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Supplementary Material

Modelling initial attack success on forest fires suppressed by air attack in the province of Ontario, Canada

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Appendix 1. Descriptions of the fire, environment, and suppression-related variables examined in modelling.

Fire-related variables

The following fire-related variables were explored in modelling:

Fire cause (F_{cause}): Either human-caused or lightning-caused fires. Fire cause can be estimated at the time of fire report by fire management personnel using knowledge concerning location and lightning activity in the area. We used the fire cause listed in the final fire report for each fire.

Fuel volatility (F_{fuel}): We classified the Canadian Forest Fire Behavior Prediction (FBP) System fuel type (Forestry Canada Fire Danger Group 1992) estimated by the AAO for the fire into one of three different fuel volatility categories depending on the susceptibility for crown fire behaviour and predicted rate of spread. Table 3 in text shows the FBP System fuel types classified for this air attack study into low, moderate, and high fuel volatility categories. Generally, the low fuel volatility group includes deciduous fuels, grass, and mixed fuels (e.g., stands comprised of both conifer and deciduous fuels) with a prominent deciduous component. The most volatile fuels consist of conifer fuels with a low crown base height (e.g., boreal spruce or immature jack pine), along with mixed wood fuels that consist predominantly of dead conifer. Fuel volatility can be estimated at the time of fire report by fire management personnel using local knowledge of fuels in the area.

Observed fire rate of spread ($F_{ros\text{-}observed}$): The observed rate of spread (ROS) of the fire at the time of IA estimated by the AAO. In OMNRF reporting, the observed ROS is reported in categories : 0-1 meters/minute (m/min), 2-5 m/min, 6-10 m/min, 11-20 m/min, or above 20 m/min. Due to the low number of fires reported in the 20 plus m/min category, the last two categories were combined to represent all fires with an observed ROS of 11 m/min and above.

Predicted fire ROS (Predicted $F_{ros\text{-}predicted}$*):* The predicted fire ROS on initial attack estimated using the FBP System and the estimated fuel type and fire weather indices for the location and day of IA. For this predictive variable (estimated prior to dispatch), the FBP fuel type was estimated using a 20 by 20 km grid layer of fuels for the Province of Ontario. The ISI for peak-burn (≈1700 LDT) on the day of IA was interpolated to the fire location and used as the fire weather indicator in the ROS calculation.

Fire size (F_{size}*):* Size of the fire (in hectares) estimated by the AAO when aerial suppression first began.

Fire rank (F_{rank}*):* A qualitative indicator of fire behaviour on a numerical scale from 1 to 5, based on a visual assessment of the fire prior to suppression by the AAO. For example, a rank 1 is often classified as a smoldering ground fire. A rank 5 is classified as a continuous crown fire (British Columbia Wildfire Service 2021).

Environment-related variables

The following variables related to the surrounding environment were explored:

Fire weather indices (E_{ISI}, E_{BUI}, E_{FWI}*):* ISI, BUI, or FWI for peak-burn (≈1700 LDT) on the day of IA. Fire weather indices are interpolated to the fire location after being calculated daily using a network of weather stations dispersed across the province.

Fire subseason ($E_{subseason}$*):* Fire subseason was explored to see if containment using air attack varied generally by season. We classified subseason as either spring ($E_{subseason}$=0) if the fire occurred from May 1 to June 14 or summer ($E_{subseason}$=1) if the fire occurred from June 15 to September 30.

Daily fire load ($E_{fireload-region}$, $E_{fireload-province}$): the number of active fires on the landscape for the day that the fire was reported. This only includes fires that are being suppressed (i.e., no monitored fires or fires that are classified as 'being held' or contained) on the day the fire was reported. Both provincial and regional daily fire load variables were explored. The provincial fire load reflects the number of active fires in the entire province of Ontario. The regional fire load represents the number of active fires in the corresponding Northwest or Northeast fire region depending on the location of the fire. Both of these fire load definitions were used to explore the diversity in how each fire management region may allocate (or have available) resources to a fire to be contained quickly.

Suppression-related variables

The following variables related to the suppression action on each fire were explored:

Same-day attack (S_{attack}): A variable to indicate if the fire was attacked on the day it was reported. This is represented in a binary category of either yes (1) or no (0).

Response time ($S_{response}$): The time (in hours) between when the fire was first reported to the fire management agency and when the first airtanker drop occurred. A small number of fires (1%) that had a response time of over one week were removed from the analysis to avoid atypical IA situations.

Time of first drop (S_{time}): The hour during the day that the first aerial suppression drop occurred.

Number of drop (S_{drops}): The number of airtanker drops delivered during the IA mission(s) (see definition below). Any drops that occurred after 1300 on the day following on the day which IA began were not included because they would not have contributed to the "success" of the initial attack phase of suppression as defined in this study.

Volume of load (S_{volume}): The total volume dropped on the fire for all the mission(s) during the IA phase of the fire. This includes the time from when the fire was first attacked, until 1300 the next day. The volume of load was explored in addition to number of drops because this variable captures the differences resulting from the use of different airtankers in Ontario; the tank capacity of the CL-415 airtanker is over 6,000 L of water, whereas the tank capacity of the Twin Otter is approximately 2,000 L.

Duration of mission ($S_{duration}$): The total amount of time (in hours) that aerial suppression was applied to the fire during IA. The duration of mission was calculated by using the time of the first and last drop of each mission that occurred up to 1300 the next day. The total duration of aerial suppression activity was the sum of the duration of all missions that occurred during the IA phase of the fire.

