



National Park Service Yellowstone National Park Fire Ecology Annual Report Calendar Year 2025

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Grand Canyon of the Yellowstone

The National Park Service (NPS) Division of Fire and Aviation Management relies on science and long-term monitoring to inform an adaptive management approach for assessing and improving fire management programs and activities at park units. Adaptive management, along with policies, standards, and responsibilities for monitoring are described in Chapter 8 of [Reference Manual 18](#). The NPS Fire Ecology Program is responsible for the collection, analysis, and interpretation of fire effects monitoring data for park managers to use for program evaluation and decision making. This annual report is intended to partially fulfill reporting requirements for the Fire Ecology Program and does not constitute a complete analysis of any NPS fire management program or activity. Additional interpretation and reporting can be found in previous annual reports at [NPS DataStore](#) or by contacting the author(s) of this report.

Table of Contents

Executive Summary	3
A. Summary	5
B. Monitoring Results and Recommendations	11
Hazard Fuel (HZF) Monitoring Type	11
i. Canyon Government and Concession Areas.....	13
ii. Norris Government Area.....	32
iii. Old Faithful.....	44
iv. South Entrance	56
v. Tower–Roosevelt	65
vi. Heart Lake Backcountry Cabin.....	71
vii. South Riverside Backcountry Cabin.....	81
Wildfire for Resource Benefits (WFRB) Monitoring Type.....	90
i. Boundary.....	91
ii. Chickadee.....	100
iii. Falcon.....	107
iv. Meridian–2 (FMICO1T10–02)	114
C. Research, Planning, and Communication	122
D. Future Direction	124
E. References, Links, and Additional Reading	127
Appendix A. Staffing and Accomplishments	128
Appendix B. History of Fire Effects Monitoring Plots.....	132
Appendix C. Fire/Fuels Treatments and Associated Monitoring	134

Executive Summary

The 2025 fire effects monitoring season produced substantial and timely data to inform fuels management, treatment effectiveness, and long-term ecological trends across Yellowstone National Park. Although early planning suggested a light field season, fuel treatments at Canyon, South Entrance, and Norris were completed ahead of snowfall, allowing the Fire Effects Monitoring crew to collect immediate post-treatment surface fuels data on 35 unscheduled plots. These data provide rare insight into how masticated fuel beds, litter, and duff respond during the first winter following treatment and improve interpretation of treatment outcomes relative to the traditional one-year post-treatment monitoring window.

In addition to monitoring within these treatment units, the crew revisited five long-term FMH plots, including the Falcon and Chickadee sites, which had not been sampled since 2003 and 2006, respectively. These helicopter-accessed plots occur in remote whitebark pine habitat, providing valuable baseline and trend data for this federally listed threatened species. Six new hazard fuel (HZF) plots were installed in anticipation of fuel treatments at Norris (completed in 2025) and Tower–Roosevelt (planned for 2026-2027), while an additional 12 HZF plots were remeasured at Old Faithful, and the South Riverside and Heart Lake backcountry cabins. Backcountry sampling continues to be critical for assessing fuels and forest structure around historic and administrative structures and for maintaining situational awareness of fire danger across remote areas of the park.

Across all HZF treatment areas, mastication was consistently effective at reducing coarse woody (1,000-hour) fuels, with post-treatment fuel loads reduced by approximately 80-90% and well below the < 10 tons per acre management objective. These reductions substantially lower the fuel component most associated with sustained flaming, high fire severity, and crown fire initiation. When surface fuels were evaluated collectively, total fuel loads generally declined following treatment. However, when masticated material was explicitly measured and accounted for using an adjusted bulk density constant, estimated total surface fuel loads were in some cases comparable to pre-treatment levels. This reflects redistribution of woody biomass into a compacted surface layer, rather than an increase in total fuel.

Responses among finer fuel components were more variable. Fine fuels showed modest declines or little change, while litter loads increased consistently following treatment as masticated materials were thoroughly mixed with litter and duff layers. While some components of litter were often observable post-treatment, duff was often too incorporated within the fuel bed to be measured, limiting short-term quantification. These patterns highlight ongoing uncertainty in how masticated fuel beds compact and decompose over time. Continued monitoring and development of site-specific bulk density estimates remain priorities to improve confidence in fuel loading estimates and fire behavior interpretation.

Longer-term monitoring at Heart Lake and South Riverside backcountry cabins indicates that while thinning treatments were initially effective, treatment benefits have diminished over time due to increasing stand density, regeneration, ladder fuel development, and declining canopy base heights. These trends suggest a need for maintenance treatments or targeted understory thinning to sustain fuel reduction objectives and protect historic structures.

Wildfire reference sites (WFRB) continue to provide essential context for post-fire recovery. Plots within the 2000 Boundary fire perimeter reflect a classic lodgepole pine trajectory toward stem exclusion and canopy closure 25 years after fire, while the Chickadee site, which burned in 2005, shows a mixed-severity response with sustained whitebark pine presence. Falcon and Meridian-2 serve as high-value unburned reference sites, documenting long-term stand development, beetle impacts, and regeneration dynamics in remote, high-elevation forests.

Overall, the 2025 monitoring season demonstrates that mastication is highly effective at achieving near-term fuel reduction objectives, while also underscoring the importance of long-term monitoring, refined fuel characterization, and periodic maintenance treatments to sustain effectiveness over time. These results directly support adaptive fuels management, structure protection, and conservation of forest ecosystems across Yellowstone's landscape.

Key Takeaways / Management Implications

- **Mastication treatments are effectively reducing hazardous fuels.**
Across treatment areas, coarse woody (1,000-hour) fuels were reduced by roughly 80-90% and consistently met the < 10 tons per acre management objective, substantially lowering potential for high-severity surface fire and crown fire initiation.
- **Post-treatment fuel estimates depend strongly on how masticated material is accounted for.**
Higher fuel loads observed when masticated fuel beds are explicitly measured and accounted for reflect redistribution of woody biomass into surface layers rather than increased total biomass, underscoring the importance of fuel bed characterization in treatment evaluation.
- **Masticated fuel beds remain a key uncertainty.**
Compaction, decomposition, and moisture dynamics vary widely by site, reinforcing the need for continued monitoring and development of site-specific bulk density values for masticated fuel beds.
- **Treatment longevity is limited without maintenance.**
Long-term monitoring indicates that stand density, ladder fuels, and surface fuels increase over time following thinning, highlighting the need for follow-up treatments to sustain fuel reduction objectives in remote backcountry areas.
- **Expanded monitoring improves decision-making.**
Immediate post-treatment data collection and remeasurement of remote wildfire plots strengthen understanding of short- and long-term fuel and vegetation trajectories, supporting adaptive management across the park.
- **Whitebark pine monitoring provides high management value.**
Data from remote burned and unburned plots support conservation planning for this federally listed threatened species and inform fire and fuels management in high-elevation whitebark pine habitat.

A. Summary

The 2025 Yellowstone Fire Effects Crew was led by Jess Page (*Lead*) and Marlee Jennings (*Assistant Lead*), with two outstanding seasonal crewmembers: Elizabeth (Liz) Stone, returning for her third season, and Grace Cross, joining the crew for the first time. The high level of continuity and prior experience made a noticeable difference this year, allowing the crew to settle into an efficient rhythm early in the season.

Training and Early Season Work

The season began with several weeks of training and crew exercises, which accounted for approximately 7% of total crew hours. Training included the standard suite of required NPS online courses, local orientation with Yellowstone-specific topics (radio networks, bear encounters, wildlife jams), and several fire-related classes. Between training sessions, the crew completed annual maintenance visits to five remote automated weather stations (RAWS).

Helicopter flights to the Cabin Creek and Quadrant RAWS were, as always, a highlight of the season. Later in the fall, the crew returned to Cabin Creek after an animal (most likely an elk) damaged one of the sensors. This follow-up visit provided an opportunity to replace spiked plywood deterrents, a recurring necessity at this wildlife-prone station.



Figure 1. Jess, Marlee, and Grace conducting annual maintenance at the Cabin Creek (left) and Quadrant (right) Remote Automated Weather Station (RAWS).

Plot Work

The plot season began at a slower pace than anticipated, and early projections suggested a relatively light workload. However, fuel treatments at Canyon, South, and Norris were completed before snowfall, allowing the crew to take advantage of a valuable opportunity to collect immediate post-treatment surface fuels data on 35 unscheduled plots. These data will help improve understanding of how masticator chips, litter, and duff layers respond during the first winter following treatment, and how conditions differ between immediate post-treatment and the traditional one-year post-treatment monitoring window.



Figure 2. Surface fuel sampling conducted by Liz, with assistance from Girard Marotto and Craig Hertz of the Wildland Fire Module, within a recently masticated treatment unit at Canyon.

In addition, the crew revisited five Fire Monitoring Handbook (FMH) plots, two of which (Falcon and Chickadee), had not been sampled since 2003 and 2006, respectively. These helicopter-accessed plots occur in whitebark pine habitat and will provide valuable baseline and trend data for future management decisions for this federally threatened species.

The crew also installed six new hazard fuel (HZF) plots in anticipation of fuel treatment work at Norris, completed this year, and Tower–Roosevelt, scheduled for 2026. An additional 12 HZF plots were remeasured at Old Faithful, the South Riverside backcountry cabin, and the Heart

Lake backcountry cabin. As always, backcountry trips were a highlight of the season, providing critical information on fuel conditions around structures while also improving situational awareness of forest structure, fuel moisture, and fire danger. To wrap up plot work, the crew photographed three long-term photopoint locations.

Wildfire Response

During July and August, Yellowstone experienced multiple lightning storms that produced more fire starts than seen in several previous years combined, including a 48-hour period with over 1,500 lightning strikes. Early in the season, the Fire Effects Crew, joined by Nick (*Fire Ecologist*), was diverted from their first plot visit to assist with suppression efforts on the Trail Creek Fire at the southern end of Yellowstone Lake. This assignment marked Nick's first Yellowstone fire and Grace's first ever wildfire assignment. The crew accessed the fire by boat and spent several days based out of the Trail Creek cabin, making for a memorable and formative experience.



Figure 3. Jess, Grace, Nick and Keith Krause (*Fuels Specialist*) departing the Trail Creek Fire on the southeastern arm of Yellowstone Lake.



Figure 4. Jess conducting chainsaw operations on the Trail Creek Fire.

Over the course of the season, Fire Effects personnel assisted on nine of the park's 30 wildfires, filling a variety of roles including HECM, ICT5, FFT1, FAL3, FFT2, FEMO, and logistics. Crew members also supported wildfire assignments at DINO and FL, and assisted with prescribed fire operations at BICY, GRKO, MORU, JECA, and WICA. To close out the field season, and bring things full circle, Jess participated in slash pile burning at Norris, marking the final phase of a project that began earlier in the year.



Figure 5. Prescribed fire operations at Mount Rushmore National Memorial.



Figure 6. Slash pile burning within the recently masticated unit at Norris.

Monitoring Protocols

A summary of plots read by the Fire Effects Crew in Yellowstone National Park during the 2025 field season is provided below, along with the plot type (e.g., WFRB (FMH), HZF, Despain), years of data coverage, and total plots within each unit that are active or inactive (Table 1). Below are brief descriptions of plot types sampled in 2025:

- **Hazard Fuel (HZF) plots** are circular 22.56-m diameter (0.04 ha) monitoring plots designed to assess treatment effects at the stand level. Data collected within each plot include tree measurements, seedling counts, and understory vegetation sampled across 10 Daubenmire frames. Surface fuel data are collected using one Brown's planar intercept transect, or two transects in mastication units sampled post-2023, to better capture fuel bed variability. Each plot is also documented with two photographs.
- **Landscape-level Wildfire for Resource Benefit (WFRB) plots** follow Fire Monitoring Handbook (FMH) protocols and consist of 50 m × 20 m (0.1 ha) long-term monitoring plots. These plots include comprehensive tree measurements and spatial tree mapping, seedling counts, and understory vegetation sampled across 50 Daubenmire frames.

Surface fuels are measured using four Brown's planar intercept transects, and eight photographs are collected per plot to document stand and fuel conditions.

- **Photopoint (PPT) plots** are fixed locations where repeat photography is taken to capture the before and after views of treatment areas.

Active plots are maintained and remeasured at predefined, regular intervals. Inactive plots have either been formally discontinued or are maintained only to preserve plot infrastructure (e.g., rebar checked and painted) and are remeasured opportunistically rather than on a fixed schedule. A complete list of all fire effect plots installed within Yellowstone can be found in Appendix B.

Table 1. Fire effects plot workload in Yellowstone (2025)

Park	Monitoring Unit	Plot Type	Years Data Collected	Annual Total (2025)	Total Plots	
					Active	Inactive
Yellowstone	Boundary	WFRB	2002-2025	2	2	0
	Canyon	HZF	2004-2025	24	24	3
	Canyon	PPT	2004-2025	9	9	0
	Chickadee	WFRB	2005-2025	1	1	0
	Falcon	WFRB	2001-2025	1	1	0
	Heart Lake	HZF	2003-2025	2	2	0
	Meridian-2	WFRB	2006-2025	1	1	0
	Norris	HZF	2006-2025	6	6	2
	Old Faithful	HZF	2020-2025	7	12	0
	Old Faithful	PPT	2020-2025	7	7	0
	South	HZF	2004-2025	5	5	1
	South	PPT	2023-2025	5	5	0
	South Riverside	HZF	2003-2025	3	3	1
	Tower-Roosevelt	HZF	2025	4	4	0
			Totals	77	82	7

B. Monitoring Results and Recommendations

Hazard Fuel (HZF) Monitoring Type

Since 2003, permanent HZF monitoring plots have been established in most planned hazard fuel treatment units, including developed areas and backcountry cabins of Yellowstone National Park. During initial setup, treatment objectives were broadly defined based on the earlier FMECH1T99 hazard fuel monitoring type (FMH-4), which used 0.04 kg/m^3 as a critical canopy bulk density (CBD) threshold to prevent crown fire initiation.

Canopy bulk density quantifies the amount of available aerial fuel in a stand of trees, expressed as the mass of canopy fuel per unit canopy volume (Scott and Reinhardt 2001). While CBD calculations typically include only trees taller than six feet, for these analyses all trees ≥ 4.5 feet (those with a measurable diameter at breast height) were included. Scott (2003) suggested a critical CBD of 0.1 kg/m^3 under drought-season fuel moisture conditions and 25-mph open winds for horizontal crown fire propagation. However, such wind speeds occur less than 20% of the time during summer at the five RAWS throughout the park. Given the arbitrariness of the 0.04 kg/m^3 threshold, an individual assessment of each treatment unit was adopted to better account for localized environmental conditions.

To inform these assessments, plot data were combined with site-specific high fire danger weather and fuel moisture conditions in a spatial fire behavior model to evaluate each unit's potential to support or mitigate crown fire. Weather and fuel data were derived from the FireFamily Plus software platform for representative nearby stations, and plot-level data were analyzed using the Interagency Fuel Treatment Decision Support System (IFTDSS), which integrates FlamMap to generate spatially explicit crown fire activity maps. Vegetation objectives were incorporated in 2013 when all plots were converted to the standardized HZF monitoring type, ensuring consistent plot sizes and protocols across treatment areas in Yellowstone.

Note: Whitebark pine (Pinus albicaulis) was listed as threatened under the Endangered Species Act in January 2023, triggering federal protections and requiring additional review and assessment for all future projects and thinning operations. Whitebark and limber pine (P. flexilis) are physiologically similar, and reliable field identification typically requires the presence of cones and/or genetic testing. Because many five-needle pines within our monitoring plots lack visible cones, and comprehensive genetic testing across all study sites is not feasible, all five-needle pines are conservatively treated as whitebark for the purposes of this assessment.

Important Note on Fuel Load Assumptions for Masticated Fuel Beds

Fuel loading estimates presented in this report are derived from field measurements of litter, duff, and surface fuel bed depth collected along Brown's planar intercept transects. Measured depths are converted to fuel loads (tons per acre) using standard bulk density constants for litter (2.75 lbs/ft³) and duff (5.5 lbs/ft³). These constants were developed for relatively undisturbed forest floor conditions and are appropriate for pre-treatment and untreated stands. However, they do not fully represent the altered structure, fragmentation, and compaction typical of masticated fuel beds.

In masticated areas, the surface fuel bed is composed of a mixed layer of chipped woody material, litter, and duff that is mechanically churned and compacted during treatment. Because this layer is no longer well separated into distinct litter and duff horizons, standard depth-to-load conversions for litter and duff alone may underestimate the true mass of surface fuels. To better represent these conditions, masticated fuel beds are recorded in the field as a chip bed depth, and an adjusted bulk density constant representative of masticated material is applied to convert that depth to tons per acre.

To support transparent interpretation, this report presents fuel loading results in two complementary ways in selected figures: (1) using standard litter and duff depth-to-load conversions to maintain consistency with long-term monitoring protocols, and (2) using a provisional bulk density value for masticated material to convert chip bed depth to fuel load, providing an alternative estimate that better reflects the physical structure of post-treatment fuel beds. For this alternative calculation, a provisional mean bulk density value of 7.5 lbs/ft³ is applied. This provisional value likely lies toward the upper end of plausible bulk density estimates and is intended to represent relatively compacted masticated fuel beds. As such, it provides a conservative (i.e., intentionally higher) estimate of surface fuel loading and reduces the risk of underestimating treatment effects. These alternative calculations are intended to support comparative analyses and transparent reporting rather than to serve as finalized, site-specific parameters.



Figure 7. Variability in fine and coarse woody masticated materials and associated fuel loadings in masticated chip beds (from Hood et al. 2024).

i. Canyon Government and Concession Areas

Multiple fuel reduction treatments have been implemented across the Canyon area over time to accommodate increasing development and associated infrastructure. As development and treatment footprints expanded, additional monitoring plots were installed to evaluate treatment effectiveness across a broader spatial extent.

Initial Treatment (2004)

The first treatment, encompassing approximately 68 acres, was conducted in 2004 in the Canyon Concession Area, located east of several visitor cabins maintained by the park's concessionaire. Vegetation in the treatment area is dominated by lodgepole pine (*Pinus contorta* var. *latifolia*), with a smaller understory component of subalpine fir (*Abies lasiocarpa*) and members of *Pinus* subgenus *Strobus* (limber pine and whitebark pine).

The 2004 treatment utilized chainsaws to fell trees, followed by chipping and/or removal of downed material through firewood permits. The primary objective was to create defensible space around structures by reducing canopy bulk density to levels that would inhibit active crown fire spread. An additional goal was to reduce dead and down 1,000-hour fuel loads to ≤ 10 tons per acre.

Prior to treatment implementation, six monitoring plots were established within the projected treatment area. In 2015, four of these plots were converted from the FMECH1T99 monitoring type to the HZF monitoring type to standardize plot size and sampling protocols. In 2017, several visitor cabins were replaced with multi-room lodges. During a 2019 revisit, it was determined that one of the remaining plots had been partially compromised by a newly constructed sidewalk, leaving three intact plots within this treatment unit (plots 001, 002, and 006; Figure 9). These plots have been remeasured in 2015 (01YR11), 2019 (01YR15), 2024 (01YR20), and 2025 (02POST).

Secondary Treatments (2004-2012)

In the Canyon Government Area, two additional treatments were implemented across 24 acres, with the first occurring in 2004 and the second in 2012. Both treatments employed chainsaws for tree felling and chippers or firewood permits for debris removal. Three additional monitoring plots (plots 007, 008, and 009) were installed prior to the initial treatment in 2004 and subsequently remeasured in 2012 (01YR08), 2013 (02YR01), 2017 (02YR05), 2022 (02YR10), and 2025 (03POST) (Figure 14).

Expanded Thinning Treatment (2015-2016)

A larger 120 acre thinning treatment was implemented in the Canyon Government Area beginning in 2015 and completed in 2016. To support treatment evaluation, seven additional monitoring plots (plots 010-016) were installed in 2013 (00PRE) (Figure 19). These plots were remeasured following treatment in 2016 (01POST), 2020 (01YR05), and 2025 (02POST).

Recent Expanded Treatment (2024–2025)

The most recent treatment comprised 210 acres, occurred across both the Canyon Concession and Government Areas and was implemented in stages from 2024-2025. This effort included mastication to reduce canopy bulk density and increase stand-level canopy base height, followed

by hand crew treatments to further reduce downed woody debris and improve visual aesthetics throughout the treatment unit.

To support this effort, 11 additional monitoring plots (plots 017-027) were installed between 2021 and 2024 to characterize pre-treatment conditions (Figure 24). Mastication and hand crew operations concluded in spring 2025, after which all 24 monitoring plots were located, and surface fuels were measured.

A bulleted timeline summarizing treatment implementation and monitoring activities is provided below:

Canyon Plots 001, 002, 006 (*Concession Area*)

- 2004 (00PRE) – Data collection prior to first entry
- 2004 – First entry thinning treatment
- 2015 (01YR11) – Data collection 11 years after the first treatment
- 2019 (01YR15) – Data collection 15 years after the first treatment
- 2024 (01YR20) – Data collection 20 years after the first treatment
- 2024/2025 – Second entry mastication treatment
- 2025 (02POST) – Surface fuels data collection immediately post-mastication treatment

Canyon Plots 007, 008, 009 (*Government Area*)

- 2004 (00PRE) – Data collection prior to first entry
- 2004 – First entry thinning treatment
- 2012 (01YR08) – Data collection 8 years after the first treatment
- 2012 – Second entry thinning treatment
- 2013 (02YR01) – Data collection 1 year after the second treatment
- 2017 (02YR05) – Data collection 5 years after the second treatment
- 2022 (02YR10) – Data collection 10 years after the second treatment
- 2024/2025 – Third entry mastication treatment
- 2025 (03POST) – Surface fuels data collection immediately post-mastication treatment

Canyon Plots 010, 011, 012, 013, 014, 015, 016

- 2013 (00PRE) – Data collection prior to first entry
- 2015/2016 – First entry thinning treatment
- 2016 (01POST) – Data collection immediately following the first treatment
- 2020 (01YR05) – Data collection 5 years after the first treatment
- 2024/2025 – Second entry mastication treatment
- 2025 (02POST) – Surface fuels data collection immediately post-mastication treatment

Canyon Plots 017, 018, 019, 020, 021, 022, 023, 024, 025, 026, 027

- 2021/2023/2024 (00PRE) – Data collection prior to first entry
- 2024/2025 – First entry mastication treatment
- 2025 (01POST) – Surface fuels data collection immediately post-mastication treatment

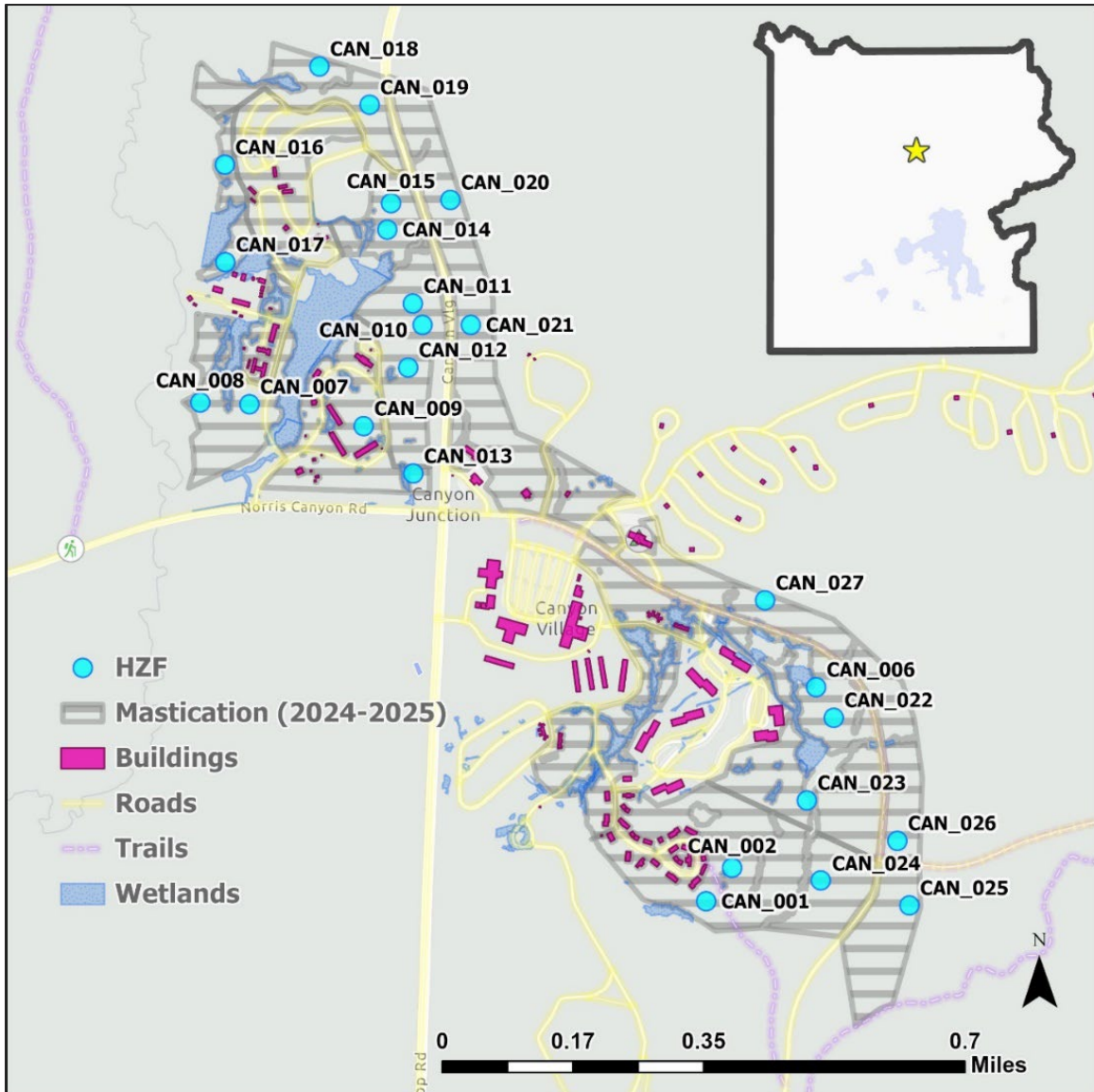


Figure 8. Map of the Canyon Concession and Government Areas showing the locations of all HZF monitoring plots (teal circles), the 2024-2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

Surface Fuels Only

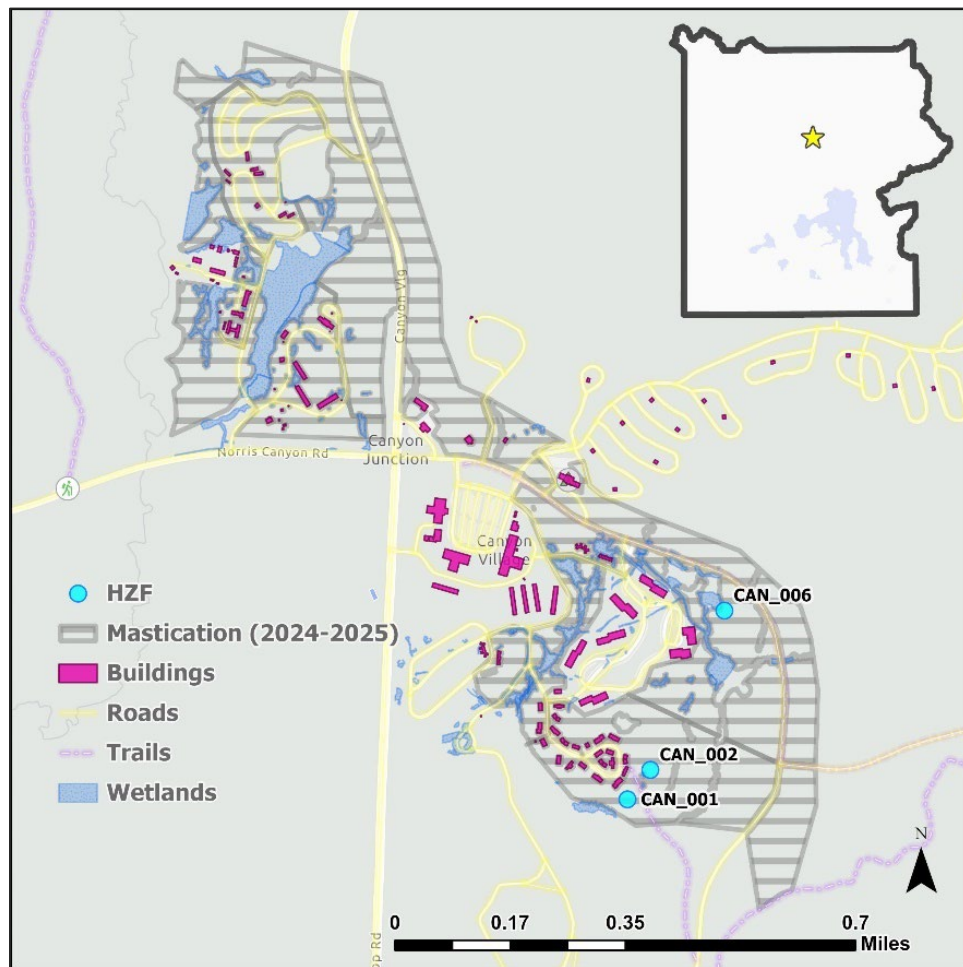


Figure 9. Map of HZF plots 1, 2, and 6 (teal circles), the 2024-2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For plots 1, 2, and 6, mean 1,000-hour fuel loads declined by 92% following the 2024-2025 mastication treatment, decreasing from 46.3 tons per acre in 2004 (*00PRE*) to 3.7 tons per acre in 2025 (*02POST*), well below the 10 tons per acre management objective (Table 2; Figure 11). When fuel components were considered collectively (including fine and coarse woody fuels, litter, and duff) total fuel loads were lower in 2025 relative to 2004, although the litter component exhibited a relative increase, rising from 3.6 tons per acre in 2004 (*00PRE*) to 14.5 tons per acre in 2025 (Figure 13 top panel).

However, to better represent conditions in masticated fuel beds, we also present an alternative calculation that applies a bulk density constant more representative of masticated material (7.5

lbs/ft³, used for the purposes of this report). Under this alternative approach, we observed around 5.8 tons per acre of litter and 23.6 tons per acre of masticated material (e.g., chipped woody debris) (Figure 13 bottom). This second calculation is intended to reflect the altered structure and packing of fuels following mastication and should be interpreted as a complementary estimate rather than a direct replacement of standard litter and duff measurements.

In masticated areas, the treatment process churns and mixes litter, duff, and woody chips into a single, heterogeneous surface fuel layer. As a result, duff is included within the surface organic material but is not consistently distinguishable or recorded as a separate component during post-treatment sampling, as it was in pre-treatment measurements. As masticated material continues to decompose and the organic layers become more differentiated over time, future monitoring is expected to better resolve and separately document the duff component. In addition, these results are based on a limited sample size (three plots), which contributes to elevated variance and comparatively wide confidence intervals for several fuel components. Accordingly, results should be interpreted with caution.

Table 2. 1,000-hour fuel monitoring results for Canyon Concession Area (plots 1, 2, and 6)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Canyon (Plots 1, 2, 6)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Canyon 1,2,6 (n = 3 plots; 2 treatments)</i> <u>00PRE (2004): 46.3 (± 58.8) tons/ac</u> <u>01YR11 (2015): 19.9 (± 26.6) tons/ac</u> <i>Difference from 00PRE to 01YR11: -57%</i> <u>01YR15 (2019): 16.7 (± 21.6) tons/ac</u> <i>Difference from 00PRE to 01YR15: -64%</i> <u>01YR20 (2024): 22.5 (± 21.6) tons/ac</u> <i>Difference from 00PRE to 01YR20: -51%</i> <u>02POST (2025): 3.7 (± 3.6) tons/ac</u> <i>Difference from 00PRE to 02POST: -92%</i>	Yes, but minimum sample size not met



Figure 10. Photograph from plot 006 illustrating post-mastication surface fuel conditions in 2025.

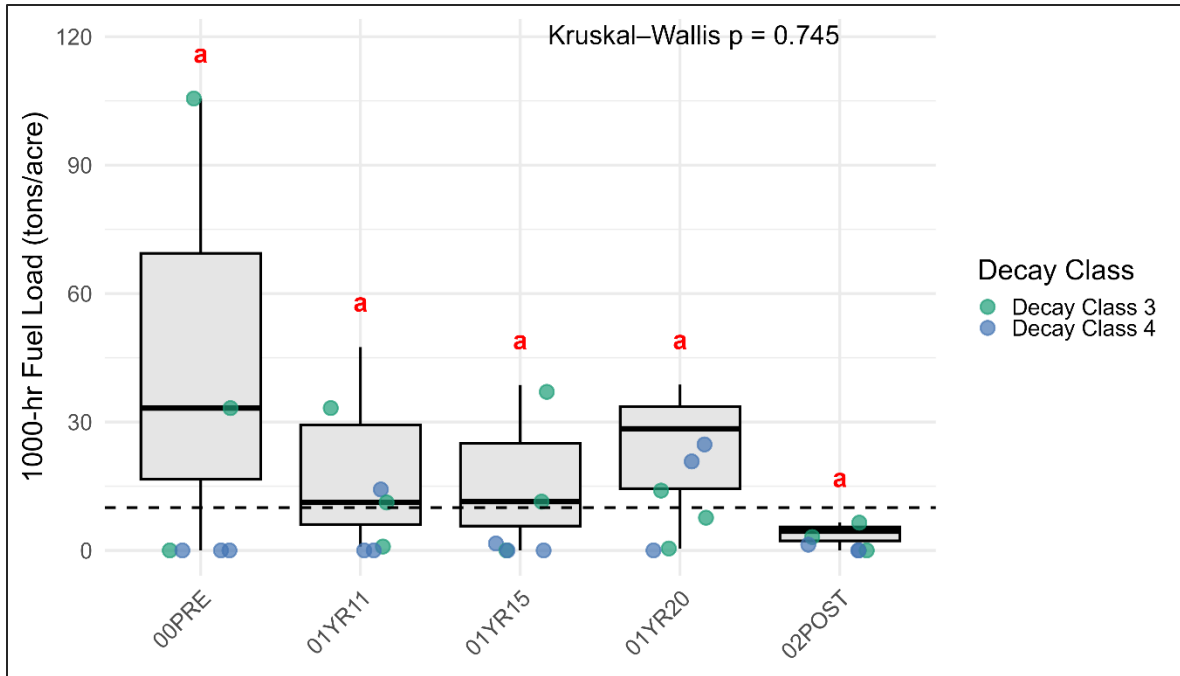


Figure 11. Average 1,000-hour fuel loads (tons per acre) for Canyon plots 1, 2, and 6. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.



Figure 12. Photograph from plot 001 illustrating post-mastication surface fuel conditions in 2025.

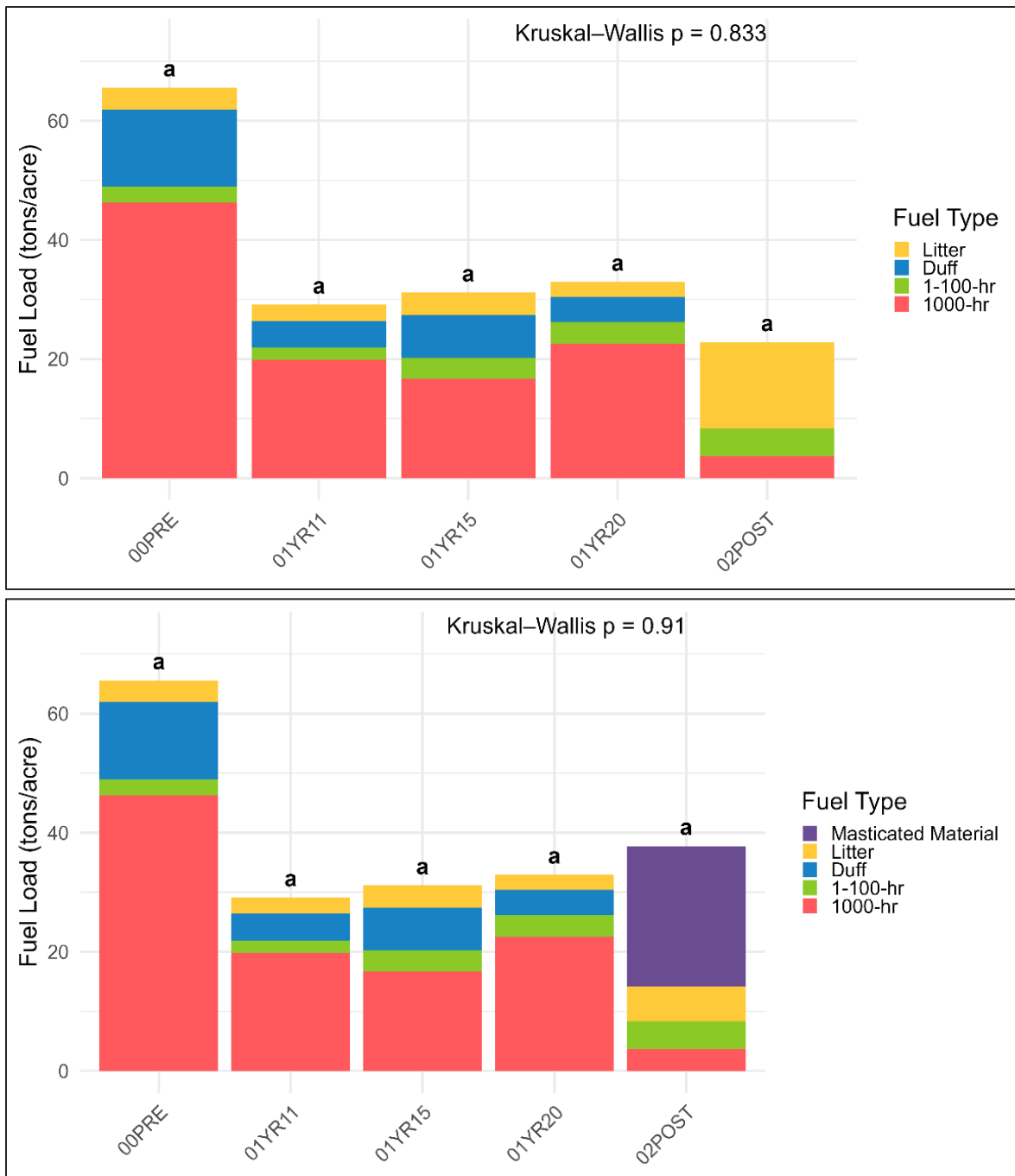


Figure 13. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Canyon plots 1, 2, and 6, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Surface Fuels Only

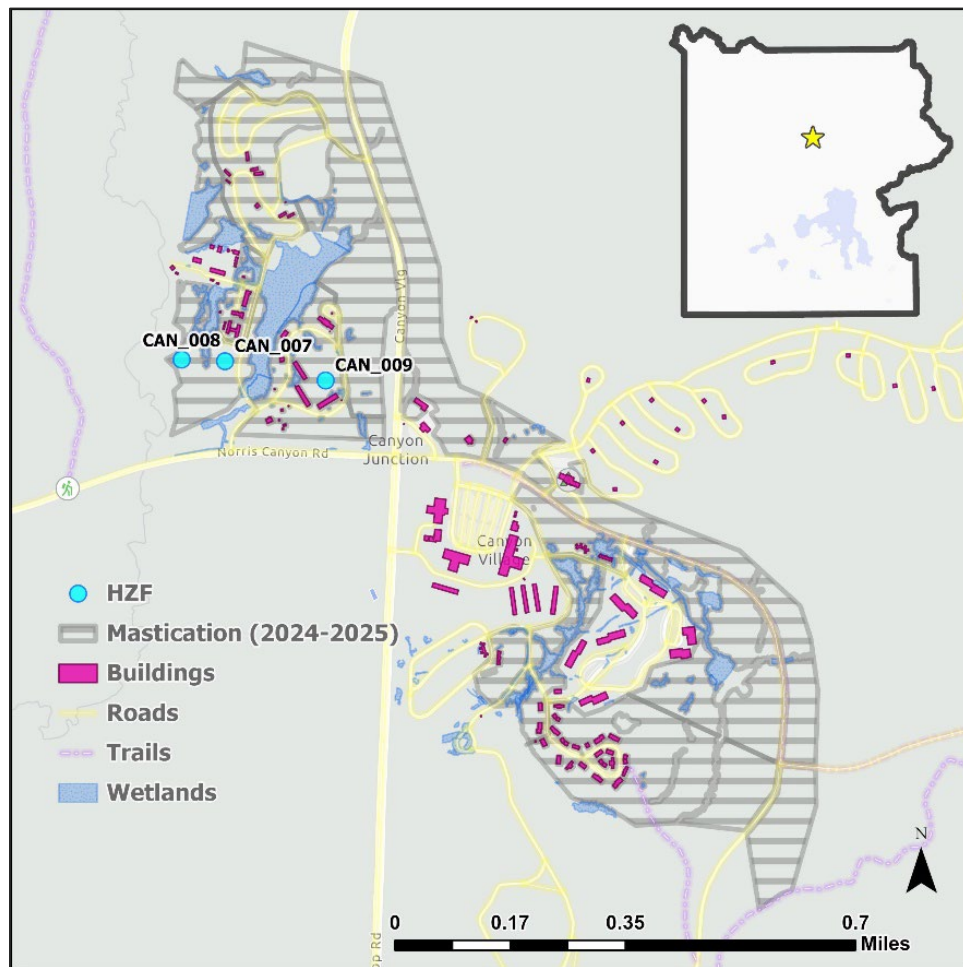


Figure 14. Map of HZF plots 7, 8, and 9 (teal circles), the 2024-2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For plots 7, 8, and 9, no 1,000-hour fuels were observed following the mastication treatment, representing a 100% reduction in 1,000-hour fuel loads relative to 2004 (*00PRE*). Post-treatment 1,000-hour fuel loads therefore met the ≤ 10 tons per acre management objective (Table 3; Figure 16).

When all fuel components were considered collectively, a statistically significant reduction in total fuel loads was observed in 2025 (*03POST*) relative to the initial 2004 (*00PRE*) measurement. Specifically, fine fuels (1–100-hour) declined from 4.1 tons per acre in 2004 to 0.9 tons per acre in 2025, while duff declined from 14.3 tons per acre to 0 over the same period. In contrast, litter loads increased from 5.1 tons per acre in 2004 to approximately 7.0 tons per acre

in 2025, most likely due to masticated material being counted as litter (Figure 18). When the masticated fuel bed was explicitly measured and incorporated using the adjusted bulk density constant for masticated fuels, estimated post-treatment surface fuel loads in 2025 consisted of approximately 3.6 tons per acre of litter and 9.1 tons per acre of masticated material. Although total surface fuel loads, including masticated material, remained the lowest observed across the monitoring record, they were no longer statistically distinct from pre-treatment conditions in 2004 (00PRE) (Figure 18).

As with plots 1, 2, and 6, results for this group are based on a limited sample size (three plots), which contributes to elevated variance within the observable data. Consequently, these findings should be viewed within the context of the sampling limitations.

Table 3. 1,000-hour fuel monitoring results for Canyon Government Area (plots 7, 8, and 9)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Canyon (Plots 7, 8, 9)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Canyon 7,8,9 (n = 3 plots; 3 treatments)</i> <u>00PRE (2004): 3.9 (± 3.7) tons/ac</u> <u>01YR08 (2012): 9.7 (± 2.2) tons/ac</u> <i>Difference from 00PRE to 01YR08: +146%</i> <u>02YR01 (2013): 4.5 (± 4.2) tons/ac</u> <i>Difference from 00PRE to 02YR01: +14%</i> <u>02YR05 (2017): 5.2 (± 5.1) tons/ac</u> <i>Difference from 00PRE to 02YR05: +33%</i> <u>02YR10 (2022): 4.9 (± 4.7) tons/ac</u> <i>Difference from 00PRE to 02YR10: +25%</i> <u>03POST (2025): 0 (± 0) tons/ac</u> <i>Difference from 00PRE to 03POST: -100%</i>	Yes, but minimum sample size not met



Figure 15. Representative photographs from plot 008 showing pre-mastication conditions in 2022 (02YR10; left) and post-mastication conditions in 2025 (03POST; right).

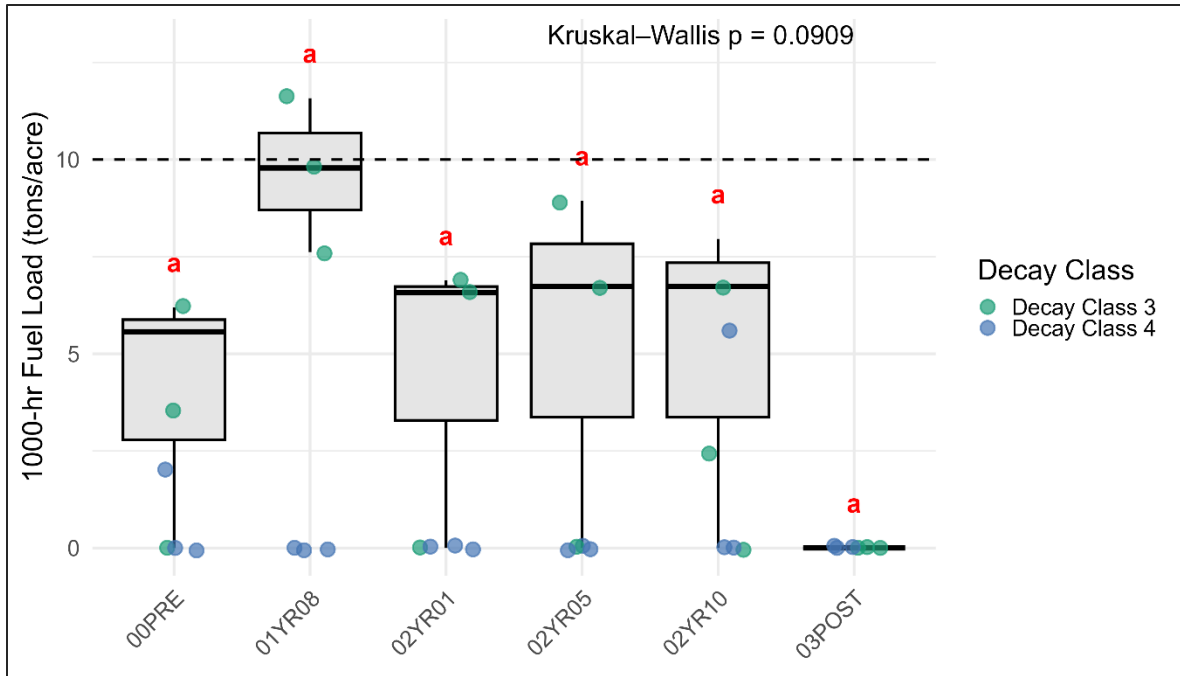


Figure 16. Average 1,000-hour fuel loads (tons per acre) for Canyon plots 7, 8, and 9. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.



Figure 17. Representative photographs from plot 009 showing pre-mastication conditions in 2022 (02YR10; left) and post-mastication conditions in 2025 (right).

