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DATA PAPER

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Assessing fuel structure in old-growth eastern hemlock dominated stands of Nova Scotia, Canada

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Abstract

Key message The dataset provides fuel structure (live and dead vegetation) measurements in old-growth eastern hemlock (*Tsuga canadensis* (L.) Carrière) dominated stands of Nova Scotia, Canada. Potential reuses of the data include mapping Fire Behaviour Prediction System fuel types, predicting fire behaviour, projecting stand succession, and comparing fuel structure over time. Link to the data set: https://doi.org/10.23687/80383951-4b60-412c-9180-4d536b3703a8. Link to the Metadata: https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/04d56c39-a3a7-4617-a09c-6950fba08259.

Keywords Eastern hemlock, Fire behaviour, Fuel structure, Insects, Old-growth forests

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1 Background

Detailed vegetation fuel typing information offered by the Canadian Fire Behaviour Prediction (FBP) System supports accurate predictions of fire behaviour under a range of fire-weather conditions (Forestry Canada Fire Danger Group 1992). However, the FBP System comprises vegetative fuel types predominantly in boreal forests of Canada (Wotton et al. 2009) and offers information on fewer fuel types for forests in other ecoregions (Baron et al. 2024) such as Wabanaki-Acadian forests of the Atlantic region of Canada. Some of these forests contain old-growth stands dominated by eastern hemlock (*Tsuga canadensis* (L.) Carrière) that provide key ecosystem services (Degrassi et al. 2019) and are culturally significant for First Nation peoples such as the Mi'kmaq (Speck and Dexter 1951). Unfortunately, the invasive hemlock woolly adelgid (*Adelges tsugae* Annand; HWA) is causing significant decline and death of eastern hemlock (Ellisson et al. 2018) throughout southern Nova Scotia, Canada. The decline of eastern hemlock caused by HWA is likely to change fuel hazards in the stands, potentially placing human values at risk of loss from more intense fires. To support fuel type mapping for the region and fire behaviour predictions by fire managers and researchers, we collected, verified, and summarised fuel structure data in 15 old-growth stands dominated by eastern hemlock from southern to central Nova Scotia. Fuel structure data included canopy, subcanopy, surface, and downed dead wood fuel strata, as well as tree regeneration. To gather information about how HWA infestations impact fuel structure in such stands, we selected them along a gradient (severely infested to uninfested) of the ongoing HWA outbreak that was initially detected in 2017 in southern Nova Scotia.

2 Methods

Using the provincial forest inventory (Nova Scotia Department of Natural Resources and Renewables 2022) and a Geographic Information System (GIS), we selected 15 old-growth stands dominated by eastern hemlock (≥ 50% eastern hemlock composition in the dominant layer and average diameter at breast height of dominant trees ≥ 30 cm) in southern and central Nova Scotia (Fig. 1). Selection was undertaken to capture a gradient of recorded hemlock woolly adelgid (HWA) impacts within these stands, with the southwesternmost stands being severely infested because that is where the infestation started and northern stands remaining uninfested to date (Canadian Food Inspection Agency 2024).

Fuels sampling plots were established in western North America for the purpose of estimating potential fire behaviour (Schwilk et al. 2009; Stephens et al. 2009; Rutherford et al. 2025). In Canada, a fuels sampling protocol was developed in the context of the Next-Generation Canadian Forest Fire Danger Rating System (CFFDRS-2025; Boucher et al. 2024). Examples of this protocol's application exist in northern forests of Canada (Zerb et al. 2025) and montane forests of Jasper National Park, Alberta (Skretting et al. 2025).