Number of airtankers ($S_{airtankers}$): The total number of airtankers that carried out air attack on the fire during IA. This includes any airtankers that were on the fire when it was first attacked to 1300 the next day.

Appendix 2. Descriptive statistic summaries for each of the covariates used in modelling.

Table A1. Number of fires (and percentages) that were considered IA successes for each of the categorical variables used in the modelling described in Table 1 in the main text. The data represent the proportions of fires in the full dataset. Note that some variables do not sum to the total number of fires because they have missing observations for some fires.

		IA failure		IA success	
		n = 541		n = 1,593	
F_{cause}	Lighting	398	(28%)	1032	(72%)
	Human	143	(20%)	561	(80%)
F_{fuel}	Low	65	(15%)	374	(85%)
	Moderate	210	(23%)	716	(77%)
	High	265	(35%)	500	(65%)
Observed F_{ros}	0-1 m/min	159	(14%)	980	(86%)
	2-5 m/min	302	(35%)	571	(65%)
	6-10 m/min	57	(61%)	37	(39%)
	11+ m/min	21	(81%)	5	(19%)
$F_{subseason}$	Spring	149	(25%)	449	(75%)
	Summer	392	(26%)	1144	(76%)
S_{attack}	Yes	478	(24%)	1500	(76%)
	No	45	(33%)	91	(67%)

Table A2. Median, standard deviation (s.d) and range for all continuous variables explored in Table 1 in the main text.

	IA failure			IA success		
	n=541			n=1,593		
	Median	s.d	Range	Median	s.d	Range
Predicted F_{ros} (m/min)	6.0	9.0	0.0 – 80	4.1	6.8	0 – 88
F_{size} (ha)	2.5	982.4	0.1 -21347	0.4	4.6	0.1 – 175
F_{rank}	3	1	1 – 5	2	1	1 – 5
E_{FWI}	15.4	6.7	0.00 – 42.7	13.7	6.4	0.5 – 42.7
E_{ISI}	6.5	3.6	0 – 22	5.7	3.1	0.3 – 27.4
E_{BUI}	47.3	17.0	9.8 – 107	46.9	18.9	6.51 – 130.21
$E_{provincefireload}$	6.0	6.8	0 – 31	5.0	6.4	0 – 36
$E_{regionfireload}$	4.0	5.5	0 – 30	3.0	5.1	0 – 30
$S_{response}$ (hours)	1.1	8.07	0.02 – 111.67	0.87	5.18	0.02 – 85.33
S_{time}	17:00	2.26	9:00 – 21:00	16:00	2.08	9:00 – 21:00
S_{drops}	29.0	33.8	1 – 213	9.0	13.09	1 – 114
S_{volume} (1,000 L)	159.4	228.6	2 – 1305.7	49.0	74.4	2 – 705
$S_{duration}$	1.33	3.24	0.03 – 41.02	0.47	0.57	0.02 – 5.33
$S_{airtankers}$	2	2	1 – 16	1.0	0.71	1 – 7

Appendix 3. Single covariate models for each variable explored in modelling. Coefficients, standard error, significance values, and the Δ AIC (i.e., the difference between the null model and full model) for each variable. Models based upon n = 1,949 observations with n = 1,463 fires classified as IA successes. The full data set was used for single covariate modelling (rather than training data) for this exploratory analysis.

	Coefficient	Standard error	p-value	Δ AIC
Fire-related variables:				
Fire cause (lightning)[a]	-0.38	0.12	0.002	8.46
Fire rank	-1.11	0.07	< 0.001	285.03
Fire size at IA (ha)	-2.23	0.12	< 0.001	542.56
Fuel volatility[b]				43.37
Moderate	-0.47	0.16	0.004	
High	-1.01	0.16	< 0.001	
Observed rate of spread[c]				164.79
2-5 m/min	-1.15	0.12	< 0.001	
6-10 m/min	-2.15	0.24	< 0.001	
11 + m/min	-3.00	0.52	< 0.001	
Predicted rate of spread	-0.04	0.007	< 0.001	30.19
Environment-related variables:				
Fire subseason (summer)[d]	-0.05	0.12	0.65	-1.80
Fire weather index	-0.04	0.008	< 0.001	26.71
Initial spread index	-0.09	0.02	< 0.001	28.91

Build up index	-0.004	0.003	0.16	-0.02
Provincial fire load	-0.01	0.01	0.09	0.81
Regional fire load	-0.03	0.01	0.008	4.82
Suppression-related variables:				
Duration of mission (hours)	-1.37	0.09	< 0.001	435.26
Number of airtankers	-0.89	0.07	< 0.001	290.11
Number of drops	-0.06	0.004	< 0.001	435.22
Response time (hours)	-0.02	0.008	0.003	8.04
Same-day attack (yes)[e]	-0.49	0.20	0.01	3.81
Time of first drop	-0.10	0.02	< 0.001	14.23
Volume of load (1,000 L)	-0.01	0.0006	< 0.001	454.41

Note. Reference categories are: [a]human-caused fires; [b]low fuel volatility; [c]0-1 m/min observed rate of spread; [d]spring fire season; [e]not same-day attack. Fire size at IA represents log base 10 transformation.

Appendix 4. Binned residual plots for the (a) full model, (b) initial attack model, and (c) fire report model. The number of bins is partitioned according to the square root of the number of observations in the model, and the average residual for each bin is plotted against the average expected value in each bin. The grey lines represent +/- 2 standard-error bounds.