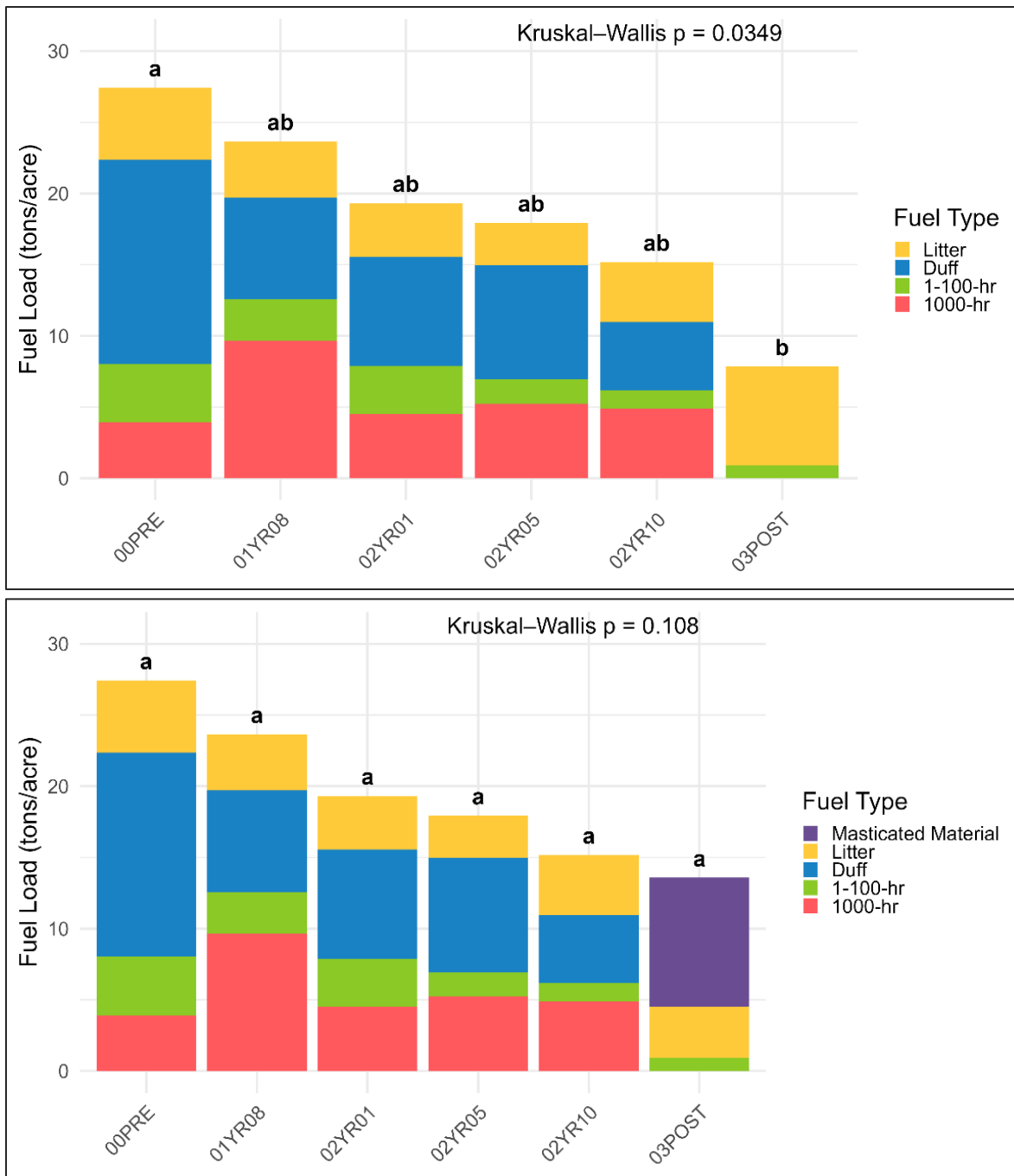


Figure 18. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Canyon plots 7, 8, and 9, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Surface Fuels Only

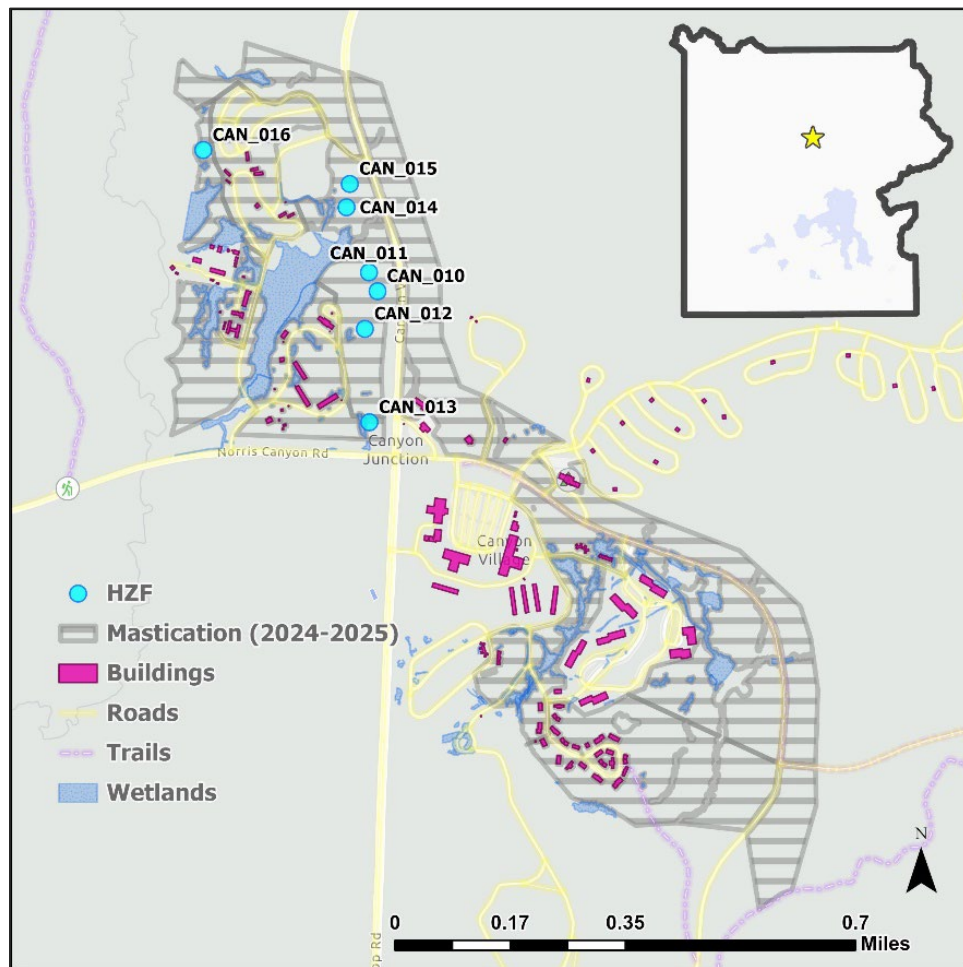


Figure 19. Map of HZF plots 10-16 (teal circles), the 2024-2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For plots 10 through 16, mean 1,000-hour fuel loads declined by 87%, decreasing from 10.7 tons per acre in 2013 (*00PRE*) to 1.4 tons per acre in 2025 (*02POST*). Post-treatment fuel loads were therefore well below the ≤ 10 tons per acre management objective within this group of plots (Table 4; Figure 21).

When all fuel components were considered collectively, a general reduction in fuel loadings was observed between 2013 and 2025. Fine fuels (1–100-hour) declined from 4.7 tons per acre in 2013 (*00PRE*) to 1.8 tons per acre in 2025. Duff was measurable in one plot within this unit, allowing duff fuel loads to be estimated; for this component, duff declined from 5.8 tons per acre

in 2013 to 4.4 tons per acre in 2025. In contrast, litter loads increased from 4.9 tons per acre in 2013 to 9.9 tons per acre in 2025 following mastication (Figure 23).

When the masticated fuel bed was explicitly accounted for using the adjusted bulk density constant, estimated post-treatment loads consisted of approximately 5.6 tons per acre of litter and 11.9 tons per acre of masticated material. These values reflect a slight increase in total surface fuel loading relative to the prior measurement in 2020 (01YR05) (Figure 23).

Although this unit includes a larger number of plots (seven plots) than other treatment units, variance remains high. The minimum sample size required to fully characterize variability within the population has not yet been met; therefore, results should continue to be interpreted with appropriate caution.

Table 4. 1,000-hour fuel monitoring results for Canyon Government Area (plots 10-16)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Canyon (Plots 10-16)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Canyon 10-16 (n = 7 plots; 2 treatments)</i> <u>00PRE (2013): 10.7 (± 7.6) tons/ac</u> <u>01POST (2016): 9.4 (± 7.7) tons/ac</u> <i>Difference from 00PRE to 01POST: -12%</i> <u>01YR05 (2020): 10.3 (± 7.4) tons/ac</u> <i>Difference from 00PRE to 01YR05: -4%</i> <u>02POST (2025): 1.4 (± 0.9) tons/ac</u> <i>Difference from 00PRE to 02POST: -87%</i>	Yes, but minimum sample size not met



Figure 20. Representative photographs from plot 011 showing pre-mastication conditions in 2020 (01YR05; left) and post-mastication conditions in 2025 (right).

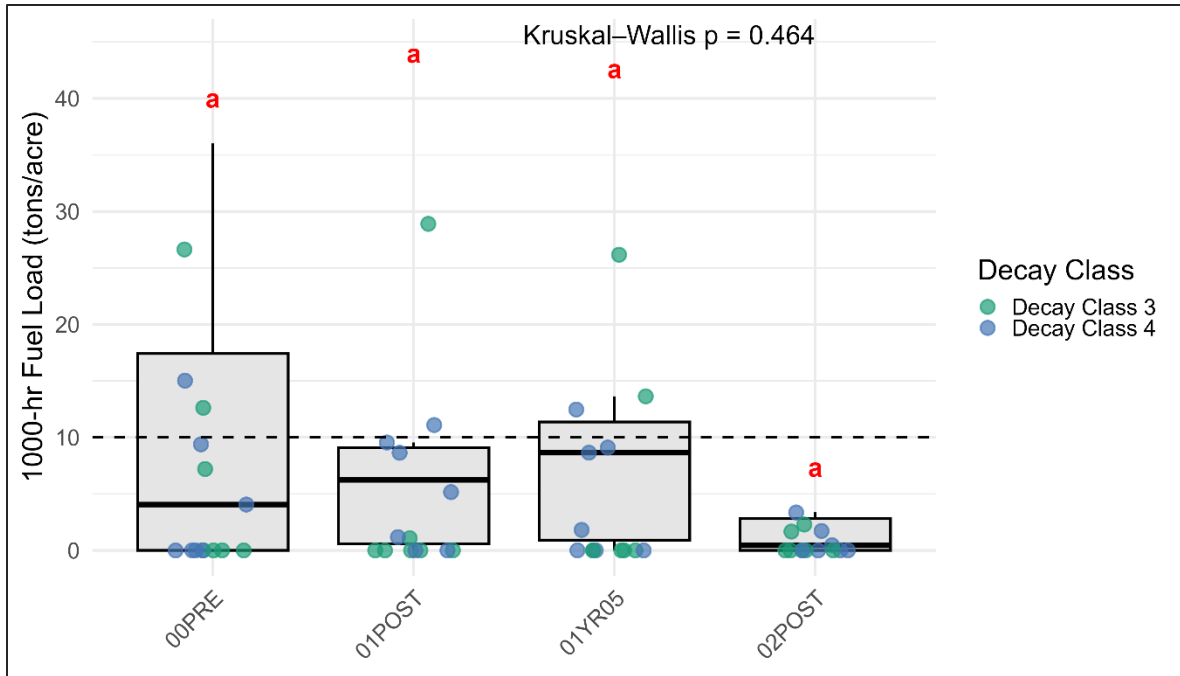


Figure 21. Average 1,000-hour fuel loads (tons per acre) for Canyon plots 10-16. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal-Wallis test with Dunn's post hoc comparisons and Holm's correction for multiple testing.



Figure 22. Photograph from plot 015 illustrating post-mastication surface fuel conditions in 2025.

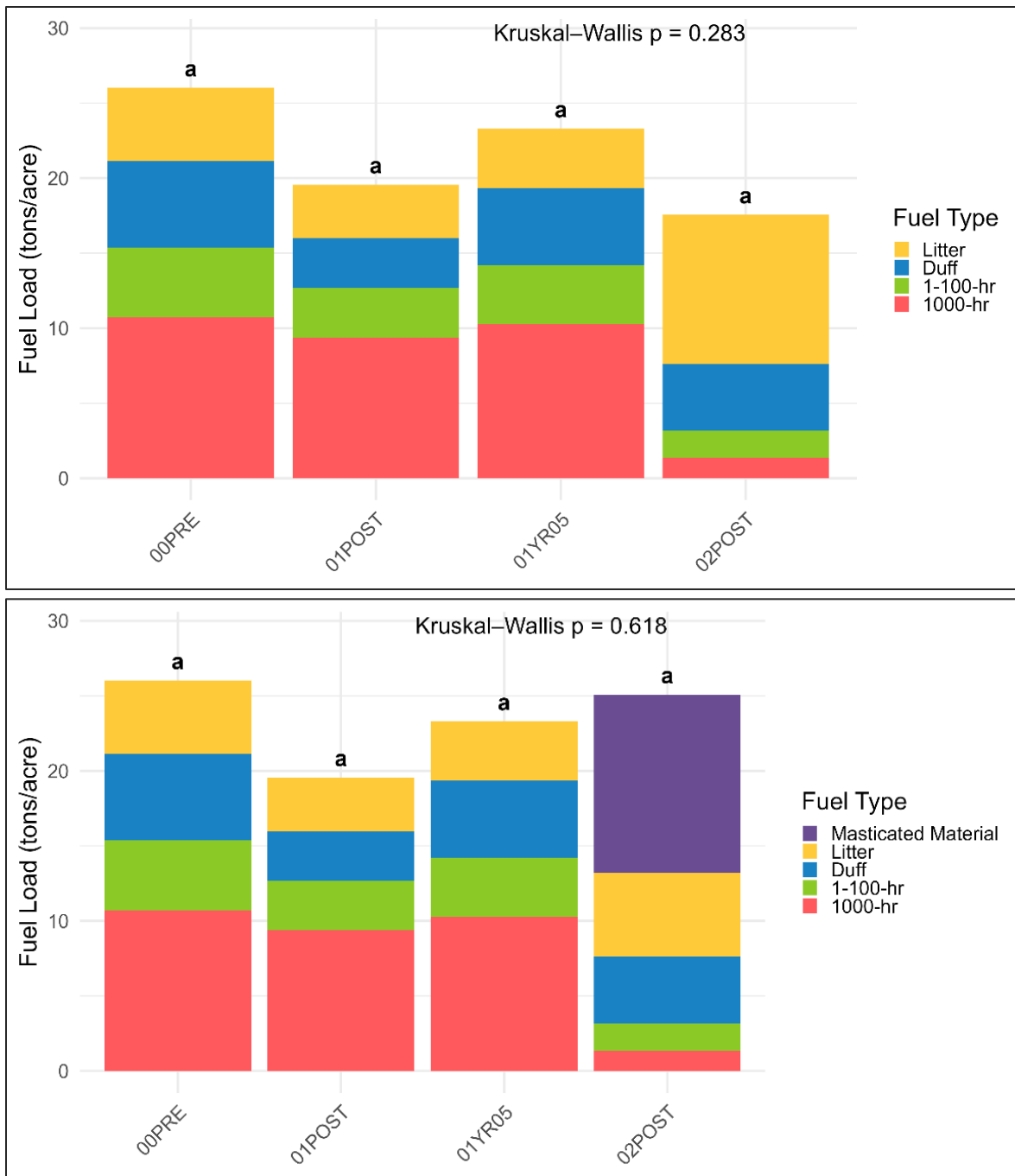


Figure 23. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Canyon plots 10-16, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Surface Fuels Only

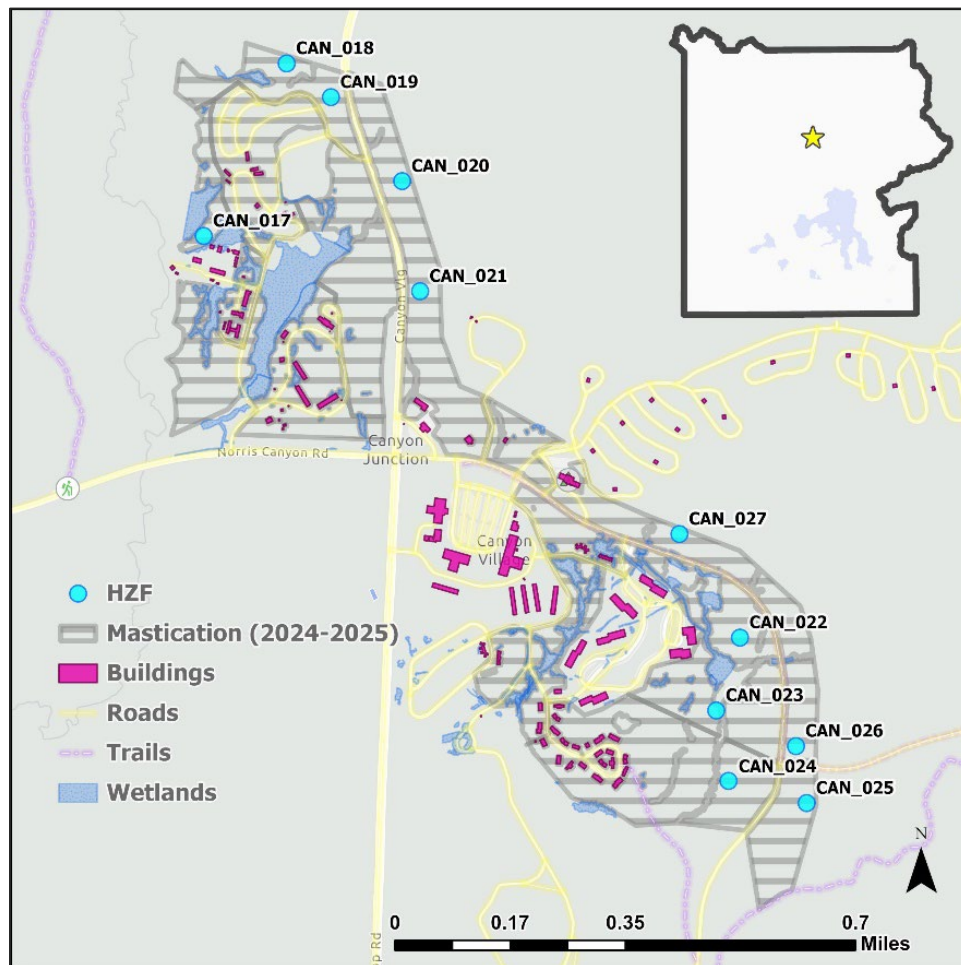


Figure 24. Map of HZF plots 17-27 (teal circles), the 2024-2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For plots 17 through 27, mean 1,000-hour fuel loads declined by 81%, decreasing from 14.4 tons per acre during the 2021-2024 pre-treatment (*00PRE*) measurements to 2.7 tons per acre in 2025 (*01POST*). Post-treatment fuel loads were reduced to levels below the ≤ 10 tons per acre management objective, indicating effective reduction of large-diameter surface fuels (Table 5; Figure 25).

For other fuel components, only modest changes were observed in fine fuels (1–100-hour), which declined slightly from 2.8 tons per acre during the *00PRE* measurements to 2.6 tons per acre in 2025. Duff was measurable in three plots within this group, allowing duff fuel loads to be estimated; for these plots, duff increased from 3.4 tons per acre in the *00PRE* measurements to

4.6 tons per acre in 2025. Litter loads increased from 4.0 tons per acre during the *00PRE* period to 8.9 tons per acre in 2025 (Figure 26).

When the masticated fuel bed was explicitly accounted for, estimated 2025 surface fuel loads consisted of approximately 3.5 tons per acre of litter and 14.9 tons per acre of masticated material. These estimates indicate an overall increase in surface fuel loading following mastication, reflecting the redistribution of biomass into the surface fuel bed (Figure 26).

Table 5. 1,000-hour fuel monitoring results for Canyon Concession and Government Areas (plots 17-27)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Canyon (Plots 17-27)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Canyon 17-27 (n = 11 plots; 1 treatment)</i> <u><i>00PRE (2021/2023/2024): 14.4 (± 5.6) tons/ac</i></u> <u><i>01POST (2025): 2.7 (± 1.6) tons/ac</i></u> <i>Difference from 00PRE to 01POST: -81%</i>	Yes, but minimum sample size not met

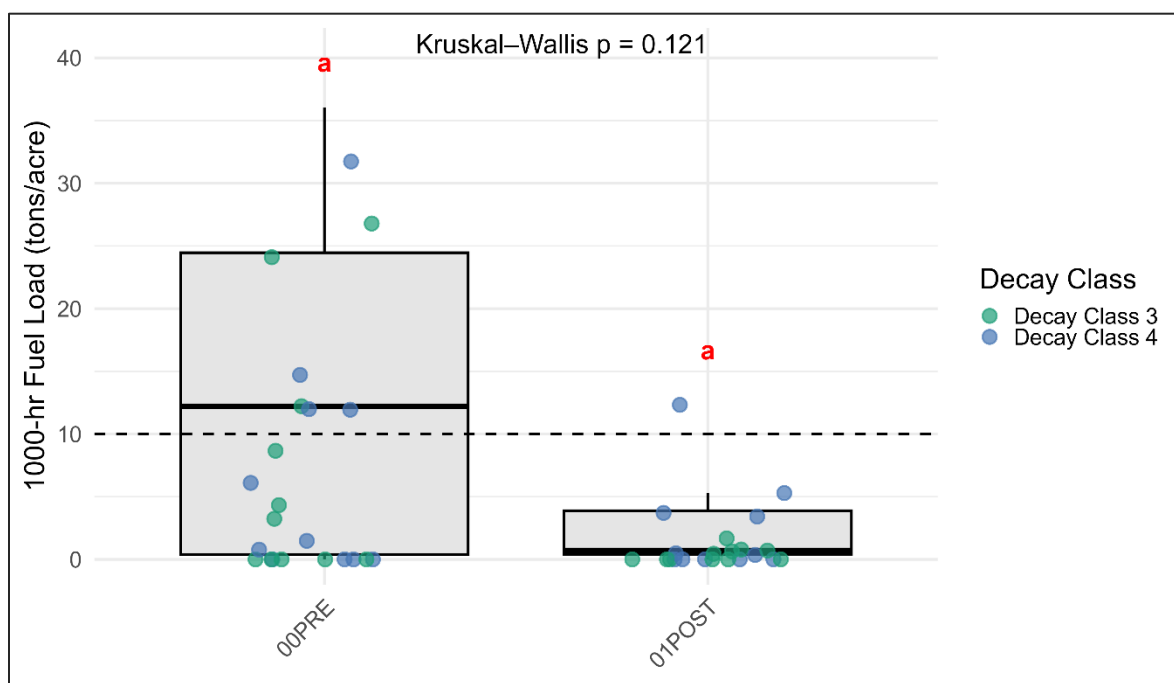


Figure 25. Average 1,000-hour fuel loads (tons per acre) for Canyon plots 17-27. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal-Wallis test with Dunn's post hoc comparisons and Holm's correction for multiple testing.

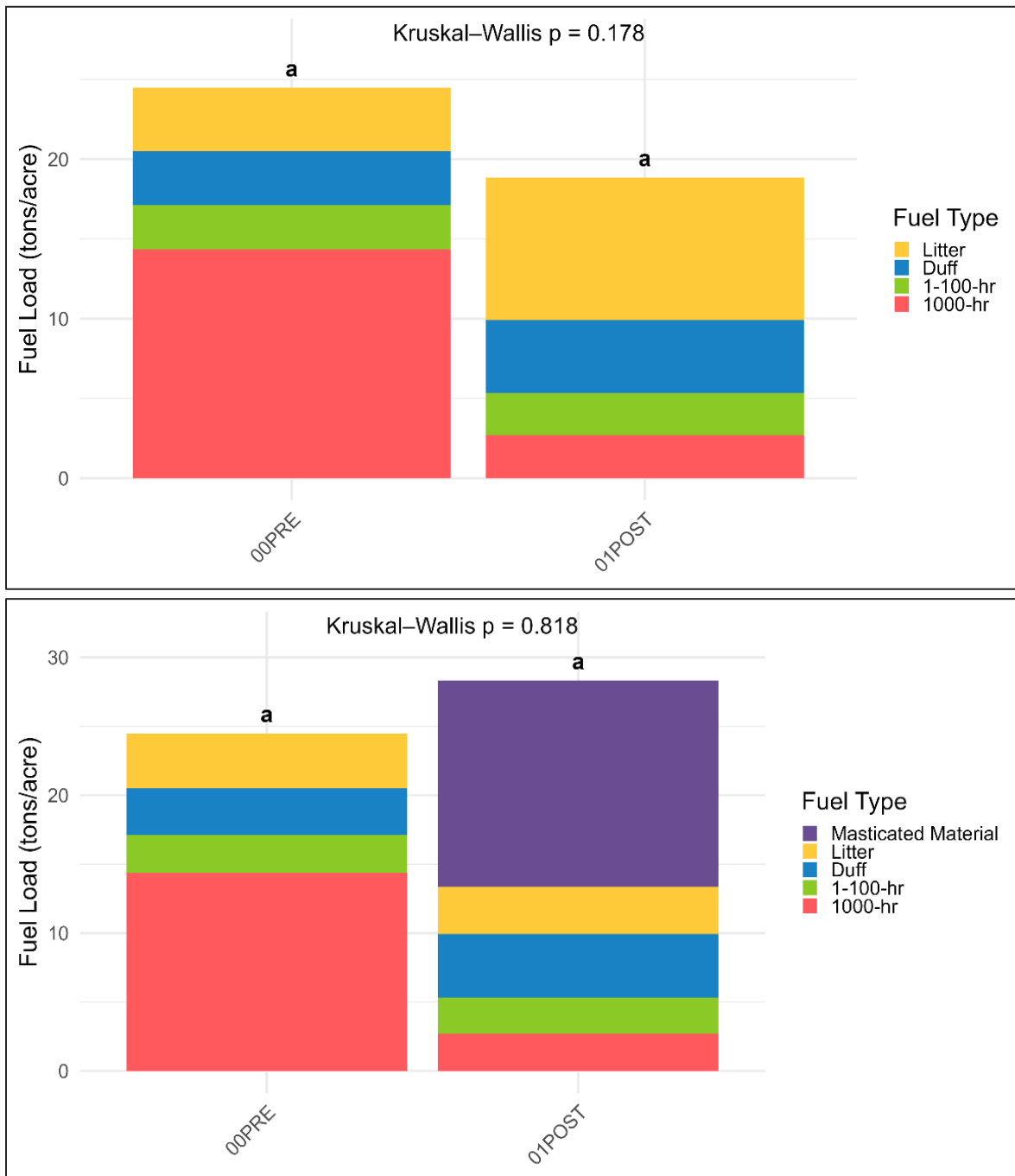


Figure 26. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Canyon plots 17-27, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Summary of Surface Fuel Loadings Post-Mastication for Canyon Monitoring Plots

Overall, mastication treatments were effective at reducing coarse woody debris (1,000-hour fuels) across all sampled plots, with post-treatment fuel loads consistently reduced to levels below the 10 tons per acre management objective. This indicates successful reduction of large-diameter surface fuels that contribute most directly to sustained flaming and long-duration heat release.

When fuel components were evaluated collectively, total surface fuel loads generally declined following treatment. However, when masticated material was explicitly accounted for using an adjusted bulk density constant representative of masticated fuel beds (7.5 lbs/ft³, applied for the purposes of this report), estimated total surface fuel loads were in some cases comparable to, or slightly higher than, pre-treatment values. This pattern reflects the redistribution of woody biomass from standing and downed coarse fuels into a compacted surface fuel layer, rather than an increase in total biomass.

The physical and temporal behavior of masticated fuel beds remains an important source of uncertainty. Masticated fuels differ substantially from traditional litter and duff in terms of particle size distribution, packing ratio, aeration, and decomposition dynamics, all of which influence bulk density, moisture retention, and fuel consumption. Over time, masticated material is expected to compact and decompose, gradually transitioning toward fuel bed characteristics more similar to conventional litter and duff layers; however, the rate and trajectory of this transition are highly site-specific and not yet well understood.

Continued surface fuel monitoring within these masticated units will be critical for improving understanding of how masticated fuel beds evolve over time and how these changes influence overall fuel bed structure and fire behavior potential. A key objective for upcoming monitoring efforts is the development of site-specific bulk density estimates for masticated fuels, which will allow for more accurate fuel loading calculations and improve interpretation of treatment effectiveness across these units.



Figure 27. Photos from Canyon plot 025 showing stand conditions before mastication in 2023 (00PRE; left) and post-mastication in 2025 (right).

ii. Norris Government Area

The Norris Government Area of Yellowstone National Park is located approximately 22 miles south of Mammoth Hot Springs, in the north-central portion of the park. Hazard fuel reduction activities in this area began in 2005-2006, when an initial treatment was implemented across approximately 16 acres. A second, expanded treatment was conducted in 2009, encompassing 42 acres and fully incorporating the original 2005-2006 treatment unit.

Both early treatments utilized chainsaws for hand thinning, with downed woody material either removed through firewood permits or piled and burned on site. Vegetation in the treatment area is dominated by lodgepole pine, a condition influenced in part by the widespread presence of nutrient-poor rhyolitic soils across much of the central Yellowstone Plateau.

To evaluate treatment effectiveness and determine whether project objectives were achieved, six monitoring plots were installed in 2006, one year following the initial treatment entry (plots 001 through 006), however two of the plots were later decommissioned. The remaining plots (001, 002, 003, 006) were remeasured in 2015 (*02YR06*), 2020 (*02YR11*), 2024 (*02YR15*) and 2025 (*03POST*) (Figure 29).

In summer 2025, a larger mastication treatment was implemented across an expanded 36-acre area. Mastication was followed by hand crew thinning and piling of downed material, with piles burned during the winter of 2025. To better assess the effects of this expanded treatment, two additional monitoring plots (plots 007 and 008) were installed in spring 2025 prior to treatment implementation (Figure 34). Following mastication, all six monitoring plots were located, and surface fuels were measured.

A brief timeline summarizing treatment activities and monitoring protocols is provided below:

Norris Plots 001, 002, 003, 006

- 2005/2006 – First entry thinning treatment
- 2006 (*01POST*) – Data collection immediately after the first treatment
- 2009 – Second entry thinning treatment
- 2015 (*02YR06*) – Data collection 6 years after the second treatment
- 2020 (*02YR11*) – Data collection 11 years after the second treatment
- 2024 (*02YR15*) – Data collection 15 years after the second treatment
- 2025 – First entry mastication treatment
- 2025 (*03POST*) – Surface fuels data collection immediately post-mastication treatment

Norris Plots 007, 008

- 2025 (*00PRE*) – Data collection prior to first entry
- 2025 – First entry mastication treatment
- 2025 (*03POST*) – Surface fuels data collection immediately post-mastication treatment

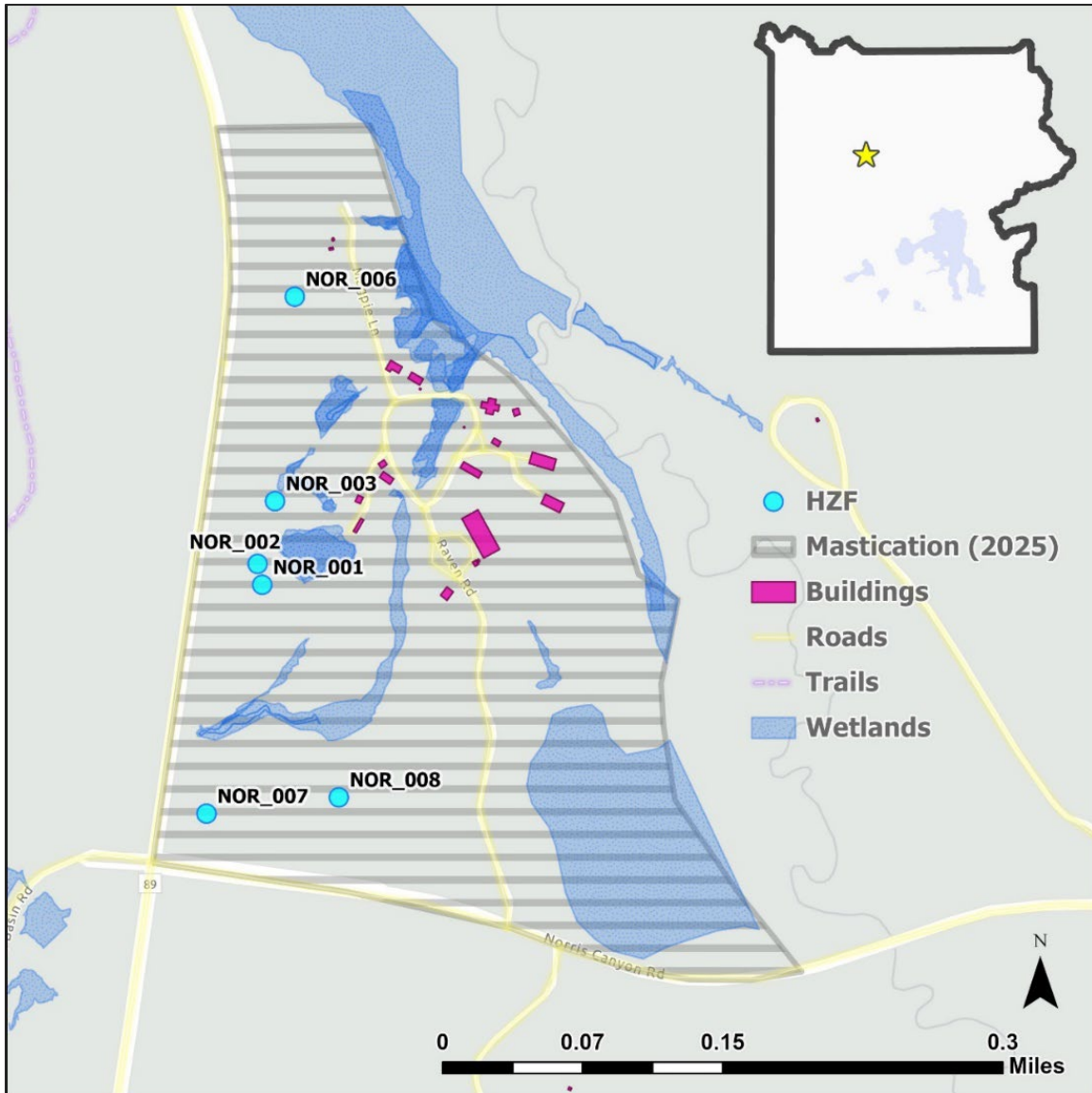


Figure 28. Map of the Norris Government Area showing the locations of all HZF monitoring plots (teal circles), the 2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

Surface Fuels Only

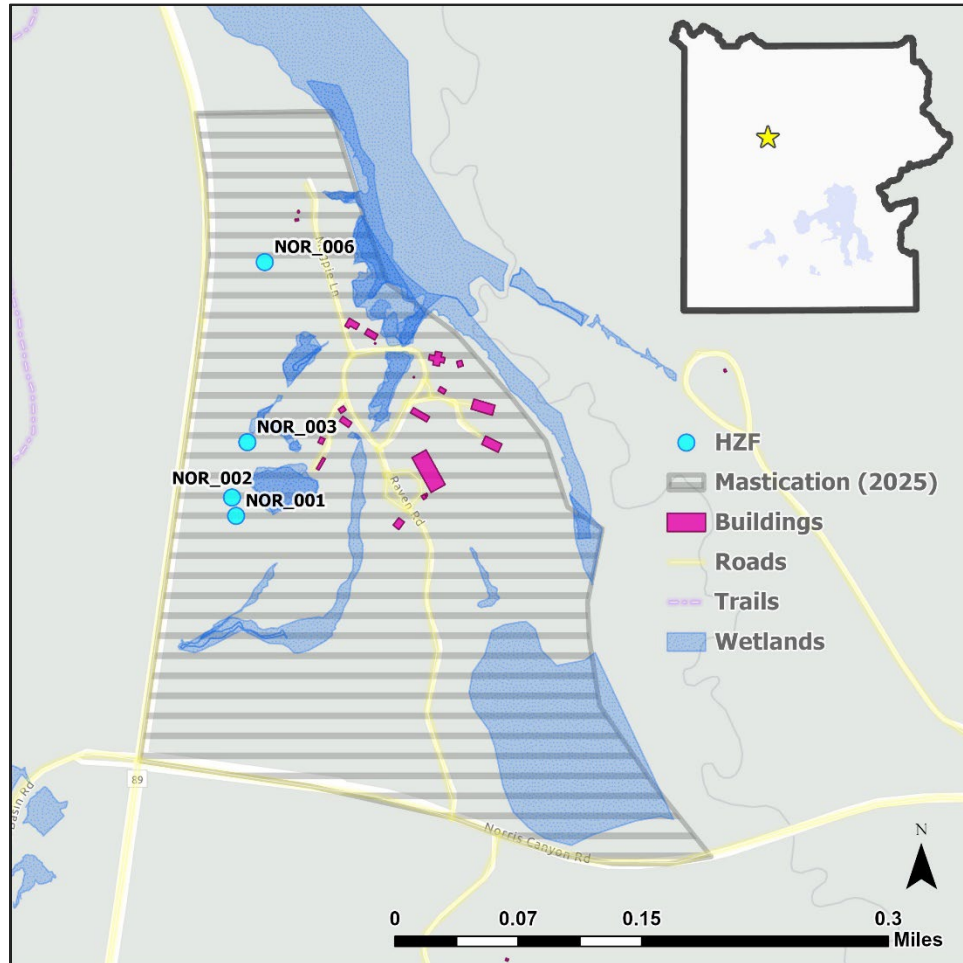


Figure 29. Map of HZF plots 1, 2, 3, and 6 (teal circles), the 2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For Norris plots 1, 2, 3, and 6, a statistically significant reduction in 1,000-hour coarse fuels was observed between the initial 2006 (*01POST*) measurement and 2025 (*03POST*). Mean 1,000-hour fuel loads declined by 85%, from 6.1 tons per acre to 0.9 tons per acre, well below the 10 tons per acre management objective established for HZF treatment areas (Table 6; Figure 31).

When considering all fuel components, only modest changes were observed in fine fuels (1–100-hour), which declined slightly from 2.8 tons per acre in 2006 to 2.6 tons per acre in 2025. In contrast, litter loads increased from 2.2 tons per acre to 10.5 tons per acre over the same period. Overall, combined surface fuel loads were significantly lower in 2025 relative to the prior measurement in 2024 (*02YR15*) (Figure 33).

When masticated fuel beds were explicitly accounted for and measured, estimated surface fuel loads in 2025 remained lower than earlier measurements but no longer differed significantly. Under this adjusted calculation, estimated post-treatment fuel loads consisted of approximately 5.3 tons per acre of litter and 14.1 tons per acre of masticated material (Figure 33).

As with other treatment units, these results are based on a limited sample size (four plots), resulting in elevated variance in the data, which limits the strength of inference from these results. Continued monitoring will be necessary to better characterize long-term treatment effects and fuel bed development in this area.

Table 6. 1,000-hour fuel monitoring results for Norris Government Area (plots 1, 2, 3, and 6)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Norris (Plots 1, 2, 3, 6)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	Norris 1,2,3,6 ($n = 4$ plots; 3 treatments) <u>01POST (2006): 6.1 (± 2.5) tons/ac</u> <u>02YR06 (2015): 19.9 (± 10) tons/ac</u> Difference from 01POST to 02YR06: +226% <u>02YR11 (2020): 21.6 (± 9.9) tons/ac</u> Difference from 01POST to 02YR11: +255% <u>02YR15 (2024): 24.6 (± 8.1) tons/ac</u> Difference from 01POST to 02YR15: +304% <u>03POST (2025): 0.9 (± 1.1) tons/ac</u> Difference from 01POST to 03POST: -85%	Yes, but minimum sample size not met



Figure 30. Photographs from plot 002 showing pre-mastication conditions in 2024 (02YR15; left) and immediate post-mastication conditions in 2025 (right).

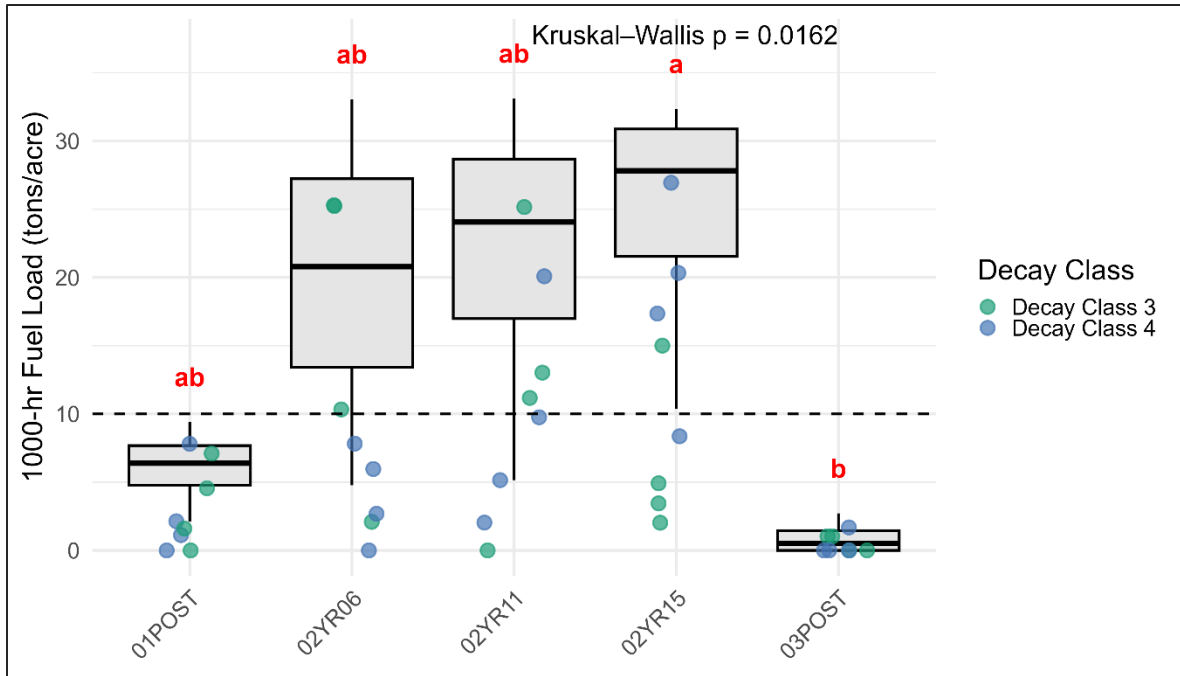


Figure 31. Average 1,000-hour fuel loads (tons per acre) for Norris plots 1, 2, 3, and 6. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.



Figure 32. Photographs from plot 006 showing pre-mastication conditions in 2024 (02YR15; left) and immediate post-mastication conditions in 2025 (right).

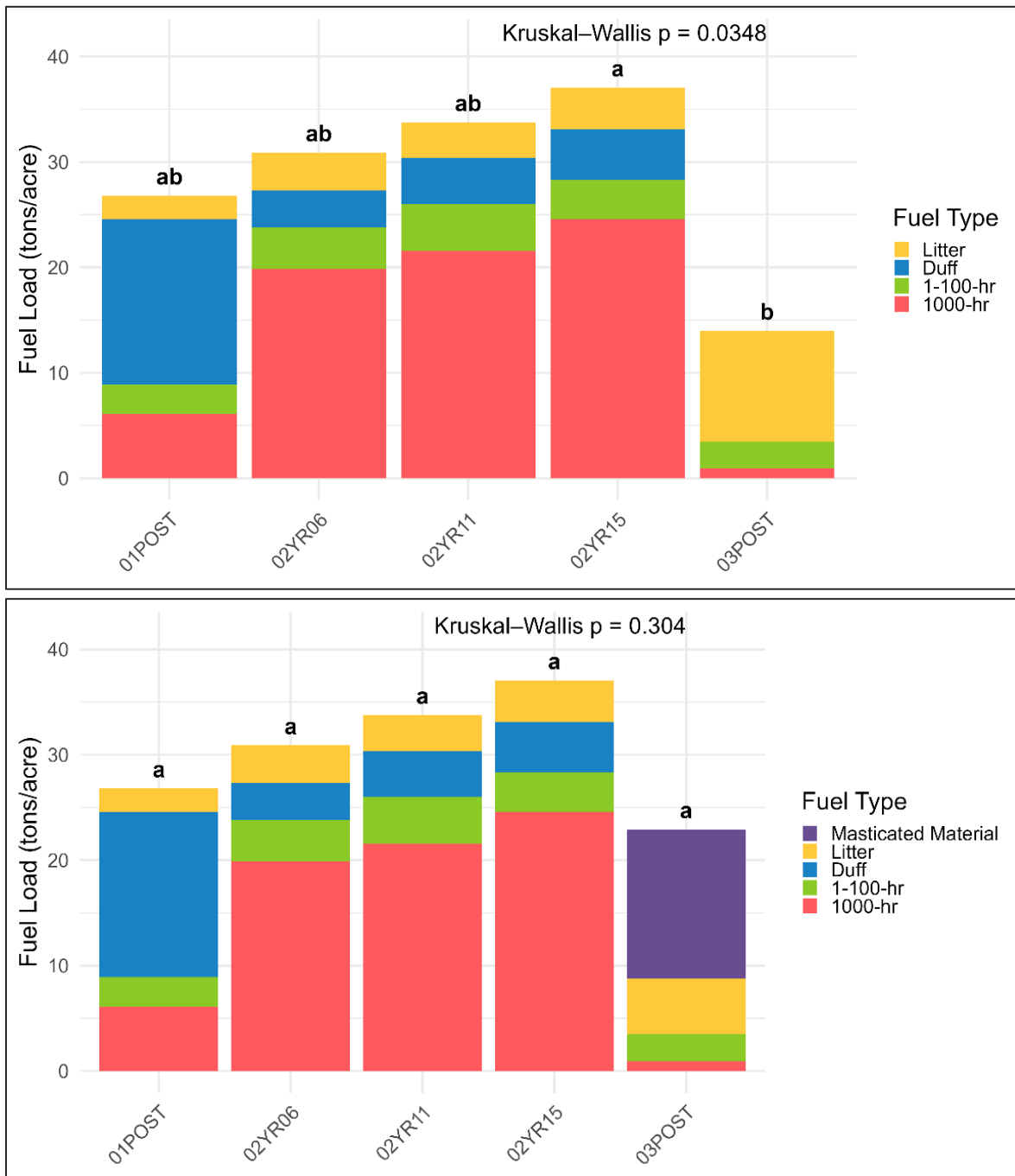


Figure 33. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Norris plots 1, 2, 3, and 6, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Norris Plots 7-8 (Government Area)

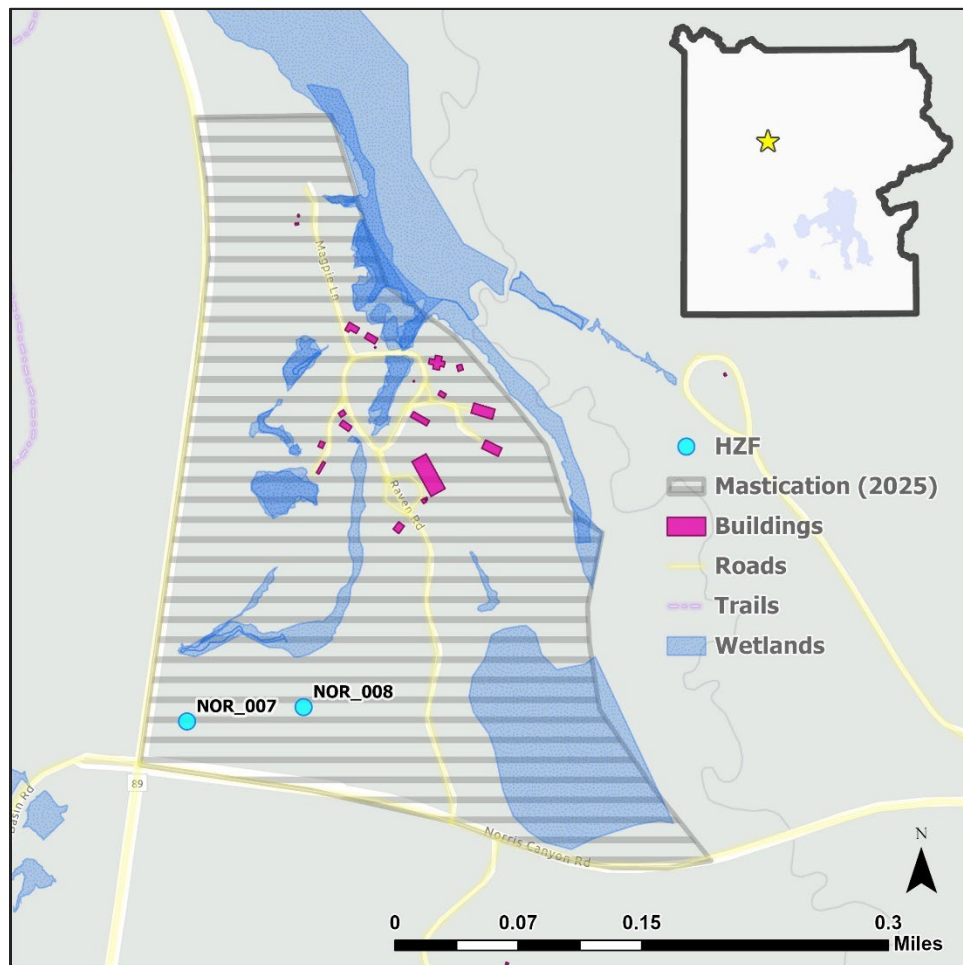


Figure 34. Map of HZF plots 7-8 (teal circles), the 2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For Norris plots 7 and 8, mean 1,000-hour fuel loads declined by 89% following mastication, decreasing from 11.6 tons per acre prior to treatment to 1.2 tons per acre approximately two months post-treatment. Post-treatment fuel loads were therefore well below the ≤ 10 tons per acre management objective for this unit (Table 7; Figure 35).

