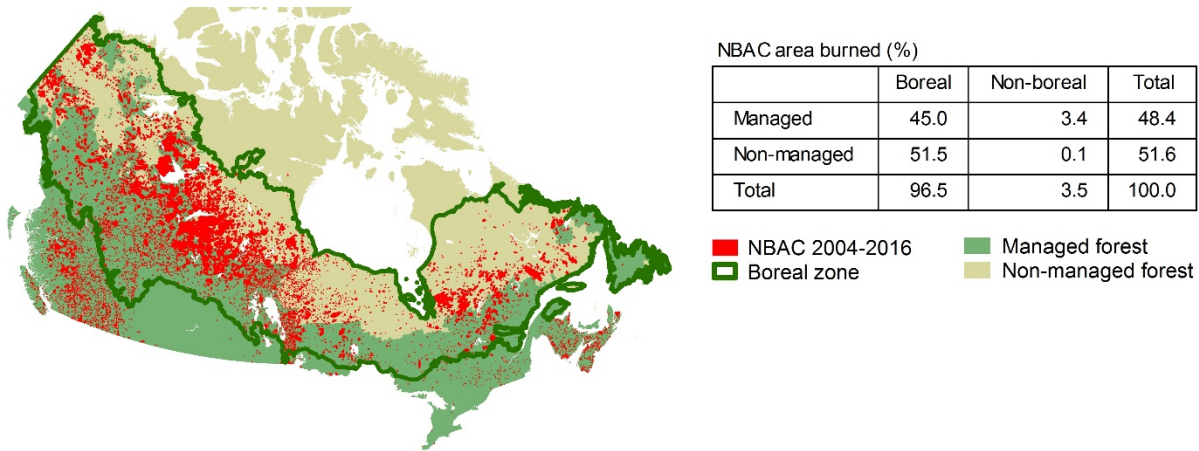


Figure S5. Proportions of burned area, as documented in the National Burned Area Composite (NBAC), over the boreal and managed forest areas of Canada, from 2004 to 2016.

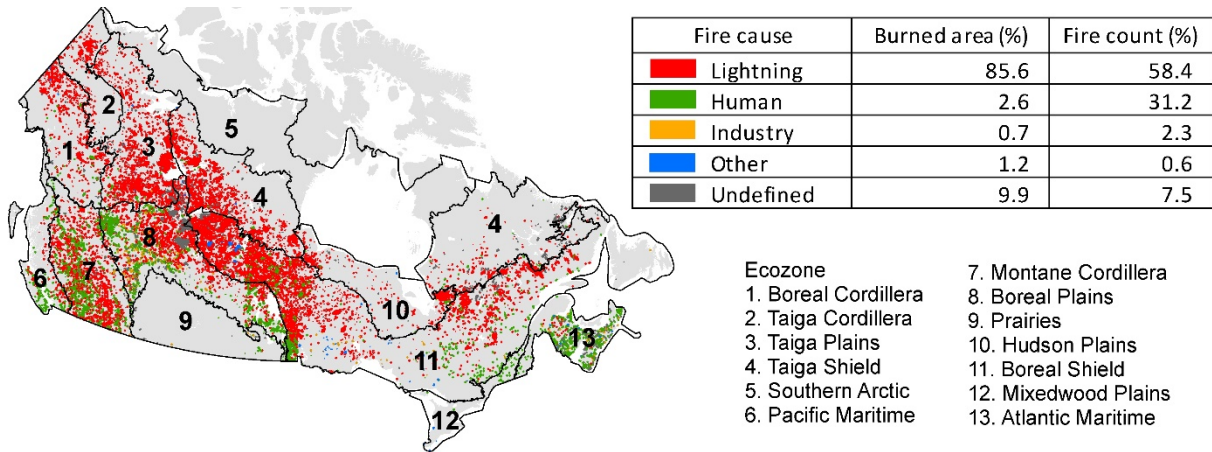


Figure S6. Cumulative spatial distribution and proportion of burned area by cause of fire from 2004 to 2016.

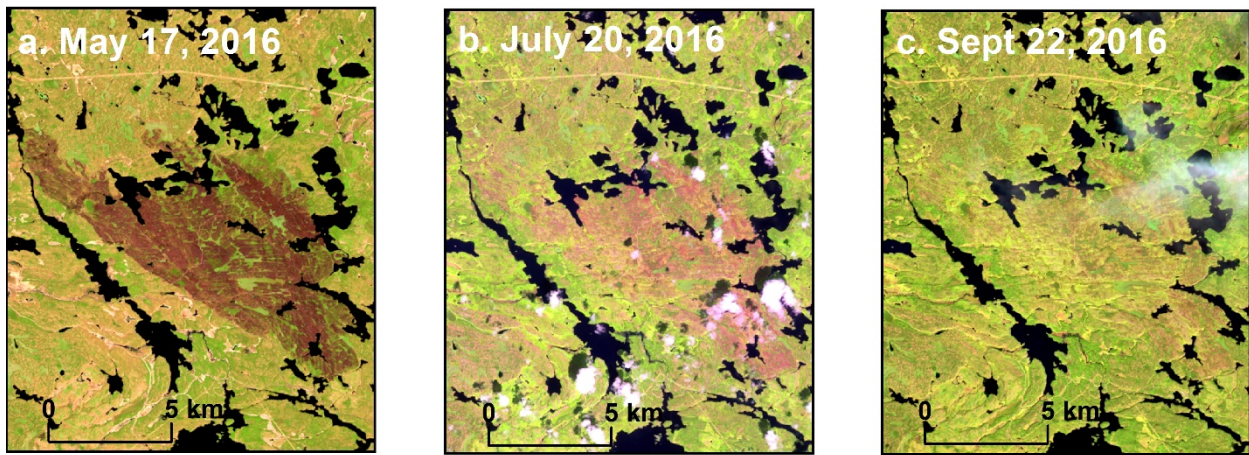


Figure S7. An example of vegetation recovery from an early spring fire that started on May 5, 2016 and ended on May 9, 2016.