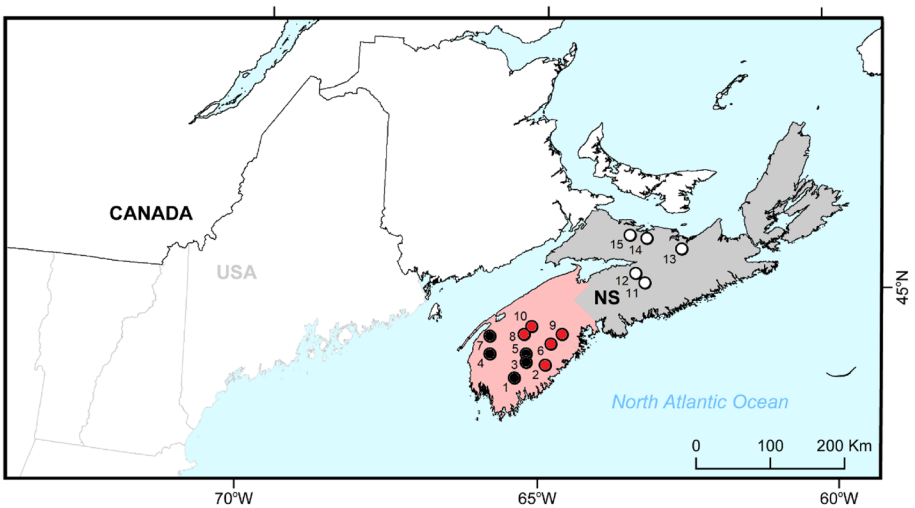


Fig. 1 Selected old-growth eastern hemlock dominated stands ($n = 15$; dots) in Nova Scotia (NS; grey and light red areas), Canada (black outlines in the map). Counties in NS that recorded hemlock woolly adelgid (HWA) infestations in 2024 are shown in light red (Canadian Food Inspection Agency 2024). Black dots indicate stands with one fuel sampling plot in severely infested areas, red dots indicate stands at the recorded edge of the HWA infestation in 2024 with two fuel sampling plots, one of which was treated with insecticide in late summer to fall 2024, and white dots indicate uninfested stands with one fuel sampling plot

In Summer 2024, we established one fuels sampling plot following Boucher et al.'s (2024) fuels sampling protocol within each of the 15 old-growth stands dominated by eastern hemlock, except for the 5 stands at the recorded edge of the HWA infestation during 2024, in which two fuels sampling plots were established (Table 1 and dataset spreadsheet labelled "1_Plot_Information"). The additional plot in each stand was established to assess the effect of chemical insecticide treatment (Quinterno et al. 2023) on eastern hemlock with the aim of reducing defoliation and mortality by HWA. Ground treatments by basal area of imidacloprid were conducted at the 5 plots in late Summer to Fall 2024.

For each plot centre point, we obtained its geographic coordinates, ellipsoidal height, and elevation above sea level using a SXblue II Global Navigation Satellite System (SXblue GPS Inc. 2017). Using a GIS and Light and Detection Ranging (LiDAR) derived digital elevation models (GeoNova 2024), we extracted slope and aspect for each plot. We obtained soil drainage and texture classes, topographic pattern, and landform class at each plot from the provincial Ecological Land Classification (Nova Scotia Department of Natural Resources and Renewables 2023).

In our dataset, each fuel sampling plot included one 400 m^2 canopy fuel plot, one 50 m^2 subcanopy fuel plot, one 100 m^2 surface fuel plot, two 40 m downed dead wood transects, and four 1 m^2 regeneration microplots. At each fuel sampling plot centre point, we established a canopy fuel plot with a radius of 11.28 m (400 m^2) and a subcanopy fuel plot with a radius of 3.99 m (50 m^2). Within each canopy fuel plot, we tagged and recorded the distance from the plot centre point and azimuth of all trees with a height ≥ 1.3 m and diameter at breast height (dbh) ≥ 9 cm, their species (Canadian Council of Forest Ministers 2014), dbh, state (alive, red stage, grey stage, or other), stem condition (intact or broken), bark condition (intact, peeling off ≥ 30% of the stem, or completely gone), presence or absence of lichen, and total height (for additional details please refer to the guide and the Data Dictionary linked with the dataset). For all conifers ≥ 9 cm dbh, we also measured live crown base height and dead crown base height. Within each subcanopy fuel plot, we recorded the species, dbh, state, stem condition, bark condition, presence or absence of lichen, and total height of all trees with a height ≥ 1.3 m and dbh < 9 cm. For these trees, we also measured live crown base height and dead crown base height of all conifers.