A similar reduction was observed in fine fuels (1–100-hour), which declined from 6.1 tons per acre prior to treatment to 4.4 tons per acre post-treatment. Duff was not observable in either plot following mastication and therefore could not be reliably quantified. In contrast, litter loads increased from 4.7 tons per acre pre-treatment to 11.4 tons per acre post-treatment (Figure 36).

When masticated fuel beds were explicitly measured and accounted for using the adjusted bulk density constant, estimated post-treatment loads consisted of approximately 6.5 tons per acre of litter and 13.2 tons per acre of masticated material. Although inclusion of masticated material

increased estimated total surface fuel loads, results still indicate an overall reduction in cumulative surface fuels following treatment (Figure 36).

It is important to note that post-treatment measurements were collected within a relatively short time frame (approximately two months following mastication) and observed fuel bed conditions may continue to change as masticated material settles, compacts, and decomposes. In addition, results are based on a limited sample size (two plots), resulting in high variability in the data; the minimum number of plots required to fully characterize variability across this unit has not yet been met. Interpretation of these results should account for the associated uncertainty and continued monitoring will be necessary to assess longer-term treatment effects.

Table 7. 1,000-hour fuel monitoring results for Norris Government Area (plots 7 and 8)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Norris (Plots 7-8)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	Norris 7,8 ($n = 2$ plots; 1 treatment) <u>00PRE (2025): 11.6 (± 13) tons/ac</u> <u>01POST (2025): 1.2 (± 0.3) tons/ac</u> <u>Difference from 00PRE to 01POST: -89%</u>	Yes, but minimum sample size not met

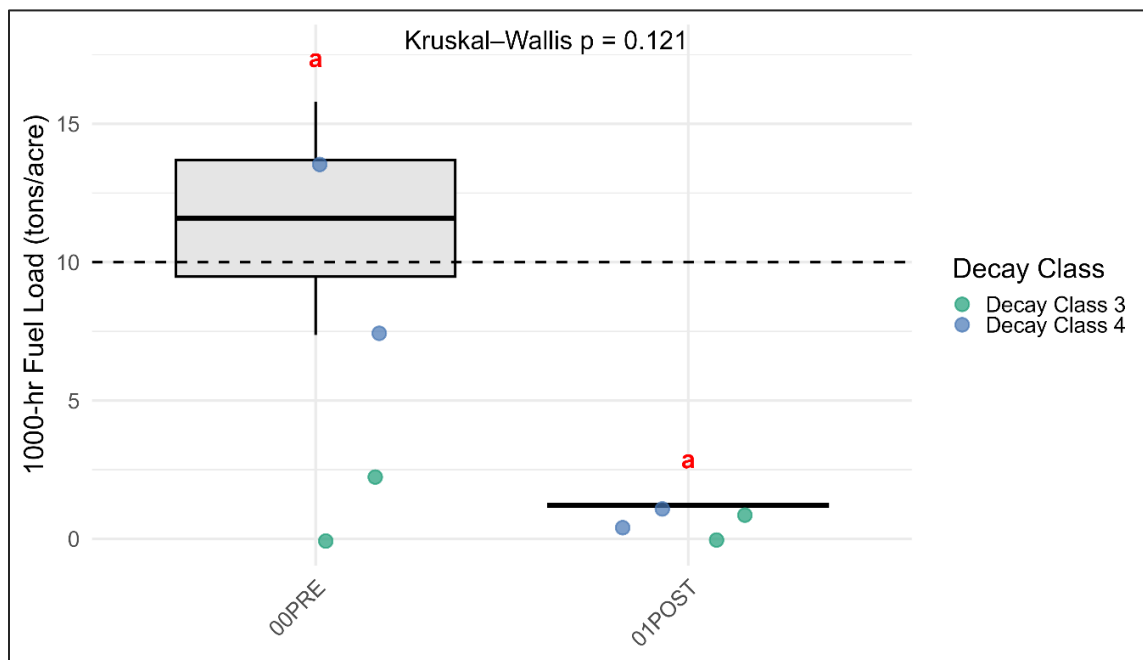


Figure 35. Average 1,000-hour fuel loads (tons per acre) for Norris plots 7 and 8. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.

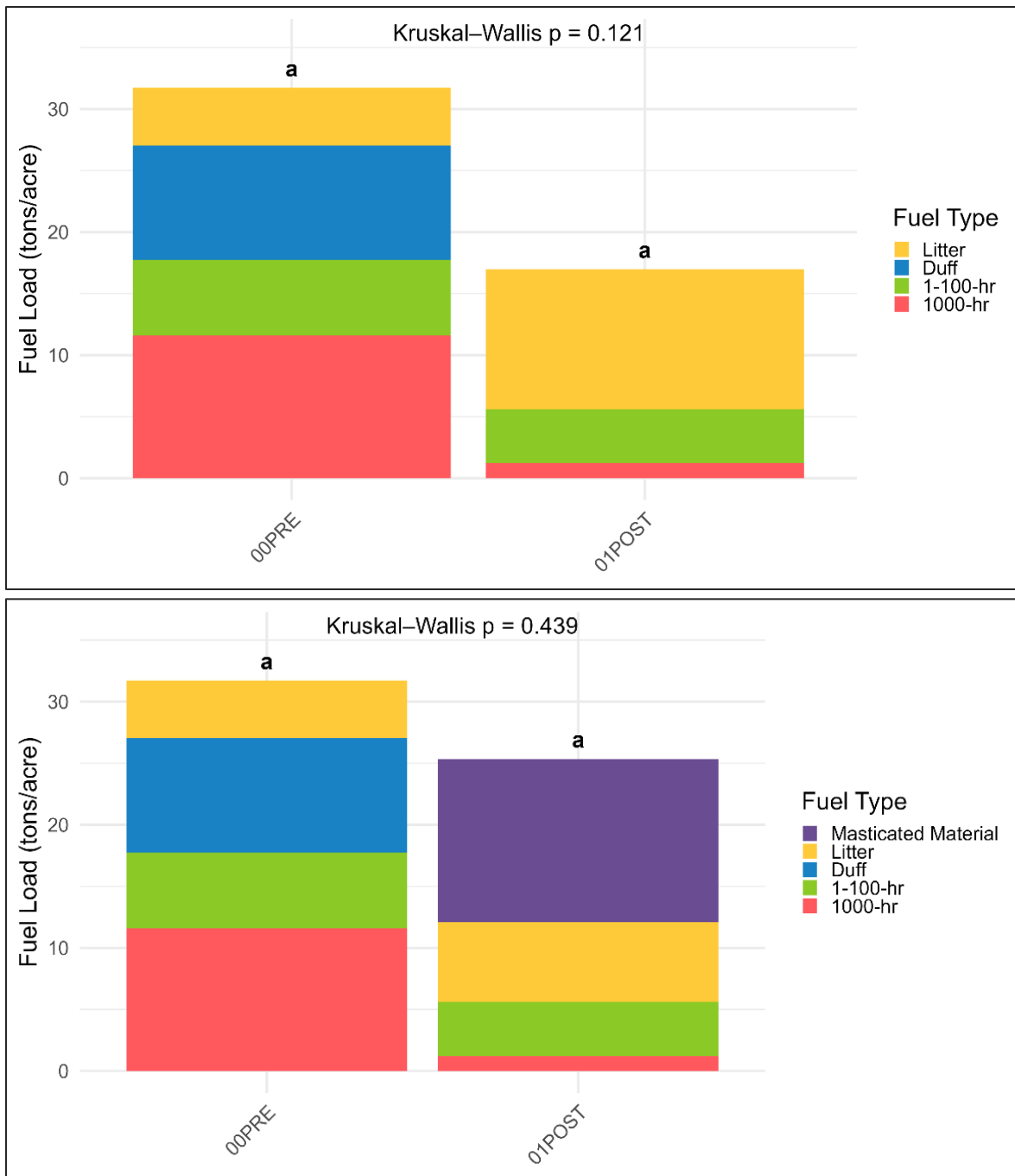


Figure 36. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Norris plots 7 and 8, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Based on *00PRE* (pre-mastication) data, the Norris Government Area represents a relatively dense, lodgepole pine-dominated stand with a smaller whitebark pine component and scattered subalpine fir primarily confined to the understory. Stand density, as quantified by the Stand Density Index (SDI), which is a species-independent metric that integrates trees per acre and average tree size (quadratic mean diameter) to describe relative crowding, was moderate to high (SDI = 264; Table 8). This value indicates a stand in which trees are actively competing for growing space and resources but have not yet reached maximum density or widespread self-thinning conditions.

Basal area was correspondingly high (~124 ft²/ac), with overstory stocking strongly dominated by lodgepole pine (759 trees/ac). Whitebark pine occurred at lower densities (91 trees/ac), and subalpine fir was not present in the >1-inch diameter class (Table 8; Figure 38). Collectively, these metrics characterize a closed, competitive conifer stand with limited available growing space before treatment.

Regeneration within the stand before treatment was heavily skewed toward lodgepole pine, with approximately 15,105 lodgepole seedlings/ac, indicating substantial recruitment and strong potential for future stand infilling. Whitebark pine regeneration was present but limited (202 seedlings/ac), while subalpine fir regeneration was minimal (10 seedlings/ac; Table 9; Figure 38). If these regeneration patterns were allowed to persist, the stand would likely experience increasing stem density and competition over time, with associated reductions in canopy base height and increases in both vertical and horizontal fuel continuity as seedlings recruit into the sapling and subcanopy layers.

Canopy fuel characteristics before treatment further reflect this structure. Canopy bulk density was 0.093 kg/m³, consistent with moderate canopy fuel continuity for a lodgepole pine dominated stand. Mean canopy base height was 3.9 m, indicating that live crowns begin at a relatively low to moderate height above the forest floor. Under dry and windy conditions, and where surface or ladder fuels are present, this vertical structure may facilitate localized torching and upward fire spread, particularly in areas of concentrated surface fuel accumulation.

Due to time and resource constraints, post-mastication monitoring focused primarily on surface fuel measurements, and full remeasurement of overstory and understory plot attributes was not conducted. Future reporting efforts will evaluate the effects of mastication on canopy structure and species composition as additional data are collected.



Figure 37. Photographs from plot 008 showing pre-mastication conditions in spring of 2025 (*00PRE*; left) and immediate post-mastication conditions in summer of 2025 (right).

Table 8. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac). Average values are depicted along with the range of individual plot-level data to illustrate across-plot variability.

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2025	00PRE	0.093 (0.093 – 0.094)	3.9 (3.2 – 4.8)	264 (255 – 272)	124 (118 – 130)

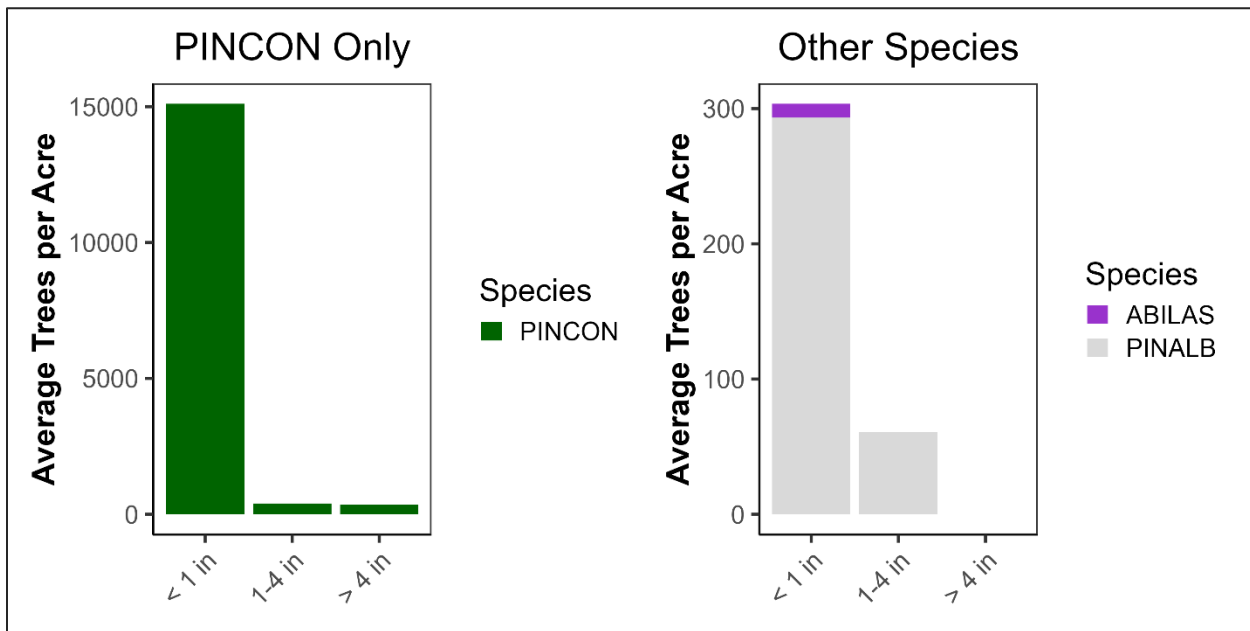


Figure 38. Trees per acre by diameter size class (inches) for Norris plots 7 and 8 during the 2025 (00PRE) monitoring period. Species are distinguished as lodgepole pine (PINCON; green), subalpine fir (ABILAS; purple), and whitebark pine (PINALB; gray). Note the different y-axis scales for the PINCON only plot (left) and other species plot (right). The < 1-inch size class includes both saplings and seedlings.

Table 9. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Norris Government Area (plots 7 and 8)

Species	00PRE (2025)	
	Trees	Seedlings
Lodgepole Pine (PINCON)	759	15,105
Whitebark Pine (PINALB)	91	202
Subalpine Fir (ABILAS)	0	10

Understory vegetation consisted predominately of elk sedge (*Carex geyeri*) and grouse whortleberry (*Vaccinium scoparium*), with a smaller component of raceme pussytoes (*Antennaria racemosa*) and whiteflower hawkweed (*Hieracium albiflorum*). We did not observe any invasive species across the monitoring plots (Table 10).

Table 10. Native species monitoring results for Norris Government Area (plots 7 and 8)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Norris</i> (Plots 7-8)	Monitor for native species composition change using mean relative percent cover.	<i>Norris 7,8 (n = 2 plots; 1 treatment)</i> <u>00PRE (2025): 100% ($\pm$ 0%) native spp.</u>	Yes

Summary of Surface Fuel Loadings Post-Mastication for Norris Monitoring Plots

Collectively, results across all monitoring plots indicate that mastication was highly effective at reducing coarse woody (1,000-hour) fuel loads, consistently lowering these fuels well below the 10 tons per acre management objective for treatment areas. Across plots, reductions in 1,000-hour fuels ranged from approximately 85-89%, representing a substantial and statistically significant decrease relative to pre-treatment or early post-treatment conditions. These reductions reflect successful fragmentation and redistribution of large woody material, thereby reducing potential for sustained high-intensity surface fire and crown fire initiation.

Responses among other surface fuel components were more variable. Fine fuels (1–100-hour) generally exhibited modest declines or minimal change following treatment, while litter loads increased consistently across plots, reflecting the accumulation of masticated material and redistributed surface organic matter. Duff was often not observable post-treatment, likely due to burial beneath masticated chips and litter, limiting the ability to quantify this component immediately following treatment.

When masticated fuel beds were explicitly accounted for with measurements using the adjusted bulk density constant, estimated total surface fuel loads increased relative to calculations that excluded masticated material; however, adjusted post-treatment fuel loads generally remained lower than pre-treatment levels and, in some cases, no longer differed statistically from earlier measurements. These results highlight the importance of accounting for the unique structure and bulk density of masticated fuels when evaluating treatment outcomes.

Overall, mastication effectively reduced large-diameter fuels and altered surface fuel structure, achieving near-term fuel reduction objectives across the treatment area. Observed increases in litter and masticated material underscore the need for continued monitoring to better understand compaction, decomposition, and longer-term fuel bed evolution, particularly as masticated material breaks down and duff layers become re-expressed over time.

iii. Old Faithful

The Old Faithful developed area of Yellowstone National Park is located approximately 16 miles south of Madison Junction and represents one of the park's most iconic and heavily visited destinations. Vegetation in the area is dominated by lodgepole pine, which typically occurs under a low-frequency, high-severity fire regime, characterized by predominantly stand-replacing fires with return intervals commonly ranging from 100 to >300 years (Schoennagel et al. 2003, 2006).

In 2020, a hazard fuel reduction treatment was initiated across approximately 100 acres in response to the Lonestar Fire threatening the area; treatment activities were completed in 2022. Administrative records also indicate a possible chainsaw thinning treatment conducted in 2007 over approximately 23 acres, although evidence of this earlier treatment was not readily apparent on the ground during recent assessments. The 2020-2022 Lonestar Fire mitigation treatment primarily employed mechanical mastication throughout the unit, with targeted chainsaw thinning implemented adjacent to buildings and wetlands to further reduce hazard fuels. The primary objectives of the treatment were to create defensible space around infrastructure, thereby improving protection of human life, property, and park resources, and to reduce crown fire potential and slow surface fire spread should wildfire enter or initiate within the developed area.

To evaluate treatment effectiveness and assess whether management objectives were achieved, 12 monitoring plots were installed in 2020 prior to treatment implementation (Figure 39). Of these, seven plots (plots 001, 002, 004, 007, 008, 011, and 012) were treated during the initial 2020 implementation (Figure 40), while the remaining five plots (plots 003, 005, 006, 009, and 010) were treated in fall 2022.

A brief overview of treatment activities and the associated sampling protocol is provided below:

Old Faithful Plots 001, 002, 004, 007, 008, 011, 012

- 2020 (00PRE) – Data collection prior to first entry
- 2020 – First entry mastication treatment
- 2021 (01YR01) – Data collection 1 year after the mastication treatment
- 2022 (01YR02) – Data collection 2 years after the mastication treatment
- 2025 (01YR05) – Data collection 5 years after the mastication treatment

Old Faithful Plots 003, 005, 006, 009, 010 (not included in this year's analysis)

- 2020 (00PRE) – Data collection prior to first entry
- 2022 – First entry mastication treatment
- 2023 (01YR01) – Data collection 1 year after the mastication treatment
- 2024 (01YR02) – Data collection 2 years after the mastication treatment

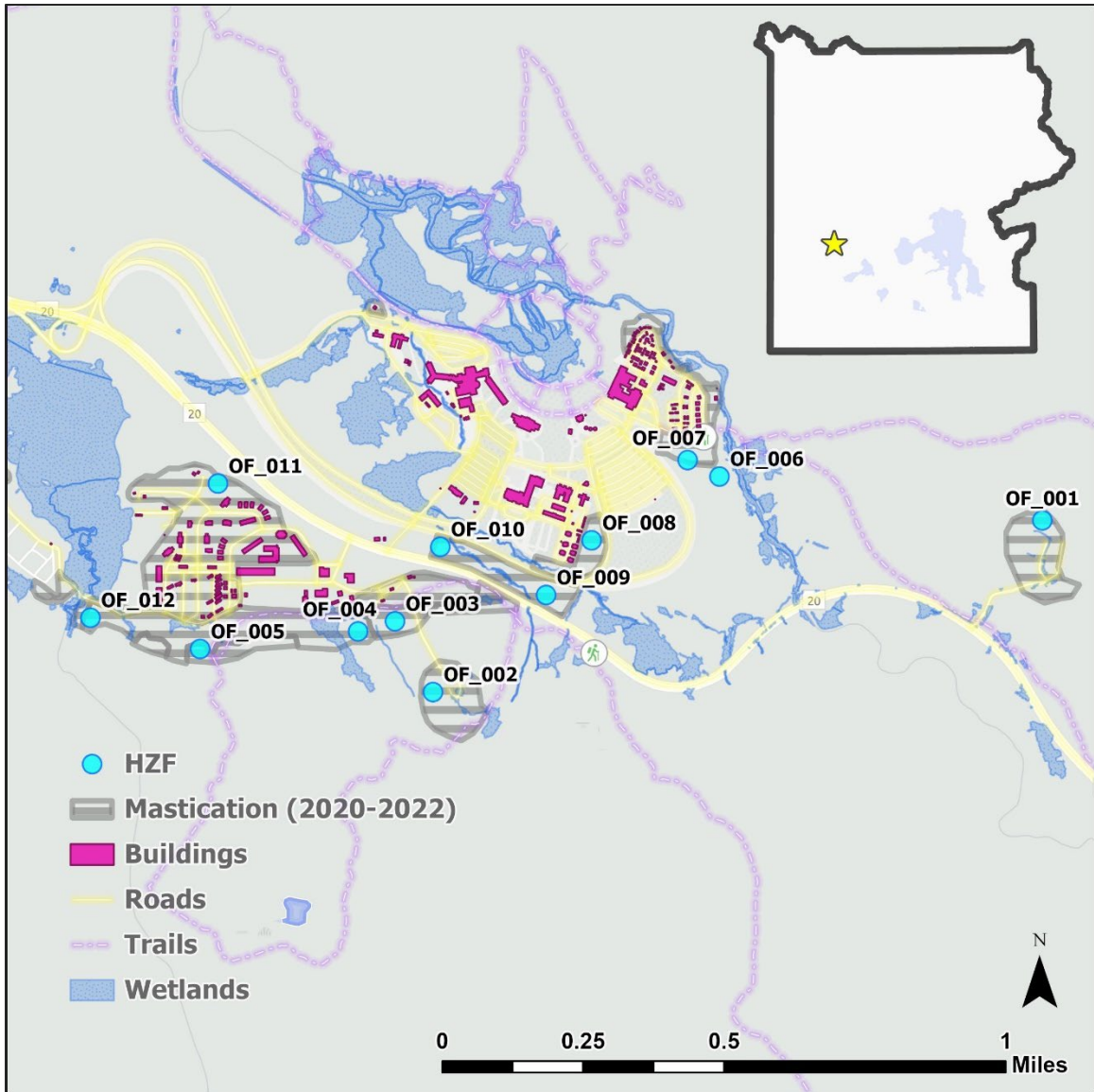


Figure 39. Map of the Old Faithful developed area showing the locations of all HZF monitoring plots (teal circles), the 2020-2022 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

Old Faithful Plots 1, 2, 4, 7, 8, 11, 12

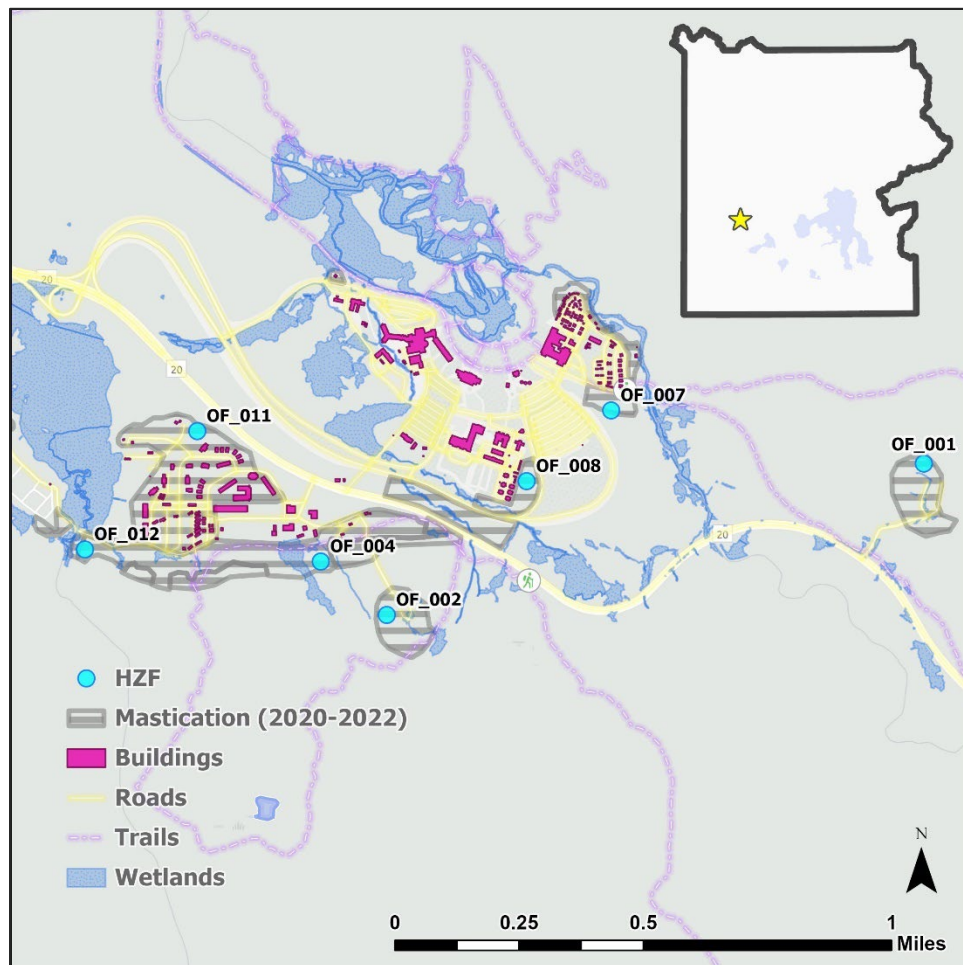


Figure 40. Map of HZF plots 1, 2, 4, 7, 8, 11, and 12 (teal circles), the 2020-2022 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

Canopy bulk density (CBD) in 2025 remained approximately 42% lower than values observed during the initial 2020 (*00PRE*) pre-mastication assessment (Table 11; Figure 41), indicating a sustained reduction in canopy fuel continuity following treatment. Although CBD increased modestly in the years following mastication, rising from 0.078 kg/m³ in 2021 (*01YR01*) to 0.081 kg/m³ in 2022 (*01YR02*) and 0.087 kg/m³ in 2025 (*01YR05*), values remain well below pre-treatment conditions.

Vertical profiles of canopy fuels indicate that CBD is currently greatest within the 15-30 ft height strata, with the most pronounced increases in 2025 occurring between approximately 20 and 30 ft (Figure 41). This pattern is consistent with post-treatment crown expansion and lateral branch growth in residual lodgepole pine following reductions in stand density.

Within lodgepole pine-dominated ecosystems, such post-treatment increases in CBD over time are expected as residual trees respond to increased light and growing space. The observed CBD

values fall within a moderate range for treated lodgepole stands and suggests that, while canopy fuels are gradually reaccumulating, overall crown fire potential remains reduced relative to pre-treatment conditions. Continued monitoring will be important to track whether CBD stabilizes or continues to increase as stand structure develops in the years following the 2020 mastication treatment.

Table 11. Canopy bulk density monitoring results for Old Faithful (plots 1, 2, 4, 7, 8, 11, and 12)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Old Faithful (Plots 1, 2, 4, 7, 8, 11, 12)	Reduce mean treatment area canopy bulk density over the entire life of the project to reduce the potential for crown fire activity.	<i>Old Faithful 1,2,4,7,8,11,12</i> <i>(n = 7 plots; 1 treatment)</i> <u>00PRE (2020): 0.150 ($\pm$ 0.024) kg/m³</u> <u>01YR01 (2021): 0.078 ($\pm$ 0.02) kg/m³</u> Difference from 00PRE to 01YR01: -48% <u>01YR02 (2022): 0.081 ($\pm$ 0.018) kg/m³</u> Difference from 00PRE to 01YR02: -46% <u>01YR05 (2025): 0.087 ($\pm$ 0.02) kg/m³</u> Difference from 00PRE to 01YR05: -42%	Yes, but minimum sample size not met

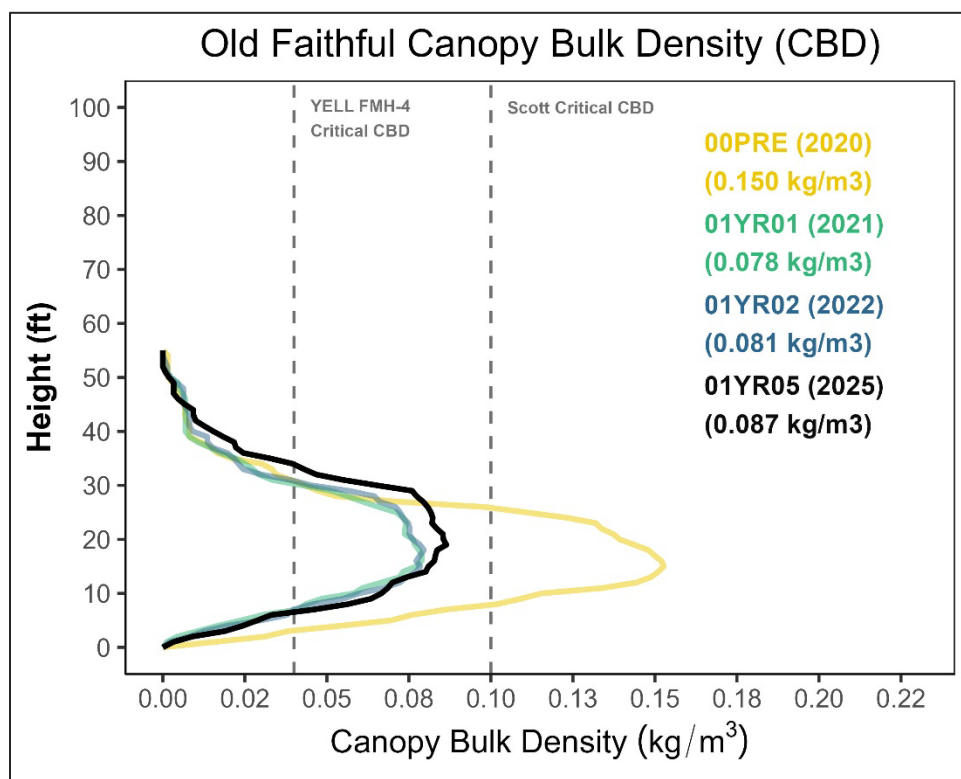


Figure 41. Canopy bulk density (kg/m³) for Old Faithful plots 1, 2, 4, 7, 8, 11, and 12, which were masticated in 2020.

Predicted fire behavior across the treatment unit shifted from a combination of surface and passive crown fire to predominantly surface fire following the 2020-2022 thinning treatments (Figure 42). Isolated portions of the unit continue to exhibit modeled potential for passive crown fire, driven by localized canopy characteristics, including elevated canopy fuel loads, lower canopy base heights, and higher canopy cover. Given the area's high visitor use and presence of irreplaceable historic infrastructure (such as the Old Faithful Inn), continued monitoring is warranted to evaluate long-term treatment effectiveness and identify locations where additional mitigation may be beneficial.

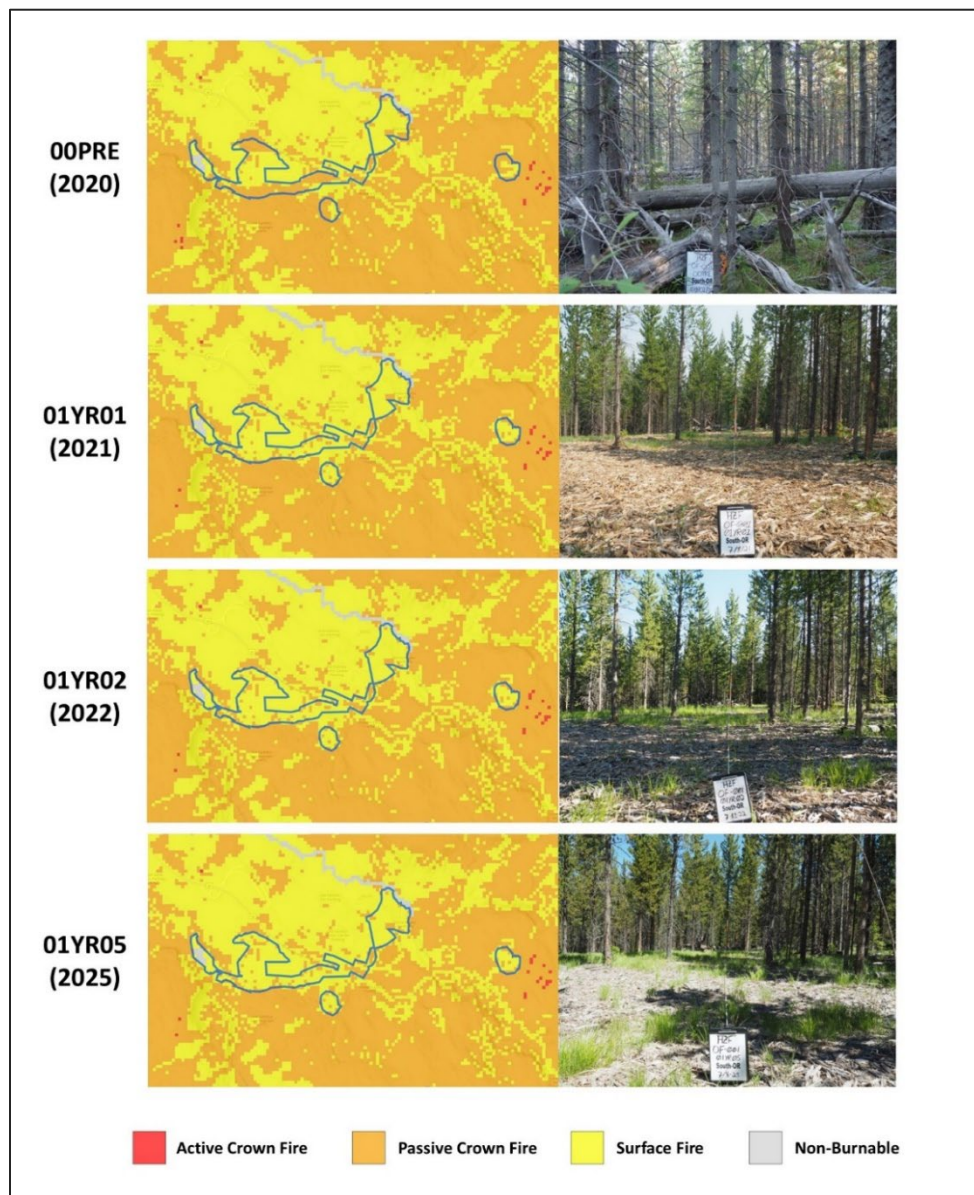


Figure 42. Modeled fire behavior for the Old Faithful treatment area (blue polygons), shown alongside representative plot photographs from each sampling period. Fire behavior was simulated in IFTDSS under very high fire danger conditions, including 15 mph southwest winds, 1-hour fuel moisture of 3%, 10-hour fuel moisture of 4%, 100-hour fuel moisture of 5%, herbaceous fuel moisture of 30%, and foliar moisture of 100%.

Within the context of this report, canopy bulk density metrics (e.g., Table 11, Figure 41) and associated fire behavior modeling outputs (e.g., Figure 42) are not presented for the Canyon and Norris treatment areas in earlier sections. These analyses require the full suite of plot-level measurements, including overstory tree, sapling, and seedling data. Due to timing and personnel constraints, post-mastication sampling in these areas was limited to surface fuel measurements only. As a result, canopy structure metrics and modeled fire behavior could not be reliably generated for the immediate post-treatment period. Future monitoring efforts in these treatment areas will incorporate complete plot remeasurements, allowing for evaluation of treatment effects on canopy structure and modeled fire behavior over time.

A substantial reduction in coarse surface fuels was observed following the 2020 mastication treatment. Mean 1,000-hour fuel loads declined by 89%, decreasing from 25.8 tons per acre in 2020 (*00PRE*) to 2.7 tons per acre in 2025 (*01YR05*). This value was slightly lower than the 2022 (*01YR02*) estimate of 2.9 tons per acre and remains well below the < 10 tons per acre management objective for the treatment area (Table 12; Figure 44).

When surface fuel components were evaluated collectively, 2025 represented the lowest observed total surface fuel loading across all monitoring periods (Figure 45). Fine fuels (1–100-hour) exhibited a modest increase, rising from 1.8 tons per acre in 2020 to 2.4 tons per acre in 2025. Duff was observable in two plots, allowing duff fuel loads to be estimated; for these plots, duff increased slightly from 0.61 tons per acre in 2020 to 1.5 tons per acre in 2025.

When masticated fuel beds were explicitly accounted for, overall fuel loads increased in post-treatment measurements, with masticated materials ranging from 14.2 tons per acre in 2021 (*01YR01*) to 12.2 tons per acre in 2022 (*01YR02*) and 13.4 tons per acre in 2025 (*01YR05*). Despite these increases, cumulative surface fuel loads remain lower than pre-mastication levels (Figure 45).

Given the heterogeneous nature of masticated fuel beds and the complex processes governing compaction and decomposition, continued monitoring will be necessary to better characterize temporal changes in surface fuels within these masticated areas. Interpretation of these results is further complicated by high variance across the seven sampled plots, underscoring the need for additional observations to more fully capture site-level variability.



Figure 43. Photographs from plot 001 showing pre-mastication conditions in 2020 (*00PRE*; left) and post-mastication conditions in 2025 (*01YR05*; right).

Table 12. 1,000-hour fuel monitoring results for Old Faithful (plots 1, 2, 4, 7, 8, 11, and 12)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Old Faithful <i>(Plots 1, 2, 4, 7, 8, 11, 12)</i>	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Old Faithful 1,2,4,7,8,11,12</i> <i>(n = 7 plots; 1 treatment)</i> <u>00PRE (2020): 25.8 (± 10.9) tons/ac</u> <u>01YR01 (2021): 3.8 (± 3.4) kg/m³</u> <i>Difference from 00PRE to 01YR01: -85%</i> <u>01YR02 (2022): 2.9 (± 2.1) kg/m³</u> <i>Difference from 00PRE to 01YR02: -89%</i> <u>01YR05 (2025): 2.7 (± 2.1) kg/m³</u> <i>Difference from 00PRE to 01YR05: -89%</i>	Yes, but minimum sample size not met

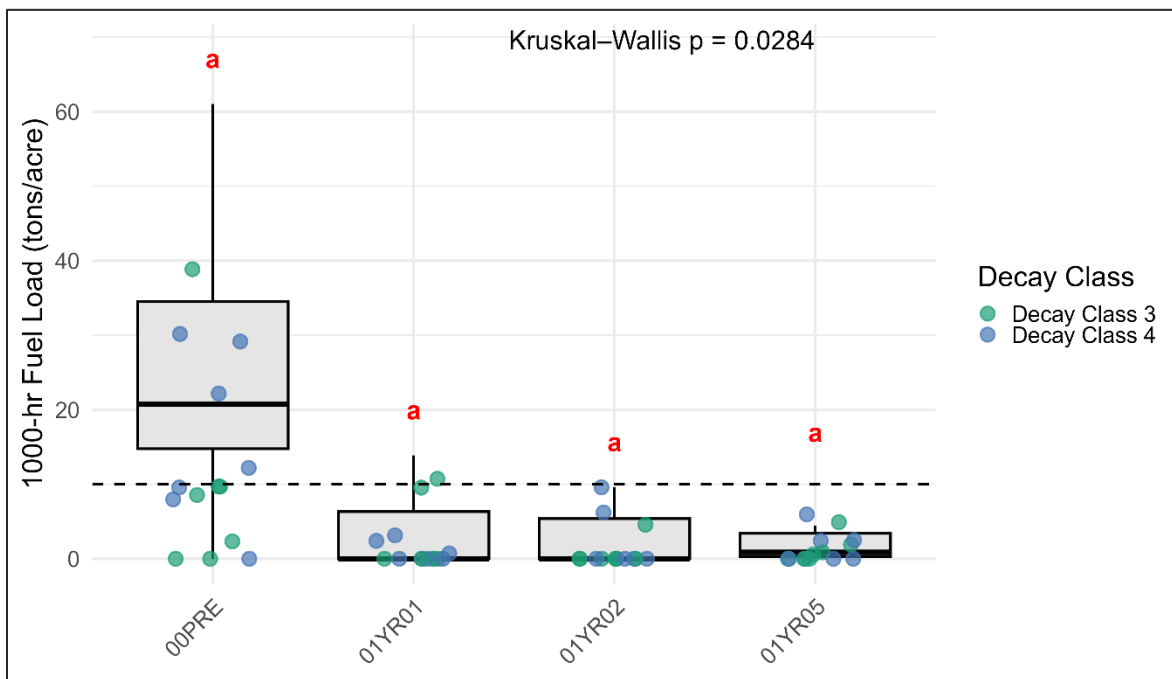


Figure 44. Average 1,000-hour fuel loads (tons per acre) for Old Faithful plots 1, 2, 4, 7, 8, 11, and 12. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.

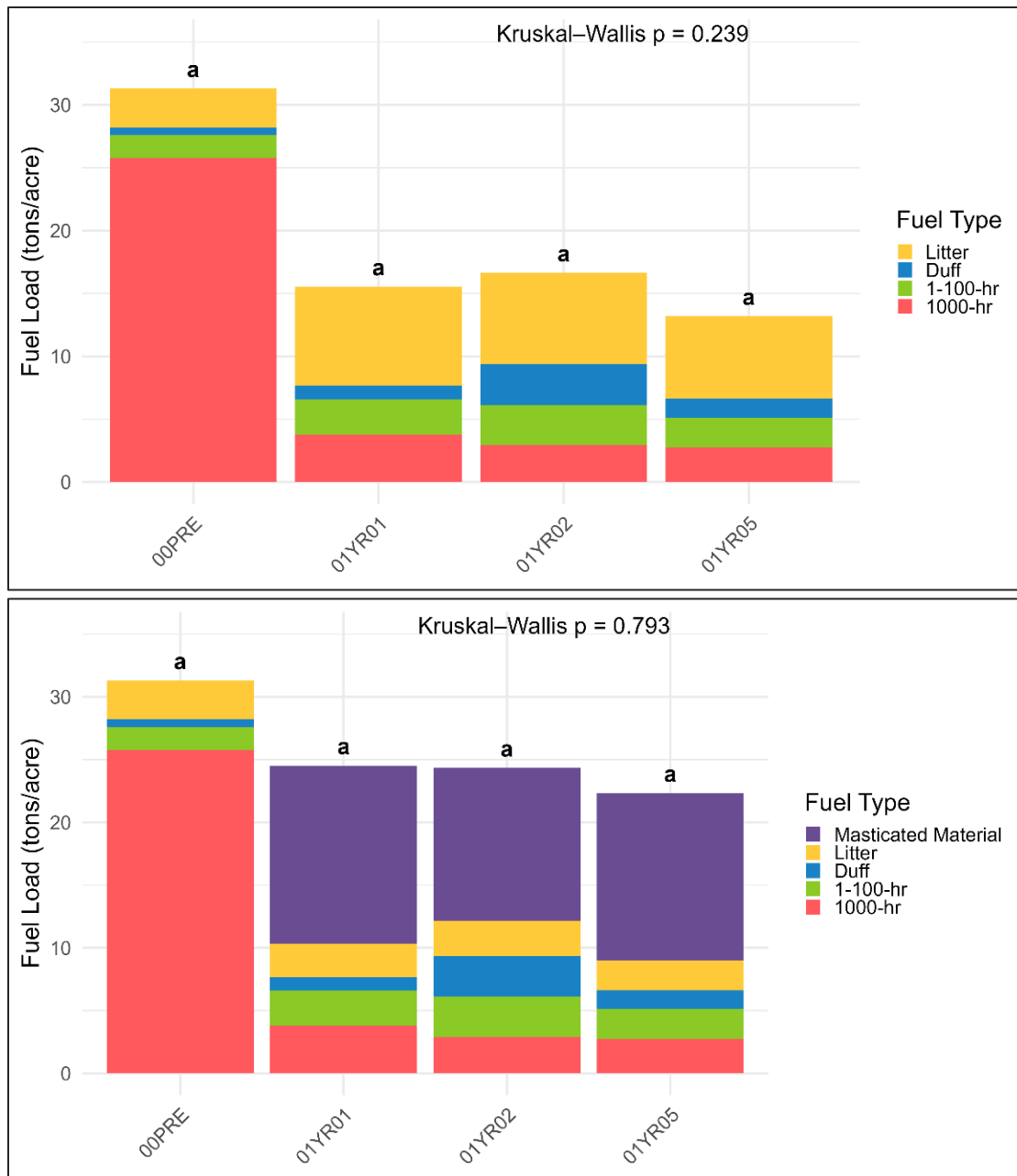


Figure 45. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Old Faithful plots 1, 2, 4, 7, 8, 11, and 12, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Prior to treatment, the Old Faithful area reflected a moderately dense, lodgepole pine-dominated stand with relatively continuous canopy fuels and limited vertical separation between surface and canopy layers. In 2020 (00PRE), canopy bulk density was 0.150 kg/m³, and mean canopy base

height was 1.4 m, conditions conducive to torching and potential crown fire initiation under dry and windy conditions. Stand density metrics reflected active competition, with an SDI of 231, basal area of 95 ft²/ac, and overstory stocking dominated by lodgepole pine (954 trees/ac), with minor components of Engelmann spruce (*Picea engelmannii*) and subalpine fir (Table 13; Figure 47). By 2025 (01YR05), mastication had substantially altered stand structure and canopy fuels. Canopy bulk densities declined to 0.087 kg/m³, representing a 42% reduction relative to pre-treatment conditions, while canopy base height increased to 2.2 m, indicating vertical separation between surface and canopy fuels. Stand density remained lower than pre-treatment levels, with an SDI of 148 and basal area of 66 ft²/ac, reflecting sustained reductions in overstory stocking (393 lodgepole pine trees/ac) despite modest post-treatment growth (Table 13).

Regeneration patterns indicate a strong lodgepole pine response to treatment. Lodgepole pine seedling density nearly doubled, increasing from 2,101 seedlings per acre in 2020 to 4,116 seedlings per acre in 2025, while regeneration of other conifer species remained comparatively limited (Table 14; Figure 47). This pattern is consistent with lodgepole pine ecology and suggests a trajectory toward renewed stand infilling and increasing competitive pressure over time. Notably, whitebark pine seedlings were observed in the understory during the 2025 sampling effort, indicating that reduced competition following treatment may be creating conditions more favorable for whitebark pine establishment. Given that enhancement of whitebark pine habitat is a primary treatment objective, this early response is an encouraging outcome.

Overall, mastication effectively reduced canopy fuel continuity, increased canopy base height, and lowered stand density relative to pre-treatment conditions. Although modest increases in canopy fuels and stand density have occurred since treatment, current conditions in 2025 remain substantially less conducive to crown fire initiation than those observed prior to treatment. Continued monitoring will be important to track future fuel accumulation and structural development as the stand recovers.

Table 13. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac). Average values are depicted along with the range of individual plot-level data to illustrate across-plot variability.

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2020	00PRE	0.150 (0.106 – 0.212)	1.4 (0.6 – 2.3)	231 (131 – 357)	95 (52 – 134)
2021	01YR01	0.078 (0.039 – 0.148)	2.1 (0.7 – 3.3)	125 (68 – 252)	55 (32 – 99)
2022	01YR02	0.081 (0.037 – 0.136)	1.9 (0.9 – 3.4)	128 (71 – 232)	57 (32 – 90)
2025	01YR05	0.087 (0.04 – 0.154)	2.2 (0.9 – 3.7)	148 (79 – 289)	66 (36 – 116)

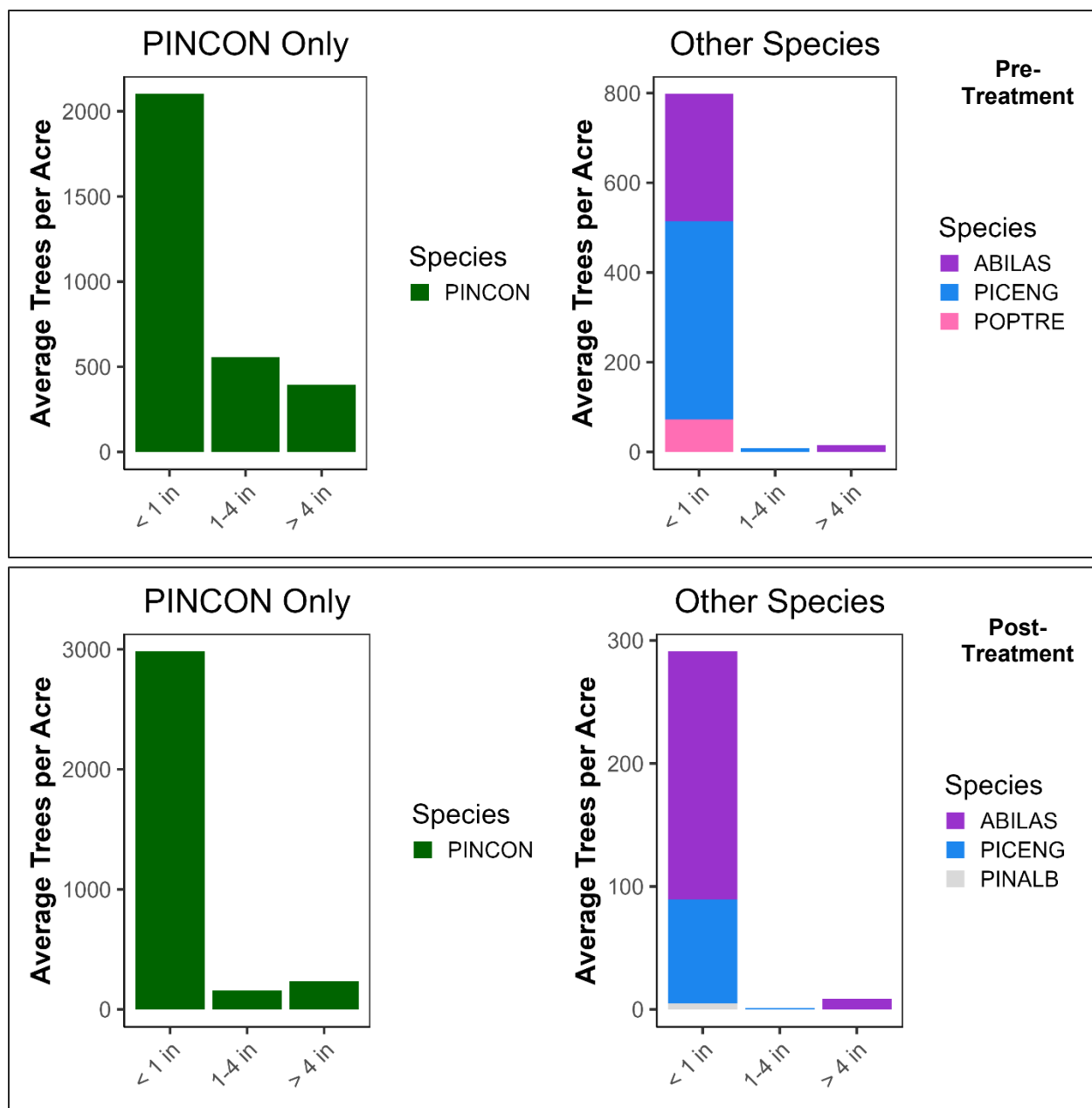


Figure 47. Trees per acre by diameter size class (inches) for Old Faithful plots 1, 2, 4, 7, 8, 11, and 12 during the 2020 (*00PRE*) pre-treatment monitoring period (top panel) and averaged values across post-treatment monitoring periods of 2021 (*01YR01*), 2022 (*01YR02*), and 2025 (*01YR05*) (bottom panel). Species are distinguished as lodgepole pine (PINCON; green), subalpine fir (ABILAS; purple), Engelmann spruce (PICENG; blue), quaking aspen (POPTRE; pink), and whitebark pine (PINALB; gray). Note the different y-axis scales for the PINCON only plot (left) and other species plot (right) across both the top and bottom panels. The < 1-inch size class includes both saplings and seedlings.

Table 14. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Old Faithful (plots 1, 2, 4, 7, 8, 11, and 12)

Species	00PRE (2020)		01YR01 (2021)		01YR02 (2022)		01YR05 (2025)	
	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings
Lodgepole Pine (<i>PINCON</i>)	954	2,101	393	1,318	387	3,509	393	4,116
Engelmann Spruce (<i>PICENG</i>)	9	442	0	84	0	95	3	75
Subalpine Fir (<i>ABILAS</i>)	14	283	9	14	9	541	9	49
Quaking Aspen (<i>POPTR</i>)	0	72	0	0	0	0	0	0
Whitebark Pine (<i>PINALB</i>)	0	0	0	0	0	0	0	14

Understory vegetation was relatively diverse, with 36 species recorded during the 2025 (*01YR05*) assessment. Dominant species included elk sedge, pinegrass (*Calamagrostis rubescens*), littleleaf pussytoes (*Antennaria microphylla*), grouse whortleberry, sulphur-flower buckwheat (*Eriogonum umbellatum* var. *majus*), and subalpine aster (*Eurybia merita*). Native species strongly dominated the understory community. Total native cover increased slightly from 98.2% in 2020 (*00PRE*) to 98.7% in 2025, indicating continued prevalence of native vegetation following treatment (Table 15). Invasive species observed included Kentucky bluegrass (*Poa pratensis*), common sheep sorrel (*Rumex acetosella*), and timothy (*Phleum pratense*); however, each species comprised less than 1% of total understory cover (Table 16).

Table 15. Native species monitoring results for Old Faithful (plots 1, 2, 4, 7, 8, 11, and 12)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Old Faithful (Plots 1, 2, 4, 7, 8, 11, 12)	Monitor for native species composition change using mean relative percent cover.	<i>Old Faithful 1,2,4,7,8,11,12</i> (<i>n</i> = 7 plots; 1 treatment) <u>00PRE (2020): 98% ($\pm$ 1.8%) native species</u> <u>01YR01 (2021): 99% ($\pm$ 0.8%) native spp.</u> Difference from 00PRE to 01YR01: +85% <u>01YR02 (2022): 98% ($\pm$ 3.2%) native spp.</u> Difference from 00PRE to 01YR02: -0.6% <u>01YR05 (2025): 99% ($\pm$ 1.9%) native spp.</u> Difference from 00PRE to 01YR05: +0.5%	Yes

Table 16. Non-native species monitoring results for Old Faithful (plots 1, 2, 4, 7, 8, 11, and 12)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Old Faithful (Plots 1, 2, 4, 7, 8, 11, 12)	Monitor species listed on park priority weed list through relative percent cover.	<i>Old Faithful 1,2,4,7,8,11,12</i> <i>*not a statistical analysis so minimum plot numbers not calculated*</i> <u>00PRE (2020):</u> 1.4% <i>Phleum pratense</i> (timothy) 0.2% <i>Rumex acetosella</i> (common sheep sorrel) 0.1% <i>Taraxacum officinale</i> (common dandelion) 0.1% <i>Trifolium repens</i> (white clover) <u>01YR01 (2021):</u> 0.7% <i>Rumex acetosella</i> (common sheep sorrel) 0.2% <i>Phleum pratense</i> (timothy) 0.2% <i>Taraxacum officinale</i> (common dandelion) <u>01YR02 (2022):</u> 1.8% <i>Poa pratensis</i> (Kentucky bluegrass) 1.6% <i>Rumex acetosella</i> (common sheep sorrel) 0.1% <i>Phleum pratense</i> (timothy) 0.1% <i>Taraxacum officinale</i> (common dandelion) <u>01YR05 (2025):</u> 0.9% <i>Poa pratensis</i> (Kentucky bluegrass) 0.8% <i>Rumex acetosella</i> (common sheep sorrel) 0.3% <i>Phleum pratense</i> (timothy)	Yes



Figure 48. Photographs from plot 004 showing pre-mastication conditions in 2020 (00PRE; left) and post-mastication conditions in 2025 (01YR05; right).

iv. South Entrance

The 2004 and 2013 South Entrance hazard fuel project consists of a single treatment unit located within the South Entrance housing area, originally encompassing 5.8 acres. The initial fuel reduction treatment was implemented in 2004, followed by a second-entry treatment in 2013 in response to the Snake Fire threatening the area. Both treatments used chainsaws and hand crews.

To evaluate treatment effectiveness, three monitoring plots were installed in 2004 prior to the initial treatment. In 2014, two of the original plots were converted from the FMECH1T99 monitoring type to the HZF monitoring type to standardize plot size and sampling methodology across hazard fuel treatment areas within the park; the remaining original plot (plot 002) was discontinued at that time (Figure 50).

In 2023, three additional monitoring plots (plots 004, 005, and 006) were installed in anticipation of a planned mastication treatment (Figure 54). In 2025, the mastication treatment was implemented across approximately 40 acres, encompassing the original treatment area and expanding the treatment perimeter to include the ranger station east of the road, as well as the housing area west of the road.

A summary timeline of treatment activities and associated monitoring efforts is provided below:

South Entrance Plots 001, 003

- 2004 (*00PRE*) – Data collection prior to first entry
- 2004 – First entry thinning treatment
- 2004 (*01POST*) – Data collection immediately following the first treatment
- 2013 – Second entry thinning treatment
- 2014 (*02YR01*) – Data collection 1 year after the second treatment
- 2018 (*02YR05*) – Data collection 5 years after the second treatment
- 2023 (*02YR10*) – Data collection 10 years after the second treatment
- 2025 – Third entry mastication treatment
- 2025 (*03POST*) – Surface fuels data collection immediately post-mastication treatment

South Entrance Plots 004, 005, 006

- 2023 (*00PRE*) – Data collection prior to first entry
- 2025 – First entry mastication treatment
- 2025 (*01POST*) – Surface fuels data collection immediately post-mastication treatment

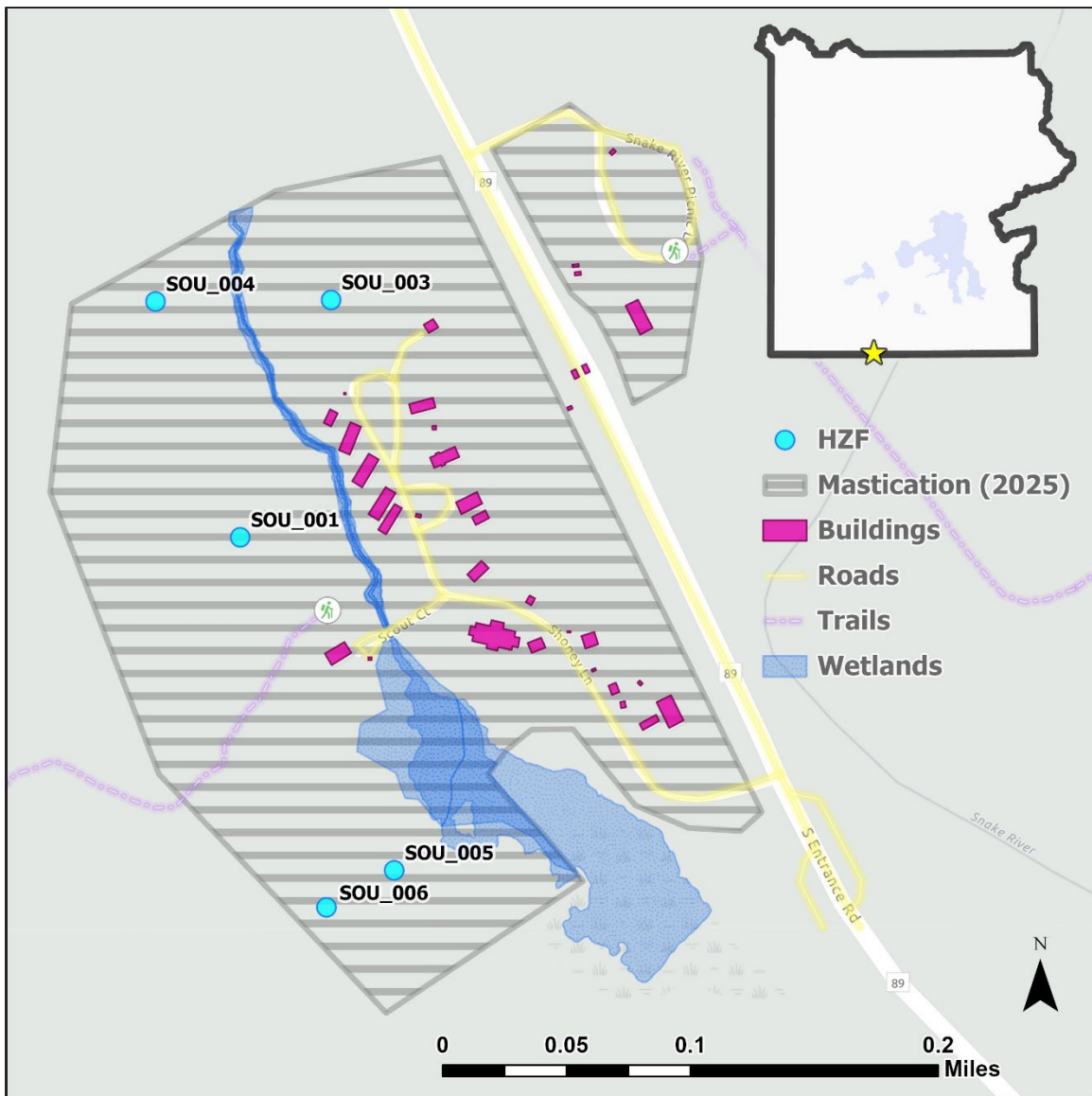


Figure 49. Map of the South Entrance treatment area showing the locations of all HZF monitoring plots (teal circles), the 2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

Surface Fuels Only

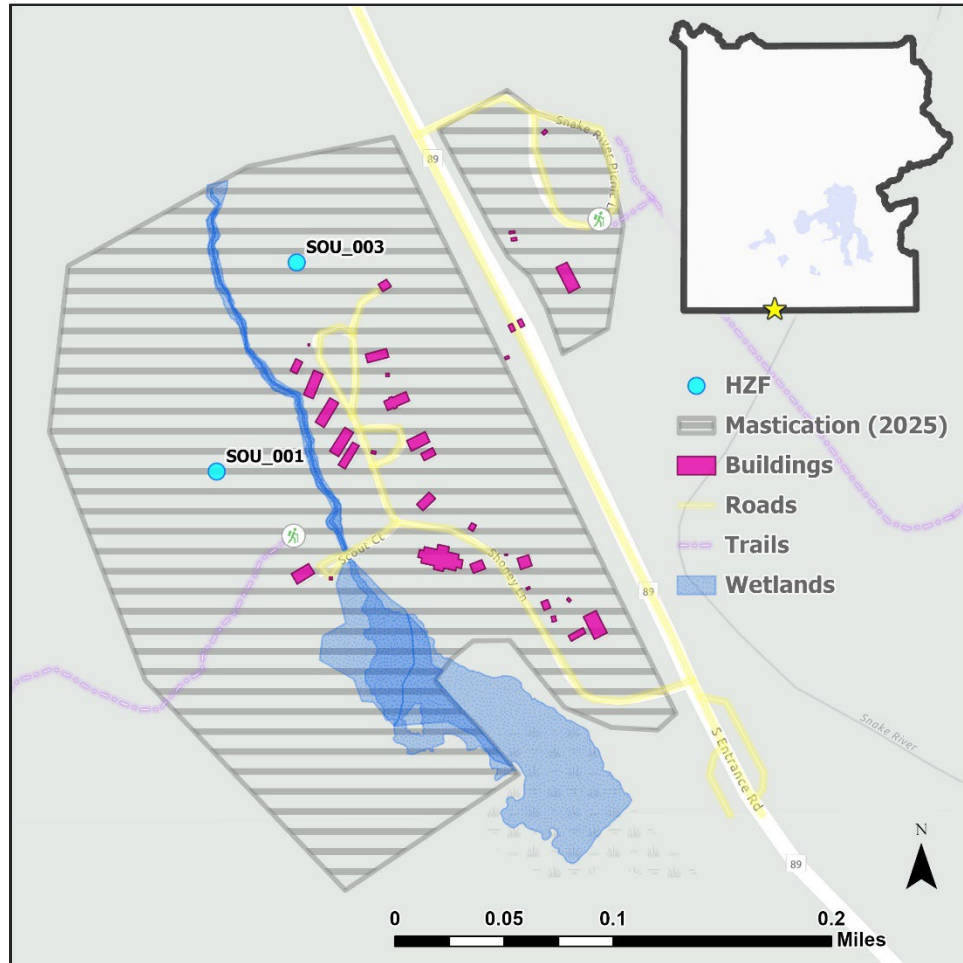


Figure 50. Map of HZF plots 1 and 3 (teal circles), the 2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For South Entrance plots 1 and 3, mean coarse woody (1,000-hour) fuel loads declined by 88% following the 2025 mastication treatment, decreasing from 11.3 tons per acre in 2004 (*00PRE*) to approximately 1.4 tons per acre in 2025 (*03POST*) (Table 17; Figure 51). Although earlier treatments in 2004 and 2013 had successfully reduced 1,000-hour fuels to below the 10 tons per acre management objective, fuel loads gradually increased over time, reaching approximately 6.4 tons per acre by 2023 (*02YR10*), ten years after the second thinning treatment. The 2025 mastication effectively reversed this trend, reducing coarse fuel loads to their lowest levels recorded since the immediate post-treatment measurement in 2004 (*01POST*) (Table 17; Figure 51).

When all surface fuel components were considered collectively, fine fuels (1–100-hour) in 2025 averaged approximately 2.1 tons per acre, compared to 5.0 tons per acre prior to any treatment in 2004 (Figure 53). Duff was not observable within the masticated fuel beds across either plot and could not be reliably quantified. In contrast, litter loads increased from approximately 3.3 tons per acre in 2004 to 5.0 tons per acre in 2025.

When masticated material was explicitly accounted for as a distinct fuel component, estimated post-treatment loads included approximately 3.6 tons per acre of masticated material, while litter loads declined to approximately 3.6 tons per acre (Figure 53). Under this accounting, total combined surface fuel loads were approximately 10.7 tons per acre in 2025, representing the lowest overall fuel loading observed since the immediate post-treatment assessment in 2004 (*01POST*), when total fuels averaged 10.3 tons per acre.

As with other treatment units, these results are based on a limited sample size (two plots), resulting in elevated variance that may confound interpretation. Accordingly, results should be interpreted with appropriate caution.

Table 17. 1,000-hour fuel monitoring results for South Entrance (plots 1 and 3)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
South Entrance (Plots 1, 3)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>South Entrance 1,3</i> (<i>n</i> = 2 plots; 3 treatments) <u>00PRE (2004): 11.3 ($\pm$ 23.2) tons/ac</u> <u>01POST (2004): 0.4 ($\pm$ 1.2) kg/m³</u> <i>Difference from 00PRE to 01POST: -97%</i> <u>02YR01 (2014): 1.8 ($\pm$ 5.7) kg/m³</u> <i>Difference from 00PRE to 02YR01: -84%</i> <u>02YR05 (2018): 3.9 ($\pm$ 11.9) kg/m³</u> <i>Difference from 00PRE to 02YR05: -66%</i> <u>02YR10 (2023): 6.4 ($\pm$ 12.6) kg/m³</u> <i>Difference from 00PRE to 02YR10: -43%</i> <u>03POST (2025): 1.4 ($\pm$ 4.2) kg/m³</u> <i>Difference from 00PRE to 03POST: -88%</i>	Yes, but minimum sample size not met

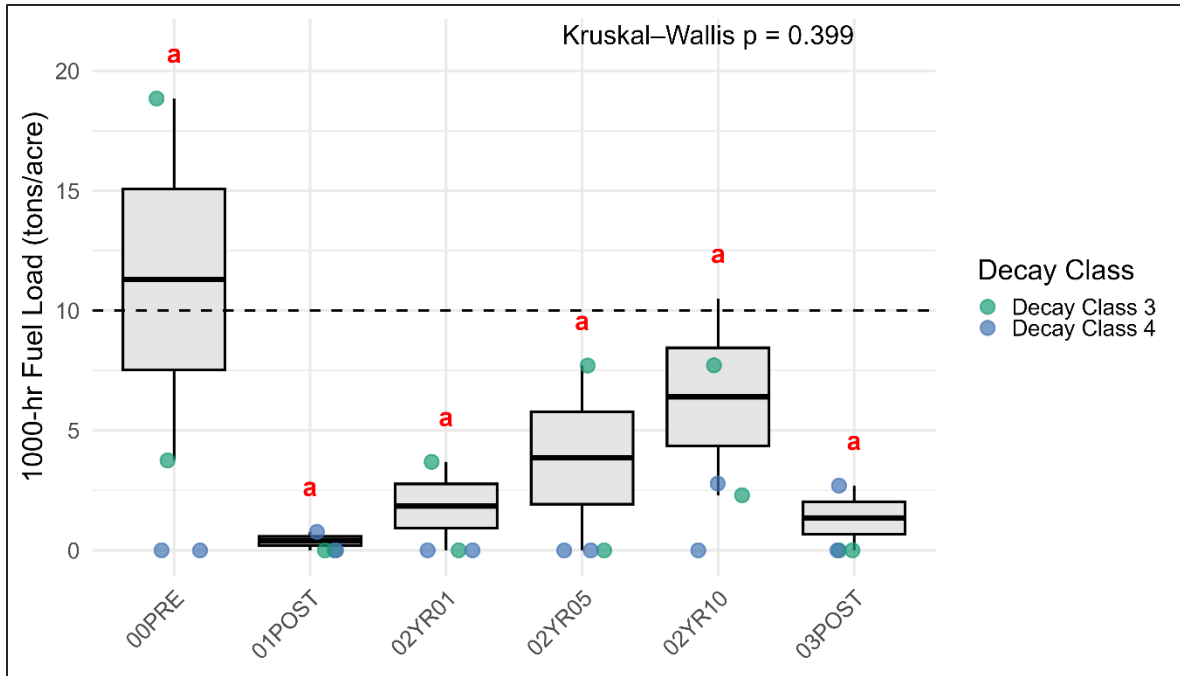


Figure 51. Average 1,000-hour fuel loads (tons per acre) for South Entrance plots 1 and 3. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.



Figure 52. Photographs from plot 003 showing pre-mastication conditions in 2023 (02YR10; left) and post-mastication conditions in 2025 (03POST; right).

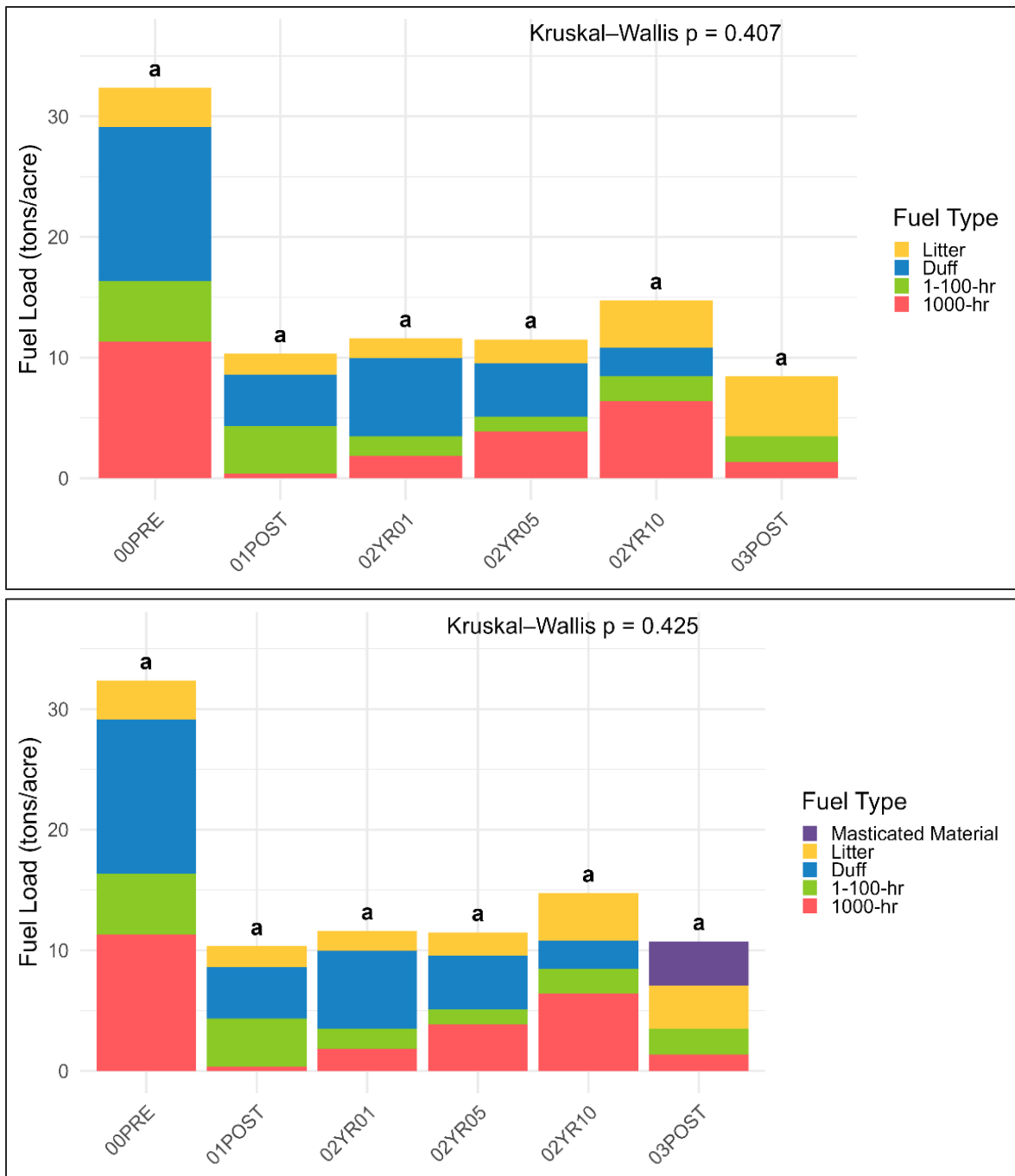


Figure 53. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for South Entrance plots 1 and 3, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

Surface Fuels Only

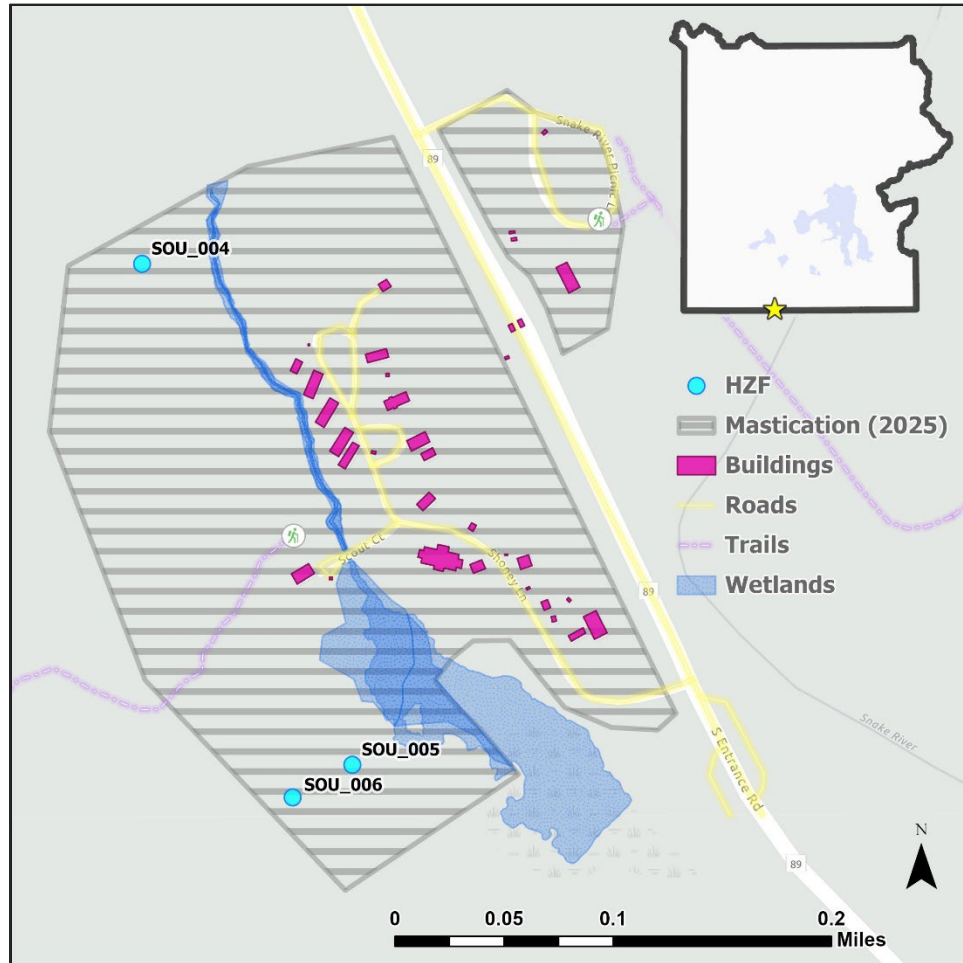


Figure 54. Map of HZF plots 4, 5, and 6 (teal circles), the 2025 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

For plots 4, 5, and 6, mean 1,000-hour fuel loads declined by approximately 79% following mastication, decreasing from 22.0 tons per acre in 2023 (*00PRE*) to 4.7 tons per acre in 2025 (*01POST*). Post-treatment coarse fuel loads therefore met the < 10 tons per acre management objective for this fuel class (Table 18; Figure 55).

When considering other surface fuel components, fine fuels (1–100-hour) decreased from approximately 5.1 tons per acre in 2023 to 3.4 tons per acre in 2025, while litter loads increased from 3.2 tons per acre to approximately 10.1 tons per acre over the same period (Figure 56). Duff was not observable through the masticated fuel bed across any of the plots and could not be quantified following treatment.

When masticated materials were explicitly measured and accounted for, estimated post-treatment loads consisted of approximately 10.4 tons per acre of masticated material, while litter loads declined to approximately 6.3 tons per acre (Figure 56).

Regardless of whether masticated fuels were treated as a distinct fuel class or incorporated within litter estimates, total surface fuel loads in 2025 remained lower than pre-treatment levels, indicating an overall reduction in surface fuels following mastication. However, as has been stated previously, these results are based on a limited number of plots and inference from these results is constrained by variability and limited sample size. As such, these results may not fully represent site-wide conditions.

Table 18. 1,000-hour fuel monitoring results for South Entrance (plots 4, 5, and 6)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
South Entrance (Plots 4, 5, 6)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>South Entrance 4,5,6</i> ($n = 3$ plots; 1 treatment) <u>00PRE (2023): 22 (± 20.9) tons/ac</u> <u>01POST (2025): 4.7 (± 4.9) kg/m³</u> Difference from 00PRE to 01POST: -79%	Yes, but minimum sample size not met

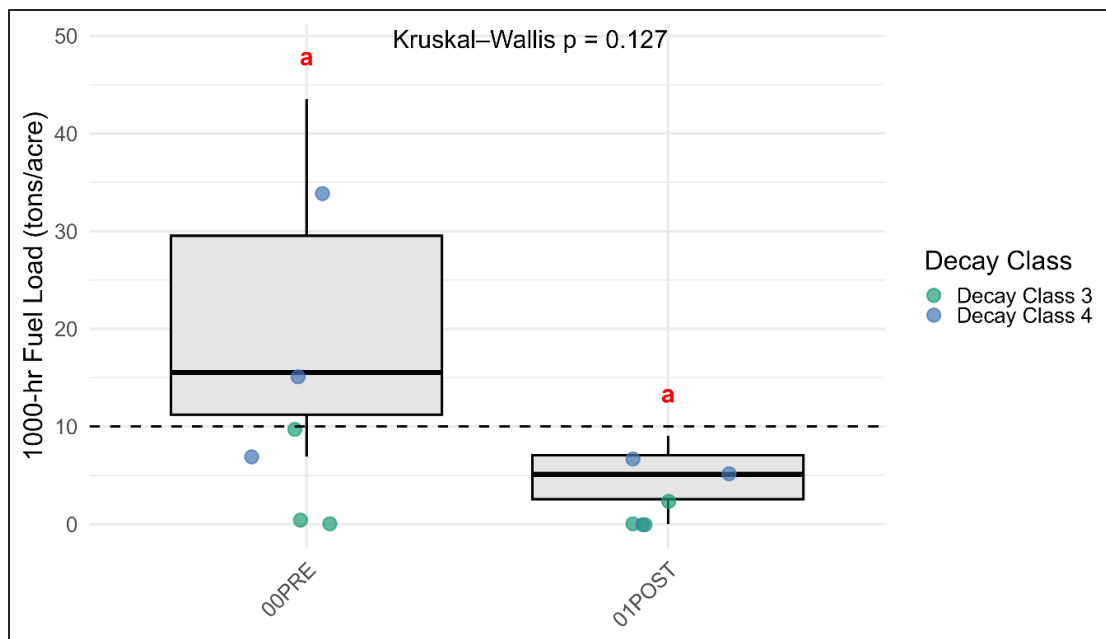


Figure 55. Average 1,000-hour fuel loads (tons per acre) for South Entrance plots 4, 5, and 6. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.

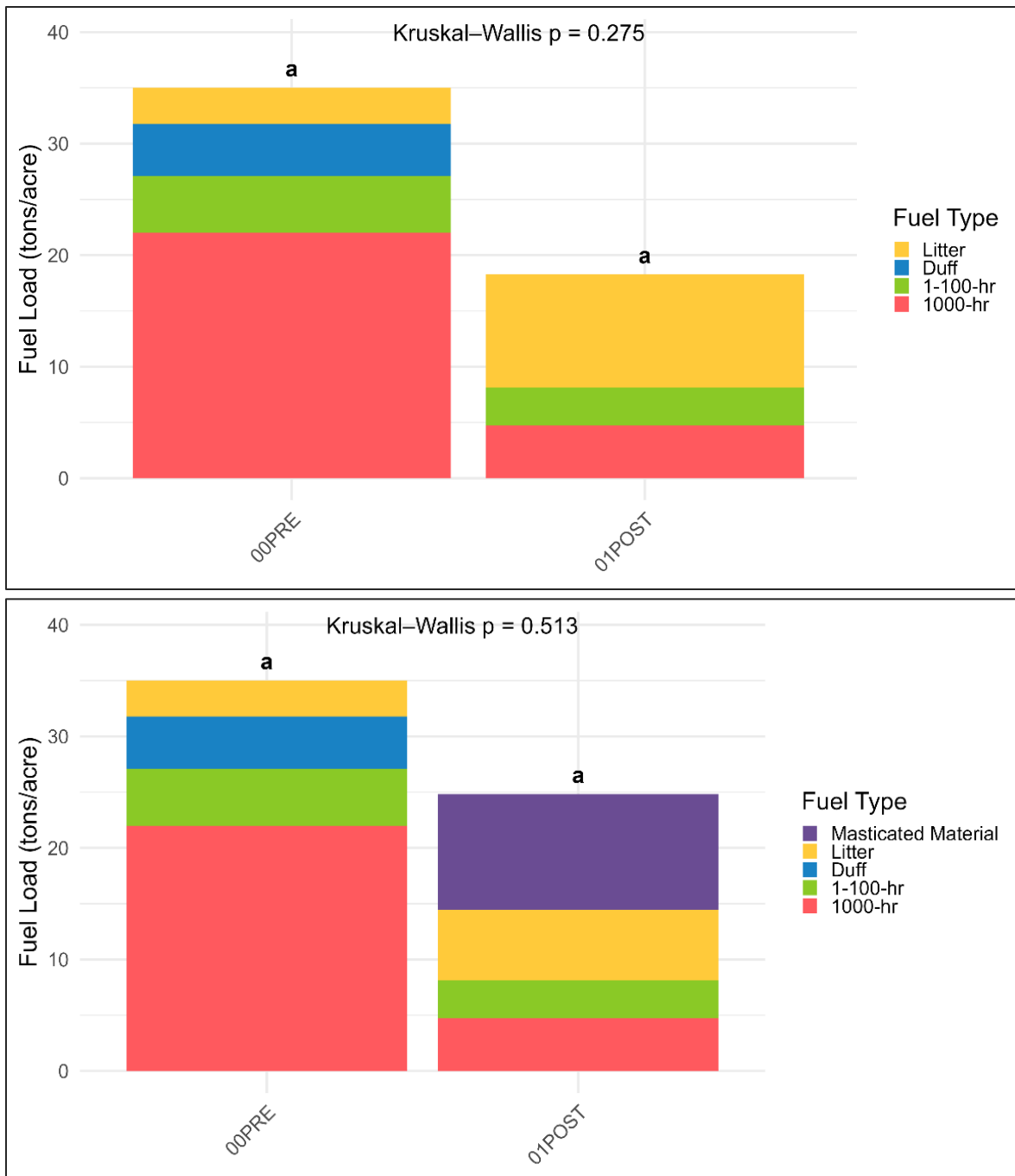


Figure 56. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for South Entrance plots 4, 5, and 6, measuring masticated material as litter (top panel). The bottom panel shows an alternative calculation in which surface fuels are re-estimated using a bulk density constant representative of masticated material (7.5 lbs/ft³; purple). This alternative representation is intended to account for the mixed and compacted structure of masticated fuel beds and provides a complementary estimate of surface fuel loading under post-treatment conditions.

v. Tower–Roosevelt

The Tower–Roosevelt area in Yellowstone National Park is located approximately 18 miles east of Mammoth Hot Springs and encompasses a historically significant, wildlife-rich portion of the park’s northeast region. The area is best known for Tower Fall and the rustic Roosevelt Lodge & Cabins (Figure 57), and is named for President Theodore Roosevelt, who famously camped in the vicinity.

Vegetation within the area is dominated by mature Douglas-fir (*Pseudotsuga menziesii*), with secondary components of Engelmann spruce, lodgepole pine, and smaller inclusions of quaking aspen (*Populus tremuloides*). A localized 15-acre thinning treatment was implemented in 2010 in response to the Antelope Fire. Building on this earlier effort, an expanded 40-acre mastication treatment is planned for 2026-2027.

To support evaluation of treatment effectiveness, four monitoring plots were installed in 2025 ahead of the expanded treatment to characterize pre-treatment stand conditions and provide a baseline for post-treatment comparisons (Figure 58).



Figure 57. Photograph of the Roosevelt Lodge and Cabins, a historic structure constructed in 1920 and a popular visitor destination.

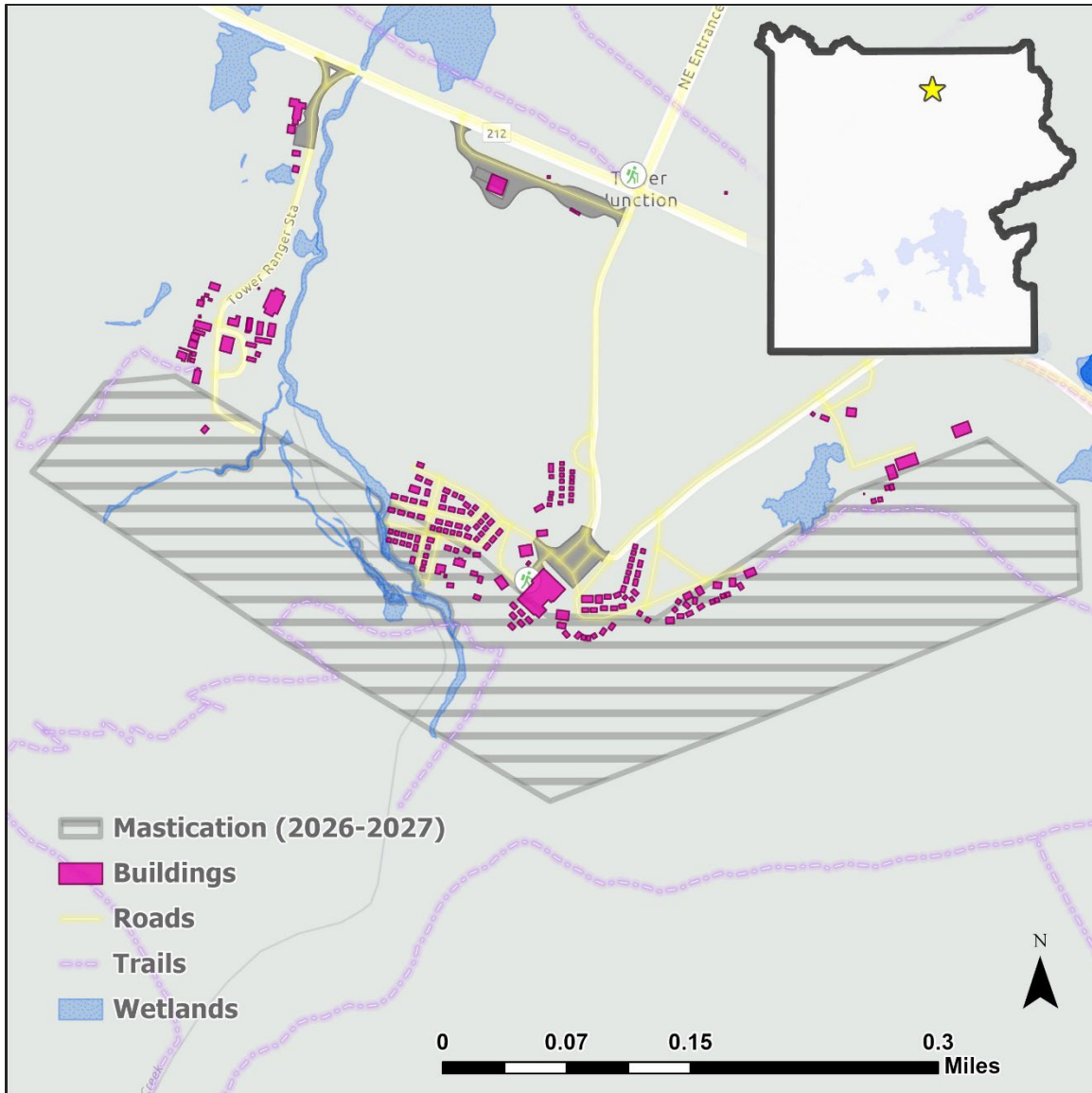


Figure 58. Map of the Tower–Roosevelt area showing the proposed 2026–2027 mastication treatment boundary (gray hatched area), buildings (pink polygons), roads (yellow lines), trails (purple lines), and delineated wetland areas (blue polygons).

Canopy bulk density is 0.126 kg/m^3 , indicating moderate canopy fuel continuity for a Douglas-fir dominated stand. Aerial fuels are concentrated primarily between approximately 30 and 70 ft, while mean canopy base height is relatively high (7.4 m), providing vertical separation between surface fuels and live crowns (Table 19; Figure 59). This vertical structure is likely to limit crown fire initiation under moderate conditions but may still support active crown fire spread during extreme fire weather, particularly given the steep terrain present throughout the project unit.

Table 19. Canopy bulk density monitoring results for Tower–Roosevelt (plots 1-4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Tower–Roosevelt</i> (Plots 1, 2, 3, 4)	Reduce mean treatment area canopy bulk density over the entire life of the project to reduce the potential for crown fire activity.	<i>Tower–Roosevelt 1,2,3,4</i> (<i>n</i> = 4 plots; pre-treatment) <u>00PRE (2025): 0.126 ($\pm$ 0.036) kg/m³</u>	To be determined

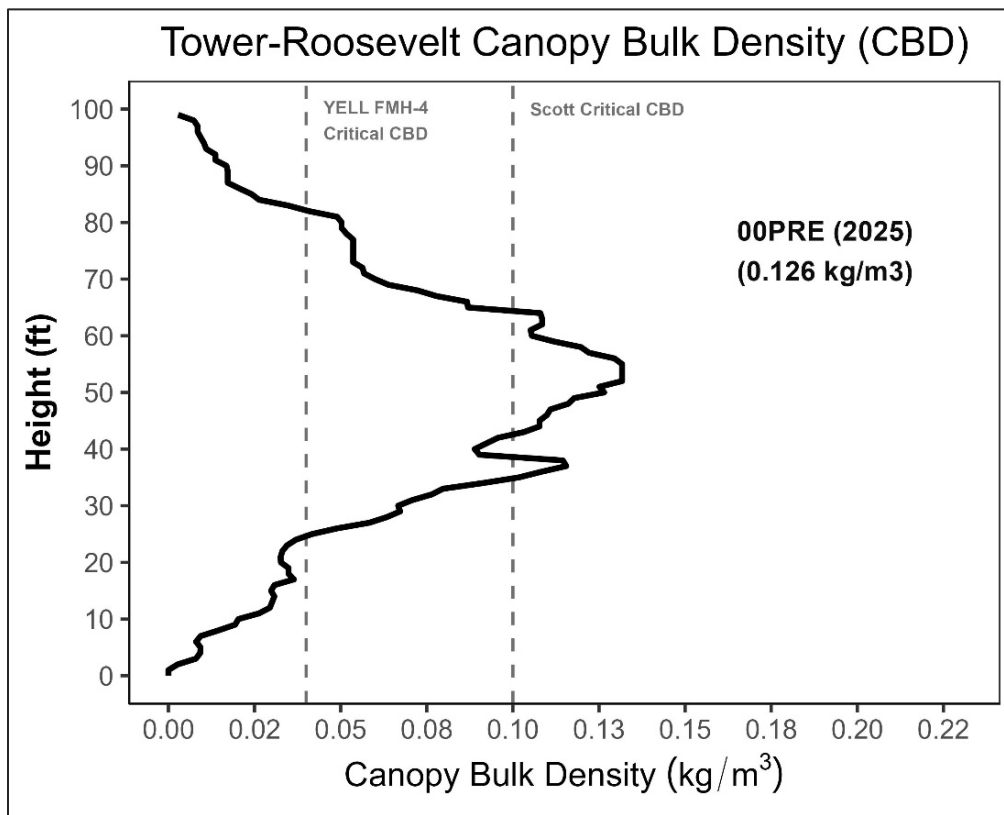


Figure 59. Canopy bulk density (kg/m³) for Tower–Roosevelt plots 1, 2, 3, and 4, which are scheduled to be masticated in 2026-2027.

Surface fuel loads across the four monitoring plots were relatively low. Mean coarse woody (1,000-hour) fuels averaged approximately 4.4 tons per acre, while fine woody fuels (1–100-hour) averaged 3.4 tons per acre. Duff and litter contributed approximately 7.2 tons per acre and 4.0 tons per acre, respectively (Table 20, Figure 60).

Table 20. 1,000-hour fuel monitoring results for Tower–Roosevelt (plots 1-4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Tower–Roosevelt</i> (Plots 1, 2, 3, 4)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Tower–Roosevelt 1,2,3,4</i> (<i>n</i> = 4 plots; <i>pre-treatment</i>) <u>00PRE (2023): 4.4 (± 3) tons/ac</u>	To be determined

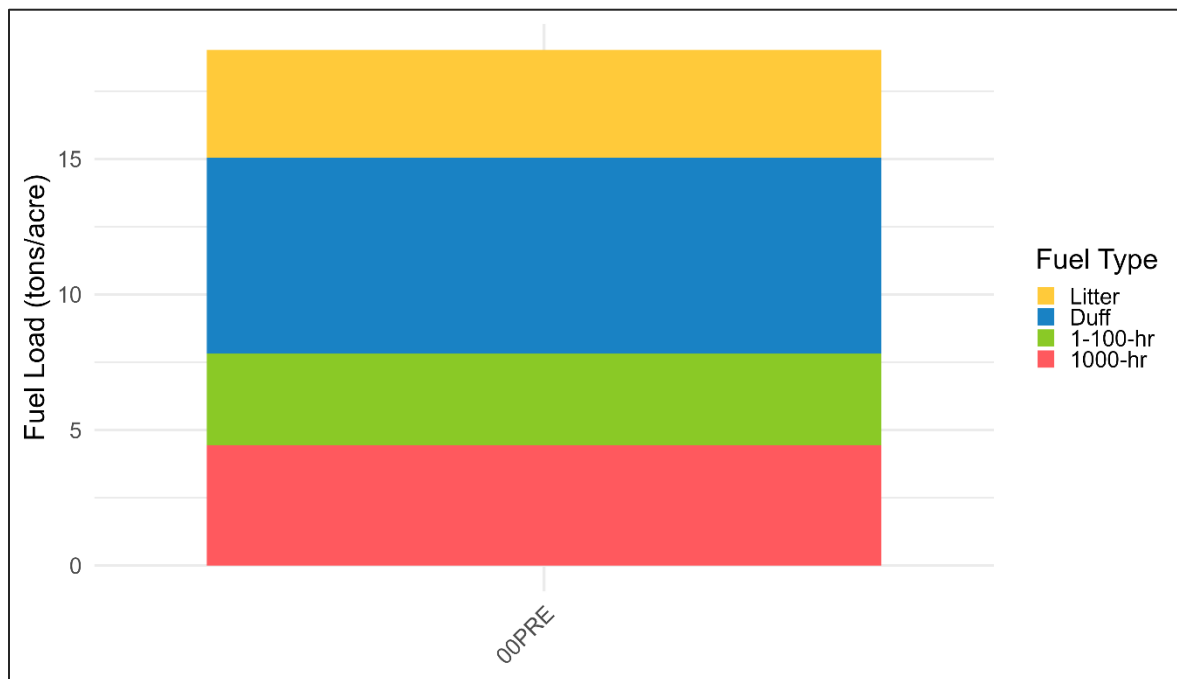


Figure 60. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Tower–Roosevelt plots 1, 2, 3, and 4.