Table 1 Characteristics of the 20 fuels sampling plots (organized from southernmost to northernmost) located in 15 old-growth eastern hemlock dominated stands in southern and central Nova Scotia, Canada. Of the 20 plots, 5 were treated with insecticide in late Summer to Fall 2024. Stands were labelled "sites" in this table and the dataset

Site ID	Plot treated	Latitude	Longitude	Ellipsoidal height (m)	Elevation (m.a.s.l)	Aspect	Slope (%)	Soil drainage	Texture	Topography
1	N	43.919596	– 65.427866	56.214	83	NE	2	Well drained	Medium	Hummocky
2	Y	44.084244	– 64.894533	70.336	96	S	2	Imperfectly drained	Medium	Smooth/Flat
2	N	44.087630	– 64.894139	80.788	106	S	2	Imperfectly drained	Medium	Smooth/Flat
3	N	44.111576	– 65.221276	74.404	100	NE	6	Well drained	Medium	Drumlinoid
4	N	44.202104	– 65.821147	51.761	71	SW	8	Well drained	Medium	Hummocky
5	N	44.215644	– 65.243040	68.570	94	E	3	Well drained	Medium	Hummocky
6	N	44.346327	– 64.810598	59.357	85	W	10	Well drained	Medium	Drumlinoid
6	Y	44.350021	– 64.812059	69.138	94	W	7	Well drained	Medium	Drumlinoid
7	N	44.417342	– 65.852630	59.926	86	S	25	Well drained	Medium	Drumlinoid
8	N	44.456233	– 65.268045	102.318	128	W	6	Well drained	Medium	Hummocky
8	Y	44.456172	– 65.269298	103.004	129	NE	4	Well drained	Medium	Hummocky
9	N	44.465570	– 64.619628	32.722	58	W	3	Well drained	Medium	Drumlinoid
9	Y	44.466105	– 64.623831	23.089	48	W	5	Well drained	Medium	Drumlinoid
10	Y	44.553041	– 65.154766	132.971	158	SE	9	Well drained	Coarse	Hummocky
10	N	44.553969	– 65.154720	141.930	167	E	0	Well drained	Coarse	Hummocky
11	N	45.106113	– 63.224280	85.970	116	NW	7	Well drained	Medium	Hills
12	N	45.211312	– 63.371935	41.222	61	SW	10	Imperfectly drained	Fine	Hummocky
13	N	45.521493	– 62.595835	116.614	134	SE	21	Well drained	Fine	Hills
14	N	45.646176	– 63.197028	39.411	55	N	4	Well drained	Coarse	Hummocky
15	N	45.685099	– 63.486993	35.805	57	NE	4	Imperfectly drained	Fine	Ridges

At each fuels sampling plot centre point, we established a surface fuel plot with a radius of 5.64 m (100 m^2) (Boucher et al. 2024). Within each surface fuel plot, we identified the type of cover (low shrub, herb, bryoid, leaf litter, needle litter, general litter) and its proportion. For low shrubs and herbs, we also identified the genus and species.