Stand structure reflects a dense, mature condition, with 283 Douglas-fir trees per acre and five Engelmann spruce trees per acre, a basal area of 194 ft²/ac, and a Stand Density Index of 312, indicating high levels of crowding approaching upper density thresholds for Douglas-fir dominated stands (Table 21; Figure 61). Conifer regeneration is limited, with approximately 101 Douglas-fir seedlings per acre, suggesting minimal near-term stand infilling (Table 22, Figure 61).

The understory community is diverse, with 58 species recorded. Dominant species include common snowberry (*Symphoricarpos albus*), with shinyleaf spirea (*Spiraea betulifolia* var. *lucida*) and prominent pinegrass. Non-native species occur at low overall cover (approximately 3.2% combined), including timothy, Kentucky bluegrass, common dandelion (*Taraxacum officinale*), and German-madwort (*Asperugo procumbens*) (Tables 23,24).

Overall, the stand is characterized by high overstory density, moderate canopy fuel continuity, and limited regeneration, underscoring the importance of continued monitoring to assess future changes in stand structure and fire behavior potential in response to the planned 2026-2027 mastication treatment.

Table 21. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac). Average values are depicted along with the range of individual plot-level data to illustrate across-plot variability.

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2025	00PRE	0.126 (0.071 – 0.174)	7.4 (2.7 – 10.9)	312 (206 – 359)	194 (134 – 226)

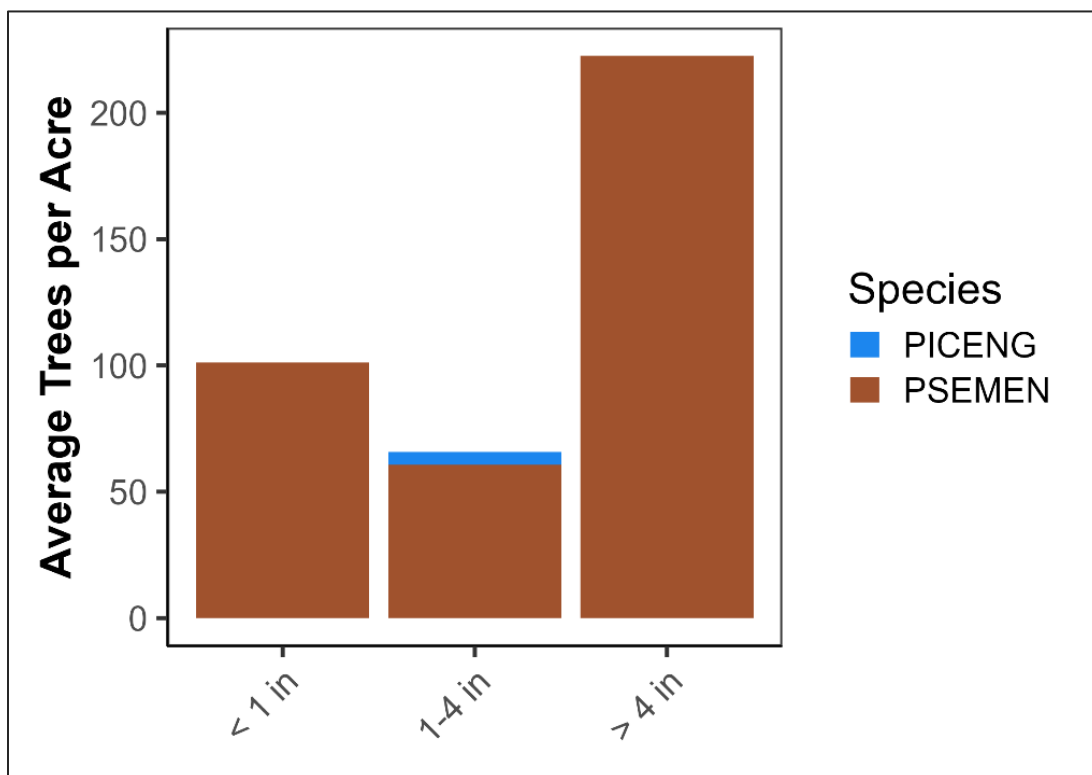


Figure 61. Trees per acre by diameter size class (inches) for Tower-Roosevelt plots 1-4 during the 2025 (00PRE) monitoring period. Species are distinguished as Douglas-fir (PSEMEN; brown) and Engelmann spruce (PICENG; blue). The < 1-inch size class includes both saplings and seedlings.

Table 22. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Tower-Roosevelt (plots 1-4)

Species	00PRE (2025)	
	Trees	Seedlings
Douglas-fir (<i>PSEMEN</i>)	283	101
Engelmann Spruce (<i>PICENG</i>)	5	0

Table 23. Native species monitoring results for Tower–Roosevelt (plots 1-4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Tower–Roosevelt</i> (Plots 1, 2, 3, 4)	Monitor for native species composition change using mean relative percent cover.	<i>Tower–Roosevelt 1,2,3,4</i> (<i>n</i> = 4 plots; <i>pre-treatment</i>) 00PRE (2025): 98% ($\pm$ 2.3%) native spp.	To be determined

Table 24. Non-native species monitoring results for Tower–Roosevelt (plots 1-4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Tower–Roosevelt</i> (Plots 1, 2, 3, 4)	Monitor species listed on park priority weed list through relative percent cover.	<i>Tower–Roosevelt 1,2,3,4</i> <i>*not a statistical analysis so minimum plot numbers not calculated*</i> <u>00PRE (2025):</u> 1.2% <i>Phleum pratense</i> (timothy) 0.8% <i>Poa pratensis</i> (Kentucky bluegrass) 0.7% <i>Taraxacum officinale</i> (common dandelion) 0.5% <i>Asperugo procumbens</i> (German-madwort)	Yes



Figure 62. Newly emerged conifer seedling with the seed cap still attached, illustrating recent germination within the litter layer.

vi. Heart Lake Backcountry Cabin

The Heart Lake Patrol Cabin, constructed in 1925, has historically served as a backcountry patrol cabin for rangers tasked with monitoring remote areas of the park and ensuring visitor and resource protection (Figure 63). The cabin remains an important operational asset for park staff working in the remote Heart Lake region.

To reduce fuel loading and mitigate potential wildfire behavior in the immediate vicinity of the structure, the Heart Lake fuel reduction project was initiated in 2005. This project consisted of two treatment units totaling approximately one acre, both located adjacent to the backcountry cabin (Figure 64), and used chainsaws.

To evaluate treatment effectiveness, three monitoring plots were installed in 2003 prior to the initial treatment. In 2015, two of the original plots were converted from the FMECH1T99 monitoring type to the HZF monitoring type to standardize plot size and sampling methodology across hazard fuel treatment areas. The plots were subsequently remeasured in 2025, marking 20 years since the original thinning treatment.

Heart Lake Plots 001, 002

- 2003 (*00PRE*) – Data collection prior to first entry
- 2005 – First entry thinning treatment
- 2015 (*01YR10*) – Data collection 10 years after the first treatment
- 2025 (*01YR20*) – Data collection 20 years after the first treatment



Figure 63. Photograph of the Heart Lake backcountry cabin, originally constructed in 1925.

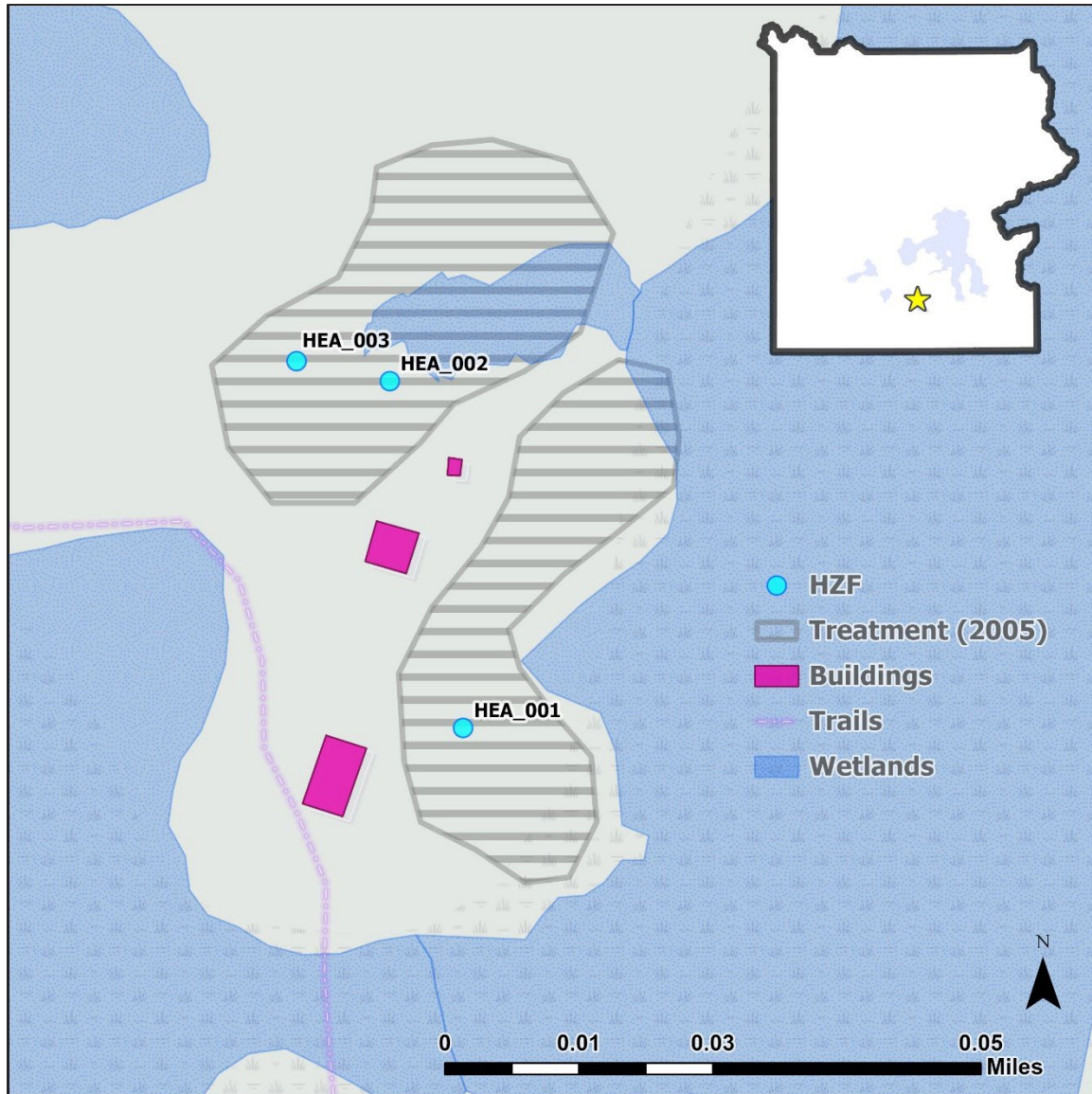


Figure 64. Map of the Heart Lake backcountry cabin area showing the locations of all HZF monitoring plots (teal circles), the 2005 thinning treatment boundary (gray hatched area), buildings (pink polygons), trails (purple lines), and delineated wetland areas (blue polygons).

For the Heart Lake project unit, canopy bulk density in 2025 (*01YR20*) was approximately 28% lower than pre-treatment conditions in 2003 (*00PRE*), declining from 0.234 kg/m^3 to 0.170 kg/m^3 (Table 25; Figure 65). However, CBD has increased relative to the prior measurement in 2015 (*01YR10*), when values averaged 0.120 kg/m^3 , indicating partial accumulation of canopy fuels over time. Vertical profiles show the highest concentration of aerial fuels occurs between approximately 5 and 40 ft, with pronounced accumulation in the 5-20 ft stratum, suggesting increased ladder fuel continuity (Figure 65).

Table 25. Canopy bulk density monitoring results for Heart Lake (plots 1 and 2)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Heart Lake (Plots 1, 2)	Reduce mean treatment area canopy bulk density over the entire life of the project to reduce the potential for crown fire activity.	<i>Heart Lake 1,2</i> (<i>n</i> = 2 plots; 1 treatment) <u>00PRE (2003): 0.234 ($\pm$ 0.028) kg/m³</u> <u>01YR10 (2015): 0.120 ($\pm$ 0.141) kg/m³</u> <i>Difference from 00PRE to 01YR10: -49%</i> <u>01YR20 (2025): 0.170 ($\pm$ 0.271) kg/m³</u> <i>Difference from 00PRE to 01YR20: -28%</i>	Yes, but minimum sample size not met

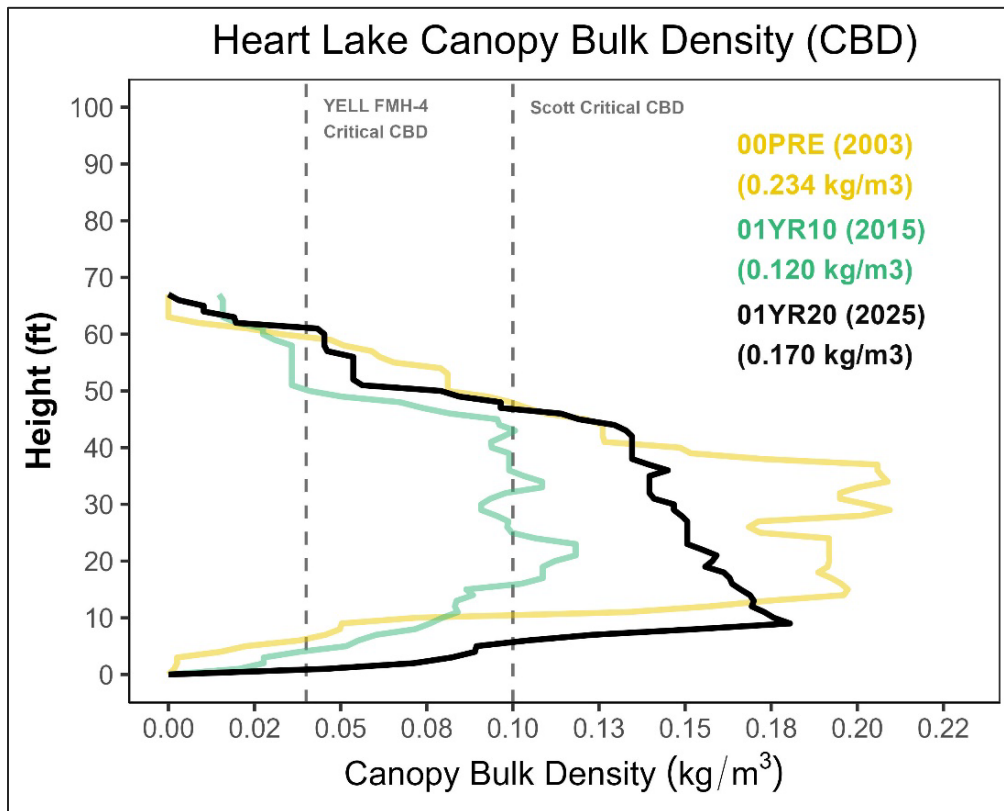


Figure 65. Canopy bulk density (kg/m³) for Heart Lake plots 1 and 2, which was treated in 2005.

Fire behavior modeling indicates a substantial reduction in crown fire potential relative to 2003 (00PRE) stand conditions, which predicted active crown fire (red) across portions of the treatment area. By contrast, simulations for the 10- and 20-year post-treatment periods following the 2005 thinning indicate a shift to predominantly surface fire behavior (yellow) (Figure 66). However, interpretation of these results is constrained by spatial resolution limitations. The

treatment unit is relatively small (approximately one acre), whereas modeled fire behavior is represented at a 30×30 m pixel scale, limiting the model's ability to fully resolve fine-scale treatment effects. In addition, the fire behavior modeling is parameterized primarily by canopy characteristics (canopy cover, canopy bulk density, and canopy base height) and does not explicitly incorporate stand density metrics or surface fuel data, which strongly influence fire behavior. These factors should be considered when evaluating overall treatment effectiveness.

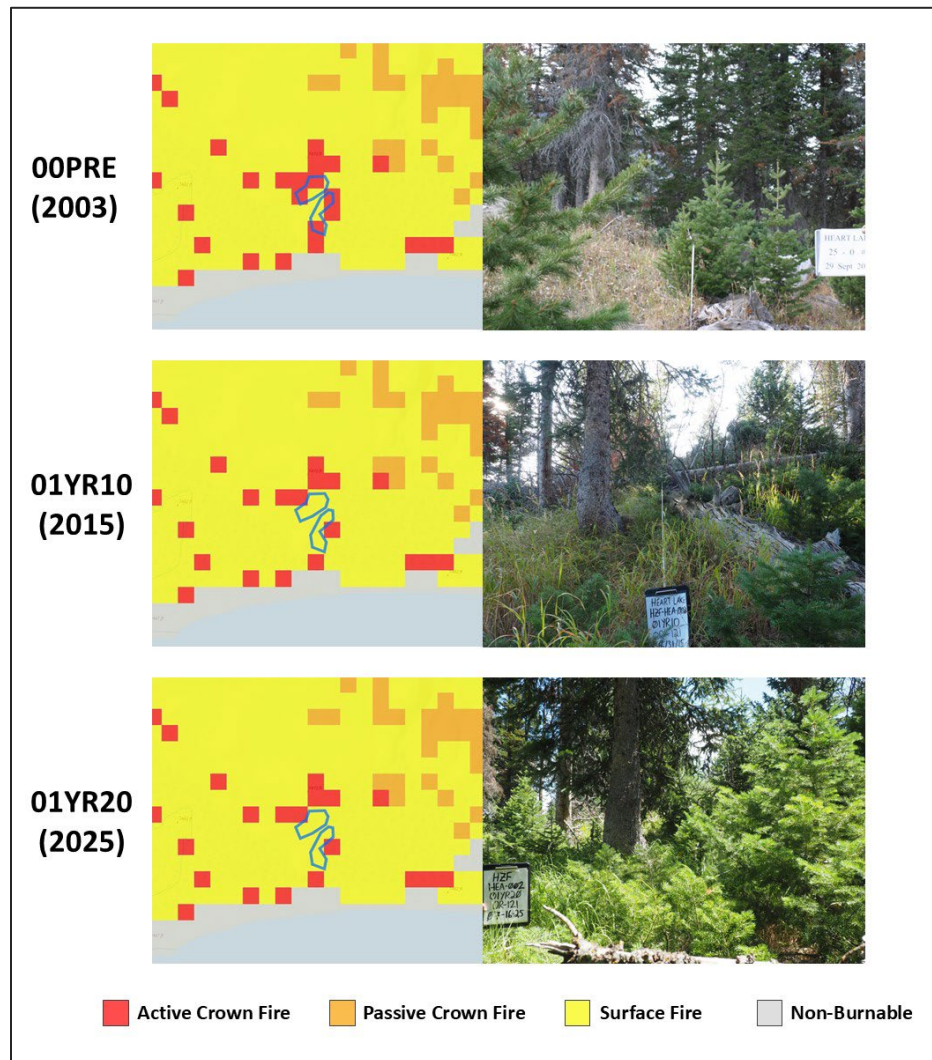


Figure 66. Modeled fire behavior for the Heart Lake treatment area (blue polygons), shown alongside representative plot photographs from each sampling period. Fire behavior was simulated in IFTDSS under very high fire danger conditions, including 15 mph southwest winds, 1-hour fuel moisture of 3%, 10-hour fuel moisture of 4%, 100-hour fuel moisture of 5%, herbaceous fuel moisture of 30%, and foliar moisture of 100%.

Surface fuel loads increased substantially over the monitoring period. Mean coarse woody (1,000-hour) fuel loads increased by approximately 56% from 14.0 tons per acre in 2003 to 21.9 tons per acre in 2025, exceeding the < 10 tons per acre management objective (Table 26; Figure 67). When surface fuel components were considered collectively, fine fuels (1–100-hour)

increased from approximately 3.0 tons per acre in 2003 to 4.4 tons per acre in 2025. Duff and litter also increased over this period, with duff rising from 1.7 to 2.8 tons per acre and litter from 2.7 to 3.4 tons per acre (Figure 68). However, interpretation of these trends should account for the limited sample size (two plots), which resulted in elevated variance across fuel components. These results should therefore be interpreted cautiously.

Table 26. 1,000-hour fuel monitoring results for Heart Lake (plots 1 and 2)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Heart Lake (Plots 1, 2)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>Heart Lake 1,2</i> (<i>n</i> = 2 plots; 1 treatment) <u>00PRE (2003): 14 (± 33.7) tons/ac</u> <u>01YR10 (2015): 16.6 (± 34) tons/ac</u> <i>Difference from 00PRE to 01YR10: +18%</i> <u>01YR20 (2025): 21.9 (± 65.2) tons/ac</u> <i>Difference from 00PRE to 01YR20: +56%</i>	No, and minimum sample size not met

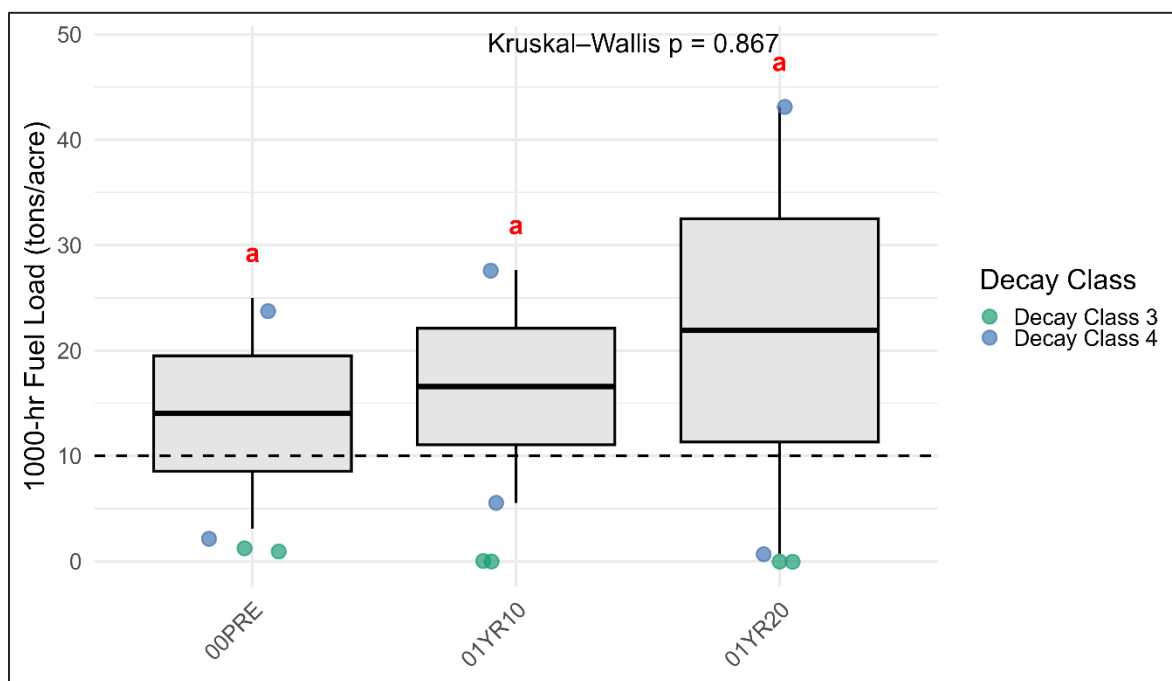


Figure 67. Average 1,000-hour fuel loads (tons per acre) for Heart Lake plots 1 and 2. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.

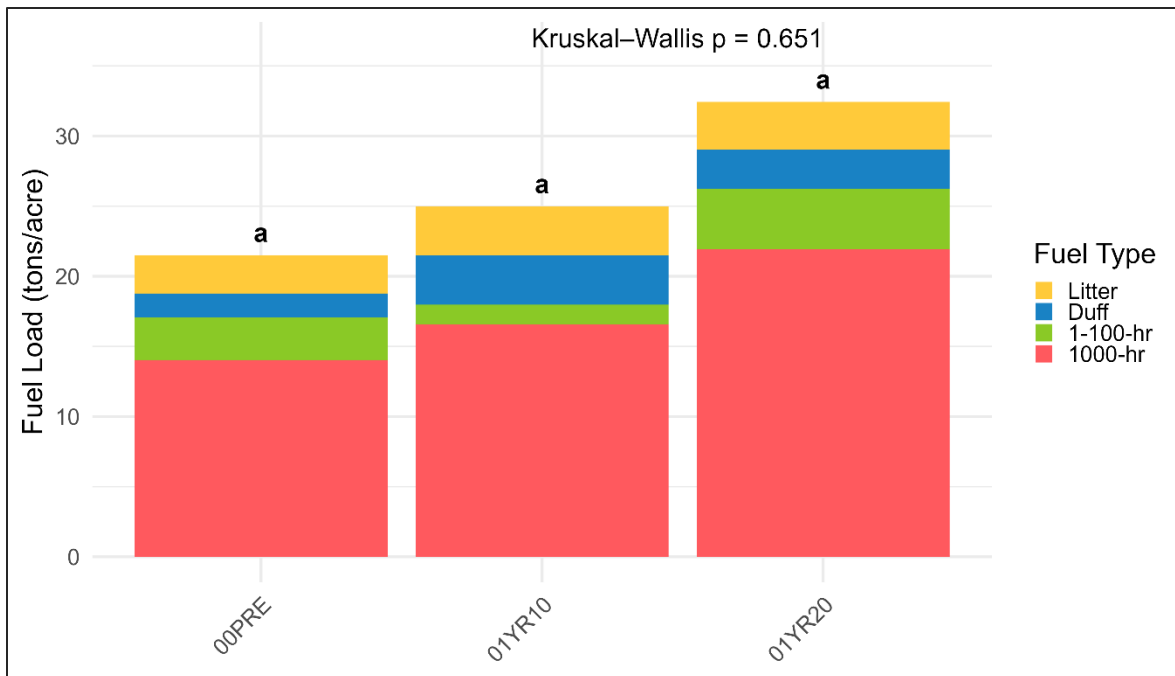


Figure 68. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Heart Lake plots 1 and 2.

This Heart Lake project unit represents a mixed-conifer lodgepole pine-subalpine fir stand that has undergone substantial structural change since the 2005 thinning treatment. By 2025 (01YR20), stand density increased relative to 2015 (01YR10) conditions, with SDI rising to 273 and basal area increasing to 160 ft²/ac, indicating renewed crowding and active competition among trees. Overstory composition shifted toward subalpine fir dominance, with subalpine fir increasing from 81 trees per acre in 2015 to 273 trees per acre in 2025, while lodgepole pine remained relatively stable (~100 trees/ac). Engelmann spruce also increased modestly (Table 27, Figure 70).

Vertical structure reflects increasing ladder fuel potential (Figure 69). Canopy base height declined from 2.6 m in 2015 to 1.3 m in 2025, consistent with infilling of lower canopy layers and crown expansion of shade-tolerant species. Regeneration patterns further reinforce this trajectory: subalpine fir regeneration remained high (2,428 seedlings/ac in 2025), lodgepole pine regeneration was absent, and Engelmann spruce regeneration persisted at low to moderate levels. The presence of whitebark pine seedlings (71 seedlings/ac) indicates limited but noteworthy recruitment of less shade-tolerant species into the understory (Table 28, Figure 70).

In general, the 2005 thinning was effective at initially reducing stand density and altering structure; however, observed increases in basal area, SDI, surface and ladder fuel development indicate that treatment effects have diminished over time. Continued dominance and recruitment of subalpine fir suggest a successional shift toward a denser, shade-tolerant stand with increasing potential for crown fire initiation. These patterns indicate a need for maintenance treatments or targeted understory thinning to sustain fuel reduction objectives, maintain vertical separation of surface and canopy fuels, and prolong treatment effectiveness. Continued monitoring will be

important to inform the timing and type of future management actions to protect this historic structure.

Table 27. Summary of overstory tree data including canopy bulk density (CBD; kg/m^3), canopy base height (m), stand density index (SDI), and basal area (ft^2/ac). Average values are depicted along with the range of individual plot-level data to illustrate across-plot variability.

Year	Read	CBD (kg/m^3)	Canopy Base Ht (m)	SDI	BA (ft^2/ac)
2003	00PRE	0.234 (0.225 – 0.243)	3.3 (2.6 – 3.9)	346 (289 – 402)	194 (168 – 219)
2015	01YR10	0.120 (0.074 – 0.166)	2.6 (1.5 – 3.7)	205 (171 – 238)	118 (93 – 143)
2025	01YR20	0.170 (0.082 – 0.258)	1.3 (0.7 – 1.9)	273 (189 – 356)	160 (103 – 217)



Figure 69. Photograph from plot 001 illustrating infilling by shade-tolerant subalpine fir, resulting in increased vertical fuel continuity and ladder fuel development.

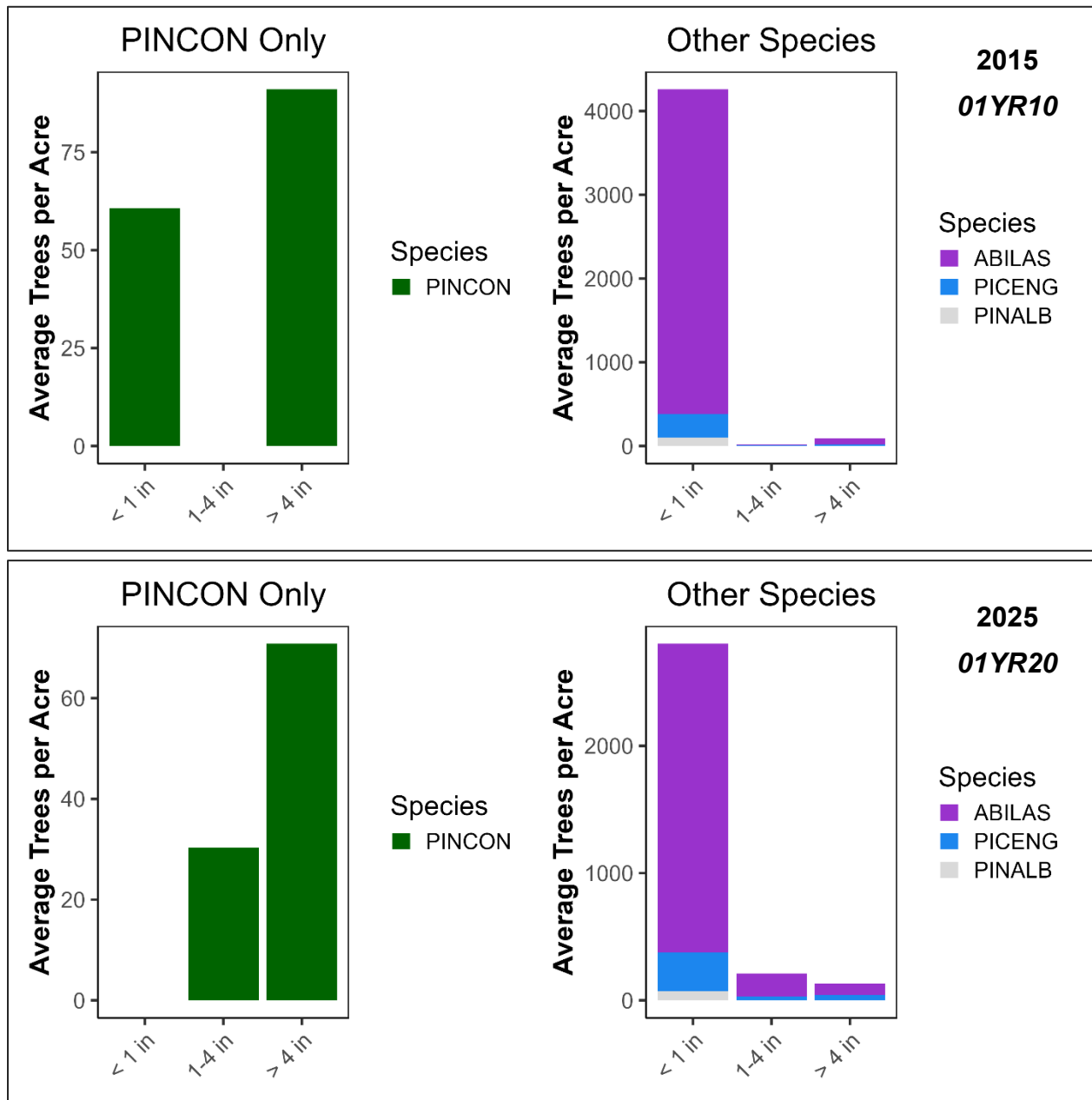


Figure 70. Trees per acre by diameter size class (inches) for Heart Lake plots 1 and 2 during the 2015 (01YR10 – top panel) and 2025 (01YR20 – bottom panel) monitoring periods. Species are distinguished as lodgepole pine (PINCON; green), subalpine fir (ABILAS; purple), Engelmann spruce (PICENG; blue), and whitebark pine (PINALB; gray). Note the different y-axis scales for the PINCON only plot (left) and other species plot (right) across both the top and bottom panels. The < 1-inch size class includes both saplings and seedlings.

Table 28. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Heart Lake (plots 1 and 2)

Species	01YR10 (2015)		01YR20 (2025)	
	Trees	Seedlings	Trees	Seedlings
Lodgepole Pine (PINCON)	91	61	101	0
Subalpine Fir (ABILAS)	81	3,875	273	2,428
Engelmann Spruce (PICENG)	30	283	71	304
Whitebark Pine (PINALB)	0	0	0	71

Note: Tree and seedling data from 2003 (00PRE) were collected prior to implementation of standardized sampling protocols and are therefore not included in comparative analyses.

Understory vegetation was moderately diverse, with 37 species recorded during the 2025 assessment. Dominant species included sweetcicely (*Osmorhiza berteroi*), interior bluegrass (*Poa interior*), and silvery lupine (*Lupinus argenteus*), with additional observations of Kentucky bluegrass, Virginia strawberry (*Fragaria virginiana*), and Northwest Territory sedge (*Carex utriculata*). Non-native species increased relative to 2015 (01YR10), with total invasive cover rising from approximately 9% to 14%. Kentucky bluegrass accounted for the largest proportion of invasive cover, followed by common dandelion (*Taraxacum officinale*), timothy, Canada thistle (*Cirsium arvense*), and orchardgrass (*Dactylis glomerata*) (Tables 29,30).

Table 29. Native species monitoring results for Heart Lake (plots 1 and 2)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Heart Lake (Plots 1, 2)	Monitor for native species composition change using mean relative percent cover.	Heart Lake 1,2 (n = 2 plots; 1 treatment) 01YR10 (2015): 91% (± 22.6%) native spp. 01YR20 (2025): 87% (± 31.9%) native spp. Difference from 01YR10 to 01YR20: -4%	Yes, but minimum sample size not met

Note: Vegetation data from 2003 (00PRE) were collected prior to implementation of standardized sampling protocols and are therefore not included in comparative analyses.

Table 30. Non-native species monitoring results for Heart Lake (plots 1 and 2)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Heart Lake (Plots 1, 2)	Monitor species listed on park priority weed list through relative percent cover.	<i>Heart Lake 1,2</i> *not a statistical analysis so minimum plot numbers not calculated* <u>01YR10 (2015):</u> 3.4% <i>Poa pratensis</i> (Kentucky bluegrass) 2.6% <i>Taraxacum officinale</i> (common dandelion) 1.8% <i>Phleum pratense</i> (timothy) 1.0% <i>Cirsium arvense</i> (Canada thistle) 0.2% <i>Trifolium repens</i> (white clover) <u>01YR20 (2025):</u> 9.5% <i>Poa pratensis</i> (Kentucky bluegrass) 2.5% <i>Taraxacum officinale</i> (common dandelion) 1.3% <i>Phleum pratense</i> (timothy) 0.2% <i>Cirsium arvense</i> (Canada thistle) 0.2% <i>Dactylis glomerata</i> (orchardgrass)	Yes

Note: Vegetation data from 2003 (00PRE) were collected prior to implementation of standardized sampling protocols and are therefore not included in comparative analyses.



Figure 71. Grace, Marlee, and Jess hiking in the backcountry of Yellowstone to conduct plot sampling.

vii. South Riverside Backcountry Cabin

The South Riverside Patrol Cabin is one of the oldest historic structures in Yellowstone National Park. In 1912, the U.S. Army proposed extending the West Boundary Trail northward from its eastern turn toward Summit Lake, thereby completing a continuous route connecting to the Riverside Soldier Station just inside the park from West Yellowstone. To support patrols along this new trail segment, the Army identified a need for two patrol cabins, however, funding and time constraints allowed for construction of only the South Riverside Patrol Cabin, which was built in 1912-1913 (Figure 72).

The cabin supported patrol operations north of Buffalo Lake and south of West Yellowstone. It is situated at approximately 7,500 ft elevation on the Madison Plateau, an area characterized by early, cold winters and limited late-season water availability. The cabin remains an important backcountry resource for park staff operating in this remote portion of the park.

To reduce wildfire risk and protect this historic structure, the South Riverside backcountry cabin hazard fuel project was implemented with chainsaws in 2005 and consists of a single treatment unit totaling approximately 1.3 acres (Figure 73). Four monitoring plots were installed in 2003 prior to treatment. In 2017, approximately 12 years post-treatment, three of the plots were remeasured and converted from the FMECH1T99 monitoring type to the Hazard Fuel (HZF) monitoring type to standardize plot size and methodology across fuel treatment areas in the park; the remaining plot (plot 002) was discontinued. The plots were subsequently revisited in 2025, marking 20 years since the initial fuel reduction treatment.

South Riverside Plots 001, 003, 004

- 2003 (*00PRE*) – Data collection prior to first entry
- 2005 – First entry thinning treatment
- 2017 (*01YR12*) – Data collection 12 years after the first treatment
- 2025 (*01YR20*) – Data collection 20 years after the first treatment

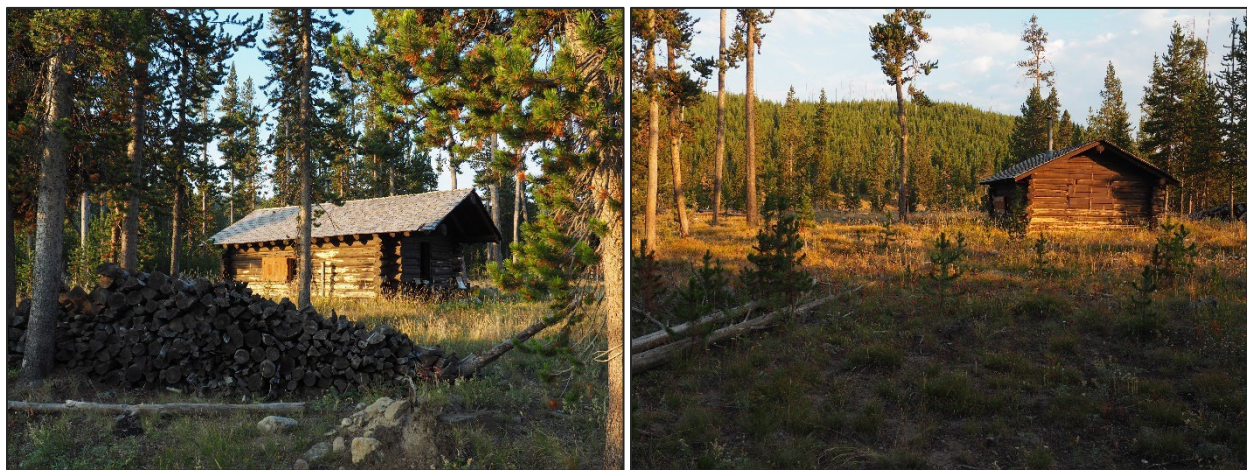


Figure 72. Photographs of the South Riverside backcountry cabin, originally constructed in 1912-1913.

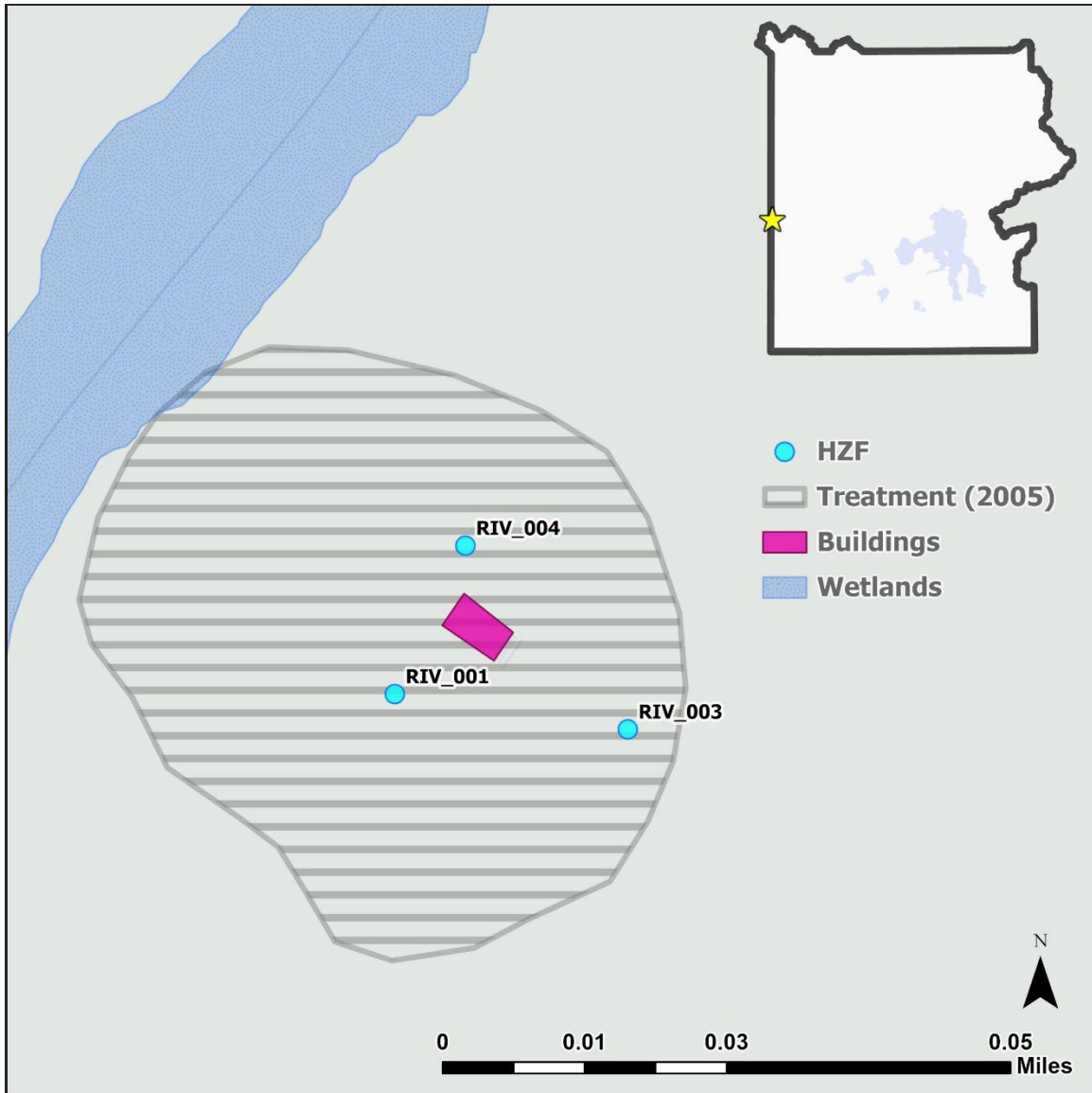


Figure 73. Map of the South Riverside backcountry cabin area showing the locations of all HZF monitoring plots (teal circles), the 2005 thinning treatment boundary (gray hatched area), buildings (pink polygons), trails (purple lines), and delineated wetland areas (blue polygons).

Canopy bulk density has increased substantially in the years following the 2005 thinning treatment, rising from 0.056 kg/m^3 during the initial 2003 (*00PRE*) assessment to 0.092 kg/m^3 in 2017 (*01YR12*) to 0.166 kg/m^3 by 2025 (*01YR20*), representing an approximate 108% increase relative to pre-treatment conditions. Vertical fuel profiles indicate aerial fuels are most concentrated within the 5-15 ft height stratum, suggesting increasing ladder fuel continuity over time (Table 31; Figure 74).

Table 31. Canopy bulk density monitoring results for South Riverside (plots 1, 3, and 4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
South Riverside (Plots 1, 3, 4)	Reduce mean treatment area canopy bulk density over the entire life of the project to reduce the potential for crown fire activity.	<i>South Riverside 1,3,4</i> (<i>n</i> = 3 plots; 1 treatment) <u>00PRE (2003): 0.056 ($\pm$ 0.038) kg/m³</u> <u>01YR12 (2017): 0.092 ($\pm$ 0.060) kg/m³</u> <i>Difference from 00PRE to 01YR12: +65%</i> <u>01YR20 (2025): 0.116 ($\pm$ 0.096) kg/m³</u> <i>Difference from 00PRE to 01YR10: +108%</i>	No, and minimum sample size not met

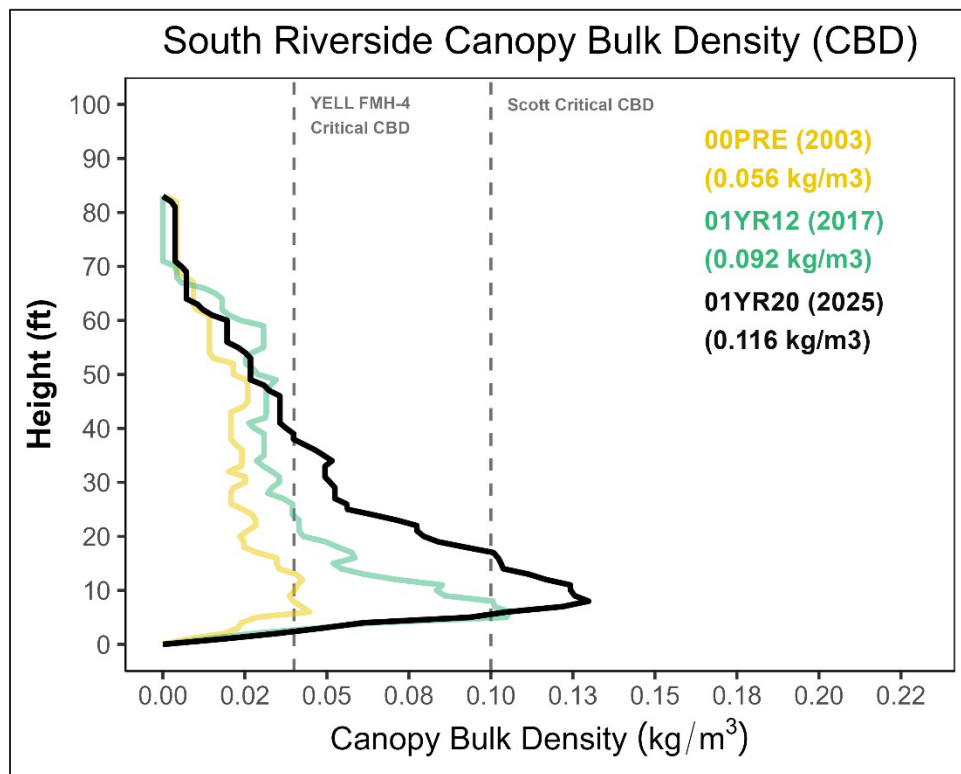


Figure 74. Canopy bulk density (kg/m³) for South Riverside plots 1, 3, and 4, which were treated in 2005.