To measure downed dead wood (DDW), we laid out two 40 m DDW transects centred at each fuel sampling plot center point orientated North–South (transect 1) and East–West (transect 2) (Boucher et al. 2024). For all eight 5-m segments of each transect, we measured the diameter of all DDW pieces > 30.0 cm crossing the transect and recorded their species, decay class, position (touching the ground or elevated), and tilt angle. For segments 2–7 on each transect (5–35 m), we measured the diameter of all DDW pieces > 7.0 cm crossing the transect and recorded their species, decomposition class, position, and tilt angle. For segments 2–3 and 6–7 on each transect (5–15 m and 25–35 m, respectively), we measured the diameter of all DDW pieces > 3.0 cm crossing the transect and recorded their species, decomposition class, position, and tilt angle. For segments 2 and 7 on each transect (5–10 m and 30–35

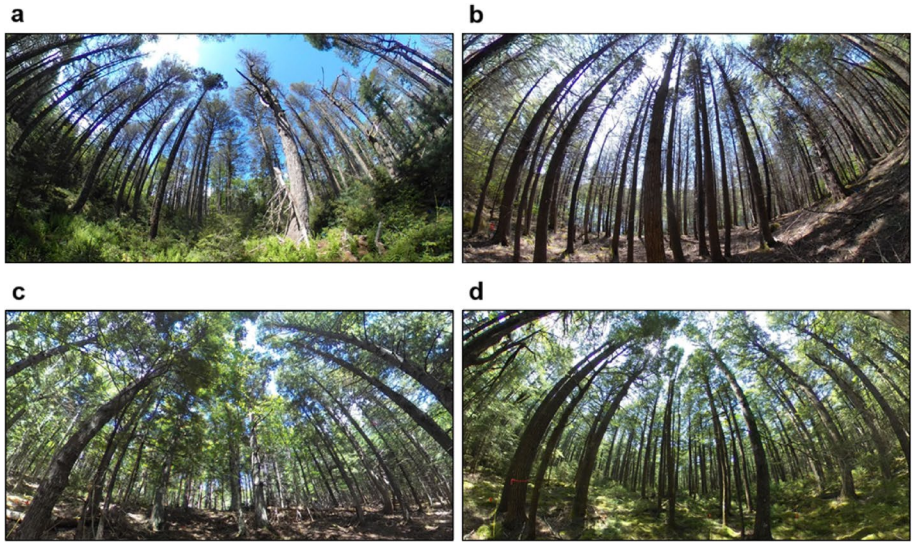


Fig. 2 Three hundred sixty degrees photographs of two fuels sampling plots in stands within areas of severe hemlock woolly adelgid infestation (Site_ID = 3, **a**; Site_ID = 7, **b**), and two fuels sampling plots in uninfested stands (Site_ID = 13, **c**; Site_ID = 15, **d**)

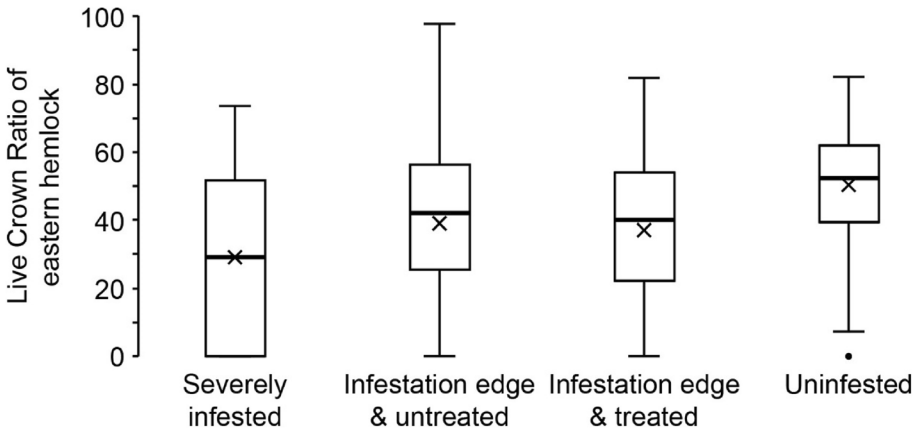


Fig. 3 Boxplots comparing the live crown ratio (LCR) of eastern hemlock ≥ 9 cm dbh in the canopy fuel plot across fuels sampling plots in stands within areas of severe hemlock woolly adelgid (HWA) infestation (severely infested; $n = 5$), at the recorded edge of the HWA infestation and untreated with insecticide (infestation edge and untreated; $n = 5$), at the recorded edge of the HWA infestation and treated with insecticide (infestation edge and treated; $n = 5$), and in uninfested stands (uninfested; $n = 5$). LCR was calculated as (height – live crown base height)/(height) × 100. In each boxplot, the thick horizontal line indicates the median, and the X indicates the mean