Fire behavior modeling indicated an increase in crown fire potential over time, with predicted fire behavior shifting from predominantly surface fire (yellow) within the treatment perimeter to more passive crown fire (orange) at 12- and 20-year post-treatment intervals (Figure 75). However, similar to the Heart Lake treatment, interpretation of these results is constrained by spatial resolution limitations, as the treatment unit is relatively small (approximately 1.3 acres) compared to the 30 m $\times$ 30 m pixel resolution used in the fire behavior model, limiting its ability to fully capture fine-scale treatment effects. In addition, the model is parameterized primarily

using canopy characteristics (canopy bulk density and canopy base height) and does not explicitly incorporate stand density metrics (i.e., SDI or basal area) or surface fuel loads, which strongly influence fire behavior. As such, the full suite of plot-level data should be considered when evaluating treatment effectiveness and changes in fire behavior potential over time.

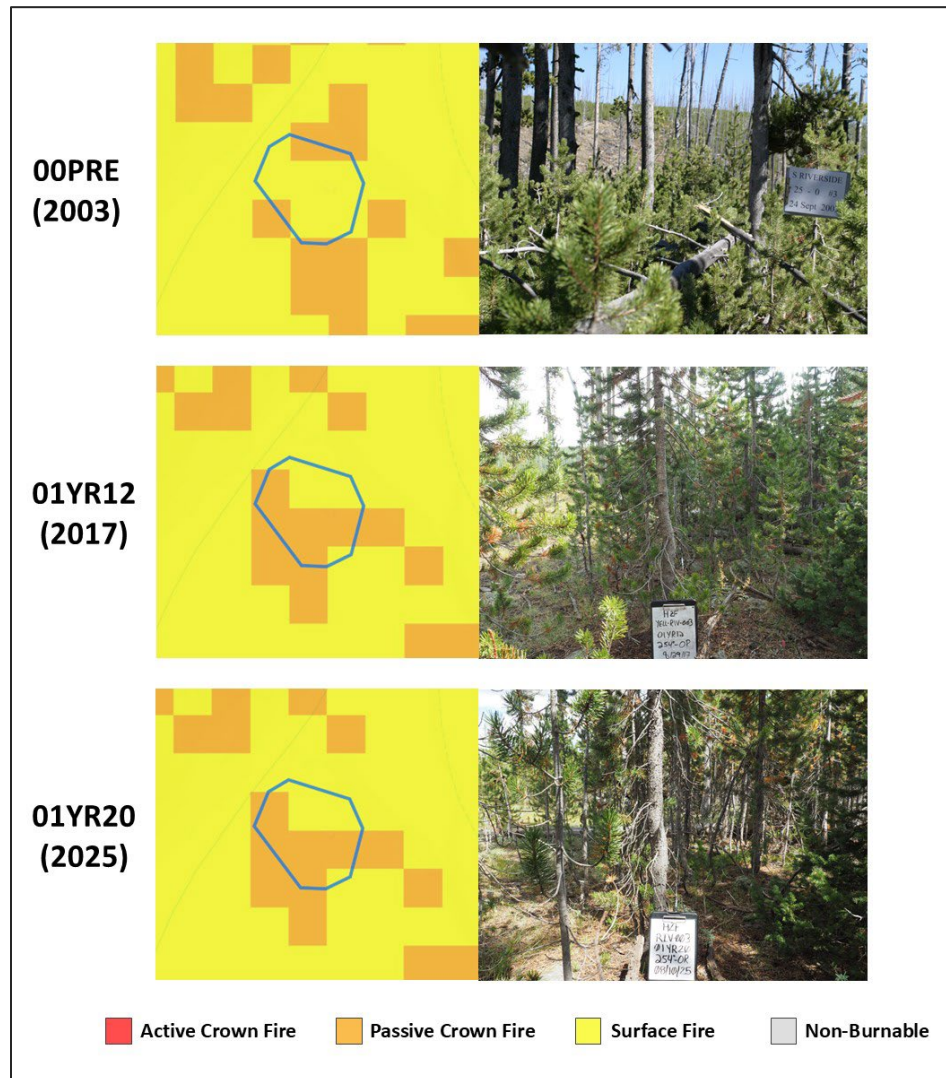


Figure 75. Modeled fire behavior for the South Riverside treatment area (blue polygon), shown alongside representative plot photographs from each sampling period. Fire behavior was simulated in IFTDSS under very high fire danger conditions, including 15 mph southwest winds, 1-hour fuel moisture of 3%, 10-hour fuel moisture of 4%, 100-hour fuel moisture of 5%, herbaceous fuel moisture of 30%, and foliar moisture of 100%.

Coarse woody (1,000-hour) fuel loads declined following treatment but have increased in recent years. Mean 1,000-hour fuels decreased from approximately 26.8 tons per acre in 2003 (*00PRE*) to 15.1 tons per acre in 2017 (*01YR12*), before increasing to 18.4 tons per acre in 2025. This represents an overall 31% reduction relative to pre-treatment conditions, although current loads remain above the < 10 tons per acre management objective established for the treatment unit (Table 32; Figure 76).

Other surface fuel components exhibited mixed trends over time. Fine fuels (1–100-hour) were largely absent in the 2003 assessment, with only 0.03 tons per acre of 1-hour fuels recorded but increased to approximately 0.5 tons per acre in 2017 and 1.0 ton per acre by 2025. In contrast, duff loads declined modestly over the monitoring period, decreasing from approximately 1.8 tons per acre in 2003 to 1.1 tons per acre in 2025. Litter loads remained relatively stable, increasing slightly from approximately 1.8 tons per acre to 1.9 tons per acre over the same period (Figure 77). Interpretation of these trends should account for the high variance across the three sampled plots, which may confound detection of treatment effects.

Table 32. 1,000-hour fuel monitoring results for South Riverside (plots 1, 3, and 4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
South Riverside (Plots 1, 3, 4)	Reduce mean 1,000-hour fuel loads to ≤ 10 tons/acre over the entire life of the project, as measured from pretreatment conditions.	<i>South Riverside 1,3,4</i> (<i>n</i> = 2 plots; 1 treatment) <u>00PRE (2003): 26.7 ($\pm$ 28.2) tons/ac</u> <u>01YR12 (2017): 15.1 ($\pm$ 17.1) tons/ac</u> <i>Difference from 00PRE to 01YR12: -43%</i> <u>01YR20 (2025): 18.4 ($\pm$ 13.3) tons/ac</u> <i>Difference from 00PRE to 01YR20: -31%</i>	No, and minimum sample size not met

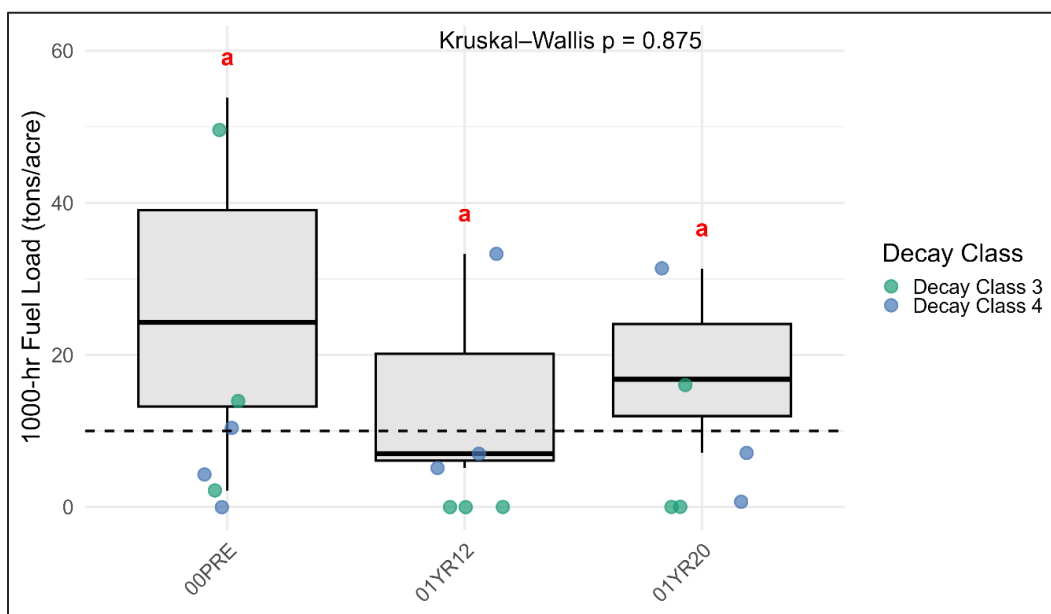


Figure 76. Average 1,000-hour fuel loads (tons per acre) for South Riverside plots 1, 3, and 4. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). The horizontal black dashed line indicates the management objective of 10 tons per acre for reduced 1,000-hour fuel loading. Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.

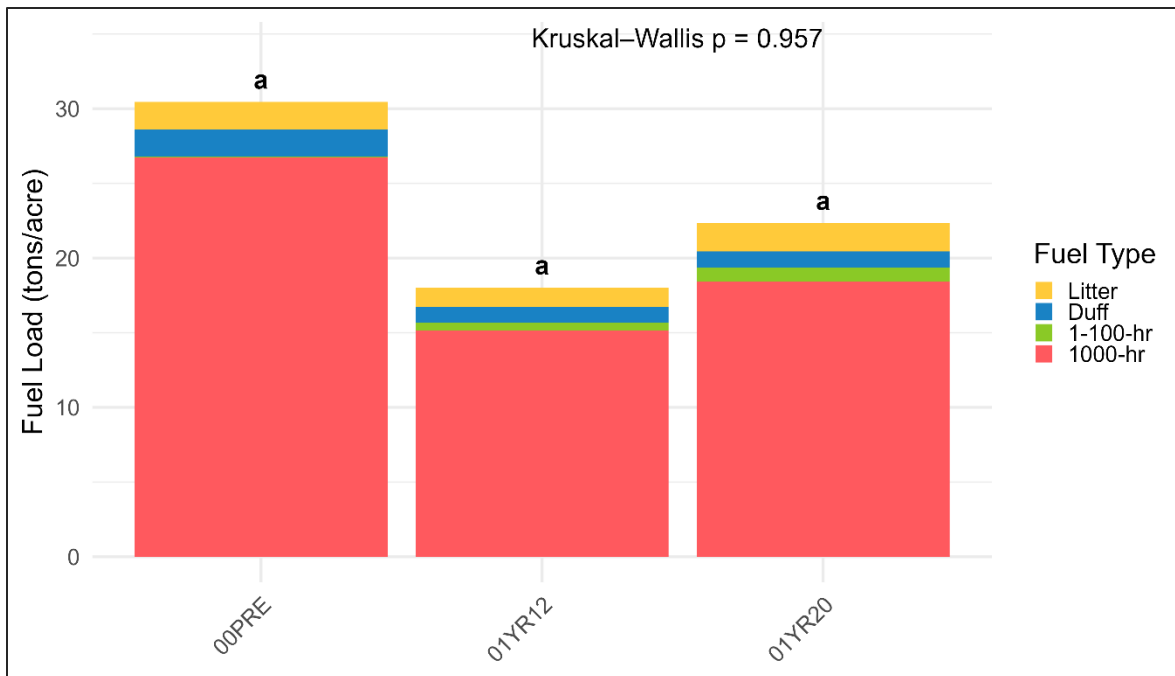


Figure 77. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for South Riverside plots 1, 3, and 4.

Stand density around the South Riverside backcountry cabin has increased steadily since treatment, reflecting ongoing growth and recruitment. SDI rose from 107 prior to treatment to 185 in 2017 and 228 by 2025, indicating a shift from relatively open, post-treatment conditions toward a moderately dense stand with increasing competition. Basal area followed a similar trajectory, increasing from 50 ft²/ac pre-treatment to 82 ft²/ac in 2017 and 101 ft²/ac in 2025, consistent with canopy closure and crown expansion in residual lodgepole pine (Table 33).

Overstory composition remains strongly lodgepole pine dominated. Tree density increased from 857 lodgepole pine trees per acre in 2017 to 917 trees per acre in 2025, with minor but increasing components of subalpine fir (13 to 27 trees/ac) and a stable but low presence of whitebark pine (seven trees/ac) (Table 34; Figure 79). These patterns suggest gradual incorporation of shade-tolerant species into the stand while lodgepole pine continues to dominate the overstory. Vertical separation between surface fuels and live crowns has decreased over time. Canopy base height declined from 2.9 m pre-treatment to 1.5 m by 2025, indicating downward crown expansion and increasing ladder fuel continuity. This trend is consistent with both overstory growth and accumulating regeneration beneath the canopy.

Regeneration is vigorous and strongly skewed toward lodgepole pine. Lodgepole pine seedling densities increased from 1,342 seedlings per acre in 2017 to 3,042 seedlings per acre in 2025, indicating strong post-treatment recruitment and a high likelihood of future stand infilling. Subalpine fir and whitebark pine regeneration increased modestly but remain secondary components (Table 34; Figure 79). If these patterns persist, continued increases in stem density and competition are expected as seedlings recruit into the sapling and overstory layers.

In general, the 2005 thinning was effective at initially reducing stand density and altering structure; however, observed increases in stand density, basal area, and regeneration indicate treatment effects have diminished over time. Declining canopy base heights and increasing stand density suggest potential for vertical fuel continuity and crown fire initiation under adverse fire weather conditions. These trends indicate that maintenance treatments or targeted understory thinning may be needed to sustain fuel reduction objectives, limit further infilling, and extend treatment longevity. Continued monitoring will be important to inform the timing and design of future management actions.

Table 33. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac). Average values are depicted along with the range of individual plot-level data to illustrate across-plot variability.

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2003	00PRE	0.056 (0.023 – 0.092)	2.9 (0.7 – 6.7)	107 (72 – 134)	50 (30 – 64)
2017	01YR12	0.092 (0.028 – 0.129)	2.5 (1.4 – 4.1)	185 (68 – 266)	82 (36 – 114)
2025	01YR20	0.116 (0.015 – 0.177)	1.5 (0.9 – 1.9)	228 (41 – 350)	101 (18 – 152)



Figure 78. Jess, Marlee and Grace hiking into the South Riverside backcountry cabin to conduct plot sampling.

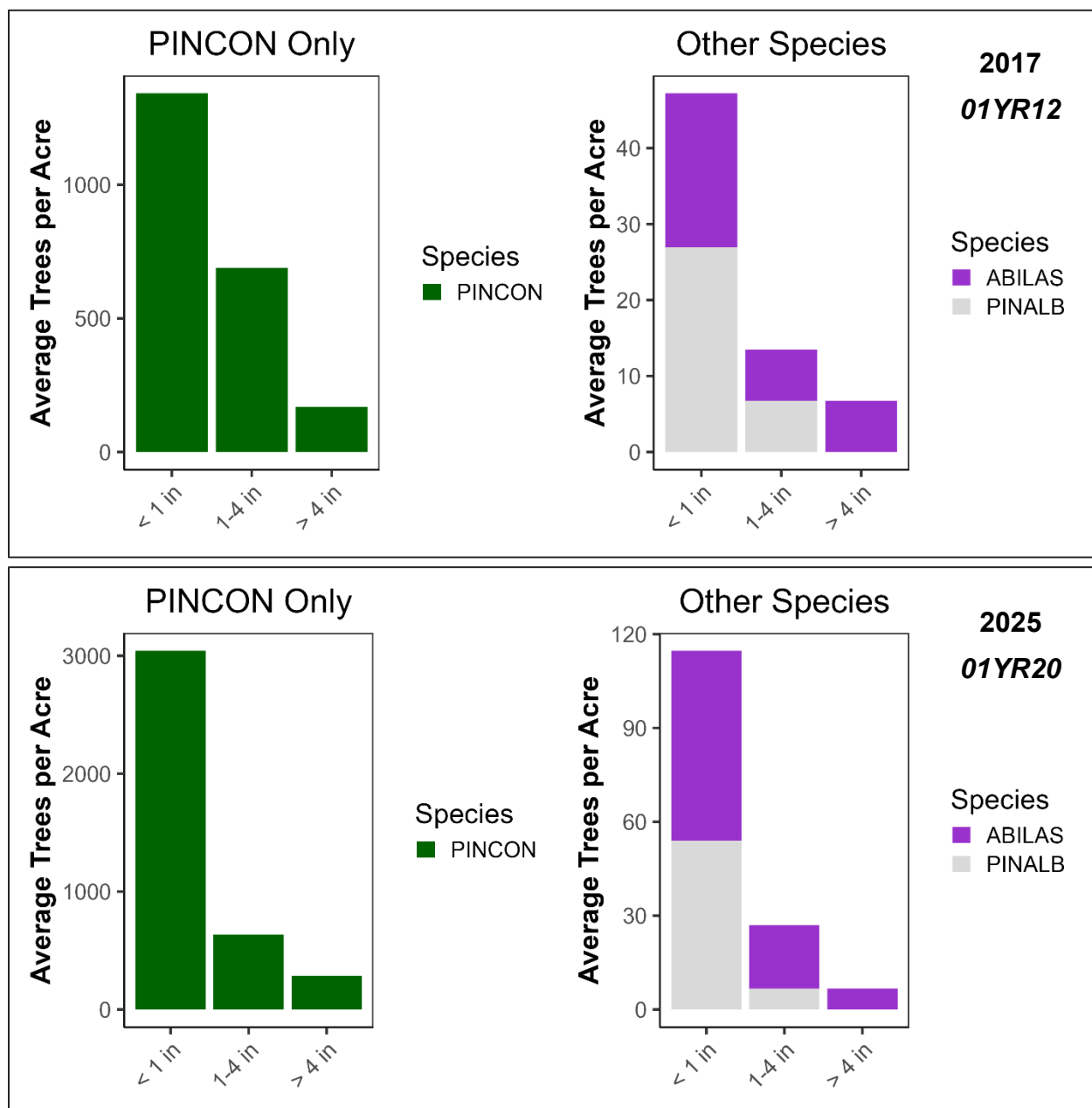


Figure 79. Trees per acre by diameter size class (inches) for South Riverside plots 1, 3, and 4 during the 2017 (01YR12 – top panel) and 2025 (01YR20 – bottom panel) monitoring periods. Species are distinguished as lodgepole pine (PINCON; green), subalpine fir (ABILAS; purple), and whitebark pine (PINALB; gray). Note the different y-axis scales for the PINCON only plot (left) and other species plot (right) across both the top and bottom panels. The < 1-inch size class includes both saplings and seedlings.

Table 34. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for South Riverside (plots 1, 3, and 4)

Species	01YR12 (2017)		01YR20 (2025)	
	Trees	Seedlings	Trees	Seedlings
Lodgepole Pine (PINCON)	857	1,342	917	3,042
Subalpine Fir (ABILAS)	13	20	27	61
Whitebark Pine (PINALB)	7	27	7	54

Note: Tree and seedling data from 2003 (00PRE) were collected prior to implementation of standardized sampling protocols and are therefore not included in comparative analyses.

Understory vegetation in 2025 was moderately diverse, with 21 species recorded. Dominant species included Ross' sedge (*Carex rossii*), followed by elk sedge, silvery lupine, and fireweed (*Chamerion angustifolium*). Non-native species cover declined relative to 2017 (01YR12), decreasing from approximately 4% of total understory cover to 1.1% in 2025. Kentucky bluegrass was the only invasive species observed during the 2025 sampling effort (Tables 35,36).

Table 35. Native species monitoring results for South Riverside (plots 1, 3, and 4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
South Riverside (Plots 1, 3, 4)	Monitor for native species composition change using mean relative percent cover.	South Riverside 1,3,4 (n = 3 plots; 1 treatment) 01YR12 (2017): 97% ($\pm 4.2\%$) native spp. 01YR20 (2025): 99% ($\pm 1.5\%$) native spp. Difference from 01YR12 to 01YR20: +2%	Yes, but minimum sample size not met

Note: Vegetation data from 2003 (00PRE) were collected prior to implementation of standardized sampling protocols and are not available for comparative analyses.

Table 36. Non-native species monitoring results for South Riverside (plots 1, 3, and 4)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
South Riverside (Plots 1, 3, 4)	Monitor species listed on park priority weed list through relative percent cover.	South Riverside 1,3,4 *not a statistical analysis so minimum plot numbers not calculated* 01YR12 (2017): 3.1% <i>Poa pratensis</i> (Kentucky bluegrass) 0.8% <i>Taraxacum officinale</i> (common dandelion) 01YR20 (2025): 1.1% <i>Poa pratensis</i> (Kentucky bluegrass)	Yes

Wildfire for Resource Benefits (WFRB) Monitoring Type

Permanent wildfire for resource benefit (WFRB) monitoring plots were established in advance of naturally ignited wildfires to evaluate ecological effects of fires managed under what are now referred to as point protection or monitoring strategies. A total of 17 active WFRB plots are currently installed within Yellowstone National Park. These plots were established between 1999 and 2007, with 10 plots having burned and 7 remaining unburned to date.

An additional nine plots were installed during this period; however, only three of these have burned. Due to their remote locations (often requiring helicopter access) these plots are considered inactive and are not included in routine monitoring. There are currently no plans to install additional WFRB plots, as these plots are relatively large and logistically burdensome, and most monitoring objectives can now be met using smaller, more efficient plot designs and/or through external research efforts.

At the time of installation, the WFRB Monitoring Type Description Sheet (FMH-4) did not include specific, measurable objectives. Instead, the stated purpose of these plots was broadly defined as monitoring long-term changes in non-native plant species, fuel loading, and plant communities following fires managed for resource benefit. To better align monitoring with fire management program needs, a revised set of objectives was developed in 2023 by the park fire ecologist in collaboration with fire managers.

The current WFRB monitoring objectives are to:

- Limit non-native plant establishment to less than a 10% increase relative to pre-treatment conditions, assessed at 1, 2, 5, 10, and subsequent 5-year postfire intervals, using relative percent cover within the burned perimeter.
- Quantify mean species absolute cover and compare post-fire values to pre-fire conditions to assess fire effects on understory vegetation at 1, 2, 5, 10, and subsequent 5-year intervals.
- Measure mean species richness (number of unique species) and compare post-fire values to pre-treatment levels to evaluate changes in understory vegetation diversity over time.
- Measure mean tree density by species and size class at 1, 2, 5, 10, and subsequent 5-year post-fire intervals to evaluate tree mortality, regeneration, and recruitment patterns within the burned perimeter.
- Measure mean 1,000-hour fuel loads at 1, 2, 5, 10, and subsequent 5-year post-fire intervals, and compare these values to pre-fire conditions to assess the time required for coarse woody fuels to return to pre-fire levels.

i. Boundary

The area containing the two Boundary plots was initially burned during the 1988 Snake River Complex Fire and subsequently reburned in 2000 during the Boundary Fire (approximately 339 acres) (Figure 80). The Boundary Fire was managed as a wildfire for resource benefit (WFRB) event (now referred to as a monitoring strategy) and represented one of the earliest documented instances of a wildfire reburning within a 1988 fire perimeter.

In response to this unique disturbance history, the Boundary plots were established to help fire managers better understand vegetation recovery, fuel accumulation, and successional trajectories in areas that experienced repeated wildfire (Figure 81).

A brief timeline summarizing site history and plot installation is provided below:

Boundary Plots 002, 003

- 1988 - First wildfire (Snake River Complex)
- 2000 (00PRE) - Data collection prior to second wildfire
- 2000 - Second wildfire (Boundary Fire)
- 2000 (01POST) - Data collection immediately following Boundary Fire
- 2001 (01YR01) - Data collection 1 year after the Boundary Fire
- 2002 (02YR02) - Data collection 2 years after the Boundary Fire
- 2003 (02YR03) - Data collection 3 years after the Boundary Fire
- 2004 (02YR04) - Data collection 4 years after the Boundary Fire
- 2010 (01YR10) - Data collection 10 years after the Boundary Fire
- 2015 (01YR15) - Data collection 15 years after the Boundary Fire
- 2020 (01YR20) - Data collection 20 years after the Boundary Fire
- 2025 (01YR25) - Data collection 25 years after the Boundary Fire



Figure 80. Post-fire conditions at Boundary plots 002 (left) and 003 (right), photographed in 2000.

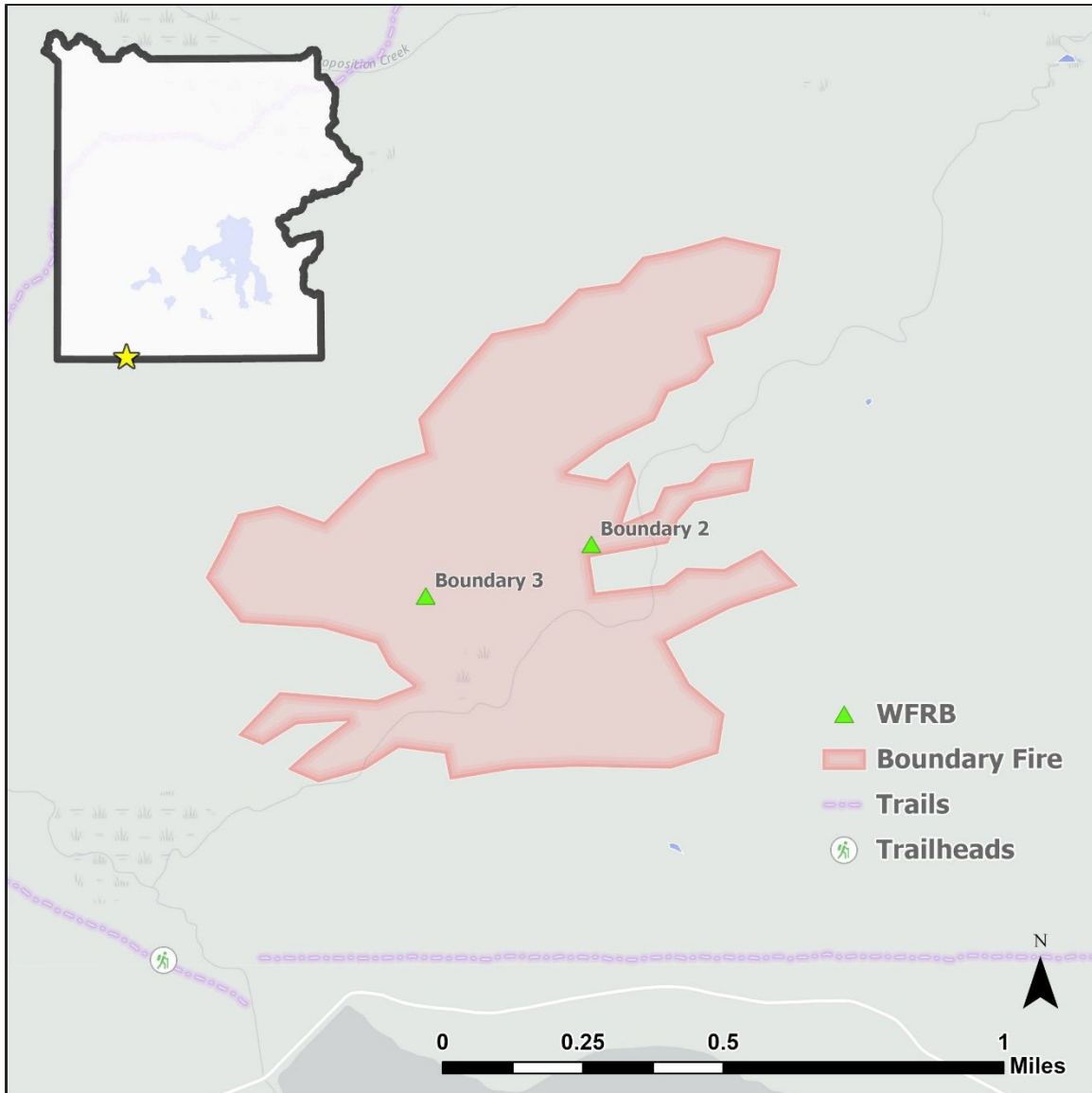


Figure 81. Map of the Boundary Fire area showing the locations of the WFRB monitoring plots (green triangles), the 2000 Boundary Fire (red polygon), trails (purple lines), and trailheads (icon symbol).

Average coarse woody (1,000-hour) fuel loads have varied over time but were lowest across the 25-year monitoring record in 2025 (*01YR25*), averaging approximately 17.7 tons per acre. This represents a 47% reduction relative to pre-fire conditions in 2000 (*00PRE*), when coarse woody fuels averaged 33.4 tons per acre (Table 37; Figure 82). However, differences in coarse woody fuel loads among sampling years were not statistically significant, based on the nonparametric Kruskal–Wallis test with a Holm-adjusted Dunn post hoc correction.

When surface fuel components were evaluated collectively, total fuel loads in 2025 were also at their lowest observed levels. Fine woody fuels (1–100-hour) declined from approximately 2.6 tons per acre in 2000 to 0.6 tons per acre in 2025, while combined litter and duff decreased from

approximately 8.8 tons per acre to 3.8 tons per acre over the same period (Figure 83). However, as with coarse fuels, no statistically significant differences were detected among years. However, interpretation of these trends should consider that variance was high across the two monitored plots, which limits statistical power and reduces the extent to which observed patterns are representative of surface fuel conditions across the broader fire area. These results should be evaluated with due consideration of these constraints.

Table 37. 1,000-hour fuel monitoring results for Boundary (plots 2 and 3)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Boundary (Plots 2, 3)	Measure mean 1,000-hour fuel loads at 1, 2, 5, 10, and subsequent 5-year post-fire intervals.	<i>Boundary 2,3</i> <i>(n = 2 plots; 2 wildfires)</i> <u>00PRE (2000): 33.4 (± 34.6) tons/ac</u> <u>01POST (2000): 19.5 (± 7.4) tons/ac</u> <i>Difference from 00PRE to 01POST: -42%</i> <u>01YR01 (2001): 23.1 (± 0) tons/ac</u> <i>Difference from 00PRE to 01YR01: -31%</i> <u>01YR02 (2002): 30.2 (± 16.9) tons/ac</u> <i>Difference from 00PRE to 01YR02: -9%</i> <u>01YR03 (2003): 26.0 (± 6.1) tons/ac</u> <i>Difference from 00PRE to 01YR03: -22%</i> <u>01YR04 (2004): 25.9 (± 11.9) tons/ac</u> <i>Difference from 00PRE to 01YR04: -22%</i> <u>01YR10 (2010): 23.4 (± 15.3) tons/ac</u> <i>Difference from 00PRE to 01YR10: -30%</i> <u>01YR15 (2015): 24.6 (± 17.2) tons/ac</u> <i>Difference from 00PRE to 01YR15: -26%</i> <u>01YR20 (2020): 22.6 (± 27.4) tons/ac</u> <i>Difference from 00PRE to 01YR20: -32%</i> <u>01YR25 (2025): 17.7 (± 15.1) tons/ac</u> <i>Difference from 00PRE to 01YR25: -47%</i>	Yes, but minimum sample size not met

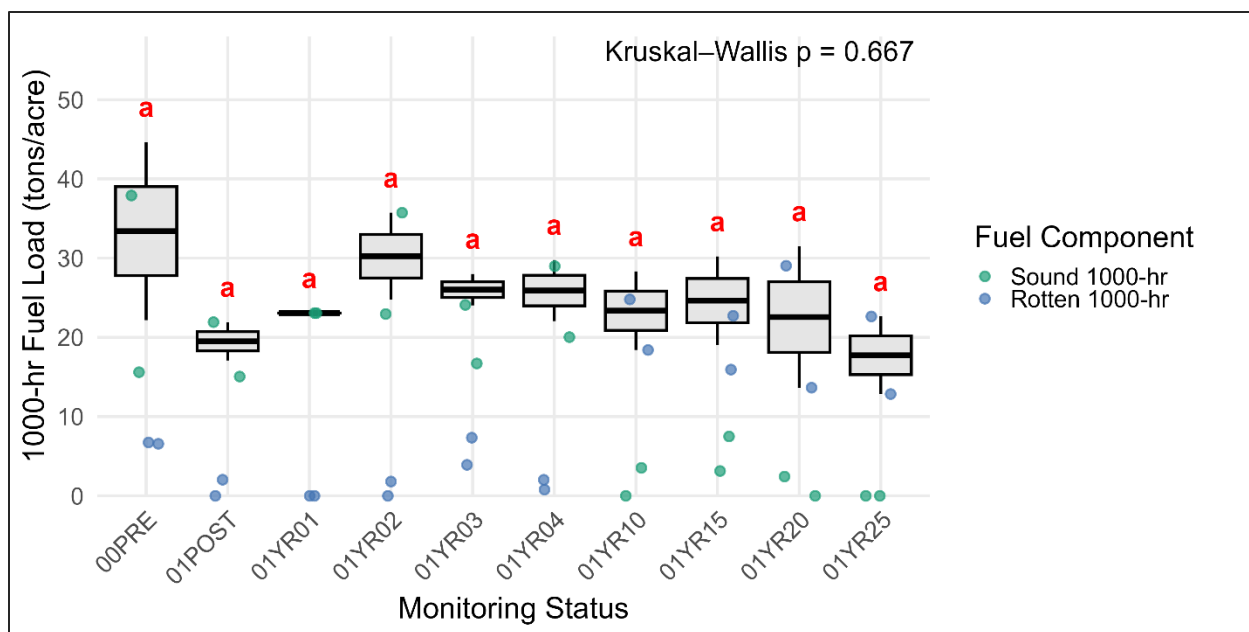


Figure 82. Average 1,000-hour fuel loads (tons per acre) for Boundary plots 2 and 3. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). Red letters denote statistically significant differences among groups based on a nonparametric Kruskal-Wallis test with Dunn's post hoc comparisons and Holm's correction for multiple testing.

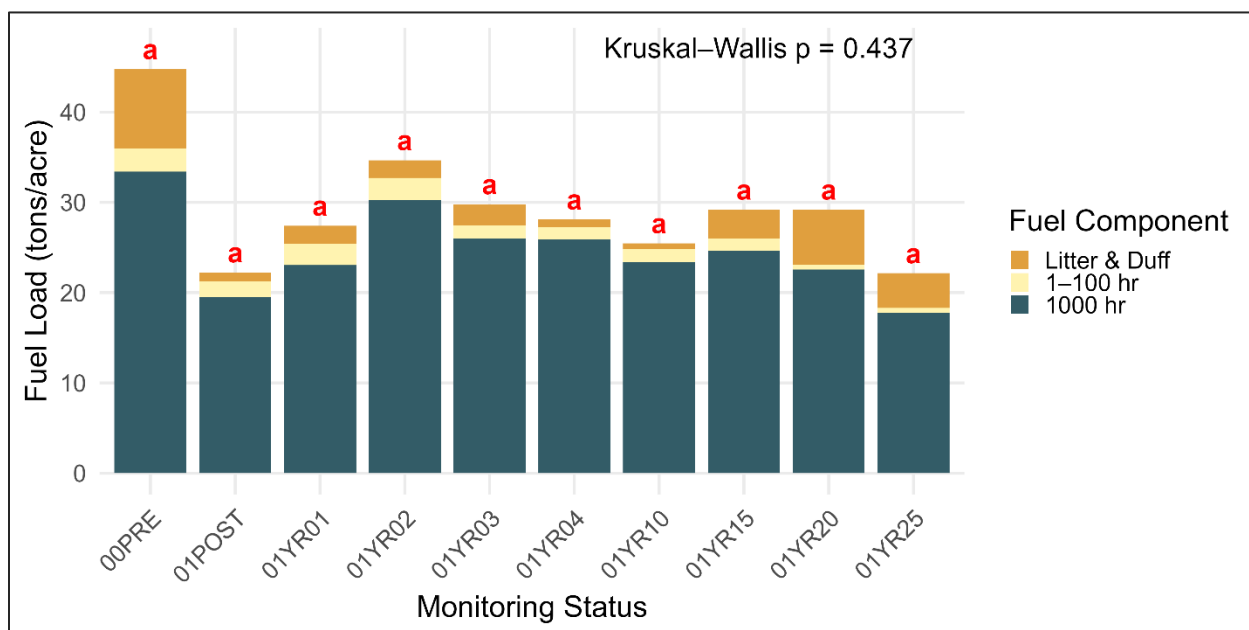


Figure 83. Average fuel loads (tons per acre) by fuel size class (1-100-hour, 1,000-hour, litter, and duff) for Boundary plots 2 and 3.

For the Boundary fire plots, stand conditions in 2000 (*00PRE / 01POST*) reflect an early post-disturbance environment characterized by near total overstory removal, extremely low stand density, and dominance of regeneration rather than established trees. Basal area, stand density index (SDI), and canopy fuels were effectively negligible, while regeneration was abundant, with > 2,500 lodgepole pine seedlings per acre and a smaller but notable component of quaking aspen.

Early post-fire establishment phase (2000-2004)

During the first several years following the 2000 Boundary fire (2000-2004), the stand remained in a seedling-dominated state. Tree densities were very low (≤ 16 trees per acre), basal area remained near zero (< 0.2 ft²/ac), and SDI values were ≤ 0.5 , indicating minimal competition (Table 38; Figure 85). Regeneration was dominated by lodgepole pine, with intermittent pulses of aspen seedlings, consistent with post-fire colonization dynamics following high-severity fire in a lodgepole pine dominated forest. Canopy metrics during this period were effectively zero and should be interpreted cautiously given the absence of developed crowns and the limited applicability of canopy measures at this stage.

Stem exclusion initiation (2010–2015)

By 2010 (*01YR10*), the stand had transitioned into an early stem-exclusion phase. Lodgepole pine densities increased sharply to 453 trees per acre, basal area rose to 7.2 ft²/ac, and SDI increased to 26, indicating the onset of crowding. Quadratic mean diameter (QMD) increased to 2.53 in, reflecting rapid juvenile growth. By 2015 (*01YR15*), these trends intensified: tree density increased to 785 lodgepole pine trees per acre, basal area to 21.9 ft²/ac, and SDI to 69 (Table 38). Canopy fuels became increasingly measurable during this period, although canopy base height estimates remained unreliable prior to standardization of sampling methodology. Regeneration remained active throughout this phase, with continued lodgepole pine recruitment and the first consistent appearance of whitebark pine seedlings, suggesting limited but ongoing establishment of more shade tolerant species (Figure 85).

Canopy closure and increasing competition (2020-2025)

By 2020 (*01YR20*) and continuing through 2025 (*01YR25*), the stand exhibits characteristics of a closed-canopy, mid-seral lodgepole pine forest. In 2025, tree density was over 1,300 trees per acre, basal area increased to ~ 70 ft²/ac, and SDI rose to 191, indicating substantial competition for growing space (Table 38; Figure 85). QMD increased modestly to 4.69 in, reflecting continued diameter growth under increasingly crowded conditions.

Canopy structure has become more defined, with canopy base height first reliably quantified in 2025 at 1.6 m, indicating vertical fuel continuity. Lodgepole pine continues to dominate the overstory, while quaking aspen and whitebark pine persist primarily in the regeneration layer. Seedling densities remain high, particularly for lodgepole pine and aspen, suggesting ongoing recruitment and potential for further stand infilling.

Overall, this site demonstrates a classic post-stand replacing fire trajectory in a lodgepole pine system, progressing from initial regeneration dominance to stem exclusion and increasing canopy closure over a 25-year period following fire. The reburn history did not prevent successful lodgepole pine re-establishment but likely reinforced even aged stand development. Increasing stand density, basal area, and canopy continuity observed by 2025 indicate

competitive pressures and fuel accumulation are now key drivers of stand dynamics, with implications for future fire behavior and long-term forest structure.

Table 38. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac). Average values are depicted along with the range of individual plot-level data to illustrate across-plot variability.

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2000	00PRE	0.002 (0 – 0.004)	0 (0 – 0)	2 (0 – 4)	0.5 (0 – 1)
2000	01POST	0.002 (0 – 0.004)	0 (0 – 0)	2 (0 – 4)	0.5 (0 – 1)
2001	01YR01	0	0 (0 – 0)	0.5 (0 – 1)	0.1 (0 – 0.2)
2002	01YR02	0	0 (0 – 0)	0.5 (0 – 1)	0.1 (0.1 – 0.2)
2003	01YR03	0	0 (0 – 0)	0.5 (0 – 1)	0.2 (0.1 – 0.3)
2004	01YR04	0	0 (0 – 0)	0.5 (0 – 1)	0.2 (0.1 – 0.3)
2010	01YR10	0.018 (0.005 – 0.031)	0 (0 – 0)	26 (6 – 46)	7.2 (2.1 – 12.4)
2015	01YR15	0.047 (0.011 – 0.083)	0 (0 – 0)	69 (11 – 127)	21.9 (4.5 – 39.4)
2020	01YR20	0.080 (0.015 – 0.144)	0 (0 – 0)	171 (21 – 321)	59.1 (9.5 – 108.7)
2025	01YR25	0.087 (0.028 – 0.146)	1.6 (1.4 – 1.8)	191 (43 – 338)	69.8 (20.2 – 119.5)



Figure 84. Grace and Marlee hiking to the Boundary monitoring plots for sampling.

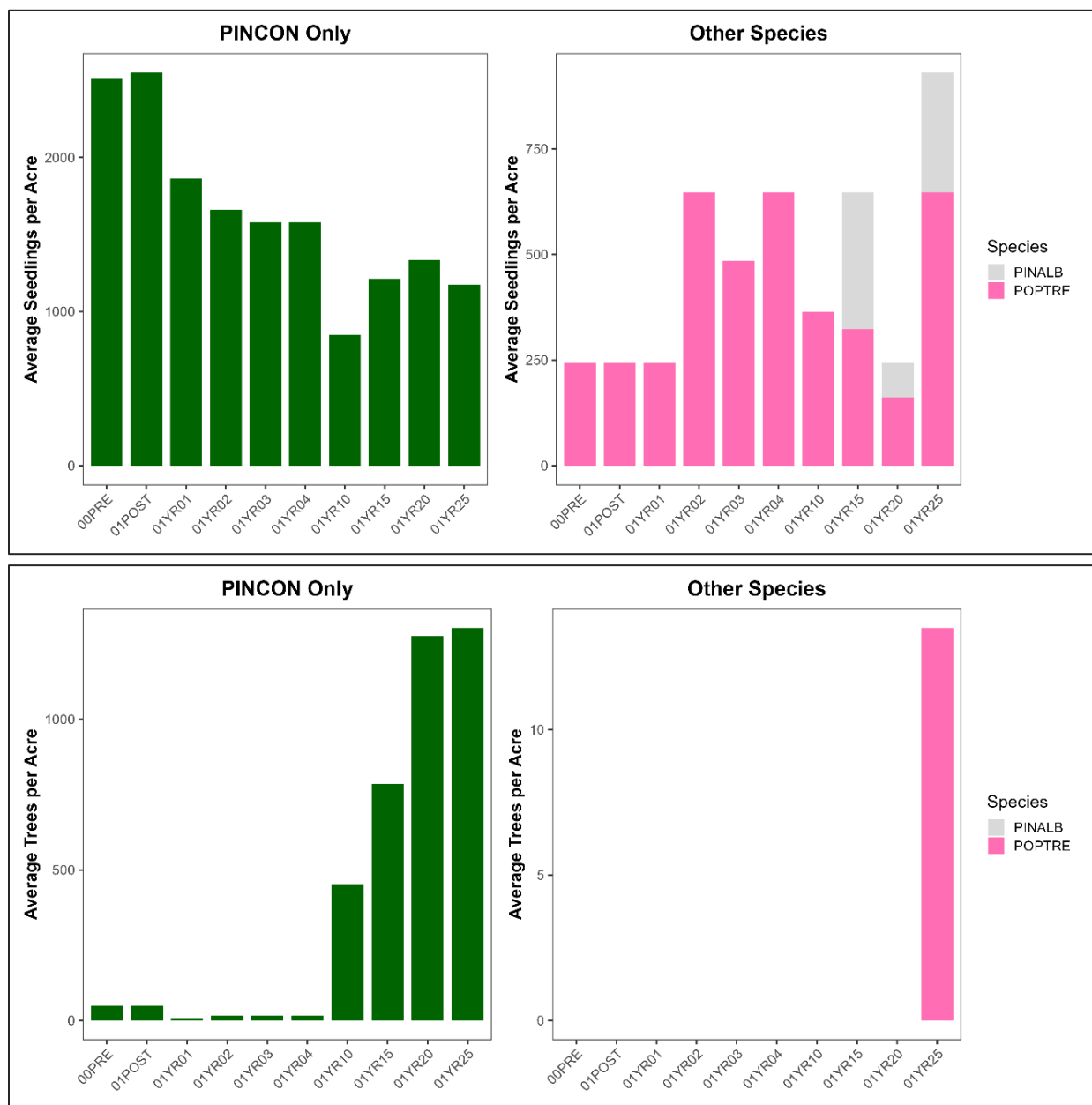


Figure 85. Seedlings per acre (< 1 in DBH – top panel) and trees per acre (> 1 in DBH – bottom panel) for Boundary plots 2 and 3 from 2000 (00PRE) through 2025 (01YR25). Species are distinguished as lodgepole pine (PINCON; green), quaking aspen (POPTRE; pink), and whitebark pine (PINALB; gray). Note the different y-axis scales for the PINCON only plot (left) and other species plot (right) across both the top and bottom panels.

Table 39. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Boundary (plots 2 and 3)

Species	00PRE (2000)		01POST (2000)		01YR01 (2001)		01YR02 (2002)	
	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings
Lodgepole Pine (<i>PINCON</i>)	49	2,509	49	2,550	8	1,862	16	1,659
Quaking Aspen (<i>POPTRE</i>)	0	243	0	243	0	243	0	647
Whitebark Pine (<i>PINALB</i>)	0	0	0	0	0	0	0	0
Species	01YR03 (2003)		01YR04 (2004)		01YR10 (2005)		01YR15 (2015)	
	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings
Lodgepole Pine (<i>PINCON</i>)	16	1,578	16	1,578	453	850	785	1,214
Quaking Aspen (<i>POPTRE</i>)	0	486	0	647	0	364	0	324
Whitebark Pine (<i>PINALB</i>)	0	0	0	0	0	0	0	324
Species	01YR20 (2020)		01YR25 (2025)					
	Trees	Seedlings	Trees	Seedlings				
Lodgepole Pine (<i>PINCON</i>)	1,277	1,335	1,303	1,174				
Quaking Aspen (<i>POPTRE</i>)	0	162	13	647				
Whitebark Pine (<i>PINALB</i>)	0	81	0	283				

Understory vegetation within the Boundary Fire burn area has remained overwhelmingly native, with native species comprising more than 99% of total understory cover through 2025. Dominant native species include elk sedge, along with pinegrass, bluebell (*Campanula rotundifolia*), and silvery lupine. A minor presence of common dandelion was first detected in 2010 and has consistently accounted for less than 1% of total cover. This invasive species declined to its lowest recorded level in 2025, representing approximately 0.04% cover (Tables 40,41).



Figure 86. Photographs from plots 002 and 003 showing the emergence of quaking aspen in the foreground.

Table 40. Native species monitoring results for Boundary (plots 2 and 3)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Boundary (Plots 2, 3)	Quantify mean species absolute cover and compare post-fire values to pre-fire conditions to assess fire effects on understory vegetation at 1, 2, 5, 10, and subsequent 5-year intervals.	<i>Boundary 2,3</i> (<i>n</i> = 2 plots; 2 wildfires) <u>01YR01 (2001): 100% ($\pm$ 0%) native spp.</u> <u>01YR02 (2002): 100% ($\pm$ 0%) native spp.</u> <i>Difference from 01YR01 to 01YR02: 0%</i> <u>01YR03 (2003): 100% ($\pm$ 0%) native spp.</u> <i>Difference from 01YR01 to 01YR03: 0%</i> <u>01YR04 (2004): 100% ($\pm$ 0%) native spp.</u> <i>Difference from 01YR01 to 01YR04: 0%</i> <u>01YR10 (2010): 99.7% ($\pm$ 0.7%) native spp.</u> <i>Difference from 01YR01 to 01YR10: -0.3%</i> <u>01YR15 (2015): 99.8% ($\pm$ 0.1%) native spp.</u> <i>Difference from 01YR01 to 01YR15: -0.2%</i> <u>01YR20 (2020): 99.7% ($\pm$ 0.3%) native spp.</u> <i>Difference from 01YR01 to 01YR20: -0.3%</i> <u>01YR25 (2025): 99.9% ($\pm$ 0.1%) native spp.</u> <i>Difference from 01YR01 to 01YR25: -0.05%</i>	Yes

Note: Vegetation data from 2000 (00PRE / 01POST) were collected prior to implementation of standardized sampling protocols and are not available for comparative analyses.

Table 41. Non-native species monitoring results for Boundary (plots 2 and 3)

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
Boundary (Plots 2, 3)	Limit non-native plant establishment within the burned perimeter to less than a 10% increase relative to pre-treatment conditions, assessed at 1, 2, 5, 10, and subsequent 5-year postfire intervals, using relative percent cover.	<i>Boundary 2,3</i> <i>*not a statistical analysis so minimum plot numbers not calculated*</i> <u>01YR10 (2010):</u> 0.3% <i>Taraxacum officinale</i> (common dandelion) <u>01YR15 (2015):</u> 0.2% <i>Taraxacum officinale</i> (common dandelion) <u>01YR20 (2020):</u> 0.3% <i>Taraxacum officinale</i> (common dandelion) <u>01YR25 (2025):</u> 0.04% <i>Taraxacum officinale</i> (common dandelion)	Yes

ii. Chickadee

The Chickadee site is located in an extremely remote area of the central Yellowstone Plateau and is characterized as a lodgepole pine-dominated forest with a substantial whitebark pine component. The area burned during the 2005 Chickadee Fire, which ultimately affected approximately 90 acres (Figure 87). To document fire effects, a monitoring plot was installed in 2005 prior to the fire and was remeasured later that same year following the burn (Figure 88). However, data collected during the 2005 post-fire visit (*01POST*) were incomplete and likely do not accurately reflect immediate post-fire conditions on the ground.

The plot was revisited in 2006 (*01YR01*), after which monitoring was discontinued for an extended period due to the site's remoteness and lack of reliable trail access. Data collected during the 2005 and 2006 sampling efforts documented the presence of whitebark pine at the site. Given the ecological importance of whitebark pine and its status as a federally listed threatened species, the Chickadee site was subsequently identified as a priority candidate for remeasurement to improve understanding of whitebark pine occurrence and post-fire dynamics in remote regions of the park.

In 2025, the plot was successfully relocated and remeasured, marking 20 years since the fire. During this visit, sampling methods were updated to align with current monitoring standards and best practices. It is important to note that data collected during the 2005-2006 sampling events predate these standardized protocols; therefore, some datasets, particularly those related to vegetation sampling, are not directly comparable to measurements collected in 2025.

A brief timeline summarizing the site's fire history and sampling efforts is provided below.

Chickadee Plot

- 2005 (*00PRE*) - Data collection prior to first wildfire
- 2005 - First wildfire (Chickadee Fire)
- 2005 (*01POST*) - Data collection immediately following Chickadee Fire
- 2006 (*01YR01*) - Data collection 1 year after the Chickadee Fire
- 2025 (*01YR20*) - Data collection 20 years after the Chickadee Fire



Figure 87. Immediate post-fire conditions at the monitoring plot following the Chickadee Fire (2005).

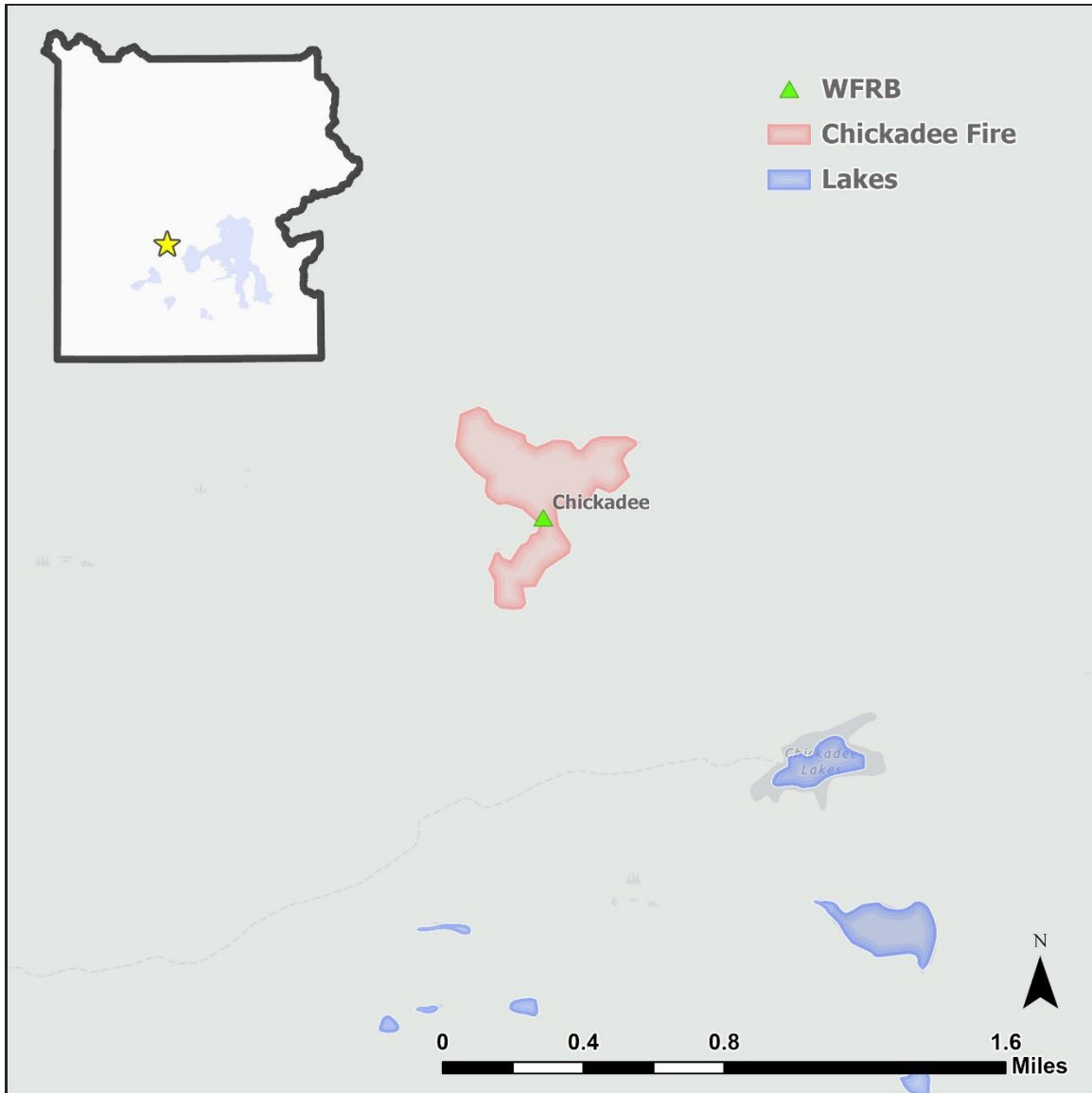


Figure 88. Map of the Chickadee Fire area showing the locations of the WFRB monitoring plot (green triangle), the 2005 Chickadee Fire (red polygon), and adjacent lakes (blue polygons).

Coarse woody (1,000-hour) fuel loads declined during the immediate post-fire period but have subsequently increased over time. Mean 1,000-hour fuels decreased by approximately 20% between the immediate post-fire (*01POST*) and 1-year post-fire (*01YR01*) assessments, declining from approximately 53 tons per acre to 42 tons per acre by 2006. In the years following, coarse woody fuels increased steadily, reaching approximately 49 tons per acre by 2025 (Table 42; Figure 89). These values represent some of the highest coarse woody fuel loads observed during the 2025 sampling campaign and may contribute to elevated fire severity potential under future fire scenarios.

Other surface fuel components exhibited more stable or declining trends. Fine fuels (1–100-hour) remained relatively unchanged over the monitoring period, decreasing slightly from

approximately 2.6 tons per acre in 2005 (00PRE) to 2.5 tons per acre in 2025. Litter loads declined more substantially, from approximately 12.5 tons per acre in 2000 to 8.6 tons per acre in 2025. When all fuel components were considered collectively, total surface fuel loads in 2025 were approximately 12% lower than pre-fire conditions, declining from roughly 69 tons per acre to 60 tons per acre (Figure 90).

Table 42. 1,000-hour fuel monitoring results for Chickadee

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Chickadee</i>	Measure mean 1,000-hour fuel loads at 1, 2, 5, 10, and subsequent 5-year post-fire intervals.	<i>Chickadee</i> (n = 1 plot; 1 wildfire) 00PRE (2005): 53.4 (± 12.3) tons/ac 01POST (2005): 42.5 (± 15.1) tons/ac Difference from 00PRE to 01POST: -21% 01YR01 (2006): 42.2 (± 14.9) tons/ac Difference from 00PRE to 01YR01: -21% 01YR20 (2025): 49.3 (± 9.4) tons/ac Difference from 00PRE to 01YR02: -8%	Yes, but minimum sample size not met

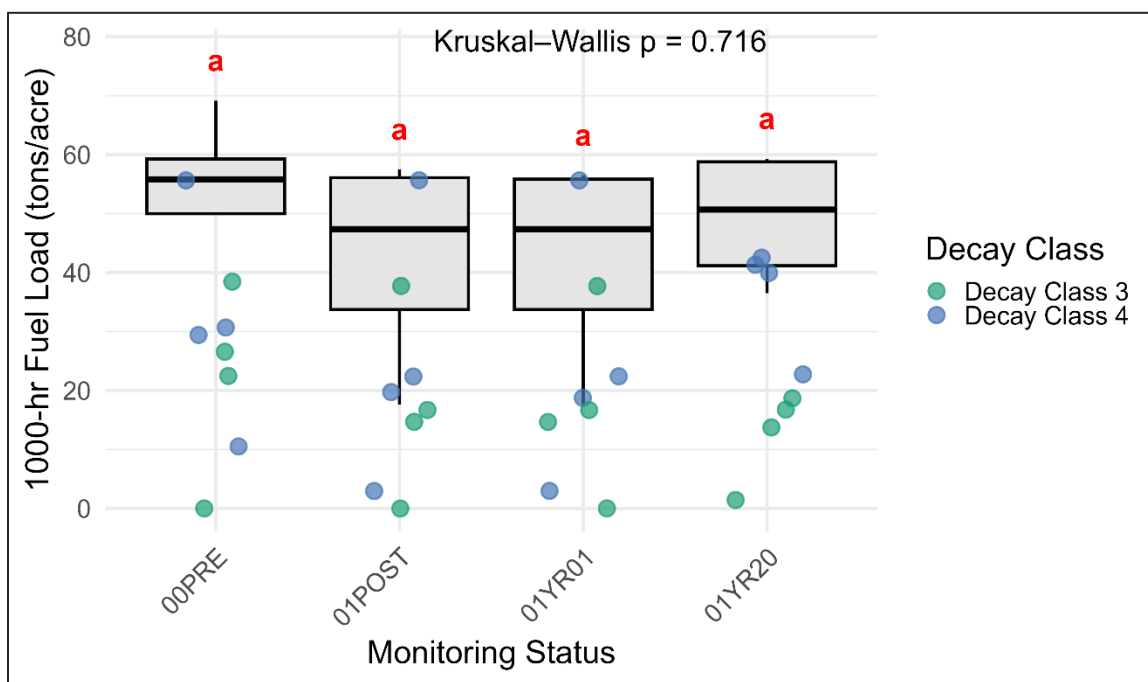


Figure 89. Average 1,000-hour fuel loads (tons per acre) for Chickadee. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). Red letters denote statistically significant differences among groups based on a nonparametric Kruskal-Wallis test with Dunn's post hoc comparisons and Holm's correction for multiple testing.

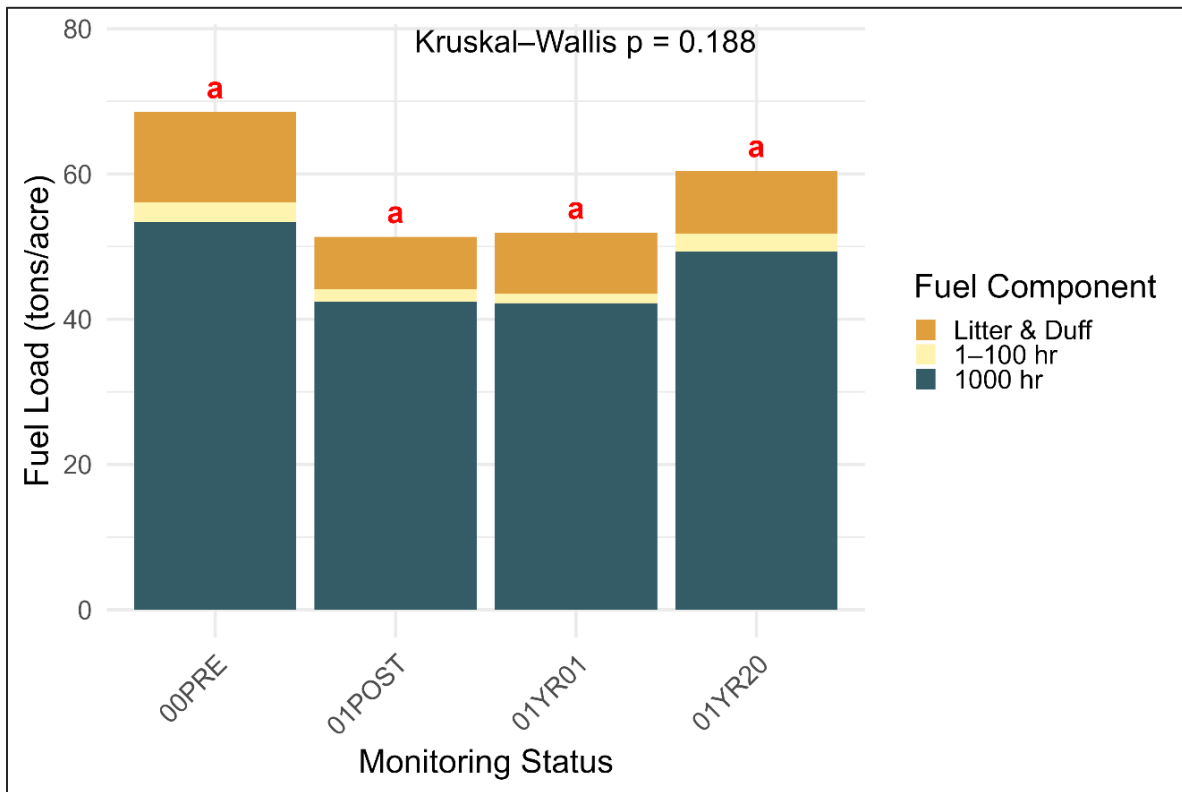


Figure 90. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Chickadee.

Prior to the Chickadee Fire, the stand exhibited moderate to high density and a well-developed overstory. Stand Density Index (SDI = 266) and basal area (~153 ft²/ac) reflected a crowded stand composed primarily of lodgepole pine (214 trees per acre) and a notable whitebark pine component (125 trees per acre). Regeneration was abundant, with high densities of both lodgepole pine (5,423 seedlings per acre) and whitebark pine (3,480 seedlings per acre), indicating strong recruitment potential for both species prior to disturbance (Tables 43,44; Figure 92).

Data collected during the 2005 post-fire visit should be interpreted with caution, as incomplete measurements and anomalous values suggest this dataset does not reliably capture true post-fire stand conditions. The 2006 (*01YR01*) assessment provides a more representative early post-fire snapshot. At that time, overstory structure remained relatively intact, with SDI = 255 and basal area ~147 ft²/ac, suggesting that fire effects at this location were heterogeneous rather than uniformly stand-replacing (Table 43). Both lodgepole pine and whitebark pine persisted in the overstory, and regeneration remained substantial and evenly distributed between the two species.

By 2025, the stand exhibited clear evidence of long-term structural change. Stand density and basal area declined substantially relative to pre- and early post-fire conditions, with SDI decreasing to 121 and basal area to ~121 ft²/ac, reflecting cumulative effects of fire, delayed mortality, and subsequent self-thinning. Overstory composition shifted toward increased

representation of whitebark pine, which increased to 186 trees per acre, while lodgepole pine declined to 142 trees per acre. Subalpine fir was present at low densities (32 trees per acre), indicating gradual infilling by shade-tolerant species (Tables 43,44, Figure 92).

Regeneration in 2025 was robust across all conifer species. Lodgepole pine regeneration was especially high (11,412 seedlings per acre), while whitebark pine (3,966 seedlings per acre) and subalpine fir (1,214 seedlings per acre) were also well represented. This regeneration pattern indicates strong post-fire recruitment and highlights the site's continued importance as whitebark pine habitat, particularly given the species' status as a federally listed threatened species. However, in the absence of additional disturbance (e.g., low-severity fire or other thinning mechanisms), the high density of lodgepole pine seedlings may lead to competitive exclusion of whitebark pine and subalpine fir, potentially shifting future stand composition toward increased lodgepole pine dominance.

Overall, this site reflects a mixed-severity fire response in a lodgepole pine-whitebark pine system, with partial overstory survival, sustained regeneration, and long-term shifts in stand structure over two decades following fire. The persistence and apparent increase of whitebark pine in both the overstory and regeneration layers underscore the management significance of this remote site. Given the long monitoring gap and the site's inaccessibility, the 2025 remeasurement provides valuable insight into long-term post-fire trajectories and offers an important reference point for informing whitebark pine conservation and fire management strategies in remote areas of the park.

Table 43. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac).

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2005	00PRE	0.129	2.4	266	153
2005	01POST	--	--	--	--
2006	01YR01	0.123	2.4	255	147
2020	01YR20	0.101	1.2	208	121



Figure 91. Current site conditions observed in 2025, 20 years post-Chickadee Fire.

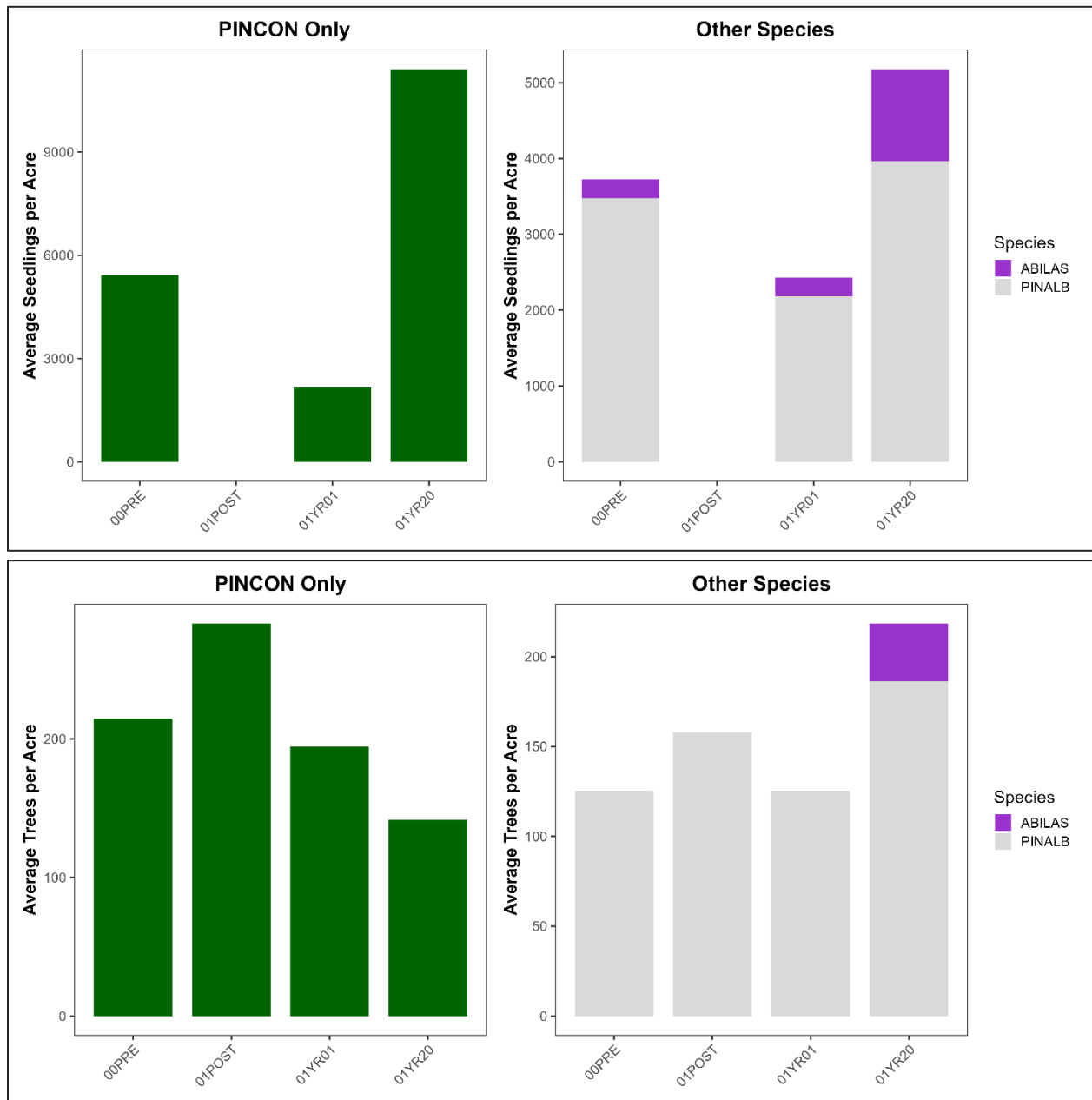


Figure 92. Seedlings per acre (< 1 in DBH – top panel) and trees per acre (> 1 in DBH – bottom panel) for Chickadee from 2005 (*00PRE*) through 2025 (*01YR20*). Species are distinguished as lodgepole pine (PINCON; green), whitebark pine (PINALB; gray), and subalpine fir (ABILAS; purple). Note the different y-axis scales for the PINCON only plot (left) and other species plot (right) across both the top and bottom panels.

Table 44. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Chickadee

Species	00PRE (2005)		01POST (2005)		01YR01 (2006)		01YR20 (2025)	
	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings
Lodgepole Pine (<i>PINCON</i>)	214	5,423	283	0	194	2,185	142	11,412
Whitebark Pine (<i>PINALB</i>)	125	3,480	158	0	125	2,185	186	3,966
Subalpine Fir (<i>ABILAS</i>)	0	243	0	0	0	243	32	1,214

Understory vegetation was composed entirely of native species, with grouse whortleberry as the dominant species and a smaller component of Ross' sedge (Table 45). Pre-2025 understory vegetation data were not available for this site; therefore, these results reflect conditions observed during the 2025 sampling effort only.

Table 45. Native species monitoring results for Chickadee

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Chickadee</i>	Quantify mean species absolute cover and compare post-fire values to pre-fire conditions to assess fire effects on understory vegetation at 1, 2, 5, 10, and subsequent 5-year intervals.	<i>Chickadee</i> (<i>n</i> = 1 plot; 1 wildfire) <u>01YR20 (2025): 100% ($\pm$ 0%) native spp.</u>	Yes, but pre-fire data are not available for comparison

Note: Vegetation data from 2005 (00PRE / 01POST) and 2006 (01YR01) were collected prior to implementation of standardized sampling protocols and are not available for comparative analyses.



Figure 93. Grace measuring tree diameter at breast height (left) and Nick with Grace collecting 1,000-hour fuel data (right).

iii. *Falcon*

The Falcon site is located in the southeastern corner of the park within the Thorofare, an area widely regarded as one of the most remote locations in the contiguous United States. Access is limited to extended backcountry travel, typically requiring 30+ mile one-way hikes or horseback access, and the site is characterized by extremely rugged terrain.

The Falcon monitoring plot was installed in 2001 ahead of the 2001 Falcon Fire, which ultimately burned approximately 3,288 acres (Figure 94). Although the fire intermingled with the 1988 Mink Fire burn scar, it burned well south of the plot location; consequently, the Falcon plot remained unburned (Figure 95). Due to the site's extreme remoteness and access challenges, only one additional visit was made in 2003 (*00PR02*), after which no further sampling occurred until 2025.

Data collected during the 2001 and 2003 sampling efforts were limited in scope, with several datasets either missing or unreliable (e.g., no understory vegetation data were collected, and only tree data were recorded in 2003). Despite these limitations, available site-level information indicated the presence of a notable whitebark pine component, prompting prioritization of the site for remeasurement to improve understanding of whitebark pine dynamics in an unburned, remote landscape.

In 2025, the plot was successfully relocated and resampled using current FMH standards and protocols. Given the limitations of the earlier datasets, the 2001 sampling event was reclassified as *00PR01*, the 2003 visit as *00PR02*, and the 2025 measurement was designated as *00PRE*. As such, the 2025 dataset now serves as a reliable baseline for assessing pre-fire stand conditions in this remote area of the park.

A brief timeline summarizing site history and monitoring activities is provided below:

Falcon Plot

- 2001 – Falcon Fire burns south of plot installation
- 2001 (*00PR01*) – Initial data collection (flawed / incomplete data)
- 2003 (*00PR02*) – Data collection 2 years after *00PR01* read (flawed / incomplete data)
- 2025 (*00PRE*) – Data collection prior to wildfire (using current standards / protocols)



Figure 94. Aerial photographs of the 2001 Falcon Fire in the remote southeastern portion of the park.

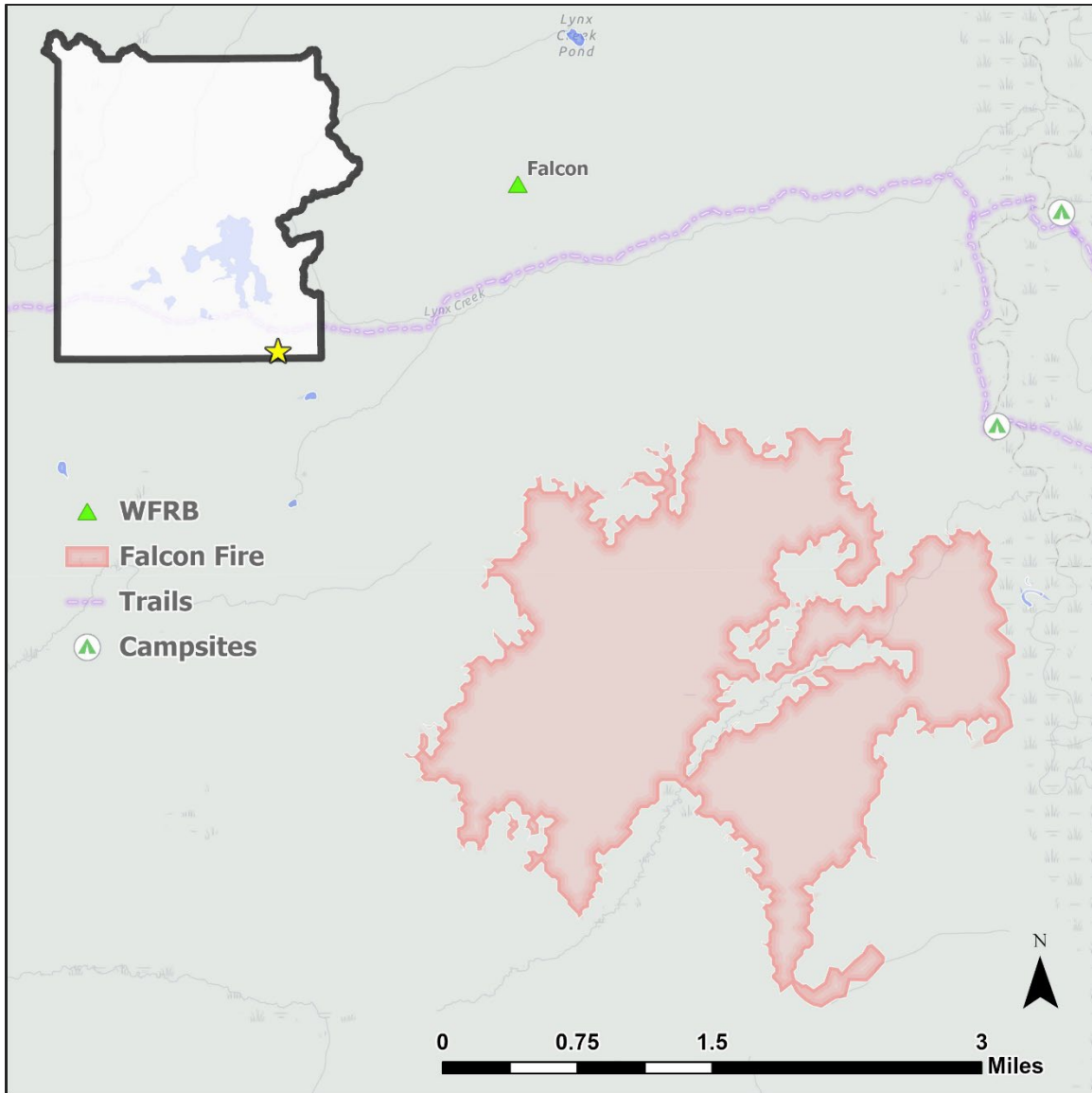


Figure 95. Map of the Falcon Fire area showing the locations of the WFRB monitoring plot (green triangle), the 2001 Falcon Fire (red polygon), backcountry trails (purple lines), and campsites (icon symbol).

Surface fuel loads at the Falcon site remained relatively low overall, with coarse woody (1,000-hour) fuels below 10 tons per acre across all measurements. However, a substantial increase in coarse fuels was observed between 2001 (*00PR01*) and 2025, rising by approximately 272%, from ~2.3 tons per acre to ~8.6 tons per acre (Table 46; Figure 96).

In contrast, fine woody fuels (1–100-hour) showed a modest decline over the same period, decreasing from approximately 4.1 tons per acre in 2001 to 3.6 tons per acre in 2025. Litter and duff exhibited a similar downward trend, declining from approximately 6.1 tons per acre to 4.7 tons per acre. When all surface fuel components were considered collectively, total surface fuel loads increased from approximately 12.5 tons per acre in 2001 to 16.8 tons per acre in 2025,

largely driven by the accumulation of coarse woody material (Figure 97). Although, it should be noted that variance across surface fuel measurements was high, and the limited number of observations may not fully capture average site conditions. As such, these findings should be viewed within the context of the sampling limitations.

Table 46. 1,000-hour fuel monitoring results for Falcon

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Falcon</i>	Measure mean 1,000-hour fuel loads at 1, 2, 5, 10, and subsequent 5-year post-fire intervals.	<i>Falcon</i> <i>(n = 1 plot; unburned)</i> <u>00PR01 (2001): 2.3 ($\pm$ 7.1) tons/ac</u> <u>00PRE (2005): 8.6 ($\pm$ 14.1) tons/ac</u> <u>Difference from 00PRE to 01POST: +272%</u>	Yes, but post-fire data do not yet exist for comparison

Note: Coarse woody fuels data from 2001 (00PR01) were not collected and are therefore not available for comparative analyses.

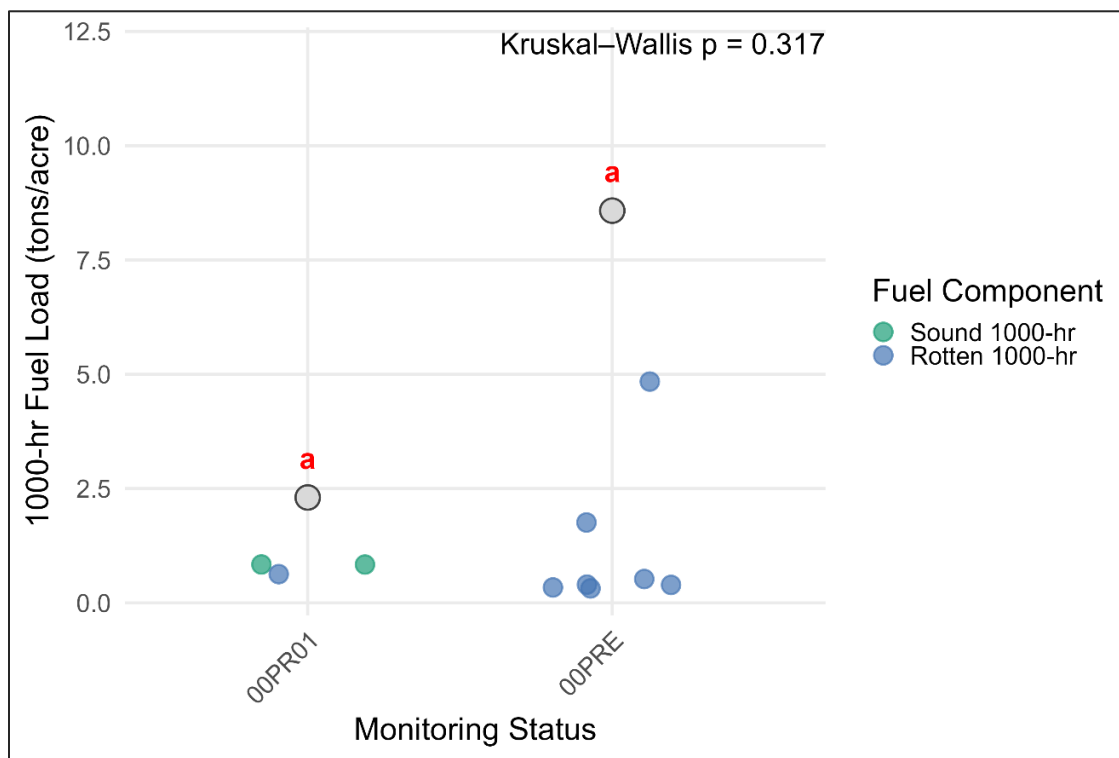


Figure 96. Total 1,000-hour fuel loads (tons per acre) at the Falcon site by monitoring status. Because fuels were sampled along a single transect for each monitoring status, there is no within-group replication and boxplots are not appropriate. Instead, total 1,000-hour fuel loads are shown as filled circles, while individual log-level fuel contributions are displayed as jittered points and distinguished by decay class (decay class 3, sound logs, teal; decay class 4, rotten logs, blue). Red letters indicate statistically significant differences among monitoring statuses based on a nonparametric Kruskal–Wallis test followed by Dunn’s post hoc comparisons with Holm’s correction for multiple testing.

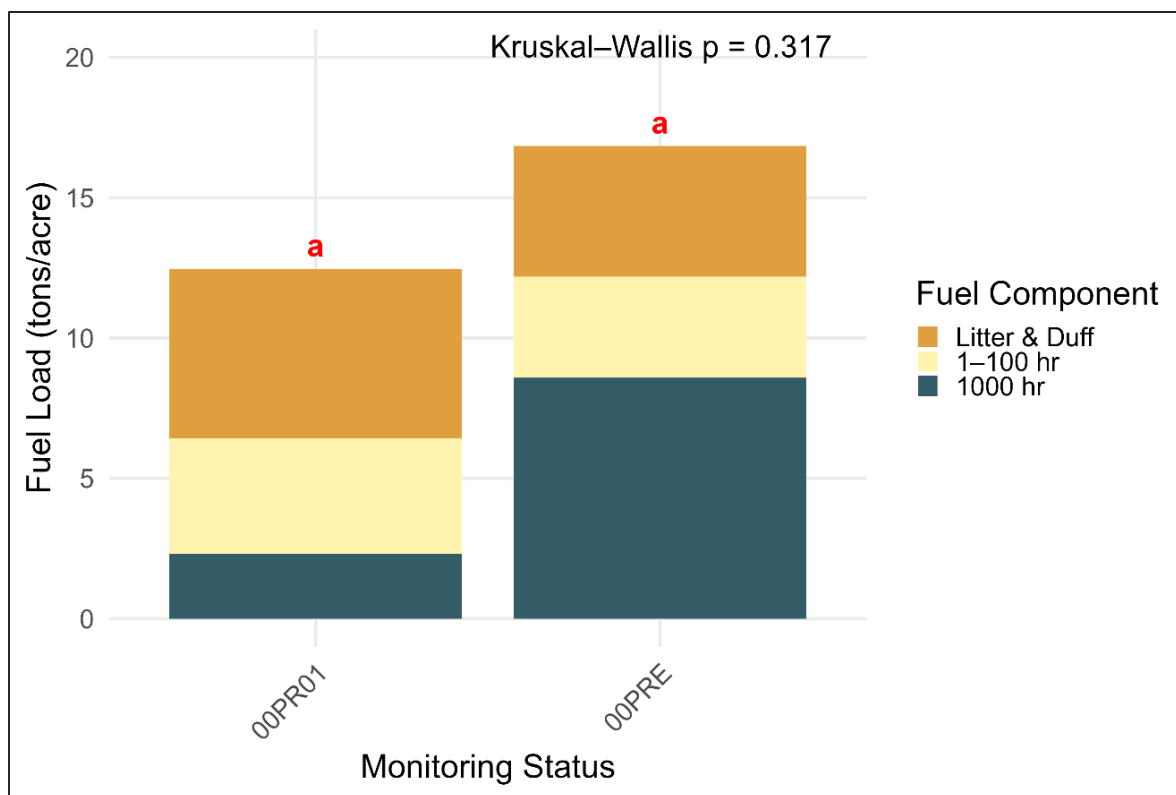


Figure 97. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Falcon.

The high-elevation, unburned Falcon site is an important example of a whitebark pine dominated forest in a remote portion of the park, with smaller components of subalpine fir and Engelmann spruce. Initial sampling in 2001 (*00PR01*) documented a dense, mature stand characterized by high stand density (SDI = 352), substantial basal area (212 ft²/ac), and relatively high canopy bulk density, reflecting a closed, competitive overstory dominated by whitebark pine (Table 47, Figure 99). At that time, whitebark pine regeneration was present but moderate, suggesting ongoing recruitment beneath a dense canopy.

By 2003 (*00PR02*), the stand exhibited a marked reduction in overstory density and basal area, with whitebark pine tree density declining by approximately 50%. These changes are consistent with documented mountain pine beetle activity first observed in 2001, which likely contributed to overstory mortality and canopy opening (Figure 98). Correspondingly, stand density index and basal area declined sharply, and canopy structure shifted toward a more open condition. Seedling densities declined relative to 2001, potentially reflecting short-term post-disturbance dynamics following beetle-related mortality (Table 48, Figure 99).

When the site was resampled in 2025 (*00PRE*), more than two decades after the last measurement, the stand showed evidence of partial structural recovery and active regeneration. Overstory density, basal area, and SDI had increased relative to 2003 but remained well below 2001 levels, indicating a stand in intermediate recovery rather than full re-closure (Table 47). Whitebark pine remained the dominant overstory species, with modest increases in subalpine fir and Engelmann spruce contributing to a slightly more mixed conifer composition (Figure 99).

Regeneration in 2025 was exceptionally robust, particularly for whitebark pine (10,603 seedlings per acre), accompanied by substantial recruitment of subalpine fir (3,399 seedlings per acre) and a smaller spruce component (Table 48, Figure 99). This regeneration pulse suggests that earlier canopy opening (likely initiated by beetle activity) created favorable conditions for seedling establishment and underscores the site’s continued importance as whitebark pine habitat. The strong whitebark pine regeneration signal is especially notable given the species’ status as a federally listed threatened species and the site’s unburned condition, providing valuable insight into whitebark pine dynamics outside of recent fire influence.

Overall, the Falcon site reflects a disturbance-mediated transition from a dense, mature whitebark pine stand toward a more structurally open forest with vigorous regeneration. Its remote location, lack of recent fire, and strong whitebark pine response make it a high-value reference site for understanding long-term whitebark pine persistence, beetle impacts, and recovery trajectories in high-elevation ecosystems.

Despite the site’s extreme remoteness, white pine blister rust (*Cronartium ribicola*) was observed on 4 of 33 sampled whitebark pine trees (~12%) during the 2025 remeasurement, indicating active pathogen presence (Figure 100). This finding underscores the ubiquitous nature of blister rust, as *C. ribicola* spores are capable of long-distance dispersal on the order of hundreds of kilometers (≥ 300 km) under favorable atmospheric conditions (Kinloch 2003; Geils et al. 2010). Given the ecological importance of whitebark pine and the combined pressures of disease, insects, and climate stress, continued long-term monitoring at this site will be critical for assessing future impacts of blister rust and informing management strategies in remote whitebark pine habitat throughout the Greater Yellowstone Ecosystem.

Table 47. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac).

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2001	00PR01	0.350	2.1	352	212
2003	00PR02	0.056	0.6	76	33
2025	00PRE	0.111	1.5	151	72



Figure 98. Mountain pine beetle-induced mortality documented during the 2003 (00PR02) sampling effort.

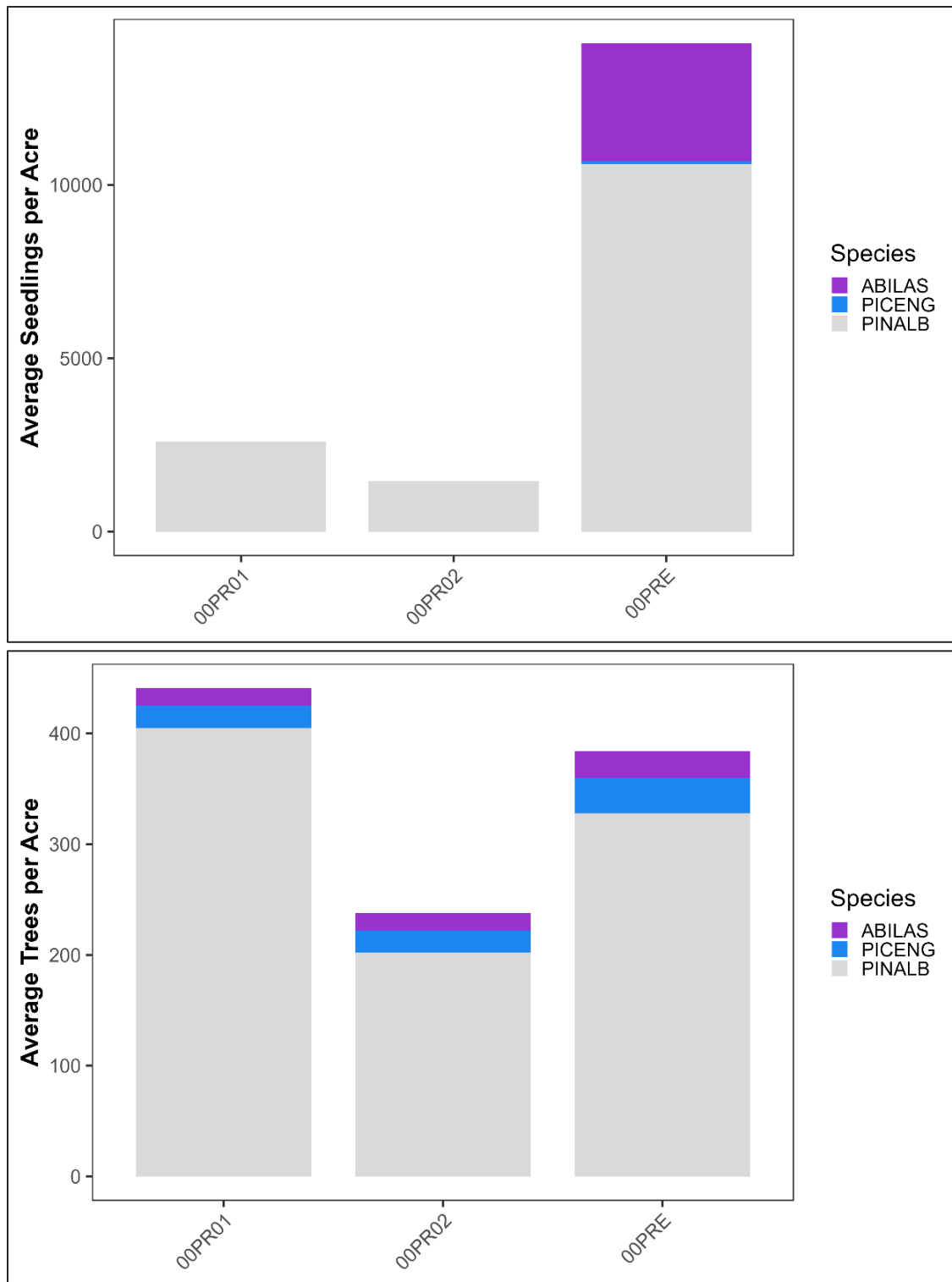


Figure 99. Seedlings per acre (< 1 in DBH – top panel) and trees per acre (> 1 in DBH – bottom panel) for Falcon from 2001 (00PR01), 2003 (00PR02) and 2025 (00PRE). Species are distinguished as whitebark pine (PINALB; gray), subalpine fir (ABILAS; purple), and Engelmann spruce (PICENG; blue).

Table 48. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Falcon

Species	00PR01 (2001)		00PR02 (2003)		00PRE (2025)	
	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings
Whitebark Pine (PINALB)	405	2,590	202	1,457	328	10,603
Subalpine Fir (ABILAS)	16	0	16	0	24	3,399
Engelmann Spruce (PICENG)	20	0	20	0	32	81

Understory vegetation was composed entirely of native species, with grouse whortleberry as the dominant species, followed by Ross' sedge, Parry's arnica (*Arnica parryi*), and Parry's rush (*Juncus parryi*) (Table 49).

Table 49. Native species monitoring results for Falcon

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Falcon</i>	Quantify mean species absolute cover and compare post-fire values to pre-fire conditions to assess fire effects on understory vegetation at 1, 2, 5, 10, and subsequent 5-year intervals.	<i>Falcon</i> (<i>n</i> = 1 plot; unburned) 00PRE (2025): 100% ($\pm$ 0%) native spp.	Yes, but post-fire data do not yet exist for comparison

Note: Vegetation data from 2001 (00PR01) and 2003 (00PR02) were collected prior to implementation of standardized sampling protocols and are therefore not available for comparative analyses.



Figure 100. Live, mature whitebark pine (left two images) and white pine blister rust symptoms observed on whitebark pine (right image).

iv. Meridian–2 (FMICO1T10–02)

The Meridian–2 site is located in the northeastern corner of the park, near the Warm Creek Trail and the Northeast Entrance. The site lies adjacent to the broader perimeter of the 1988 Storm Creek Fire; however, fire effects in this area were patchy, and the immediate vicinity of the Meridian–2 plot did not burn (Figure 102).

The site occurs near the transition between the northeastern Yellowstone Plateau and the Beartooth Plateau, a high-elevation, glaciated landscape within the Absaroka-Beartooth Wilderness of Montana and Wyoming. The Beartooth Plateau includes Granite Peak, the highest point in Montana (12,799 ft), and exerts an important influence on regional climate. Orographic uplift associated with the Beartooth Range enhances precipitation from prevailing westerly and southwesterly air masses, resulting in cooler temperatures and relatively mesic conditions compared to much of the central Yellowstone Plateau.

Soils in this portion of the park are derived primarily from Absaroka volcanic rocks, which are generally intermediate to mafic in composition (e.g., andesitic and basaltic materials), in contrast to the silica rich rhyolitic substrates that dominate the central plateau. These more nutrient-rich parent materials, combined with cooler and wetter conditions, support greater overstory and understory species diversity than is typically observed in the rhyolitic lodgepole pine dominated landscapes that occur throughout much of Yellowstone.

The Meridian–2 monitoring plot was initially installed in 2006 (00PR01) and revisited in 2016 (00PR02). The 2025 measurement was designated as 00PRE and serves as a baseline assessment of current stand and fuel conditions for this area. A brief timeline summarizing plot installation and sampling history is provided below:

Meridian–2 Plot

- 1988 – Storm Creek Fire burns to the north and east of plot installation
- 2006 (00PR01) – Initial data collection
- 2016 (00PR02) – Data collection 10 years after 00PR01 read
- 2025 (00PRE) – Data collection prior to wildfire (using current standards / protocols)



Figure 101. Photographs from the Q2-Q3 transect documenting the fall of a large Engelmann spruce between 2006 (left) and 2025 (right).