m, respectively), we tallied all fine woody debris (≥ 0.01 and ≤ 1.00 cm) and small woody debris (> 1.00 cm and ≤ 3.00 cm) that crossed the transect.

To assess tree regeneration, we placed four 1 m^2 regeneration microplots along the DDW transects at 10 m from the fuels sampling plot center point (Boucher et al. 2024). In each microplot, we counted all regenerating trees (i.e. seedlings and saplings) by height class (class 1 = 0 cm to 14.9 cm; class 2 = 15 cm to 59.9 cm; class 3 = 60 cm to 1.29 cm) and recorded their species.

To obtain an overview of fuel structure, we captured at each fuel sampling plot center point a 360° photograph. The 360° photographs were captured with a Ricoh Theta 360° SC2 camera (Ricoh Co., Ltd 2024) at 2 m above the ground. The 360° photographs are linked with the Dataset and can be viewed using the Ricoh Theta application (https://support.theta360.com/en/download/pcmac/; last accessed on April 15, 2025).

3 Access to the data and metadata description

The dataset is available from the Government of Canada Open Government Portal https://doi.org/https://doi.org/10.23687/80383951-4b60-412c-9180-4d536b3703a8 (Chavardès et al. 2024). Metadata including variable names and their descriptions can be found in the Data Dictionary linked with the dataset at: https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/04d56c39-a3a7-4617-a09c-6950fba08259.

4 Technical validation

Each table in the dataset was visually cross-checked and verified with the Skimr package (Waring et al. 2024) in R (R Core Team 2023). Notably, we verified that variables were consistently labelled throughout the tables; there was no missing data, data labelled "NA" was explained in the Data Dictionary, data fell within expected ranges (e.g. lack of outliers, verification of height-to-diameter ratios for trees), and plant species were correctly labelled.

5 Reuse potential and limits

We acknowledge that the sample size of the dataset is relatively low, and the scalability to other regions of Canada with old-growth eastern hemlock dominated stands may be limited. Nevertheless, the data can be reused in several simple ways, like comparing the potential mortality impacts of HWA on eastern hemlock in infested and uninfested stands (Figs. 2, 3, and 4). Moreover, the data provides detailed local information about the fuel structure in old-growth eastern hemlock dominated stands that can support the revision of algorithms applied to generate the national fuel type map (Canadian Forest Service 2024). The data can be reused as inputs to fire behaviour prediction models and systems, including the Forest Vegetation Simulator (Dixon 2002) and its Fire and Fuels Extension (Rebain 2010), crown fire initiation model (Cruz and Alexander 2016), conifer pyrometrics model (Perrakis et al. 2023; Skretting et al. 2004), and the Fire Behaviour Prediction System of the CFFDRS-2025 (Canadian Forest Service Fire Danger Group 2021). Prior to running the fire behaviour prediction models