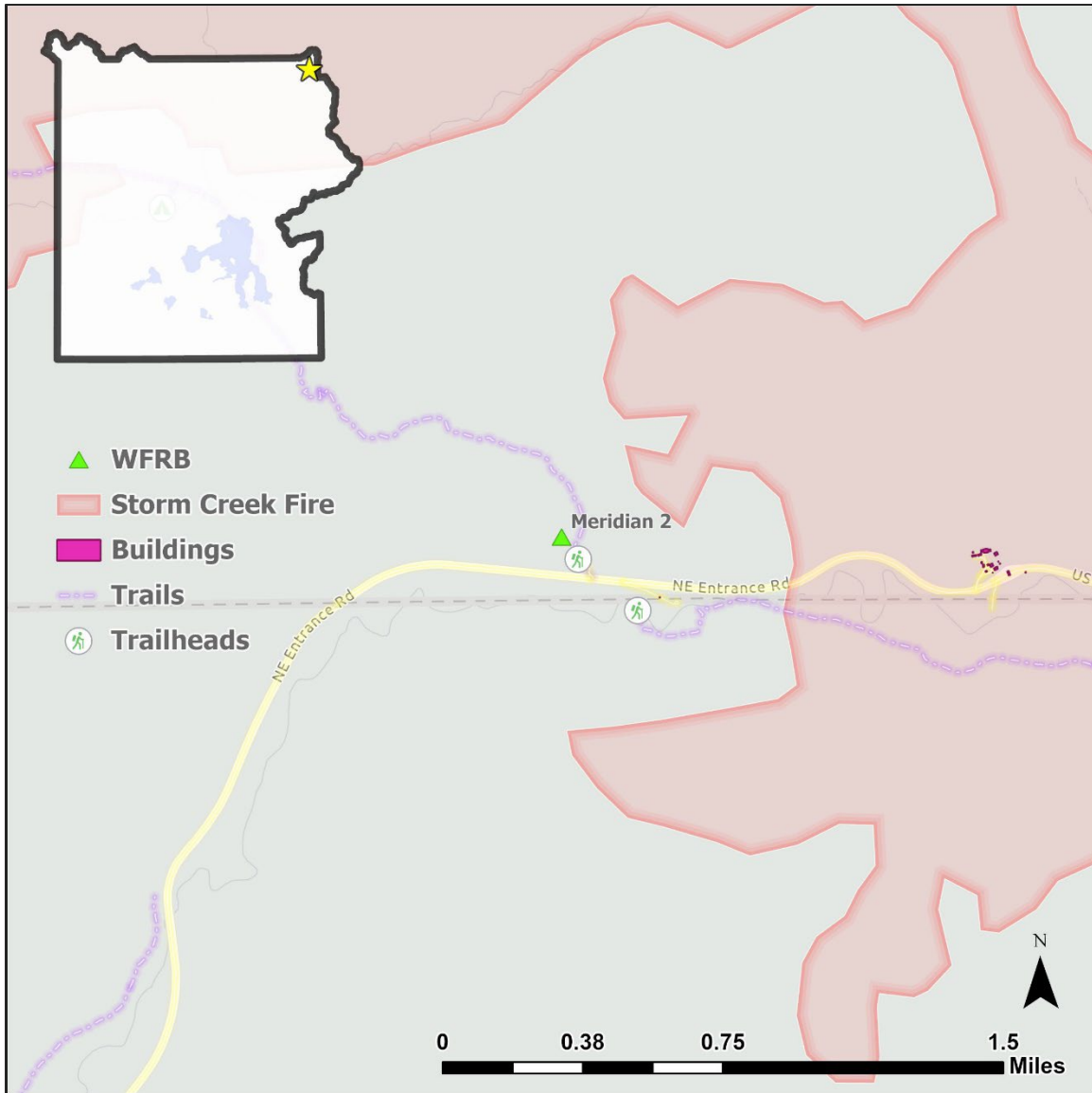


Figure 102. Map of the Meridian-2 area showing the locations of the WFRB monitoring plot (green triangle), the 1988 Storm Creek Fire (red polygon), backcountry trails (purple lines), trailheads (icon symbol), and buildings (pink polygons).

At the Meridian-2 site, coarse woody fuels (1,000-hour) declined substantially over the monitoring period, decreasing from approximately 92.5 tons per acre in 2006 to 46.6 tons per acre in 2016, and further to 33.2 tons per acre in 2025, representing an overall 64% reduction relative to 2006 (Table 50; Figure 103). This long-term decline likely reflects progressive decomposition of downed woody material in this relatively mesic environment over nearly two decades since the initial measurement.

Trends in other surface fuel components were more variable. Fine woody fuels (1–100-hour) declined modestly from 9.3 tons per acre in 2006 to 7.7 tons per acre in 2016 but increased to their highest observed level in 2025 (10.9 tons per acre). In contrast, litter and duff exhibited

consistent declines over time, decreasing from approximately 40.8 tons per acre in 2006 to 27.3 tons per acre in 2016 to 17.3 tons per acre in 2025 (Figure 104).

When all fuel components were considered collectively, total surface fuel loads declined markedly, from approximately 143 tons per acre in 2006 to 82 tons per acre in 2016, and further to 61 tons per acre in 2025, representing a statistically significant overall reduction of approximately 57% from 2006 to 2025 (Figure 104). However, interpretation of these results is constrained by high variability and limited sample size (one plot). As such, observed trends should be interpreted cautiously and may not fully represent site-wide conditions.

Table 50. 1,000-hour fuel monitoring results for Meridian–2

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Meridian–2</i>	Measure mean 1,000-hour fuel loads at 1, 2, 5, 10, and subsequent 5-year post-fire intervals.	<i>Meridian–2</i> (<i>n</i> = 1 plot; unburned) 00PR01 (2006): 92.5 ($\pm$ 39.3) tons/ac 00PR02 (2016): 46.6 ($\pm$ 20.1) tons/ac Difference from 00PR01 to 00PR02: -50% 00PRE (2025): 33.2 ($\pm$ 19.5) tons/ac Difference from 00PR01 to 00PRE: -64%	Yes, but minimum sample size not met

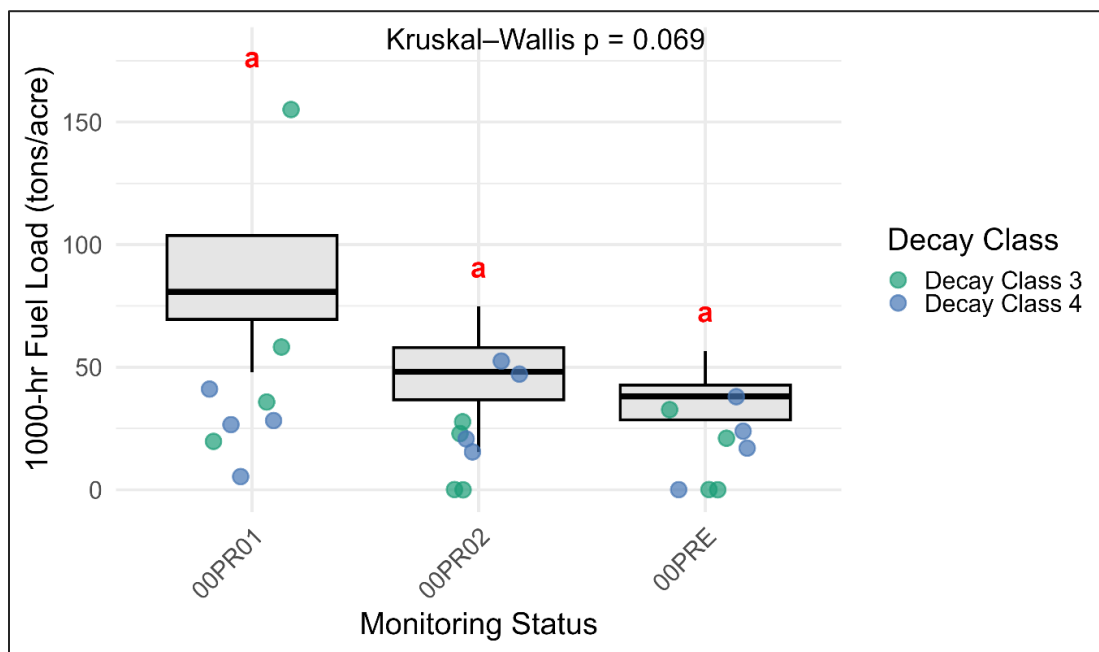


Figure 103. Average 1,000-hour fuel loads (tons per acre) for Meridian–2. Boxplots depict the median (solid line), interquartile range (first and third quartiles; boxes), and data range (whiskers). Fuel loads are shown separately for decay class 3 (sound logs; teal) and decay class 4 (rotten logs; blue). Red letters denote statistically significant differences among groups based on a nonparametric Kruskal–Wallis test with Dunn’s post hoc comparisons and Holm’s correction for multiple testing.

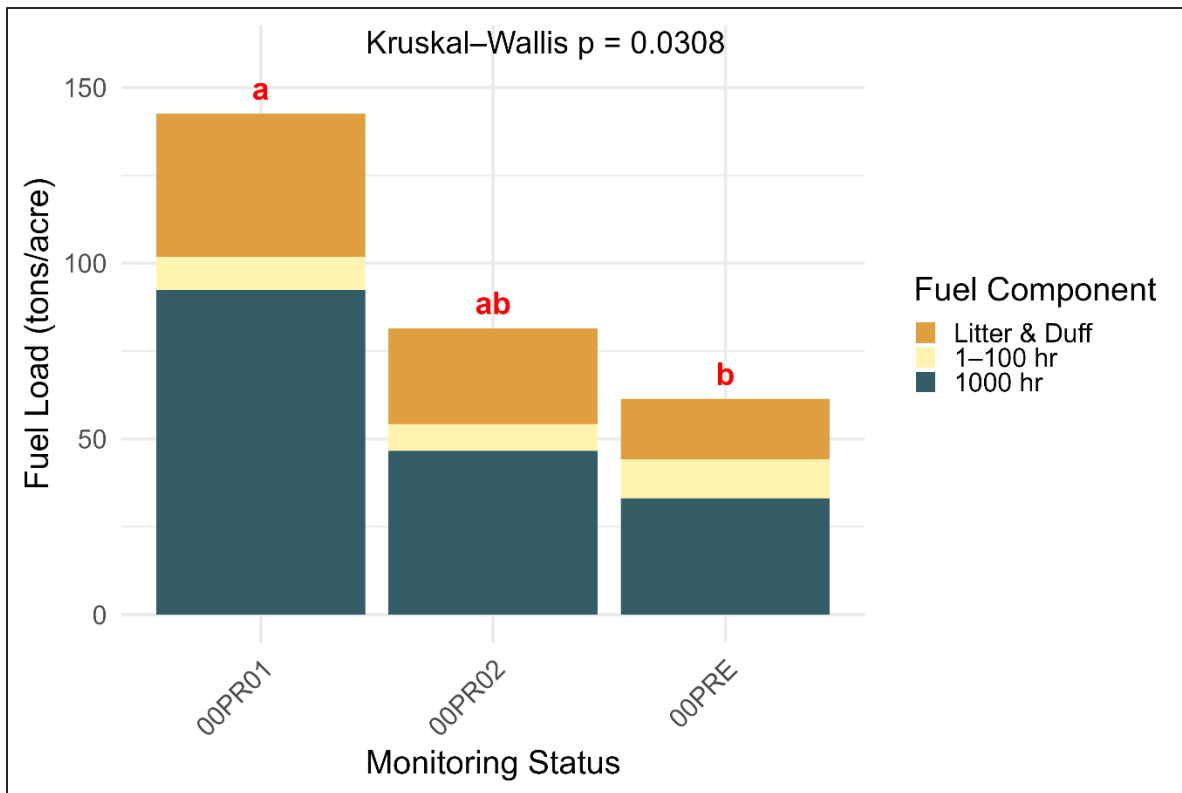


Figure 104. Average fuel loads (tons per acre) by fuel size class (1–100-hour, 1,000-hour, litter, and duff) for Meridian–2.

The Meridian–02 site represents a mesic, Engelmann spruce dominated forest that exhibits characteristics typical of long-unburned, high-elevation spruce forests, including relatively high basal area, moderate-to-high stand density, and a diverse understory community.

Across the monitoring period, overstory structure has remained relatively stable. Stand density index increased from 200 in 2006 (00PR01) to 212 in 2016 (00PR02) and 229 in 2025 (00PRE), while basal area increased from 120 ft²/ac to 141 ft²/ac over the same period (Table 51). Tree density remained consistent, with approximately 295 Engelmann spruce trees per acre recorded in both 2016 and 2025, and quadratic mean diameter increased modestly from 8.7 to 9.3 inches, reflecting incremental growth and stand maturation (Figure 107).

Canopy structure indicates increasing canopy continuity over time. Canopy bulk density remained relatively stable between 2006 and 2016 (~0.11 kg/m³) but increased substantially by 2025 (0.219 kg/m³), consistent with ongoing crown expansion and increasing foliage density in the absence of disturbance. Canopy base heights measured in 2006 and 2016 were relatively low and stable (approximately 3.3 - 3.4 m), suggesting limited vertical separation between surface fuels and live crowns (Table 51).

Regeneration has increased markedly over time. Engelmann spruce seedling density increased from 81 seedlings per acre in 2006 to 567 seedlings per acre in 2016, and further to 1,133 seedlings per acre in 2025, indicating active recruitment beneath a closed canopy. The appearance of whitebark pine regeneration (81 seedlings per acre) in 2025 suggests some

localized establishment of shade-tolerant or mid-tolerant conifers, contributing to future compositional diversity (Table 52; Figure 107).

Collectively, these patterns reflect a stable, late-successional spruce stand undergoing gradual densification and canopy closure under mesic conditions. In the absence of fire or other major disturbance, continued increases in canopy continuity and advanced regeneration are likely.

Table 51. Summary of overstory tree data including canopy bulk density (CBD; kg/m³), canopy base height (m), stand density index (SDI), and basal area (ft²/ac).

Year	Read	CBD (kg/m ³)	Canopy Base Ht (m)	SDI	BA (ft ² /ac)
2006	00PR01	0.113	3.3	200	120
2016	00PR02	0.118	3.4	212	127
2025	00PRE	0.219	<i>Data not available</i>	229	141



Figure 105. Photographs from P2-Origin showing changes in stand conditions from 2016 (left) to 2025 (right).



Figure 106. Photographs from Q3-Q2 showing changes in stand conditions from 2016 (left) to 2025 (right).

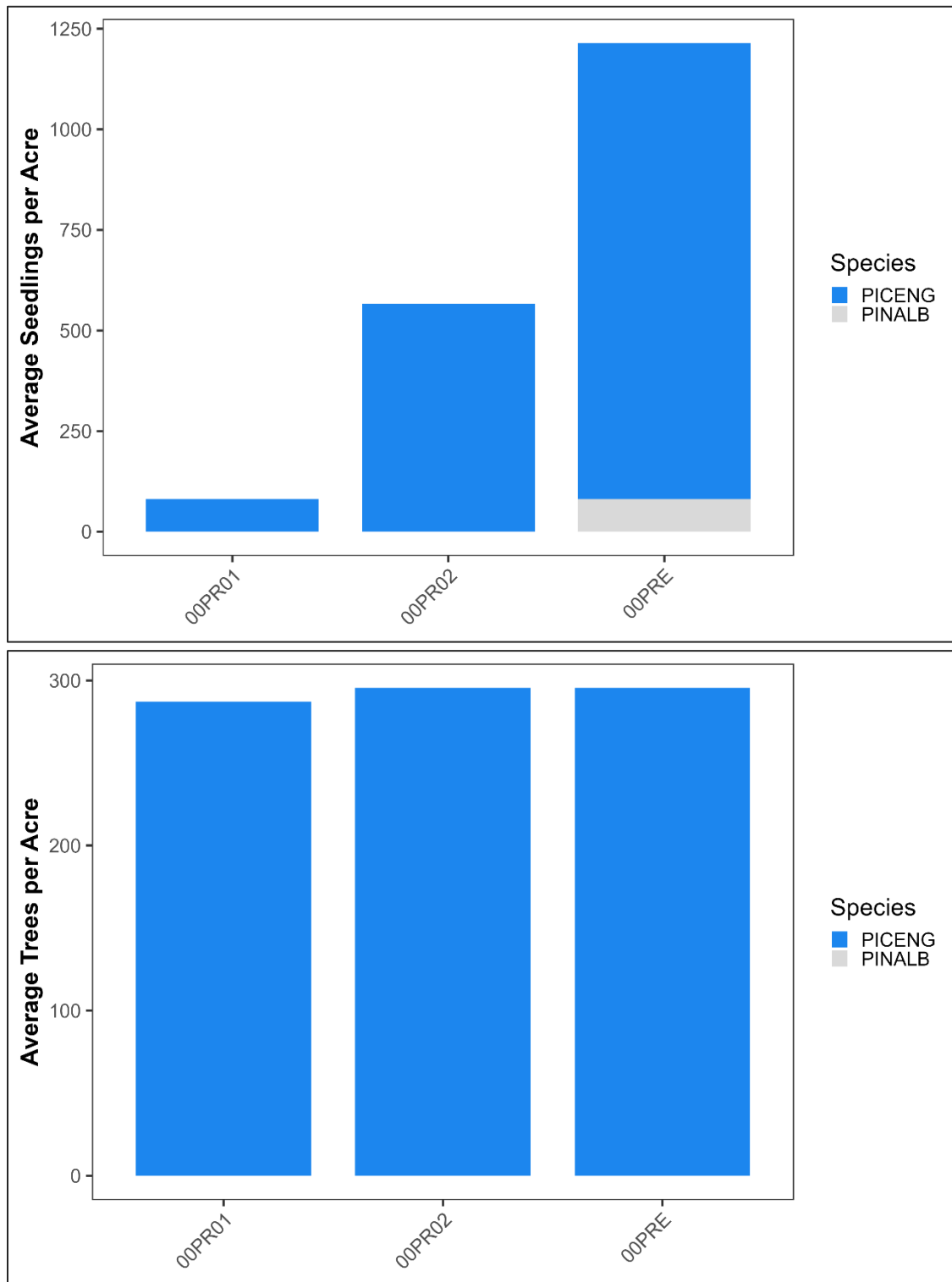


Figure 107. Seedlings per acre (< 1 in DBH – top panel) and trees per acre (> 1 in DBH – bottom panel) for Meridian-2 from 2006 (00PR01), 2016 (00PR02), and 2025 (00PRE). Species are distinguished as Engelmann spruce (PICENG; blue) and whitebark pine (PINALB; gray).

Table 52. Trees per acre (> 1 in DBH) and seedlings/saplings per acre (< 1 in DBH), summarized by species for Meridian–2

Species	00PR01 (2006)		00PR02 (2016)		00PRE (2025)	
	Trees	Seedlings	Trees	Seedlings	Trees	Seedlings
Engelmann Spruce (PICENG)	287	81	295	567	295	1,133
Whitebark Pine (PINALB)	0	0	0	0	0	81



Figure 108. Grace, Marlee, and Jess hiking to the Meridian–2 monitoring plot for sampling.

Understory vegetation at the site was highly diverse, with 52 unique species identified across the plot. Dominant species included field horsetail (*Equisetum arvense*), Virginia strawberry, Richardson’s geranium (*Geranium richardsonii*), and western showy aster (*Eurybia conspicua*), with additional common species such as twinflower (*Linnaea borealis*), starry false lily-of-the-valley (*Maianthemum stellatum*), blue wildrye (*Elymus glaucus*), and *Ribes* spp. also well represented. Native species continued to dominate the understory, accounting for approximately 97.9% of total cover in 2025, a slight decline from 98.4% native cover in 2016 (00PR02). The only non-native species detected was common dandelion, which increased modestly from approximately 1.6% cover in 2016 to 2.1% cover in 2025 (Tables 53,54).

Table 53. Native species monitoring results for Meridian–2

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Meridian–2</i>	Quantify mean species absolute cover and compare post-fire values to pre-fire conditions to assess fire effects on understory vegetation at 1, 2, 5, 10, and subsequent 5-year intervals.	<i>Meridian–2</i> <i>(n = 1 plot; unburned)</i> <u>00PR02 (2016): 98.4% native spp.</u> <u>00PRE (2025): 97.9% ($\pm$ 0%) native spp.</u> <i>Difference from 00PR02 to 00PRE: -0.5%</i>	Yes, but post-fire data do not yet exist for comparison

Note: Vegetation data from 2006 (00PR01) were collected prior to implementation of standardized sampling protocols and are not available for comparative analyses.

Table 54. Non-native species monitoring results for Meridian–2

Monitoring Unit	Management Objective	Monitoring Results (80% confidence interval)	Objective Achieved?
<i>Meridian–2</i>	Limit non-native plant establishment within the burned perimeter to less than a 10% increase relative to pre-treatment conditions, assessed at 1, 2, 5, 10, and subsequent 5-year postfire intervals, using relative percent cover.	<i>Meridian–2</i> <i>*not a statistical analysis so minimum plot numbers not calculated*</i> <u>00PR02 (2016):</u> 1.6% <i>Taraxacum officinale</i> (common dandelion) <u>00PRE (2025):</u> 2.1% <i>Taraxacum officinale</i> (common dandelion)	Yes, but post-fire data do not yet exist for comparison



Figure 109. Herd of bison on the road to the Meridian–2 monitoring plot.

C. Research, Planning, and Communication

Research Coordination and Development

Several opportunities for future research have been identified through ongoing coordination with Dr. Monica Turner and her research laboratory. This collaboration focuses on understanding vegetation trajectories across the Greater Yellowstone Ecosystem (GYE) under changing climate and disturbance regimes, with particular emphasis on areas that have experienced repeated fire outside the typical fire-return interval for lodgepole pine. These reburned landscapes may exhibit shifts in species composition and stand structure that are not yet well understood.

In support of this effort, Dr. Turner submitted a research proposal, accompanied by letters of support from Nick Kichas (Fire Ecologist at Yellowstone National Park) and Paul Hood (Fire Ecologist at Grand Teton National Park), that would leverage an extensive network of existing monitoring plots and post-disturbance vegetation datasets. The proposed work aims to address fundamental questions about forest recovery and resilience within the GYE and would provide valuable context for long-term management planning.

Fuels Research and Monitoring Development

As noted elsewhere in this report, additional work is planned to collect masticated fuels, litter, and duff samples within treated units to develop site-specific bulk density values. These values are expected to improve the accuracy and interpretability of masticated fuel load estimates and to better characterize how these fuel beds change over time. Although this work is still in the planning stages, it remains a priority as time and resources allow, given its relevance to the fire and fuels management program.

Emerging Monitoring Priorities

Widespread Douglas-fir mortality observed across the park's northern range has emerged as a priority issue requiring further investigation. Preliminary efforts are underway to design a monitoring strategy capable of capturing spatial and temporal patterns of mortality and associated fuel and hazard implications. In parallel, collaboration with Colter Mumford, the park's Vegetation Ecologist, has expanded to include discussions of sagebrush ecotone dynamics and disturbance ecology, particularly where sagebrush habitats interface with Douglas-fir forests. These collaborative efforts will continue to support data-informed management decisions in these transitional ecosystems.

Data Integration and Reporting

To improve compliance reporting and trend analysis, Nick developed new reporting scripts to better capture patterns of whitebark pine growth and regeneration within Hazard Fuel (HZF) plots. In addition, Nick met with Dr. Hillary Robison, the park's Deputy Chief of the Yellowstone Center for Resources, and the whitebark pine monitoring crew to better understand their data collection efforts and management needs. Ongoing coordination will explore opportunities to integrate these datasets with park ecology monitoring to better inform management direction within whitebark pine habitats.

Communication and Outreach

Communication and outreach remain core components of the ecology program. In January, Nick delivered a public presentation to the Cody Culture Club in Cody, Wyoming, reviewing the 1988

fires and subsequent vegetation recovery for an audience of nearly 300 people. The presentation was well received and prompted robust discussion on fire ecology, lodgepole pine dynamics, and landscape-scale management.

Additionally, Nick led a fire ecology-focused field tour for over 20 students from the University of Wisconsin–Oshkosh, covering fire history, fire management strategies, fuels treatments, and emerging challenges and opportunities in the park. Student engagement was high, with thoughtful questions and insightful discussion, making the visit a valuable educational and outreach experience.



Figure 110. Fire ecology field visit to the 2016 Maple Fire led by Dr. Nickolas Kichas with students from the University of Wisconsin–Oshkosh.



Figure 111. Fireweed (*Chamerion angustifolium*) growing along a stream.

D. Future Direction

The fire effects monitoring team, led by Jess Page and Marlee Jennings, continues to demonstrate exceptional leadership in managing complex, multi-decadal monitoring schedules while consistently producing high-quality data that support robust analysis and reporting. Jess's outstanding botanical expertise, wealth of knowledge, and superior guidance combined with Marlee's advanced GIS skills and evolving EMS/SAR skillsets have been critical to the continued success and evolution of the fire ecology data program. Their professionalism, adaptability, and commitment to wildland fire operations, ecological monitoring, and data integrity have been especially notable given ongoing challenges - particularly barriers to consistent use of electronic data collection devices stemming from IT compliance requirements and authentication limitations in remote field settings. Despite these constraints, the team has developed effective workarounds to ensure accurate and reliable data collection.



Figure 112. Grace and Marlee working on the Cliff Fire.

In parallel, Nick made significant progress in expanding the program's analytical and reporting capacity through the development of new R-based tools and scripts. Notably, Nick created flexible surface fuels analysis scripts that allow for rapid adjustment of bulk density values to better represent masticated fuel beds - an approach highlighted throughout this report. Additional

tools include a whitebark pine compliance reporting framework that estimates trees per acre with statistically robust 80% bootstrapped confidence intervals, along with automated summaries of cone production and blister rust occurrence to support timely assessment of priority treatment areas.

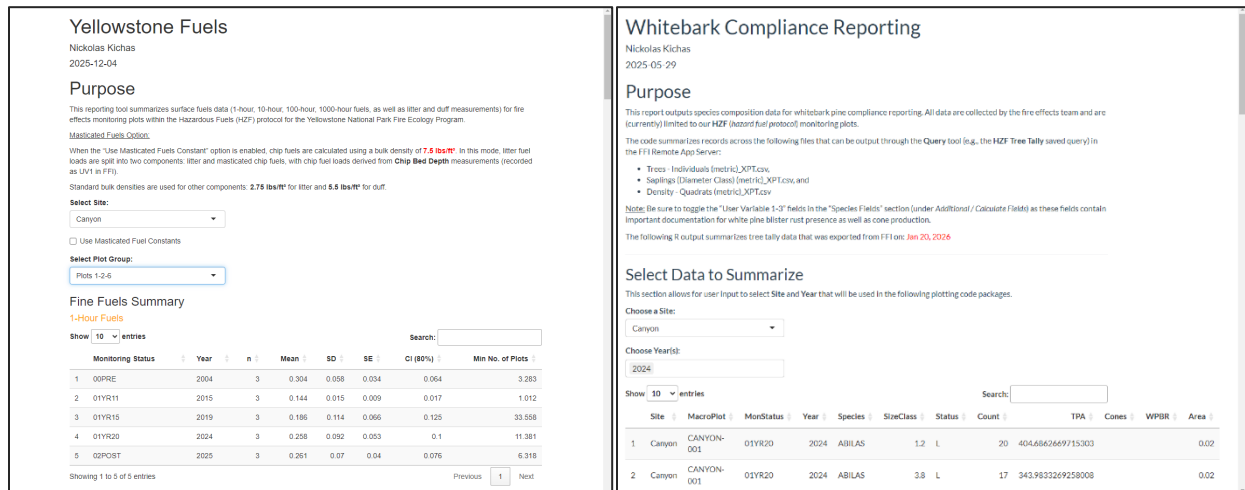


Figure 113. Shiny-based R applications developed to dynamically analyze surface fuel data (left) and whitebark pine metrics (right) across HZF monitoring plots.

Nick also developed a QA/QC utility to flag data inconsistencies beyond standard review processes, a PDF archiving tool to automate collation of annual monitoring outputs into printable formats, and a fire history reporting tool that integrates InFORM and local fire records to summarize fire frequency, size, ignition source, management strategy, and containment timelines. This tool also tracks repeated fire name usage to assist managers in selecting incident names that avoid redundancy.

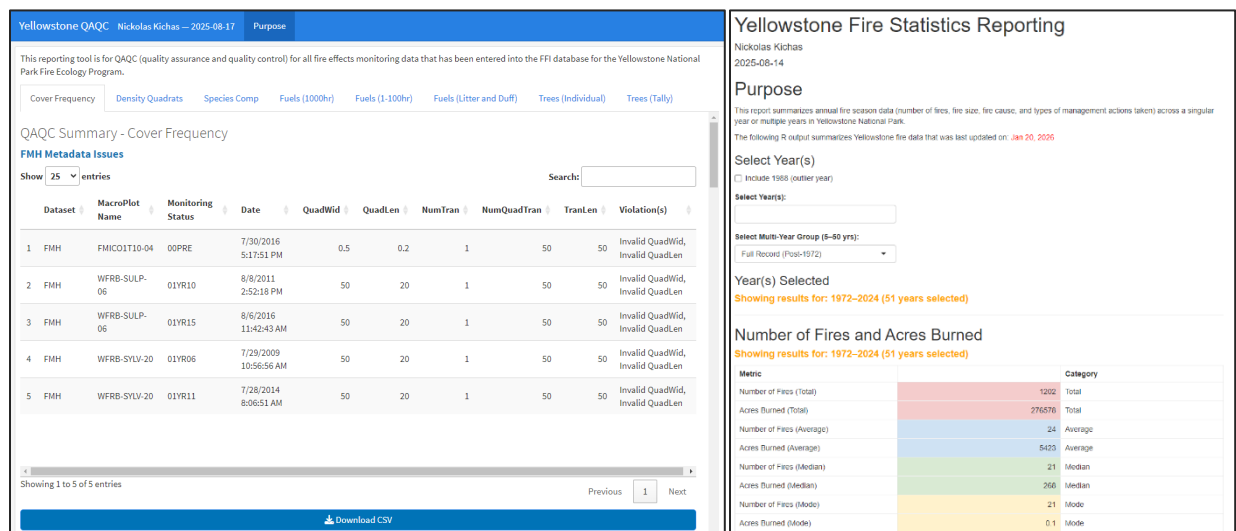


Figure 114. Shiny-based R applications developed to assist with QA/QC of monitoring data (left) and facilitate fire history reporting (right).

Looking ahead, future work will focus on expanding and refining these reporting tools, developing new products that support additional monitoring types and protocols across numerous parks, and continuing to build analytical and technical skills across program staff to maximize efficiency and adaptability. Planned efforts also include closer alignment of fire ecology and monitoring activities with the new United States Wildland Fire Service (USWFS), ensuring that monitoring outputs directly support service-level mission objectives and agency priorities.

The upcoming migration of the fire ecologist position to the GW-401 series and fire effects monitoring positions to the GW-0456 series represents an important transition for the program. These changes are expected to influence recruitment, retention, and the technical skillsets of future applicants, and the program will continue to adapt to leverage these opportunities while maintaining a strong emphasis on data quality, innovation, and long-term monitoring continuity.



Figure 115. Nick, Jess, Marlee, and Grace posing for a group photo near the Cabin Creek RAWS.

E. References, Links, and Additional Reading

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The most updated FFI data base is uploaded to NPS Data Store annually. Here is a link to the 2024 Yellowstone FFI Database:

DataStore - Yellowstone National Park FFI Fire Effects Monitoring Data (nps.gov)
<https://irma.nps.gov/DataStore/Reference/Profile/2314241>

Appendix A. Staffing and Accomplishments

Table A-1. Fire Ecology Staffing 2025

Ecologist and Monitors	Position	Appointment Length	Training and Development
Nickolas Kichas	Fire Ecologist	PFT	<u>Workshops:</u> • IMR Fuels Management Workshop • IMR R workshops <u>Trainings:</u> • S-290 (<i>Intmd. Wildland Fire Behavior</i>) • S-390 (<i>Intmd. Wildland Fire Behavior Calculations</i>) • S-490 (<i>Adv. Wildland Fire Behavior Calculations</i>) • M-580 (<i>Fire in Ecosystem Management</i>) • RX-310 (<i>Intro to Fire Effects</i>) • N-9042 (<i>Wildland Fire Resource Advisor</i>) • NPS GIS Data collection & Management • ESRI GIS (<i>Cartography</i>) • ESRI GIS (<i>Imagery Foundations & Frontiers</i>) • NPS Supervisory Foundations • Data Camp (<i>Advanced R Applications</i>) • RT-130 (<i>Wildland Firefighter Refresher</i>) • HAZWOPER • First Aid / CPR / Bloodborne Pathogens • YELL Radio Use / Bear Safety / Fire Extinguishers • Snowmobile Use and Maintenance • Ethics / FOIA / USERRA / Vet Employment • IMT-FISSA / No Fear Act • Prohibited Practices / Whistleblower Protections <u>Task Books:</u> • Initiated FEMO task book
Jessica Page	Lead Monitor	STF – 22 pay periods	<u>Workshops:</u> • Move Better (<i>physical fitness</i>) • IMR R workshops • IMR LiDAR workshop <u>Trainings:</u> • RT-372 (<i>Helicopter Manager Single Resource</i>) • RT-130 (<i>Wildland Firefighter Refresher</i>) • A-100 (<i>Basic Aviation Safety</i>) • A-110 (<i>Aviation Transport of HAZMAT</i>) • A-200 (<i>Mishap Review</i>) • GIS Training (<i>Field Maps and AGOL</i>) • HAZWOPER • First Aid / CPR / Bloodborne Pathogens • YELL Radio Use / Bear Safety / Fire Extinguishers • Snowmobile Use and Maintenance • IMR Seasonal Recruitment • IMT-FISSA • Ethics / FOIA / USERRA / Vet Employment • No Fear Act • Prohibited Practices / Whistleblower Protections • Overview of Continuity Principles

Marlee Jennings	Monitor	STF – 22 pay periods	<u>Assignments:</u> • 14-day FEMO assignment to EVER/BICY • 5-day Rx to GRKO • 14-day FFT1(t) assignment to DINO • 3-day SAR as GISS(t) • ICT5(t) Moss Fire • 14-day assignment to FL with Wildland Fire Module <u>Workshops:</u> • Move Better (<i>physical fitness</i>) <u>Trainings:</u> • RX-310 (<i>Intro to Fire Effects</i>) • RT-130 (<i>Wildland Firefighter Refresher</i>) • A-100 (<i>Basic Aviation Safety</i>) • A-200 (<i>Mishap Review</i>) • ICS-800 (<i>National Response Framework</i>) • GIS Training (<i>Field Maps and AGOL</i>) • BLS CPR Refresher / Bloodborne Pathogens • EVOC (<i>Emergency Vehicle Operator Course</i>) • HAZWOPER • YELL Radio Use / Bear Safety / Fire Extinguishers • Snowmobile Use and Maintenance • IMT-FISSA / FOIA / HIPPA Privacy Essentials • Overview of Continuity Principles <u>Task Books:</u> • Initiated GISS task book
Elizabeth Stone	Monitor	Temporary – 6 pay periods (July-October)	<u>Trainings:</u> • S-290 (<i>Intmd. Wildland Fire Behavior</i>) • RT-130 (<i>Wildland Firefighter Refresher</i>) • HAZWOPER • First Aid / CPR / Bloodborne Pathogens • YELL Radio Use / Bear Safety / Fire Extinguishers • IMT-FISSA / Ethics / FOIA / No Fear Act • Overview of Continuity Principles
Grace Cross	Monitor	Temporary – 8 pay periods (May-August)	<u>Workshops:</u> • Move Better (<i>physical fitness</i>) <u>Trainings:</u> • S-130 (<i>Firefighter Training</i>) • S-190 (<i>Intro to Wildland Fire Behavior</i>) • L-180 (<i>Human Factors in the Wildland Fire Service</i>) • ICS-100 (<i>Intro to Incident Command System</i>) • ICS-700 (<i>Intro to Incident Management System</i>) • HAZWOPER • First Aid / CPR / Bloodborne Pathogens • YELL Radio Use / Bear Safety / Fire Extinguishers • IMT-FISSA / Ethics / FOIA / No Fear Act • Overview of Continuity Principles • NPS Intro to SAR <u>Task Books:</u> • Initiated FEMO and HECM taskbooks

Table A-2. Fire Ecologist 2025 Accomplishments/Focus Areas

Category	Percent Time	Accomplishments and/or areas of activities
Planning	6%	Supporting Section 7 compliance reporting for whitebark pine, including evaluating monitoring needs and reporting requirements with Yellowstone Center for Resources whitebark pine monitoring staff. Contributing to fire monitoring plan review and updates and working closely with the Lead Fire Effects Monitor to prioritize sampling efforts and refine multi-year monitoring schedules. Assisting with plot installation planning and site selection at Tower–Roosevelt and Norris in advance of mastication treatments.
Presentations	2%	Delivered a fire ecology presentation to the Cody Culture Club and led a fire ecology field tour for students from the University of Wisconsin–Oshkosh, focusing on fire history, fuel treatments, and post-fire ecological dynamics.
Meetings/task groups	5%	Participating in whitebark pine coordination meetings, FFI-R working group meetings, and workshop development efforts. Contributing to fuel treatment planning discussions, ensuring alignment between treatment objectives and long-term monitoring needs.
Wildfire assignments	1%	Supported wildfire operations through FEMO training assignment on the Trail Creek Fire and provided logistical planning assistance for multiple fire incidents throughout the season.
Prescribed fire/fuels treatment projects	1%	Advanced proficiency with the WFDSS NextGen system for documenting fire incidents and continued training and application of IFTDSS to evaluate fuel treatment effectiveness and modeled fire behavior.
Research	4%	Conducting research on long-term fuel moisture dynamics, including ongoing evaluation of 1,000-hour fuel moisture samples and statistical testing to identify potential sampling bias. Investigating fuel constants and bulk density assumptions for masticated fuel beds. Continuing whitebark pine research, including analyses of establishment patterns, growth trajectories, cone production, and blister rust prevalence.
Field work/data collection	8%	Assisted with sampling of three FMH plots and multiple HZF plots, including two new plot installations at Norris and four at Tower–Roosevelt, with aerial (helicopter) transport to two RAWs for annual maintenance and data collection at two remote FMH plots.
Data management	18%	Conducting a comprehensive review of datasets and data standards across monitoring protocols to support development of QA/QC script and PDF archival tool. Reviewing and organizing long-term fuel moisture datasets for analysis relative to NFDRS fuel moisture thresholds for critical fire behavior.
Data analysis	35%	Performing long-term analyses of vegetation and fuel moisture data and developing R-based scripts and reporting tools to improve efficiency and reproducibility. Compiled and quality-checked fire history records for development of fire history reporting tool and expanding analytical scripts to support multiple monitoring protocols and potential application in other parks.

Supervision/ admin tasks	1%	Prepared to assume supervisory responsibilities for lead, assistant, and seasonal fire effects monitoring staff beginning in FY26. Completed NPS Supervisory Foundations training and revised EPAP critical element objectives in preparation for the transition.
Training	18%	Completed a range of professional training courses, including M-580, S-290, S-390, S-490, RX-310, N-9042, multiple GIS trainings, and the standard suite of NPS and DOI required trainings.
Miscellaneous	1%	Conducted routine office duties, including daily briefings and weekly supervisory meetings. Exploring and developing analytical and reporting approaches to support a variety of emerging projects and program needs.

Table A-3. Fire Effects Crew 2025 Accomplishments/Focus Areas

Category	Percent Time	Notes
Data collection	23%	5 FMH plots, 6 HZF install, 47 HZF rereads, Photopoints at 3 locations, 28 site visits to 3 fuel sampling locations.
Wildfire assignments	15%	Marlee traveled on two out of park assignments with the WFM, and all crewmembers assisted on several suppression incidents within the park as, FEMO, FOBS, FFT1, FFT2, FAL3, ICT5, HMGB, HECM and unofficial Logistics.
Prescribed fire/fuels treatment projects	3%	Marlee participated in Rx burns at GRKO and BICY; Jess helped with pile burning in YELL as well as Rx burns at MORU, WICA and JECA.
Travel out-of-park for plot or project work	0%	
Data entry/management	13%	Time spent fine tuning excel templates for data entry, manually entering data into FFI, managing data in FFI, preparing, or archiving data, and conducting data quality control activities.
Data analysis	1%	Lead spent time analyzing FF+ and WIMS outputs to determine best weather station(s) to predict fire danger and performed some analysis in FFI.
Administrative activities	5%	Payroll, travel authorization/voucher, credit card reconciliation etc., hiring two crewmembers and associated tasks.
Training	7%	See training listed in Table A-1 above for detailed list of in person and online classes, webinars and conference attendance.
Miscellaneous	33%	Weather station rehab and data management, general office time, SAR assists, working with helitack on project work, PT, vehicle maintenance, janitorial duties, morning meetings and time spent collecting information on weather and fuels for daily briefings.

Appendix B. History of Fire Effects Monitoring Plots

Table B-1. All Fire Effects Plots Established

Park	Monitoring Unit	Plot Type	Years Collected	Total Plots	
				Active	Inactive
Yellowstone	Despain / 1988 Fire	Despain (pre-FMH)	1977-2024	14	2
	Abiathar	FMH Forest Plots	2007-2021	2	
	Boundary (<i>burned</i>)	FMH Forest Plots	2000-2025	2	
	Broken Ankle	FMH Forest Plots	2004		1
	Chickadee (<i>burned</i>)	FMH Forest Plots	2005-2025	1	
	Crevice	FMH Forest Plots	2001-2004		1
	Deaf Jim (<i>burned</i>)	FMH Forest Plots	2001-2021	1	
	Deep Creek	FMH Forest Plots	2001-2012		1
	Electric (<i>burned</i>)	FMH Forest Plots	1999-2021	1	
	Falcon	FMH Forest Plots	2001-2025	1	
	Little	FMH Forest Plots	2001-2021	1	
	Meridian	FMH Forest Plots	2006-2025	3	1
	Phlox (<i>burned</i>)	FMH Forest Plots	2002-2022	1	
	Plateau	FMH Forest Plots	2000		2
	Promontory (<i>burned</i>)	FMH Forest Plots	2004-2022	1	
	Specimen (<i>burned</i>)	FMH Forest Plots	2002-2004		2
	Stone (<i>burned</i>)	FMH Forest Plots	2001-2021	1	1
	Sulphur (<i>burned</i>)	FMH Forest Plots	2001-2021	1	
	Sylvan (<i>burned</i>)	FMH Forest Plots	2003-2023	1	
	Norris Rx	FMH Forest Plots	2006-2022	4	
	Norris Blowdown	Fuel Transects	2014-2019	4	
	Norris Rx	Fuel Transects	2006-2022	9	
	1988 Reburn (Maple)	HZF	2016-2021	4	
	Buffalo Plateau	HZF	2003-2024	2	
	Bechler	HZF	2023	8	
	Canyon	HZF	2004-2025	24	3
	East	HZF	2003-2022	7	4
	Grant	HZF	2009-2023	24	9
	Harebell	HZF	2003-2018		5
	Heart Lake	HZF	2005-2025	3	
	Lake	HZF	2003-2024	18	4
	Norris North	HZF	2006-2025	6	2
	Northeast	HZF	2003-2021	9	4
	Old Faithful	HZF	2020-2025	12	
	South Entrance	HZF	2004-2025	5	1
	South Riverside	HZF	2003-2025	3	1
	Tower	HZF	2025	4	
	West	HZF	2004-2024	4	
	Winter Creek	HZF	2003		4
	Bechler	Photopoints	2024	4	
	Canyon	Photopoints	2004-2023	9	
	East	Photopoints	2003-2023	9	1
	Grant	Photopoints	2009-2023	7	
	Lake	Photopoints	2003-2023	9	1
	Nez Perce	Photopoints	2008-2023	13	
	Norris Blowdown	Photopoints	2014-2024	2	
	Northeast	Photopoints	2003-2023	20	
	Old Faithful	Photopoints	2020-2022	7	
	West	Photopoints	2004-2024	8	
	Photoseries	Photoseries	2001-2005		38

	Fire Line Explosive	3 Daubenmire Transects/Plot	1996-2006		9
Total			1977-2025	269	97

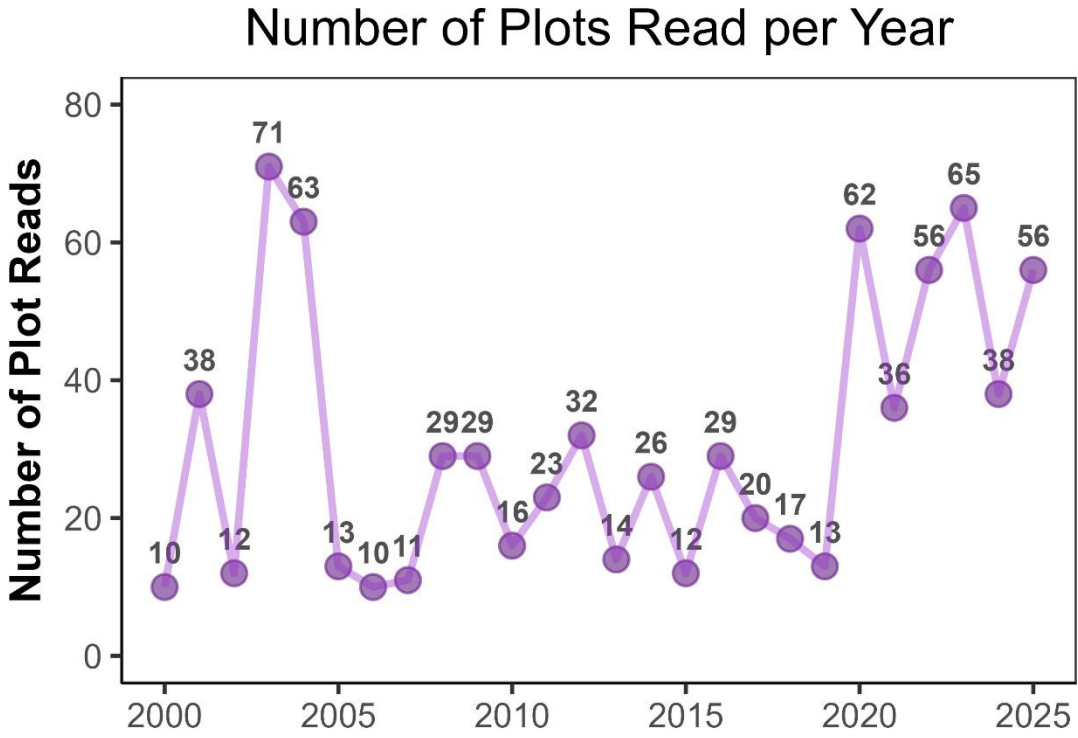


Figure B–1. Summary of annual plot remeasurements in Yellowstone, excluding Composite Burn Index (CBI) assessments and photopoint (PPT) data.

Appendix C. Fire/Fuels Treatments and Associated Monitoring

In 2025, fire effects monitoring was conducted across seven treatment areas, including two backcountry cabin sites, encompassing approximately 388 acres of treated area and an additional 42 acres of planned future treatment at Tower–Roosevelt. Although time and resource constraints limited our ability to implement the full suite of Hazard Fuel (HZF) monitoring protocols at all sites, we successfully completed immediate post-mastication surface fuel assessments at key locations. Specifically, surface fuel data were collected for all 24 active plots at Canyon, as well as the six active plots at Norris, and five active plots at the South Entrance. These datasets provide a valuable foundation for ongoing and future analyses aimed at evaluating changes in fuel loading within masticated units and assessing how fuel conditions evolve over time across treatment areas.

Table C-1. Summary of 2025 Fire/Fuels Treatments and Associated Monitoring

Park	Treatment Area	Monitoring Conducted	Acres
Yellowstone	Canyon	Yes (HZF surface fuels / PPT)	210
	Norris	Yes (HZF surface fuels)	36
	Old Faithful	Yes (HZF / PPT)	100
	South Entrance	Yes (HZF surface fuels / PPT)	40
	Tower–Roosevelt	Yes (HZF)	42
	Heart Lake Cabin	Yes (HZF)	1
	South Riverside Cabin	Yes (HZF)	1.3
Total			430.3