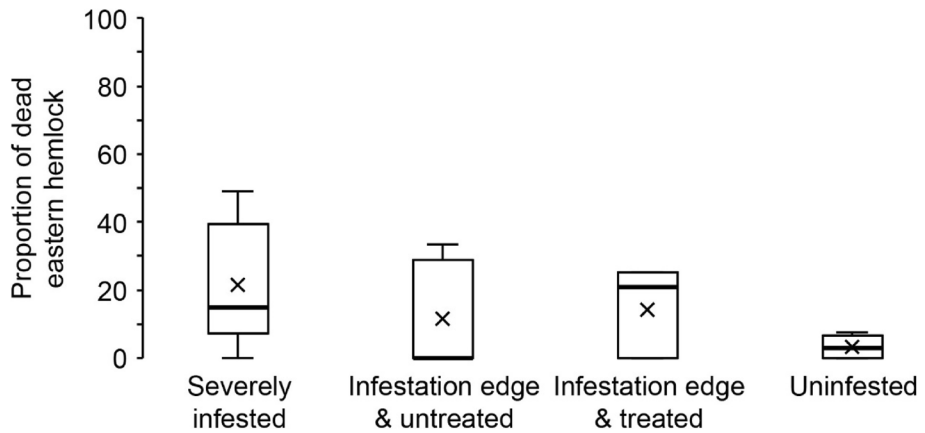


Fig. 4 Boxplots comparing the proportion of dead eastern hemlock ≥ 9 cm dbh in the canopy fuel plot across fuels sampling plots in stands within areas of severe hemlock woolly adelgid (HWA) infestation (severely infested; $n = 5$), at the recorded edge of the HWA infestation and untreated with insecticide (infestation edge and untreated; $n = 5$), at the recorded edge of the HWA infestation and treated with insecticide (infestation edge and treated; $n = 5$), and in uninfested stands (uninfested; $n = 5$). The proportion in each fuels sampling plot was calculated as the (number of dead eastern hemlock)/(number of living and dead eastern hemlock) × 100. In each boxplot, the thick horizontal line indicates the median, and the X indicates the mean

or systems, the fuel structure data can serve as inputs to calculate canopy fuel loads and bulk densities, dead and downed woody debris fuel loads, and surface fuel loads. In addition, the regeneration data can offer insights on stand compositional trajectories. With repeated assessments of fuels at the same locations over time, the data provides a baseline that can be compared against altered fuel complexes due to the ongoing HWA infestation (for example, did chemical treatment limit dead fuel and ladder fuel buildup) and possible interactions between infestation impacts and other forest-impacting disturbances like North Atlantic tropical cyclones (Abella 2018). Furthermore, the data can be compared against alternative treatments to limit HWA infestations, including biological control (Emilson and Stastny 2019). Finally, should the stands burn, the data would provide critical information about fire behaviour and impacts in a poorly researched fuel complex in Canada.

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Authors' contributions
Conceptualization: RDC, CE, SH, MK, SY, JM, MS, JB, AC-G; methodology: RDC, CE, SH, JB, AC-G, KEA; formal analysis and investigation: RDC, KEA, JFF; writing—original draft preparation: RDC, CE; writing—review and editing: RDC, CE, SH, MK, SY, JM, MS, PB, EKW, HJ, JB, AC-G, KEA, LECB, BB-G, ADL, RJF; funding acquisition: RDC, CE, MK, JB, AC-G; resources: CE, SH, MK, SY, JM, MS, PB, EKW, HJ, JB, AC-G, KEA, LECB, BB-G, ADL, RJF; supervision: RDC, CE, SH, MK. The authors read and approved the final manuscript.

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Data availability
The dataset generated during the current study is available in the Government of Canada Open Government Portal, https://doi.org/https://doi.org/10.23687/80383951-4b60-412c-9180-4d536b3703a8.

Declarations

Ethics approval and consent to participate
The authors declare that they obtained the approval of the Nature Conservancy of Canada (NCC) ethics committee for conducting the study in Matatall Lake and Silver River Wilderness Area NCC reserves, the Nova Scotia Environment ethics committee for conducting the study in Ponhook Lake and Big Bon nature reserves, and the Nova Scotia Parks ethics committee for conducting the study in Wentzell's Lake and Balmoral Mills provincial parks.

Consent for publication
All authors gave their informed consent to this publication and its content.

Competing interests
The authors declare that they have no competing interests.

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